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24TH FOREST PRODUCTS RESEARCH CONFERENCE

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CSIRO
DIVISION OF FOREST PRODUCTS
CLAYTON, VICTORIA, AUSTRALIA

VOLUME 1

24TH FOREST PRODUCTS RESEARCH CONFERENCE

15-18 November 1993
CSIRO Division of Forest Products,
Bayview Avenue, Clayton, Victoria

VOLUME 1

***KEYNOTE ADDRESS:** Dr Robert Bain, Executive Director
National Association of Forest Industries, Canberra

(10.30 a.m. 15 November)

SESSION 1 Optimal Use of Fibre Resources (1.30 p.m. 15 November)

Paper, Fibres and People - A Life's Work, The Alex McKenzie Memorial Lecture. - Anthony J. Michell, CSIRO Division of Forest Products

1/1 An Overview of the National Pulp Mills Research Program with an Emphasis on the Bleaching Research - Peter J. Nelson, CSIRO Division of Forest Products

1/2 The Cooperative Research Centre for Hardwood Fibre and Paper Science - Anthony J. Michell, CRC for Hardwood Fibre and Paper Science, CSIRO Division of Forest Products

1/3 A Rapid Means of Estimating Pulpwood Quality - Anthony J. Michell, CSIRO Division of Forest Products

1/4 Extended Delignification of Mature Eucalypt Wood - Noel B. Clark, Geoffrey M. Irvine and Concettina Recupero, CSIRO Division of Forest Products

(1/5 Was always intended to be a Poster Presentation)

1/6 Adding Value to Secondary Timber Products Used in Horticulture by Laboratory Analysis and Quality Control - David P. Wraight, Forest Service - QDPI

1/7 Characterisation of the Chlorinated Organic Substances in Filtrates from Bleaching Eucalypt Kraft Pulp - Terrence J. Smith, Ross H. Wearne and Adrian F.A. Wallis, CSIRO Division of Forest Products

1/8 A Quantitative Description of Fibre Development in *Eucalyptus globulus* - Brad G. Ridoutt, Roger Sands, Cooperative Research Centre for Hardwood Fibre and Paper Science, School of Forestry, The University of Melbourne, and Geoffrey M. Downes, Cooperative Research Centre for Hardwood Fibre and Paper Science, CSIRO Division of Forest Products

SESSION 2 Biodegradation and Chemical Treatments (4.30 p.m. 15 November and 9.00 a.m. 16 November)

2/1 Condition of Natural Durability Specimens from the CSIRO In-Ground Field Test after 23 Years of Exposure - John D. Thornton, Gary C. Johnson, CSIRO Division of Forest Products, and Nam-Ky Nguyen, CSIRO Biometrics Unit

2/2 The Implications of the Building Envelope Micro-Climate to the Durability and Serviceability of Wood and Wood Products - I.S. Cole, CSIRO Division of Building, Construction and Engineering

2/3 Improving the Weather Resistance of Glue-Laminated Karri and Jarrah Composites - J. Balfas and P.D. Evans, ANU

2/4 Alternatives to Chromated Copper Arsenate (CCA) Preservatives - Innovation, Sacrifice or Commonsense - Jeanette A. Drysdale, Koppers-Hickson Timber Protection, New Zealand

2/5 Decay Evaluation of the Penetration of LOSP into *Eucalyptus regnans* Heartwood - L.J. Cookson, CSIRO Division of Forest Products and E.F. Dougal, Forestry Section, The University of Melbourne

2/6 Accelerated Field Simulator Studies - Laurie J. Cookson, James W. Creffield, John R.J. French, Harry Greaves, Gary C. Johnson, Kevin McCarthy and John D. Thornton, CSIRO Division of Forest Products

2/7 Termite Physical Barrier Protecting Forest Products - B. Ahmed and J.R.J. French, CSIRO Division of Forest Products

* 2/8 Fire and Timber Protection - David Gardner, NSW Forestry Commission

2/9 Withdrawn

* 2/10 Performance of Copper Based Preservative Treated Timber under Tropical In-Ground and Out-of-Ground Conditions of Exposure at Sites in North Queensland and Hawaii - A.R. Moffat and K.J. Archer, Queensland Department of Primary Industry

2/11 Borate Protection of Slash Pine (*Pinus elliottii*) sapwood from attack by subterranean termites (*Coptotermes* sp., Isoptera: Rhinotermitidae) - B.C. Peters and P.J. Allen, Queensland Department of Primary Industries

* 2/12 Above Ground Durability and Climate, and Their Influence on Design Reliability - A. McNaught *et al.*, Queensland Department of Primary Industry

2/13 Establishment and Preliminary (5 Yr) Results of a Major Above-Ground Timber Durability Trial in Eastern Australia - Myron Cause, Queensland Department of Primary Industry

2/14 Performance of Timber Decking at a Brisbane Site after 5½ Years Weather Exposure - Myron Cause, Queensland Department of Primary Industry and Geoff Stringer, Hyne & Son Pty Ltd

2/15 Treatability of Messmate (*Eucalyptus obliqua* L'Herit) with Trimethyl Borate - F.J. Romero, P. Vinden and P. Kho, University of Melbourne

* 2/16 Review of Novel Waterborne Preservative Treatment Techniques - P.R. Cobham, University of Melbourne

2/17 Dimensional Stability of Particle Board and Radiata Pine Wood (*Pinus radiata* D.Don) Treated with Different Resins - N. Ndegwa, P. Vinden and P Kho, University of Melbourne

2/18 Diffusion and Toxicity Evaluation of a Solid Remedial Preservative Containing Boron and Fluorine - Kevin McCarthy, CSIRO Division of Forest Products

2/19 Diffusion and Toxicity Evaluation of Commercial and Non Commercial Remedial Preservatives in Jarrah Stubs - Kevin McCarthy, CSIRO Division of Forest Products

2/20 Quality Assurance and Treated Timbers Has Australian Business Failed It's Customers? - Marshall Segan, The Pine Centre, North Coburg, Victoria

2/21 An accelerated Field Simulator Study of the Natural Durability of Heartwood from Mature and Regrowth Trees - Gary C. Johnson, John D. Thornton, CSIRO Division of Forest Products, and Nam-Ky Nguyen, Biometrics Unit, CSIRO Institute of Animal Production and Processing

2/22 Soft Rot Prevention in CCA-Treated Spotted Gum Poles Using Koppers CN Emulsion - Alan Moffat, Queensland Department of Primary Industry and Peter Carruthers, Koppers-Hickson Timber Protection

* 2/23 Wood Fibre Racetracks - M.A. Tighe and G.C. Johnson, CSIRO Division of Forest Products

SESSION 3 Primary Conversion, Drying and Utilisation (2.00 p.m. 16 November)

3/1 Recent Sawing and Machining Research, World-Wide - W.M. McKenzie, Consultant, Caulfield North, Victoria

3/2 Equilibrium Moisture Contents of Timbers Commonly Used in Western Australia - Gary K. Brennan and Judith A. Pitcher, Department of Conservation and Land Management, WA

3/3 Withdrawn

3/4 Timber Drying and Acoustic Emission - James Booker, University of Tasmania

3/5 Withdrawn

3/6 Mathematical Modelling of Wood Drying - John W. Sutherland, CSIRO Division of Forest Products

3/7 The Effect of Preheating on Collapse and Internal Checking in Mountain Ash - S.C. Chafe, CSIRO Division of Forest Products

3/8 Dimensional Analysis and the Conventional Drying of Wood - Aleck J. Hunter, CSIRO Division of Forest Products

3/9 Computer Aided Wood Identification Using CSIROID - J. Ilic, CSIRO Division of Forest Products

3/10 The Effect of Prefreezing on Collapse, Internal Check Development and Drying Rate in *Eucalyptus regnans* F. Muell. - Jugo Ilic, CSIRO Division of Forest Products

3/11 Hygroscopicity Characteristics of Radiata Pine Dried at High Temperature - R.L. Northway, CSIRO Division of Forest Products

3/12 Drying and Degrade Development Characteristics of Plantation-Grown *Eucalyptus regnans* - Richard Northway and Andrew Rozsa, CSIRO Division of Forest Products

3/13 Potential for Plantation-Grown Eucalypts as a Resource for Sawn Products in South-Eastern Australia - G. Waugh and J.L. Yang, CSIRO Division of Forest Products

3/14 Hoop Pine Seasoning Problems and Solutions- Graeme Palmer, Queensland Department of Primary Industries

3/15 Forest Industries Research at the School of Forestry University of Melbourne - Peter Vinden, University of Melbourne

3/16 Withdrawn

3/17 The Importance of the S3 Cell Wall Layer in Collapse Prevention and Wood Hardness - Rolf Booker, NZ Forest Research Institute

3/18 Mechanical Properties of Tasmanian Oak Relevant to Seasoning - Trevor Innes, University of Tasmania/Australian Furniture Research and Development Institute

SESSION 4 Reconstituted Wood Products (9.00 a.m. 17 November)

4/1 Carbonisation of Plantation Eucalypts: - Yields of Pyrolytic Products from Chipped Sawmill Edgings - Paul Y.H. Fung, Soo H. Ng, Velauthapillai Muruganathan and Adrian de Vos, CSIRO Division of Forest Products

4/2 Temperature Effects on the Production of Pyroligneous Liquors from Eucalypt Woodchips - Paul Y.H. Fung, Soo H. Ng, Velauthapillai Muruganathan and Adrian de Vos, CSIRO Division of Forest Products

4/3 Molecular Weight of a Phenolic Resin Determined by NMR - M.J. Reilly and Y. Yazaki, CSIRO Division of Forest Products

4/4 Molecular Weight Distribution of Phenolic Resins Determined by Different GPC Techniques - S.D. Terrill and Y. Yazaki, CSIRO Division of Forest Products

4/5 Can We Make Universal Type Wood Adhesives? - Y. Yazaki, CSIRO Division of Forest Products

4/6 Development and Properties of Universal Type Phenolic Resin - P.J. Collins, CSIRO Division of Forest Products

4/7 Eucalypt LVL Potential Using Phenolic Resins - David Syme, NSW Forestry Commission

4/8 Eucalypt Peeling and Gluing Studies: an Ongoing Survey by the Forestry Commission of NSW - John Wade (retired), Previously NSW Forestry Commission

4/9 Utilisation of Pinebark via Steam Treatment - Terry D. Lomax, Keith L. Mackie and Dale R. Smith, New Zealand Forest Research Institute

SESSION 5 Growth for End-Use (1.00 p.m. 17 November)

5/1 Influence of Climate on Wood Formation in Radiata Pine - Geoff Downes, Rob Evans and Patricia Brennan, CSIRO Division of Forest Products

5/2 Rapid Measurement of Radiata Pine Pulpwood Quality - Robert Evans, Geoff Downes, David Menz and Sharee Stringer, CSIRO Division of Forest Products

5/3 Plantation Eucalypts - Survival of the Fittest - Max D. Williams, CSIRO Division of Forest Products

5/4 Stem Deformation in Plantation Grown Radiata Pine - Geoff Downes, CSIRO Division of Forest Products

5/5 Environmental Constraints on Growth and Kraft Pulp Yield of *Eucalyptus globulus* and *E. nitens* - Chris Beadle, Charles Turnbull, CRC for Temperate Hardwood Forestry Tasmania and Geoffrey Dean, APPM, Burnie

* 5/6 The Physical and Chemical Wood Properties of NZ Radiata Pine, A Superior Thermomechanical Wood Resource? - John G. Nyakuengama, University of Melbourne

SESSION 6 Structural Applications (9.00 a.m. 18 November)

6/1 Australian Standards for Structural Timber - R.H. Leicester, CSIRO Division of Building, Construction and Engineering

6/2 The Effect of a Plywood Stiffener on Top Plate Uplift Performance - Bob Clinch and Moses Virivolomo, University of Central Queensland

* 6/3 In-Grade Study of Australian Pine - Stephen Bolden, Pine Australia; F.G. Young, CSIRO Division of Building, Construction & Engineering and D. Grant, NSW Forestry Commission

6/4 New Developments for Stress Laminated Timber Bridges - Keith I. Crews, University of Technology, Sydney

6/5 Softwood Versus Steel Framing - A Review - J. Georgiou, Deakin University

6/6 Timber Framing Versus Steel Framing in Housing - Darryl Jones, Timber Promotion Council of Victoria

6/7 A Review of Durability Design Methods for Timber Structures - G.R. Stringer, Hyne & Son Pty Limited

6/8 The Application of Johansen's Yield Theory to Australian Nailed Timber Joints - G.R. Stringer, Hyne & Son Pty Limited

6/9 The Wood Strength of Regrowth Blackbutt of Four Age Groups from 25 Years to 70 Years Old - Peter Chapman, NSW Forestry Commission

6/10 Structural Softwood Timber Model - H.O. Breitinger, CSIRO Division of Building, Construction and Engineering

6/11 Strength and Deformation Due to Mechano-Sorptive Effects - J.P. Lu, CSIRO Division of Building, Construction and Engineering

6/12 The Design of Rafter Overhangs - M.J. Syme, L. Pham and R.H. Leicester, CSIRO Division of Building, Construction and Engineering

6/13 Design of Flooring with Sheet Decking - J. Yang, L. Pham and R.H. Leicester, CSIRO Division of Building, Construction and Engineering

6/14 Quality of Surface Measures for Concrete Formwork Constructed from Timber Components - H.R. Milner, Monash Timber Engineering Centre and P. Nio, Department of Civil Engineering, Monash University

6/15 Simulation of Glued Laminated Timber Bending Strengths Using Lamination Tension Test Data - R. Nestic and H.R. Milner, Monash Timber Engineering

6/16 Nailed Plywood Gusset Knee Joints in Plywood Web Box-Beam Portal Frames - Alastair C. Woodard and Henry R. Milner, Monash Timber Engineering

* See Volume 2, to be published immediately after the Conference.

PAPER, FIBRES AND PEOPLE - A LIFE'S WORK
THE ALEX MCKENZIE MEMORIAL LECTURE

Anthony J. Michell

CSIRO Division of Forest Products

Private Bag 10, Rosebank MDC, Clayton, Vic. 3169

INTRODUCTION

Alex McKenzie joined the Chemical Research Laboratories of CSIRO at Fishermen's Bend in 1944. He transferred to the Division of Forest Products in 1953 and remained with that Division through its multiplicity of reorganisations until his untimely death in June this year, a fortnight ahead of his planned retirement.

Alex's career falls naturally into a number of phases.

The years 1944 - 1952, at Fishermens Bend were spent working with Sir Robert Price, later Chairman of CSIRO, investigating the chemistry of alkaloids as part of a much larger project in the Chemical Research Laboratories seeking to find biologically active agents from Australia's rich and unusual collection of plant species. During this time Alex became an accomplished glassblower which was to prove very useful to his colleagues in Forest Products in later years.

PAPER STRUCTURE, FIBRE MODIFICATIONS AND MILL PROBLEMS

His transfer to Forest Products in 1953 involved him in a promotion to Experimental Officer and a large change in the nature of his research. It also marked the commencement of a very fruitful collaboration with Dr Huntly Higgins on a number of

major topics. These included: The structure and properties of paper, the reactivity of cellulose, periodate oxidation of cellulose, influence of alkali on cellulose fibres, effects of drying on cellulose fibres and the problem of maintaining pulp strength, conformability and surface texture of cellulose fibres in relation to pulp strength and origin of the difference between sulphate and sulphite pulps. The first-named gave birth to a series of twenty one papers the last of which was published in 1984.

One of the other things which McKenzie and Higgins did at this time was to examine the significance of swelling and hydrogen bonding in interfibre adhesion in paper. They did so by studying the effects of esterifying the fibres with acetic anhydride and other reagents before the fibres were made into paper, and produced a number of plots (Fig. 1)

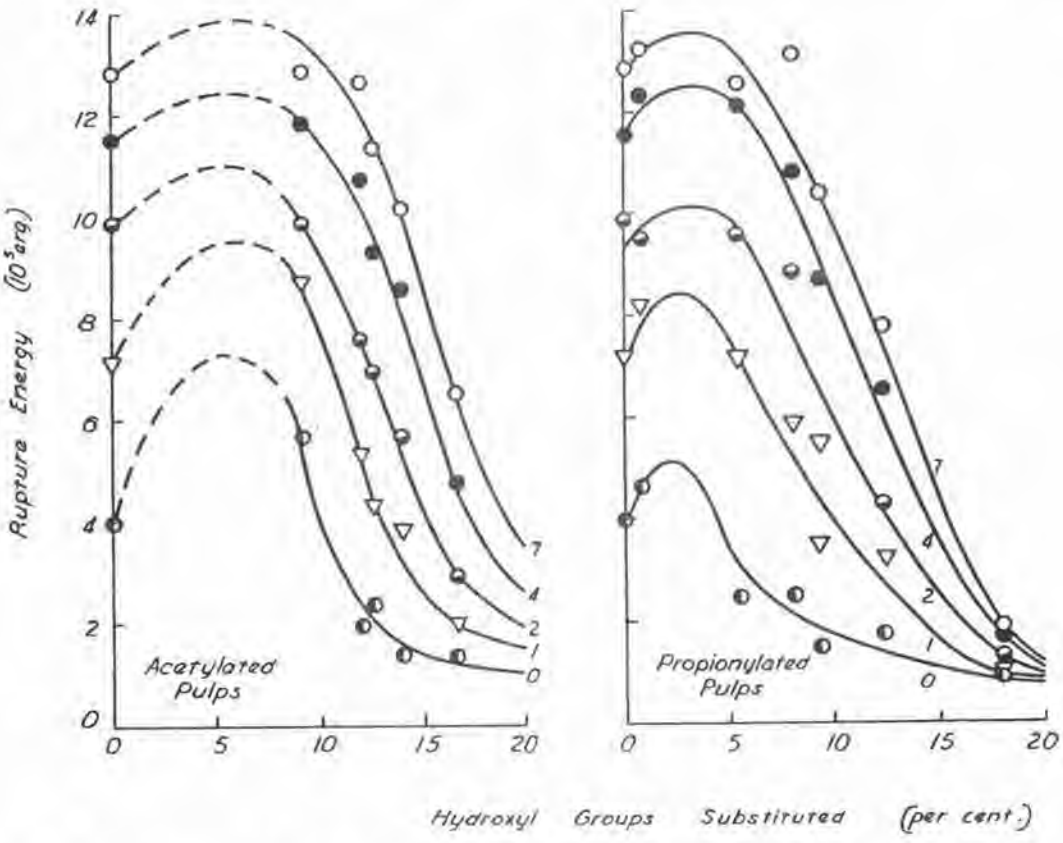

Fig. 1 Changes in rupture energy of paper with percentage substitution of fibre hydroxyl groups

showing the effect of the degree of substitution of the hydroxyl groups in the fibres on the rupture energy of paper made from the treated fibre. These data came to the notice of Alfred Nissan, at that time Professor at Renesselear Polytechnic and later Corporate Research Director of Westvaco Pulp and Paper Company, who used them in his attempts to derive the elastic modulus of paper, regenerated cellulose and similar hydrogen bonded solids from the molecular and thermodynamic parameters of the hydrogen bond. The numbers he obtained from his calculations were quite sensible despite the gross oversimplifications he had to make. Though controversial Nissan's theory remains to this day.

The early part of this period saw the evolution of the four yearly Cambridge and Oxford Symposia which are now widely regarded as being the premier meetings concerned with the science of papermaking. Authors from the Division were well to the forefront in contributing to the early conferences and in establishing their reputation. In the early 1960's Alex became very interested in colloidal aspects of papermaking systems and particularly in the nature of the charges on papermaking fibres and additives and the ways in which changes to these charges affected the papermaking system. The work was summarised in a major paper with Balodis, Harrington and Higgins, to the 1965 Cambridge Symposium entitled "The effects of hydrophilic colloids and other non-fibrous materials on fibre flocculation and network consolidation".

Despite this rather theoretical work Alex always had a strong practical outlook. In the 1960's Tasmanian paper mills, particularly Australian Newsprint Mills at Boyer had been experiencing problems arising from hard and intractable deposits causing blockages in pipelines and pumps, on washer wires and in many other places in the mill. Such deposits could only be removed by mechanical means such as scraping or by washing with concentrated mineral acids, principally nitric acid. This was unpleasant, dangerous

and time-consuming. The problem arose from the pulping of overmature eucalypts under alkaline conditions leading to the breakdown of the ellagitannins in the wood to ellagic acid which then complexed with certain metallic ions to form the deposit. McKenzie on a visit to the Boyer mill noted that the deposition did not occur after bleach liquor had been added to the pulp in a particular range of pH. This became the basis of a much safer and more rapid method of deposit removal from the washers which he developed along with Pearson and Stephens from the mill.

Another problem Higgins and McKenzie researched in the '60s was the effects of drying on cellulose fibres and the problem of maintaining pulp strength. This of course has considerable relevance in the present to the use of recycled fibres. When they began their research however, a more pressing concern was the inability of paper mills to get papers of the same strength from a rewetted pulp lap as could be obtained at the pulp mill from the freshly produced pulp. One company found a deficit of up to 30 percent in the bursting strength obtained from reslushed pulp. I should explain that it is not uncommon for pulp and paper mills to be on sites many miles apart with the pulp being transported from one to the other. Most mills seek to avoid the costs of transporting large weights of water from one site to the other and therefore press as much water out of the pulp as they can and also subject the pulp to some heat. Approaches used by Higgins and McKenzie included prevention of hydrogen bond formation on drying, introduction of reversible bonding systems, the elimination of surface tension effects and prevention or elimination of fibre collapse. In the last named approach they used the Division's experience on treatments developed for the prevention of collapse of wood cells on drying. They found that use of sodium chloride which is effective in reducing collapse in wood was ineffective but the use of sucrose and glycerol at similar concentrations was almost completely effective. None of the treatments has come into mill use because of the added costs.

PAPER AND PACKAGING

The next major change in Alex's career came in 1967 when a group of fibre box makers having formed the Australian Fibreboard Container Manufacturers Association entered into a research contract with the Division to undertake research into the properties and performance of fibreboard containers and Alex was appointed leader of the research program. Unlike the present day the industry then consisted of a large number of small manufacturers unable to provide much in the way of technical backup for their products so the contract required that this as well as research be done. After spending time in the plants to familiarise himself with their operations Alex began writing technical information sheets to provide the required support. In the five years before the breaking up of the Association and the termination of the contract in 1972 Alex produced twelve technical reports on subjects including: warping of corrugated fibreboard, liner adhesion of corrugated fibreboard, prediction of box compression strength and the effect of corrugating medium and flute type on rough handling resistance.

Following the cessation of the contract Alex spent several years working in the composites area researching the possible use of paper composite threads substituting the jute or polypropylene threads in a wool bale. He went on to look more generally at the possibilities for using wood fibres to reinforce plastics, in particular, polypropylene.

PAPER ASSOCIATIONS

Alex had joined Appita - then the Australian Pulp and Paper Industries Technical Association - in 1953, the year he transferred to Forest Products and maintained close links with the Association throughout his career. He served as a member of Appita's Executive Committee from 1969-78 and was elected President in 1976. He also acquitted himself well in the onerous task of editor of the Appita Journal from 1973-76. He went

on to serve as Chairman of the Technical Committee and was a long time member of Testing Committee. He was the second recipient of the Oertel Nadebaum Award for service to Appita and shortly before his death he was elected as an Honorary Life Member of Appita. In the wider sphere he served as Vice President, Australia - Pacific Region of the International Association of Scientific Papermakers.

EVALUATION OF PULP FOR PAPERMAKING

In 1977 the work of the pulp evaluation laboratory was reorganised and Alex was placed in charge. This allowed him to return to an area of work which had become his first love. He applied himself energetically to work he had left some ten years earlier but used now techniques such as high speed photography which were not available on the earlier occasion. This he used as part of extensive studies of the mechanisms of laboratory beating - an essential step in all pulp evaluations. He also looked again at the types of information which could be obtained about fibre properties from examining changes in paper tensile strength with changes in sheet density brought about by beating. Here he was tackling one of the major limitations in papermaking research - the need to obtain indirect measurements of fibre properties because of both the extreme difficulty and the high labour requirement of making measurements on individual fibres as small and as variable as wood pulp fibres, and in particular, eucalypt fibres.

Alex served CSIRO as the resident expert on the practices of the paper industry and its products. His services were also much in demand outside the CSIRO for standards committees, laboratory assessment for NATA and TELARC registration in Australia and New Zealand respectively, referee functions as to the suitability of a product for a particular use, advice to libraries on the permanence of paper and possible rehabilitation procedures. In this last period we see him continuing some of the other interests he had

developed earlier during his career with papers on subjects such as "Test methods for SAA box standards " and "Stability of dispersions in papermaking systems".

He also revisited some earlier themes and re-examined the esterification data which Nissan had used to calculate a vital constant in his theory. He came to a new conclusion, that "the reduction in wet fibre conformability , and hence in relative bonded area, brought about by esterification is sufficient to produce the observed paper strength losses without assuming that the bonding ability of the fibre surface is affected by the substitution of ester groups for free hydroxyls". He communicated his revised conclusion to Nissan and a lively correspondence ensued with the matter, to my knowledge, being unresolved.

Most recently, Alex finished a draft of a guide to pulp evaluation. His purpose in writing the guide was to help workers avoid wasting information inherent in the evaluation by providing the background needed for more effective use of the available results. He pointed out that the first physical tests on paper were designed to mimic the techniques used by the craftsman papermaker when assessing the quality of hand-made and early forms of machine-made paper. Tensile strength and tearing resistance are typical examples of procedures which were mechanised and quantified, so that quality control no longer depended on the experience and the perception of quality held by the individual papermaker. Because of the nature of paper - an assemblage of fibres, self-bonded in a viscoelastic network - its properties are highly method-dependent, as are the properties of a pulp suspension. Thus, simple calibration of a measuring device(e.g. a load cell) is insufficient to ensure an accurate test result. The interpretation of test results which Alex was advocating required that all aspects of the relationship between fibre and test sheet properties be considered. These aspects included the physical and morphological properties of the original fibres as present in the wood, any changes

occurring in the process of pulp preparation and the manner in which the pulp fibres respond to subsequent beating/refining. This knowledge had to be combined with a basic understanding of the factors influencing each of the paper properties for which test results were available.

Laboratories undertaking pulp evaluations usually have available numbers for apparent density, tensile strength, tearing resistance, bursting strength, air permeance(air resistance), freeness and such other properties as are relevant to the intended use. Alex's monograph shows how more information could be obtained from the results of these tests. He has applied the concept of related pairs of properties - pairs of properties affected by processing to different extents. Both advantageous and disadvantageous effects are included. The properties which he has used most commonly in his examples are tensile index, tear index, and sheet density, and beating is the main process considered. Three of his examples are shown below . In each example the pulps are the same. Pulp A is a commercial radiata pine kraft pulp; pulp B is also a radiata pine kraft pulp but having weaker fibres. When a plot is made of the tear index vs tensile strength of sheets made from these fibres beaten to differing degrees we find the behaviour shown in Figure 2.

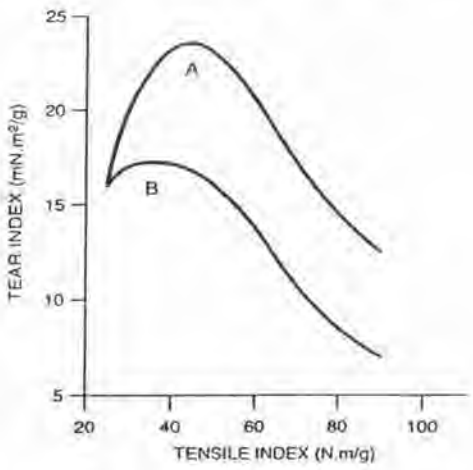

Fig. 2. Plots of tear index vs tensile index for radiata pine kraft pulps having fibres differing in strength

As we look at the curve the degree of beating follows the tensile index rising from left to right. Tear index rises initially with beating for the sheets made from both pulps, reaches a maximum and then starts to fall. The mechanism of tearing changes with beating from a pulling out of the fibres with higher absorption of energy to the lower energy absorbing process of fibre fracture. Curve B always lies below curve A because the weaker fibres break at a lesser degree of bonding and the work required to break them is less. In Figure 3 is shown a plot of tear index vs sheet density. Sheet density also increases with increasing levels of beating. At every stage, the effect of fibre weakening is visible. In the early stages, the lower tear of pulp B is related to a higher proportion of (lower energy) fibre fracture. At the latter stages, we simply have 100% fibre fracture in both cases, but the work to fracture is less for the weakened fibre.

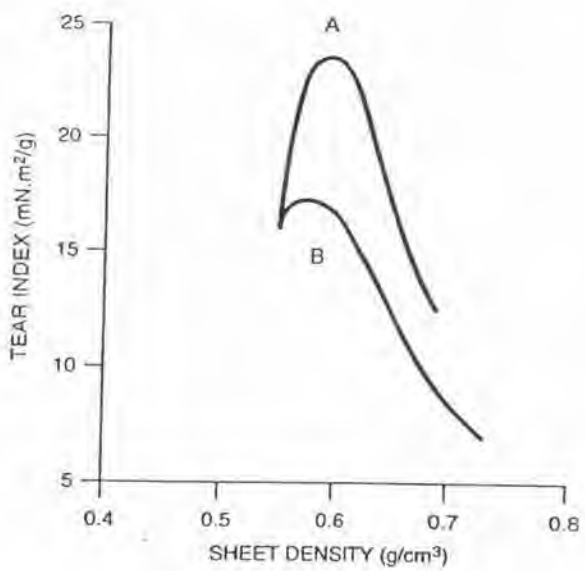

Fig. 3. Plots of tear index vs sheet density for radiata pine kraft pulps having fibres differing in strength

Figure 4 shows a plot of tensile index versus sheet density. Curve B shows the effect on tensile strength of weakening the fibre strength of curve A. As the tensile strength of the sheet approaches the limiting value set by fibre strength, the curves separate. At lower degrees of interfibre bonding, where fibre fracture is not significant, there is no obvious difference between the two pulps.

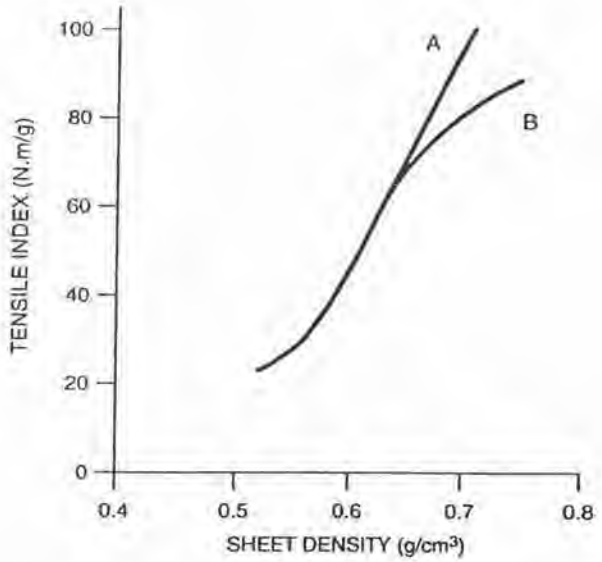

Fig. 4. Plots of tensile index vs sheet density for radiata pine kraft pulps differing in strength

Many more examples are given in the monograph of ways in which the information lying deeper within pulp evaluation data can be accessed.

The monograph entitled "A Guide to Pulp Evaluation " is being prepared for publication by CSIRO and should be available shortly.

The inclusion of people in the title of the lecture is not only because of Alex's keen support of Associations but also because he always recognized the importance of people in bringing any worthwhile endeavour to a successful conclusion. Near the end of his

guide he has devoted considerable effort to describing in detail the necessary communications between the users and the suppliers of his ideal pulp evaluation service. He also exemplified his belief in the importance of people in the way he related to the very wide range of people with whom he dealt in his various capacities.

Any attempt to summarise a man's work within the short compass of a few minutes must necessarily fail in many regards. The author has only the written material, his own memory and those of his colleagues on which to rely. Much of the work, for example, help given over the telephone to numerous enquirers, will have escaped his awareness. Nonetheless, even with these deficiencies the author hopes to have given at least some insight to the breadth and depth of Alex's work. It has been left to others to summarise his life.

The loss of Alex McKenzie is felt deeply by his colleagues not only for his encyclopaedic knowledge of the pulp and paper industry but also for his cheery disposition and wise counsel on so many aspects of life. He was one of whom it could be truly said "he was a scholar and a gentleman".

ACKNOWLEDGEMENT

The author is grateful to Dr W. Hewertson for suggesting the lecture and to Dr H.G. Higgins for advice during its preparation.

APPENDIX 1

PUBLICATIONS

(1) McKenzie, A.W. and Price, J.R. Alkaloids of the Australian *Rutaceae*. *Glycosmis pentaphylla*(Retz.) *Correa*. Aust. J. Sci. Res., A5: 519-580 (1952)

(2) McKenzie, A.W. and Price, J.R. The Alkaloids of *Gyrocarpus americanus* (Jacq.) Aust. J. Chem. 6: 180-185 (1953)

(3) McKenzie, A.W. and Higgins, H.G. The structure and properties of paper. III. Significance of swelling and hydrogen bonding in interfibre adhesion Aust. J. Appl. Sci., 6(2): 208-217, 1955

(4) McKenzie, A.W., McPherson, J.A. and Stewart, C.M. The estimation of acid-soluble lignin. Holzforschung, 9(4): 109-112, 1955

(5) McKenzie, A.W. The structure and properties of paper. VI. The effect of swelling pretreatments on interfibre bonding capacity. Aust. J. Appl. Sci., 8(1): 35-41, 1957

(6) McKenzie, A.W. and Higgins, H.G. The reactivity of cellulose. I. The effect of beating and other physical treatments on rate of acetylation Holzforschung, 10(5): 150-153, 1956

(7) McKenzie, A.W. and Higgins, H.G. The reactivity of cellulose. II. Kinetics of heterogeneous acetylation of eucalypt a-cellulose in the presence of pyridine Holzforschung, 10(6): 179-184, 1956

(8) McKenzie, A.W. The structure and properties of paper. VIII. Influence of fibre swelling on the beating process. Appita, 11(4): 84-90, 1958

(9) Higgins, H.G. and McKenzie, A.W. The structure and properties of paper. X. Periodic acid oxidation of cellulose fibres and its influence on paper properties. Aust. J. Appl. Sci., 9(2): 167-182, 1958

(10) Higgins, H.G., McKenzie, A.W. and Harrington, K.J. The structure and properties of paper. VII. Study of the mechanisms of beating and interfibre bonding by means of esterification. Tappi, 41(5): 193-203, 1958

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AN OVERVIEW OF THE NATIONAL PULP MILLS RESEARCH PROGRAM WITH AN EMPHASIS ON THE BLEACHING RESEARCH

Peter J. Nelson
CSIRO Division of Forest Products
Private Bag 10, Rosebank MDC
Clayton Vic 3169

ABSTRACT

In December 1989 the Commonwealth Government released a Pulp and Paper Industry Package which included a set of environmental guidelines for new bleached eucalypt kraft pulp mills and an outline for a research program related to these guidelines. The research program was designed to enhance the guidelines and build up Australian expertise in the relevant areas. The scope of the National Pulp Mills Research Program is outlined and the bleaching project is discussed in more detail.

INTRODUCTION

The announcement by North Broken Hill Peko and Noranda Forest that they would build a large kraft pulp mill in Northern Tasmania initiated a wide-ranging public debate about the environmental effects of the mill. The mill would have been built near the town of Wesley Vale and was to manufacture bleached kraft pulp, a large portion of which would be exported. The capital cost of the mill would have been about $1000 million and the production of bleached pulp about 400,000 tonnes/year. The treated effluent from the mill would have been discharged through a pipeline into Bass Strait. The main concern about the pulp mill was the effect on the marine environment of the complex effluent, especially the chlorinated organics formed during bleaching of the pulp.

The Commonwealth Government expressed concern about some aspects of the proposed Tasmanian State Government environmental regulations for the Wesley Vale mill and indicated that the companies would be required to meet superior guidelines and standards to be developed by the Commonwealth. The companies withdrew their proposal because it would have involved them in an unspecified period of uncertainty while the guidelines were being developed.

The Commonwealth Government proceeded with development of the guidelines and the first step was to request CSIRO to prepare a report on technical and environmental issues

related to new bleached eucalypt kraft pulp mills (1). The information on effluent composition, procedures for pollution control and known environmental impact was obtained mainly from Scandinavia and Canada. The report was the basis for the guidelines which were contained in the Pulp and Paper Industry Package (2) issued by the Government in December 1989.

The guidelines apply only to new bleached eucalypt kraft pulp mills discharging effluent into a marine environment. The main objectives of the guidelines are:

- to ensure protection of the environment from emissions generated by new bleached eucalypt kraft pulp mills

- to clarify for State Government agencies, industry and potential investors the minimum environmental requirements of the Commonwealth for new mills of this type.

The strategy to meet these objectives was devised to cater for both known and unknown impacts. The guidelines have the following key elements

- criteria for the determination of a suitable mill site

- the maximum emission levels for specified pollutants which may be discharged into the atmosphere or receiving waters are defined

- baseline studies to establish the pre-operational conditions in the receiving waters and control sites prior to operation of the mill

- a comprehensive monitoring program to ensure that any as yet unknown environmental impacts are detected early enough for remedial action to be taken before permanent damage occurs

The guidelines are dynamic in that they will reflect continuing advances in scientific knowledge and refinements in industrial technology. They will be reviewed on a regular basis (every five years or earlier if there are significant advances in technology or if unforeseen environmental impacts are observed which necessitate revision).

RESEARCH PROGRAM

The Pulp and Paper Industry Package contained, in addition to the guidelines, an allocation of funds for a research program which was started in 1990.

The assessment of global knowledge and research related to pulp mill technologies and environmental impacts of effluent has been based, by necessity, predominantly on studies carried out in the northern hemisphere. The Government recognised the need for local research on the specific effluent characteristics of mature eucalypt wood species which would be pulped in Australia, and the response of Australian marine communities to the effluents. The Research Program addresses these needs and the further necessity to enhance the level of appropriate technical expertise in Australia, to keep up to date with technological developments, and to ensure that the Commonwealth guidelines remain relevant and effective.

Some elements of the present guidelines reflect uncertainties resulting from lack of available information relating to the Australian situation when the guidelines were developed. For instance, particular compounds to be monitored in the effluents have not been fully identified and the most appropriate organisms for bioassay tests have not been designated or do not include Australian biota. Research projects have been initiated to provide information about the particular chlorinated phenols to be monitored in the effluent, the discharge limit to 2,3,7,8-tetrachlorodibenzodioxin as well as the specific organisms to be used for acute and chronic toxicity tests.

The National Pulp Mills Research Program has funded twenty six projects covering seven generic fields of research (Table 1).

Table 1 - National Pulp Mills Research Program projects

In-plant research topics

Effluent composition

- Development of standard methods for generic analyses of halogenated organics in bleached eucalypt kraft pulp mill (BEKM) effluents and environment.

- Determination of chlorinated phenolics present in effluent from BEK mills.

- High molecular weight compounds in bleached kraft filtrates.

- Characterisation of the major components (by mass) of selected effluent from bleaching of eucalypt kraft pulp.

- Measurement of dioxin levels in BEKM effluents to determine the reproducibility of the measurements.

Bleaching process

- A study of ways of increasing the use of non-chlorine-containing bleaching chemicals, increasing the effectiveness of chlorine dioxide, and improving the overall efficiency of modern bleaching sequences.

- The effects of advanced bleaching processes upon the properties of BEK pulps and chemical characteristics of their effluents.

Pulping processes

- The application to the pulping of mature eucalypts of modified extended delignification procedures which increase the amount of lignin removed in the pulping.

Effluent treatment

- Treatment of bleached eucalypt kraft effluents.

- Treatment of pulp and paper mill effluent using anaerobic-acrobic lagoons.

Emerging technologies

- Evaluation of emerging pulping and bleaching technologies. Assessment of new pulping and bleaching processes in relation to new BEK mill design.

Environmental research topics

Single species bioassays

- Algae as indicators of toxicity of BEKM effluents.

- Short-term chronic bioassay testing using eggs/embryos/larvae of Australian blennies and Pacific oysters.

- The development of rapid and sensitive bioassay techniques to determine the fertilisation-inhibiting, teratogenic and genotoxic effects of BEKM effluent.

- Develop a short-term chronic bioassay test using a copepod of the genus *Tisbe*.

Biomarkers

- Development of standardised methods for using liver P-450 isozymes and blood enzymes in the sand flathead (Platycephalus bassensis) and spiky globefish (Atopomycterus nicthemerus) as biomarkers of the marine environmental impacts of bleached eucalypt kraft mill effluents.

- The immune system as a biomarker for toxicity studies of pulp mill effluent.

Effluent dispersal

- Modelling effluent dispersion in Australian coastal waters.

- Desk study of the surface micro-layer in the context of the National Pulp Mills Research Program.

- Study of the oceanographic processes off the south western coast of Western Australia.

Mesocosms - community studies

- Development of a meiofaunal mesocosm system for testing acute and chronic effects of bleached eucalypt kraft mill effluent.

- Testing chemical stress on meiofaunal mesocosm systems.

- Development of an experimental benthic marine mesocosm system.

Design of monitoring program

- Design of monitoring programs for measuring the potential effects of BEKM discharges.

Risk assessment

- Feasibility of risk assessment.

Validation of bioassays using laboratory effluents

- Application of MFO biomonitoring protocols to treated bleached kraft effluents.

- Validation of bioassay test protocols using synthetic BEKM effluents and fractions.

BLEACHING PROJECT

The bleaching project has two main objectives (3,4). The first of these is to obtain basic information about the bleaching of kraft pulps from Australian eucalypt wood resources when modern bleaching sequences are used. The second is to find ways of decreasing the use of chlorine-containing bleaching agents with the ultimate aim of preparing fully-bleached pulp without using these chemicals.

A range of eucalypt woodchip samples was used to prepare the kraft pulps for the bleaching study. Pulps with Kappa numbers of approximately 18 were made from three export woodchip samples (Eden (NSW), Northern Tasmania and Western Australia) and two plantation samples (*Eucalyptus globulus*) grown in Tasmania and Western Australia. The plantation wood gave higher pulp yields and required less alkali for pulping than the export woodchip samples which contained appreciable quantities of wood from mature eucalypt trees.

All the kraft pulps were easily delignified under oxygen bleaching conditions and their responses were similar.

The oxygen-bleached pulps were bleached with the sequence (DC)(EO)DD ((DC) is a 70:30 mixture of chlorine dioxide and chlorine, (EO) is oxygen reinforced extraction with alkali and D is chlorine dioxide) as well as a sequence in which no molecular chlorine was used i.e. D(EO)DD. Relatively large amounts of bleaching chemicals were used to ensure that the quantities of chlorinated organics formed were the maximum likely to be produced in a commercial bleaching operation.

When pulps were bleached with the (DC)(EO)DD sequence it was found that those from the plantation woods could be bleached to a higher brightness (91 per cent ISO) than those from the export woodchips (88-90 per cent ISO). The pulp from the Western Australian export woodchips gave the lowest brightness. The brightness levels were increased by addition of hydrogen peroxide to the alkaline extraction stage.

The use of the bleaching sequence with 100 per cent chlorine dioxide, D(EO)DD, gave pulps with high brightness levels and there are no technical reasons why this sequence cannot be used to bleach eucalypt kraft pulps. A brightness level in excess of 90 per cent ISO was obtained with the pulp from the Northern Tasmanian export woodchip sample when the modified bleaching sequence D(EOP)D(EOP)D was used ((EOP) denotes addition of hydrogen peroxide to the oxygen reinforced extraction stage).

One of the anticipated outcomes from the project was the generation of data which would enable a prediction to be made of the maximum level of AOX (a measure of the amount of organochlorines) in the effluent from a new bleached eucalypt kraft pulp mill. For this reason AOX measurements on the bleaching filtrates were carried out. The major part of the total AOX is formed in the first stage ((DC) or D) of a bleaching sequence. The AOX in the untreated filtrate from bleaching of the pulps was in the range 0.7-0.9 kg/oven-dried tonne of pulp when the sequence(DC)(EO)DD was used and 0.4-0.7 when the sequence with 100 per cent chlorine dioxide was used.

It was confirmed that elimination of the pulp washing step between the first and second stages of either of the bleaching sequences reduced the total amount of the AOX in the filtrates by more than half. Use of this modification resulted in pulps with lower viscosities than those bleached in the conventional way.

The papermaking properties of the pulp from the Northern Tasmanian export woodchip sample were evaluated and the strength properties of the fully bleached pulps were equal to or superior to those of the unbleached pulp.

The results from the first phase of this project have shown that kraft pulps from Australian eucalypt wood resources can be bleached to a high brightness with bleaching sequences containing no molecular chlorine. The filtrates from the laboratory study would easily meet the current Commonwealth guidelines for AOX levels (1.0 kg/tonne air dried pulp), in many cases without secondary treatment.

The project is on-going with an emphasis on increasing the efficiency of oxygen bleaching and hydrogen peroxide treatment of eucalypt kraft pulps. The use of xylanases in bleaching of these pulps will also be studied.

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THE COOPERATIVE RESEARCH CENTRE FOR HARDWOOD FIBRE AND PAPER SCIENCE*

Anthony J. Michell
Program Leader, CRC for Hardwood Fibre and Paper Science,
C/- CSIRO Division of Forest Products, Private Bag 10, Rosebank MDC,
Clayton Vic 3169

This Australian Government's Cooperative Research Centre Program was launched in May 1990 to fund up to fifty such centres which would undertake collaborative research and education programs in fields in the natural sciences and engineering, with a strong focus on applications.

The Program has the following objectives:

- to support long-term high-quality scientific and technological research which contributes to national objectives, including economic and social development, the maintenance of a strong capability in basic research and the development of internationally competitive industry sectors;

- to capture the benefits of research, and to strengthen the links between research and its commercial and other applications, by the active involvement of the users of research in the work of the Centres;

- to build centres of research concentration by promoting cooperative research, and through it a more efficient use of resources in the national research effort;

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- to stimulate education and training, particularly in graduate programs, through the active involvement of researchers from outside the higher education system in educational activities, and graduate students in major research programs.

The Commonwealth Government provides funding up to fifty percent of the total cost of establishing and operating a centre and the participating organisations contribute the balance of the required resources in cash or in kind.

The proposal for the establishment of the Cooperative Research Centre for Hardwood Fibre and Paper Science was successful in the second round of applications and the Centre commenced operations in April 1992. The Centre brings together the skills in:

- fibre development, silviculture and post-graduate education in forestry of the University of Melbourne

- fibre science and wood chemistry and physics of the CSIRO Division of Forest Products

- pulp and paper process engineering, paper physics and technology and post-graduate education of the Australian Pulp and Paper Institute (APPI), Monash University

- tree breeding and pulp and papermaking technology of the leading Australian pulp and paper companies through The Pulp and Paper Manufacturers' Federation of Australia (PPMFA).

It meets a need well recognised in the countries which are world leaders in pulp and paper. The pulp and paper industries of the most successful exporting countries enjoy

the support, usually with strong cooperation from the central government, of cooperative research and graduate education programs focussed on the materials, operations and systems unique to the industry. These efforts are critical in providing the industry with an assured pool of well-trained scientific and technical talent not usually forthcoming from the mainstream of higher education.

The aims of the Centre are:

- to identify those properties of hardwood fibres which are critical to the performance of pulp and paper products and extend our fundamental understanding of the relationships between fibre and product properties

- to develop rapid methods for evaluating pulpwood fibre properties and apply them to the assessment of wood resources from silvicultural and tree improvement trials

- to extend our understanding of the response of fibres to pulping and papermaking processes, including recycling

- to provide advice and assistance to foresters in their efforts to improve wood quality through genetic and silvicultural research on plantation and regrowth eucalypts

- to utilise the results of the research in developing advanced dynamic simulations of, and control sensors for, pulping and papermaking processes

- to provide technologists with directions for improving processes and product quality.

Current knowledge

Paper is a web of self-bonded cellulosic fibres, its properties depend on those of the constituent fibres, their orientation in the sheet, their capacity to bond to each other and the effect of additives. In order to make paper of the highest quality, it is important to start with fibres having the right properties. It is also important to produce them at the lowest possible cost, i.e. to grow the best fibres as efficiently as possible. Achievement of these goals requires collaboration between pulp and paper technologies and foresters to establish the key fibre properties and to apply this information in growing superior trees.

Some key fibre properties are already known. Most of the work done on fibre properties overseas has been concerned with softwoods. However, earlier research done in CSIRO and the Australian industry established significant basic relationships between paper properties and eucalypt fibre dimensions, e.g., length, diameter, wall thickness and certain ratios of these dimensions. In most cases the paper properties considered were traditional strength indices such as tensile and tear index.

The achievement of this understanding was a major step forward, especially for wrapping and packing materials which must withstand severe stresses in service. Changing customer attitudes and needs and changes in printing and converting processes are placing ever varying and increasing demands on the performance of paper. Thus there is a need not only to establish improved fundamental relations between fibre properties and existing performance attributes of paper but also for new characteristics required by new uses. An obvious example of a new major use is photocopy paper which places new demands on the skills of the papermaker.

Research program

In our opinion, traditional methods of correlating fibre properties and product performance are approaching the limits of their usefulness and are becoming less capable of responding to the increasing rate of development of new products and processes. Design of tomorrow's products will require more versatile and robust relationships based upon fundamental understanding of the physical and chemical mechanisms by which fibre properties influence product performance.

Much tree breeding work has been aimed essentially at achieving high growth rates and improved form, both very worthy objectives, rather than at producing an understanding of the mechanisms by which these aims are achieved and still less at producing trees with improved fibre properties.

A large number of trees will need to be assessed with respect to their fibre properties. Traditional methods involving pulping trials are lengthy, expensive and require felling of the trees concerned. CSIRO workers are developing a range of physical and chemical techniques for the rapid examination of small specimens taken from test trees. The extent of silvicultural and genetic influences on key fibre properties will be assessed in collaboration with foresters from PPMFA member companies and the Centre for Temperate Hardwood Forestry at Hobart, Tasmania. At the University of Melbourne, emphasis will be on developing an understanding of the processes involved at the cellular level.

Fibres are modified by pulping and papermaking processes. New, rapid measurement techniques will be developed to enhance our understanding of separated fibres and the ways in which they are modified by processing. New insights will be provided into the effects of recycling on fibre properties. The new measurement techniques will be

developed into sensors for process control in pulping and papermaking. Improved understanding of the relationship between fibre properties, processes and paper quality will facilitate the development of dynamic simulations, leading to improved understanding and process control. Such simulation procedures will also be valuable in design and teaching.

Benefits to education

Establishment of the Australian Pulp and Paper Institute MEngSc course involving one year of intensive course work plus a minor thesis on an applied research project was a PPMFA initiative. The course is now in it fifth year and its graduates have been well received. It has already attracted a number of students from overseas. Master's degrees by research have commenced and a PhD research program has started in collaboration with CSIRO. Similarly, joint supervision of postgraduate research by staff of CSIRO and the School of Agriculture and Forestry at the University of Melbourne has existed since 1986. The establishment of the Centre will greatly strengthen these activities, with the added benefit to the research students of bringing them into close contact with industry. There will be complementary benefits to industry through closer contact with university research. These interactions can be expected to produce appreciable synergy.

In addition to the research itself, the Centre's educational program will involve a continuing series of research seminars and specialist lectures. These will be open to a wide audience and it is expected that they will attract a number of technical people from industry, CSIRO and government educational institutions. We believe that this complex of interactions will act as a substantial stimulus to technical progress and an interest in science and technology, not only in the pulp and paper industry, but in the wider community.

Outcomes

The economic value of a research project such as that described above is very difficult to calculate with any accuracy. However, an attempt is made below to provide order of magnitude estimates.

- ***Market share***

  Increasing emphasis on pulp quality is evident among overseas producers of bleached eucalypt kraft pulp. If the discount for inferior quality were $25 to $50 per tonne, this would represent a loss of around $10 million per year for a 500 000 tonne per day mill producing the lower quality pulp. Market penetration and share for an Australian export mill will depend on the maintenance of high quality. Loss of 10% of sales for a mill of this size would represent a loss in revenue of the order of $30 million per year.

- ***Pulp substitution***

  Improved quality of local eucalypt pulp is estimated to hold the potential for a saving in foreign exchange of several million dollars by replacement of imports. Such a quality increase might also allow increased use of clay, with a further potential saving of similar magnitude.

- ***Productivity gains***

  Success in developing improved trees giving an increase in pulp yield could have a value of the order of some hundreds of millions of dollars over a five-year period. The development of advanced control systems, envisaged in the Centre's program, should also result in significantly reduced production costs.

Conclusion

The setting up of the Centre represents a milestone in the history of the Australian pulp and paper industry. Never before has such a body of expertise, involving a leading research organisation and two leading universities been brought to bear on its technical problems in a collaborative effort. The Centre's aims are nothing less than to secure the Australian industry's competitive commercial position and its reputation as a world leader in eucalypt fibre science and technology.

A Rapid Means of Estimating Pulpwood Quality

ANTHONY J. MICHELL*

Program Leader, CRC for Hardwood Fibre and Paper Science,
CSIRO Division of Forest Products, Private Bag 10, Rosebank MDC, Clayton 3169,
Australia.

ABSTRACT

Rapid measurements of pulpwood quality are required if tree breeding experiments are to be able to produce the desired improvements. Measurements of a number of alternative wood properties which can be made rapidly and might correlate with pulpwood quality have been tried but each has its shortcomings. Such measures include lignin content, hot water and alkali extractives contents and basic density. In this paper vibrational spectroscopy and multivariate data analysis are combined to give estimates of properties such as pulp yields in kraft pulping to Kappa number 15 and soda demand, with residual standard deviations of less than two units. Estimates of the lignin, hot water and alkali extractives contents were obtained with similar precision.

INTRODUCTION

Plantation forests seem certain to become an increasingly important source of Australian pulpwood. Improvements to this future resource by breeding can effectively reduce associated costs as well as lead to improvements in product quality. However, the realisation of these potential benefits is hampered by gaps in our fundamental knowledge. Research into the inheritance of wood and pulping properties has demonstrated that these are generally highly heritable and that the variations have a high impact on the overall cost of production[1]. Little is known, however, about the attributes of eucalypt plantation woods and how these vary with site, silviculture and genetics. Studies of large numbers of trees are necessarily involved [2, 3] and present methods of assessment are too slow and expensive. They also require too large samples for measurements on young trees which need to remain standing for breeding purposes and for further studies such as age-to-age correlations. Solutions to these problems will require the development of both proper methods for obtaining small scale samples and rapid means of assessing their pulpwood quality.

This paper is concerned with the use of vibrational spectroscopy and multivariate data analysis as a means of assessing pulpwood quality. The use of vibrational spectroscopy is considered feasible because it requires only small samples, is rapid and regions of vibrational spectra have been found to be so characteristic of chemical substances that they have been likened to human fingerprints[4]. What is needed are methods of relating the spectral band frequencies and intensities to pulpwood qualities. Newly developed multivariate statistical techniques give promise of being able to provide the necessary transformations[5].

There are two vibrational spectroscopic regions available - the mid-and near-infrared and both have been used to obtain chemical information about woods. Samples can be examined by using either transmission or reflection techniques. Most qualitative studies have used transmission in the mid-infrared region [6-9] with samples dispersed in either potassium bromide or paraffin mulls to reduce scattering. In this method sample preparation is relatively easy and the spectra can be interpreted in terms of vibrations of bonds in the major chemical components of wood. However, quantitative measurements are difficult because of the need to weigh accurately a few milligrams of wood and disperse it evenly in about 250 mg of salt. We have found a means of ameliorating this difficulty and have used the transmission method in this study.

Data Analysis

In the past spectroscopic analyses were carried out by observing changes in the absorbance or intensity of a single band with changes in concentration of the component of interest. Multivariate analysis, enables the concentration of the component to be related to the intensities of numerous bands.

The data analysis begins with finding essential useful variations in two sets of data, i.e. with establishing regression relationships between two data sets In our case the data are on the one hand the pulpwood quality characteristics such as yield, chemical demand, lignin content etc and on the other the band absorbances in the vibrational spectrum. A set of known data - a training set - is used to model the relationship. This is called "calibration" and is carried out by a Partial Least Squares Regression (PLS). The next step is to use the model to predict the values of further known data. This is known as "validation". Finally the model is used to predict new unknown pulpwood quality values. Through "prediction" the pulpwood quality values can be estimated in new samples based upon new measured spectral band intensities and the regression model previously created. The aim is to replace necessarily slow pulping and gravimetric analyses requiring large volumes of wood with rapid spectral measurements directly on small amounts of the wood itself.

EXPERIMENTAL

Sampling of wood and testing of pulpwood quality

Details of the collection of the wood samples and their testing for pulp yield, soda charge, lignin content hot water and alkali solubles have been given [10, 11].

Spectroscopic examination

The samples were subjected to further milling in a small Wiley mill with a 70 mesh (210 μm) screen. 4mg of this meal were then dispersed without grinding in 250 mg of potassium bromide with a pestle and mortar placed in a die, evacuated and pressed into a disc.

The disc was placed in the sample space of a Mattson Alpha Centauri Fourier transform infrared(FTIR) spectrometer having a resolution of 4 cm^{-1} and a spectrum which was the average of 64 scans obtained in the range 4000 - 450 cm^{-1}. Duplicate samples were taken of each wood meal.

Data Analysis

The data has been analysed by using Unscrambler II^R (Standard Version 3.7), chemometrics software supplied by Camo A/S of Trondheim, Norway. The software provides Principal Components Analysis (PCA), Principal Components Regression (PCR) and Partial Least Squares (PLS) regression capabilities for multivariate analysis. A detailed description of the methods, techniques and application of the methods used in the Unscrambler^R software is available [12].

Wood meals from 24 trees were used in the calibration part of the analysis whilst samples from 6 trees were set aside for later validation checks. Absorbances at all the measured frequencies of peaks and troughs in the spectra (34 in number) were included in the X-data matrix entered into the program. The data for the pulp yields, soda charges, hot water solubles and lignin contents were dealt with as separate Y-data matrices.

RESULTS AND DISCUSSION

Faix and Böttcher [13] have demonstrated the effect of the particle size of the wood meal on the absorbances of bands in the mid infrared spectra of woods. In this work the meals all passed a

210 µm screen and the concentration was fixed at 1.6%. Both these numbers are larger than those prescribed by the above authors [13] for their woods but have given reliable results here following baseline correction of the spectra. The meals were not ground during mixing with the potassium bromide to avoid possible changes in their structures [14].

The wood and pulp properties of the 30 individual trees are shown in Table 1 and the FTIR spectra(4000 - 450 cm^{-1}) of four of the wood meals

Table 1 - Wood and pulp properties of individual trees

Sample	Code	Hot Water Solubles[a] (%)	Alkali Solubles[a] (%)	Soda Charge[a] (%)	Yield[a] (%)	Total Lignin (%)
B7	1	2.5	12.7	18.0	58.9	21.0
H2	2	2.8	12.2	17.0	60.2	18.4
KI1	3	2.9	15.3	19.5	57.3	20.6
B4	4	3.0	14.9	22.5	53.5	21.9
KI5	5	3.2	14.7	20.0	56.4	22.8
D2	6	4.1	15.0	18.0	58.8	20.2
D4	7	5.3	17.7	20.5	55.4	19.3
H4	8	6.0	16.9	20.5	55.2	21.8
G5	9	7.8	18.5	27.0	46.8	25.7
S9	10	7.8	18.9	27.0	48.4	23.8
G2	11	7.9	19.2	27.5	45.4	24.0
SC4	12	8.4	17.6	27.0	49.0	23.1
D3	13	8.7	21.6	27.0	46.9	23.6
B3	14	8.7	19.0	26.0	50.9	21.3
SF8	15	8.9	20.6	23.5	51.3	22.6
J3	16	9.3	20.1	27.0	44.4	25.9
SF2	17	9.3	19.2	25.5	48.8	23.4
R6	18	9.8	22.0	26.0	46.9	24.7
SC5	19	10.7	25.3	32.0	41.4	26.0
SF7	20	11.5	22.4	27.0	46.7	24.9
S1	21	12.8	23.5	35.0	40.3	25.6
J1	22	15.7	26.6	35.0	37.6	26.8
R5	23	15.9	22.9	29.0	43.0	25.4
R2	24	18.9	31.8	34.0	38.3	26.3
KI4	1	3.7	14.7	22.5	49.1	25.1
H3	2	4.6	15.0	19.0	57.9	19.3
G10	3	7.1	16.7	20.0	55.8	19.7
S10	4	9.5	20.2	25.5	48.0	22.4
J2	5	8.7	19.7	28.5	46.7	23.6
SC1	6	17.6	31.8	31.5	40.5	24.5

[a] From [10]

covering the range of yields are shown in Figure 1.

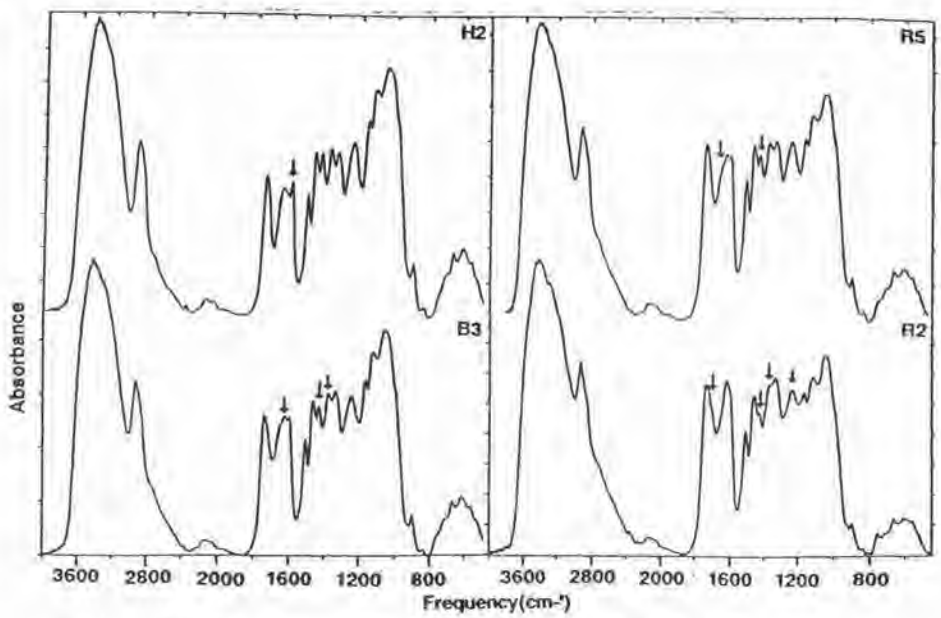

Fig. 1 - Mid-infrared transmission spectra of woods from E. globulus trees.

Sample H2 has the lowest content of hot water and alkali-extractives and R2 the largest. Changes, indicated by arrows, can be seen near 1640, 1620, 1595,1425 and 1240 cm^{-1} as the extractives contents change. The multivariate analysis picked up further important differences near 3010, 1735 and 1050 cm^{-1}. All are for peaks except for 3010 cm^{-1}. The absorbance changes here arise from a broadening of the band centred near 3350 cm^{-1} probably due to hydrogen bonding between the carbohydrate hydroxyl groups and polyphenolic groups in the extractives. Assignments of the main peaks in the spectra have been given previously [15]. Of particular interest is the region 1800 - 1550 cm^{-1} which is shown for the same four woods in Figure 2.

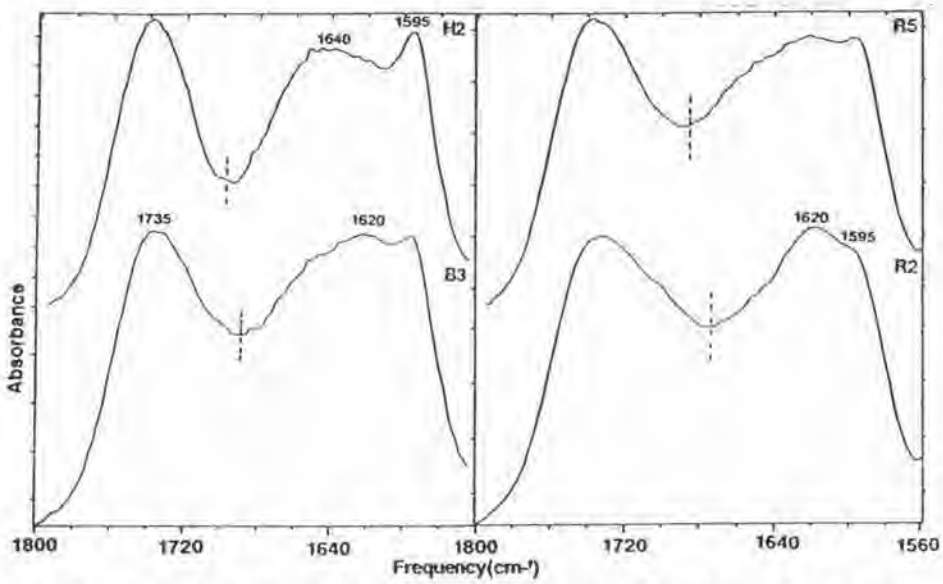

Fig. 2 - Region 1800 - 1550 cm^{-1} of infrared transmission spectra of woods from E.globulus trees.

This shows more clearly the weakening of bands near 1595, and 1650 cm^{-1} and the strengthening of bands near 1620 and 1700 cm^{-1} in the spectra of woods with increasing extractives content.

Multivariate data analysis

Figure 3 shows the frequencies at which the absorbance data was collected for the 30 wood samples for statistical processing. The results for 24 of these samples were entered as a calibration matrix and the remaining 6 (below the line in Table 1) as a validation matrix.

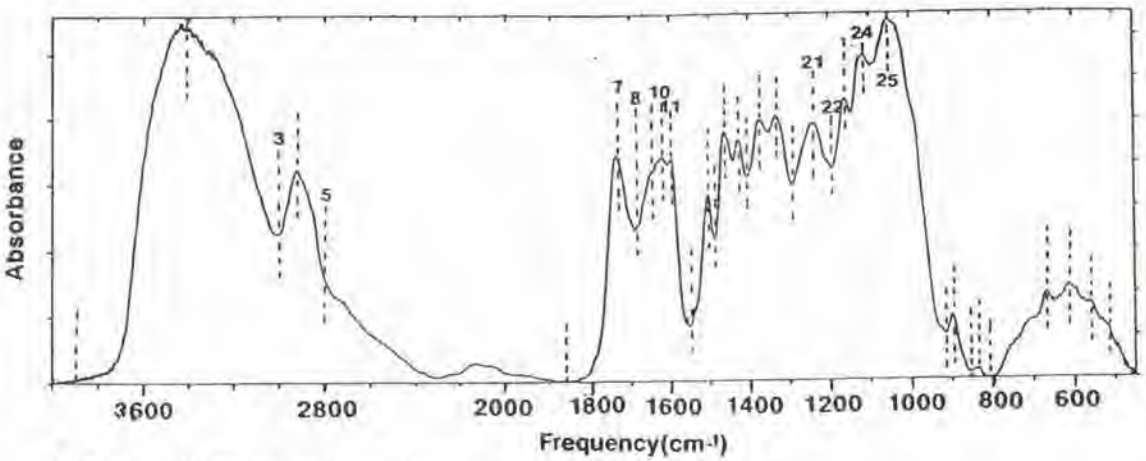

Fig. 3 - Mid-infrared transmission spectrum of E. globulus wood indicating the absorbances used in the multivariate analyses.

The next step after entering the data as matrices is to make a PLS-model as a calibration using cross validation. Here different subsets of the calibration objects are used as validation objects and the model is tested against real test objects.

Table 2 shows the effects on the variances and square error of prediction of increasing the number of factors in the model up to eight.

Table 2 - Explanation of variance and square error of prediction for eight factors (GLOBD)

Fac	% variance explained X	Y	Square error of Prediction
0	.0	.0	44.131
1	72.2	90.0	4.695
2	87.3	93.0	3.951
3	90.0	94.8	4.451
4	91.8	96.2	6.364
5	93.5	97.5	6.703
6	94.5	98.4	6.126
7	95.8	98.9	6.118
8	96.7	99.1	5.417

Although greater amounts of the variance of X and Y are explained by adding further factors the square error of prediction is at a minimum with only two factors and this then is the optimum number for the model.

We can now examine how well the two factor calibration model fits the data from which it was derived. The resultant plot is shown in Figure 6 with a correlation of 0.955 being achieved.

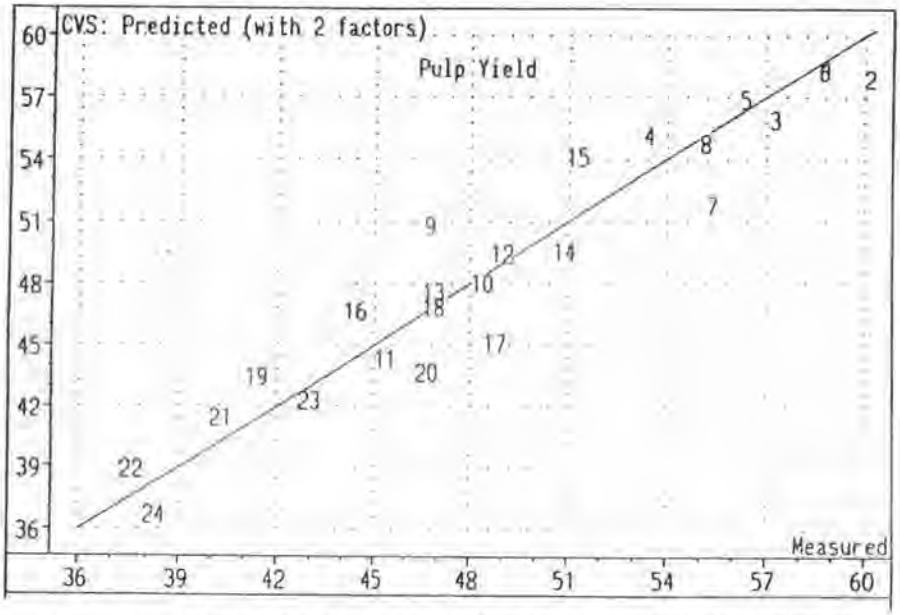

Fig. 4 - Plot of fit for pulp yield values obtained by using a multivariate model(cross validation and 2 factors) derived from absorbances at 34 frequencies vs measured yields. Line of equality is shown.

The experimental data for soda charge, lignin content, alkali and hot water solubles have been analysed by the same procedures but are too lengthy to include in full here. The data derived from chemical tests have been given [16] and those from spectroscopic measurements are shown in Table 3.

Table 3 - Correlation coefficients and residual standard deviations (RSD) of pulpwood quality values calculated from PLS models based on band absorbances in MIR spectra*

Pulpwood Quality	34 bands		10 bands		5 bands	
	Corr. Coeff.	RSD	Corr. Coeff.	RSD	Corr. Coeff.	RSD
Yield	0.955	1.6	0.973	1.8	0.974	1.9
Soda charge	0.937	2.2	0.957	1.8	0.956	1.8
Lignin content	0.804	2.3	0.860	1.5	0.848	1.6
Hot-water solubles	0.908	1.2	0.914	1.1	0.913	1.2
Alkali solubles	0.899	1.9	0.901	1.9	0.899	1.9

In the first of each of the three pairs of columns in Table 3 are the values showing the correlation coefficients for the calibration model and the data used to obtain it and in the second columns the residual standard deviations of the predictions for the validation samples. Correlation coefficients of 0.899 or better are found for the yield, soda charge, hot water and alkali solubles. The correlation coefficient for the lignin data was lowest at 0.80. Plots of the predicted vs measured validation data are given in Figure 5.

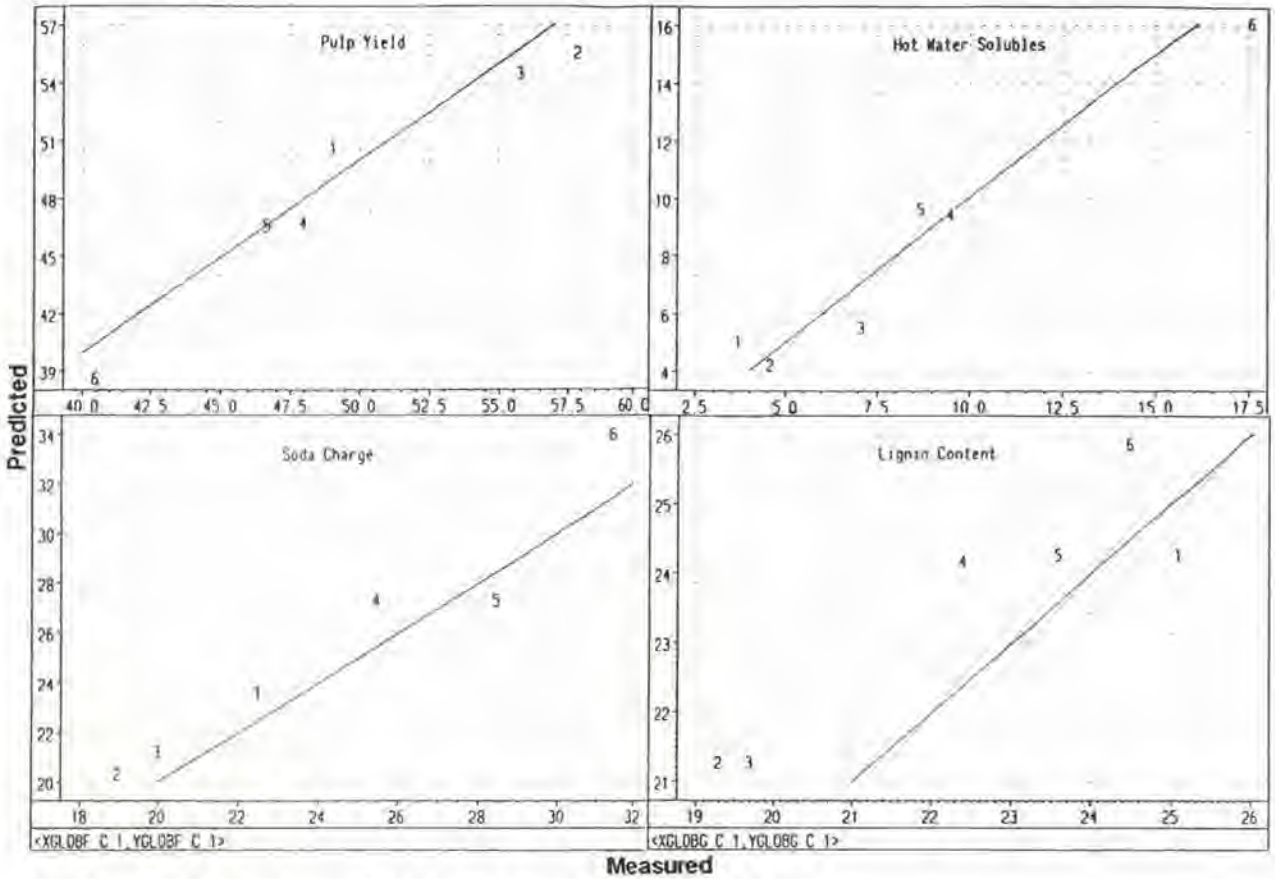

Fig. 5 - Plots of values predicted for pulp yield, soda charge, hot water solubles and lignin contents of the six validation samples by multivariate models obtained from absorbances at 5 frequencies vs measured values of the same attributes. Line of equality is shown.

Four of the six predicted values for pulp yield are low by about 1-2 units. Point 5 is on the line of equality and point 1 above. The predictions look as if they might be biased on the low side. The predictions for hot water solubles are roughly balanced about the line with three being below, one on the line and two slightly above. The predictions for alkali solubles (not shown) are similar to those for hot water solubles except that point 6 lies further below the line. The prediction for point 5 on the soda charge plot is about one unit below the line but the other predictions are all about 1-2 units above. The predictions appear to be biased on the high side. Point 1 predicted for the lignin content is one unit below the line whereas the others are 1-2 units above it. The poor result for lignin content may reflect problems arising from the extraction of the meal with M/10 sodium hydroxide before the Klason lignin analysis. Some lignin may have been solubilised here.

Setting up 34 column matrices is very time-consuming. It was therefore of interest to see how the precision of results was affected by including only those spectral bands whose absorbances contributed strongly to factors 1 and 2 as shown by loading weights plots. For pulp yield these bands were found to be nos 3,5,7,8,10,11,21,22,24 and 25. i.e 10 bands instead of 34. The

results are shown in columns 3 and 4 of Table 5 and 6. On the whole the correlations are somewhat better. In columns 5 and 6 are shown the results of further reducing the number of bands from 10 to 5 with only the absorbances of bands numbered 3,7,8,10 and 25 being included in the analysis. The results hardly differ from those obtained using the absorbances of 10 bands.

CONCLUSIONS

1. A PLS model, constructed by using Unscrambler II chemometrics software, based on absorbances at 34 frequencies in the mid infrared spectra of the woods gave fits having residual standard deviations of 2 units or less for pulp yield, soda charge, lignin content, hot water and alkali solubles.

2. Values of hot water and alkali solubles for validation samples were found to be roughly balanced about the line of equality whereas those for pulp yield and soda charge were offset 1-2 units in opposite directions. The values for lignin content also varied by 1-2 units but were strongly biased on the high side.

3. The quality of the predictions was maintained when the number of bands whose absorbances were included in the model was reduced from 34 to 10 to 5 by including only those absorbances which were shown to be important by their loading weights in the factor analysis.

4. The strong influence of the hot water extractives on the mid-infrared spectra and the pulpwood quality of the wood was evident.

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Extended delignification of mature eucalypt wood

Noel B. Clark, Geoffrey M. Irvine and Concettina Recupero
CSIRO Division of Forest Products, Private Bag 10, Rosebank MDC, Clayton 3169

ABSTRACT

Commercial mature eucalypt wood chips were pulped by the kraft process in laboratory trials designed to isolate the effects of applying the four key principles which underpin the successful extended delignification of northern hemisphere softwoods. The maximum tear index of laboratory handsheets made from each pulp was used as an indicator of pulp strength. It was found that application of three of the four principles (level alkali profile, high initial hydrosulfide ion concentration and low dissolved lignin concentration) improved the strength of the eucalypt pulp at a given Kappa number. However, the beneficial effect of the fourth principle (a low cooking temperature) could not be substantiated.

INTRODUCTION

The kraft process is the most used chemical pulping method in the world today. A hot aqueous mixture of sodium hydroxide and sodium sulfide is used to pulp the wood, removing more than 90% of the lignin originally present in the wood to produce a pulp that is strong, but usually also quite dark. Consequently, multistage bleaching sequences are needed to attain the pulp brightness required for many commercial uses. In the past, these bleaching sequences have been based largely on chlorine-containing chemicals. Unfortunately, the reaction of these chlorine compounds with residual organic material such as lignin can give rise to chlorinated organic substances in the pulp and in the bleachery effluent - materials which are often toxic and persistent in the environment. If delignification could be extended in the pulping stage, bleaching would be made easier. Chemical charges could be reduced or chlorine compounds could be substituted with less hazardous bleaching chemicals.

Extended delignification procedures are now a commercially proven way of increasing the removal of lignin from wood. However, most research and production experience has been confined to northern hemisphere softwoods. Eucalypt pulping is known to differ significantly in its kinetics and chemistry. The aim of Project A2b in the National Pulp Mills Research Program is to evaluate the application of existing extended delignification procedures to the kraft pulping of eucalypts, both mature native-grown eucalypts and young plantation-grown trees. Commercial extended delignification procedures are extremely complex, and as a result difficult to simulate in the laboratory. Initially, therefore, the research has focused on the principles which underlie the successful extended delignification of other wood species and which are now moderately well understood. This paper details the results of this preliminary work.

BACKGROUND

In a conventional kraft cook, the charge of active chemicals, which comprises a mixture of sodium hydroxide and sodium sulfide, is all added at the start. The hydroxide is capable of opening the alkyl aryl ether bonds in the lignin to give smaller fragments that then become soluble in the alkaline medium. The sulfide accelerates the lignin dissolution, partly by reacting with groups in lignin that would otherwise initiate condensation; and, by the same sulfidation reaction, facilitating the cleavage of the alkyl aryl ether bonds (Rydholm 1965).

The alkaline pulping liquors can also attack the polysaccharides, including the cellulose. Fortunately, under normal pulping conditions, the rate of attack on cellulose is much slower than the rate of attack on the lignin. However, towards the end of a conventional kraft pulp, in the so-called residual phase of the cooking process, the amount of unreacted lignin is small, while the concentration of reaction products in solution is high. These conditions slow the rate of delignification, leading to an increase in cellulose degradation. Pulp yield decreases while the consumption of alkali per unit of lignin removed increases (Grace et. al. 1989). As a result, reducing the residual lignin content in the pulp by conventional means, such as increasing the alkali charge or the cooking time, can cause serious reductions in pulp yield and strength.

Years of work in the late 70's and early 80's at the Swedish Forest Products Research Lab (STFI) and the Swedish Royal Institute of Technology led to the identification of three key factors which allow delignification to be extended without unacceptable deterioration in pulp properties (Hartler 1978, Norden and Teder 1979):

1. The alkali concentration should be levelled out over the duration of the cook as far as possible.
2. The concentration of hydrosulfide ions should be as high as possible, especially at the beginning of the main or bulk delignification phase of the kraft cook.
3. The concentration of dissolved lignin and sodium ions in the liquor should be as low as possible, especially in the final or residual phase.

Levelling out the alkali concentration means reducing the chemical concentration at the beginning of the cook and increasing it in later stages, providing a milder chemical environment for the polysaccharides while still providing a driving force for the delignification reactions. A high initial hydrosulfide ion concentration allows a faster and more complete lignin breakdown during bulk delignification. Reductions in lignin and sodium ion concentration allows further delignification and diffusion from the fibres to occur.

A fourth factor, temperature, was found to be important by Kubes et. al. (1983). The rate of polysaccharide depolymerization increases faster with increasing temperature than the rate of delignification. Thus a lower pulping temperature should improve the selectivity for delignification over cellulose depolymerization. In addition, there are advantages in having a low temperature at the

beginning and at the end of the cook. The former allows impregnation without the risk of consuming alkali by reactions on the surface of the wood chips, and the latter can reduce fibre damage caused by blowing the cooked chips from the digester, particularly in the case of softwoods.

MATERIALS AND METHODS

The wood used was a sample of mature eucalypt wood chips from the Eden forest resource in south-east New South Wales. The chips were air-dried, and screened to remove fines and any material thicker than 8 mm. Individual 600 g (oven-dry mass) samples were assembled and stored in sealed plastic bags.

Two sets of reference pulps were produced by pulping the wood chips in either a MK 6-litre recirculating digester or in 3-litre autoclaves heated in an air bath. In these reference cooks, the wood chips were heated to 170°C in one hour and held at this temperature for a further two hours. The initial sulfide charge was 10% (calculated as Na_2O on o.d. wood) and a range of initial alkali charges were used to obtain separate pulps with a spread of residual lignin contents. After pulping, the chips from each cook were fiberized in a disintegrator, and washed with cold water to remove spent liquor. Shives were removed by screening the pulps through a Packer screen with 0.2 mm wide slots. After dewatering in a press and crumbling, each pulp was analysed for residual lignin content, determined as Kappa number according to Australian Standard AS/NZS 1301.P201m-86. Handsheets were prepared according to Australian Standard AS/NZS 1301.P203s-80 from pulp beaten in a PFI mill using 24 g (o.d.) pulp charge, 10% stock concentration and 1.77 N/mm beating load (AS/NZS 1301.P202s-80), and tested according to AS/NZS 1301.P208s-89. The maximum tearing resistance of the handsheets developed with beating of the pulp was used as the indicator of pulp strength.

Several separate series of cooks were carried out to isolate the effect of each of the four key principles of extended delignification. An additional series combined the factors that were found to be effective. The variations from the standard cooking conditions in each series are detailed below. For these experiments, it was necessary to modify the MK laboratory digester to permit sampling and adjustment of pulping liquors while cooking is in progress, and to develop computer-assisted procedures for rapid liquor analysis and adjustment.

Controlled alkali profile

For these cooks, the initial alkali concentration was set at a low level - much lower than for a conventional cook. Shortly after commencement of the cook, the pulping liquor was sampled, and analysed for sodium hydroxide and sodium sulfide composition. The alkali required for conformation to a pre-determined liquor profile was calculated, and the required volume of fresh pulping liquor introduced into the digester by means of a high pressure displacement pump. The cycle of sampling, analysis and addition gave a sawtooth alkali profile which closely approximated the desired alkali level in each cook.

Sulfide concentration

In this series of cooks, the effect of a lowered sulfide concentration was studied by commencing conventional cooking at a significantly lower initial sulfide concentration (3% on an o.d. wood basis) than the 10% used for the series of reference cooks. The two sulfide levels correspond approximately to the extreme values of sulfidities (ratio of sulfide to total alkali) used in commercial practice. These cooks were carried out in the 3-litre air bath.

Lignin removal

At a pre-determined time during the later half of each cook in this series, the free cooking liquor was drained from the MK digester and replaced with fresh liquor. The replacement liquor was essentially identical in quantity, composition and temperature to the cooking liquor at the time of draining, except that dissolved lignin was absent. This was achieved by measuring the alkali and sulfide concentrations in the cooking liquor at the relevant time in a previous (identical) cook, using the procedure referred to above for analyzing the alkali and sulfide levels in the digester, making up the fresh liquor to this composition, and preheating it in a separate pressure vessel before transferring it to the MK digester by nitrogen over-pressure at the proper time.

Temperature

Conventional kraft cooks were carried out in the MK digester with the maximum pulping temperature reduced from 170°C to 165°C. The H-factor (integrated reaction rate constant) was kept constant at 2000, which meant that the total cooking time was increased from 3 to 4 hours.

RESULTS AND DISCUSSION

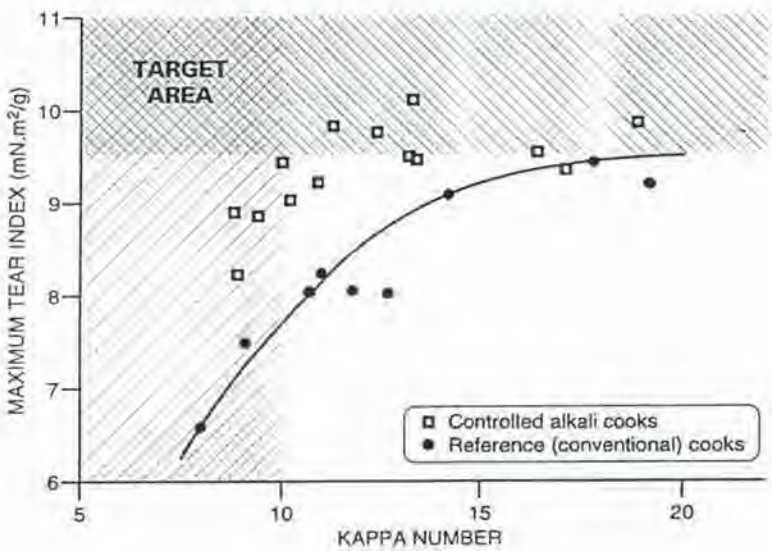
There was significant scatter in the tearing resistance and Kappa number results of the cooks. This was probably due to a combination of accumulated random errors in the preparation and testing of the handsheets, and, more importantly, variation in the quality of the wood chips used in each cook. Since the wood chips are a mixture of many tree species and ages from native-grown eucalypt forest, variation from the latter source is unavoidable.

The aim of extended delignification procedures is to reduce residual lignin content while maintaining pulp strength. Reasonable success for this particular wood sample is represented by the shaded target area on the following graphs. The boundaries of the target area were chosen to correspond to the tear index of a conventional bleachable-grade kraft pulp at less than half the normal Kappa number of about 20.

Controlled alkali

Figure 1 compares the tear indexes and the residual lignin contents of the pulps produced in the controlled alkali experiments with those of the conventional pulps. The tear indexes of the pulps produced by the conventional kraft process decreased with decreasing Kappa number, slowly at first but then more rapidly. Although the same trend was seen in the controlled alkali pulps, this occurred at significantly lower residual lignin contents, demonstrating a positive effect from the first principle of extended delignification. It is clear, however, that levelling the alkali profile is not by itself sufficient for the resulting pulp properties to fall within the tear-Kappa number target area.

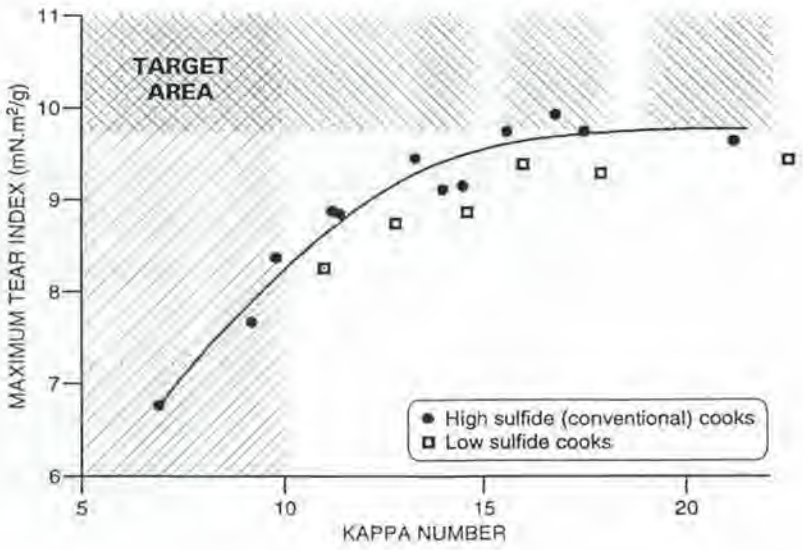
Figure 1
STRENGTH *vs* LIGNIN CONTENT



Sulfide concentration

Figure 2 compares the results of two series of kraft cooks carried out with different initial sulfide concentrations.

Figure 2
STRENGTH *vs* LIGNIN CONTENT

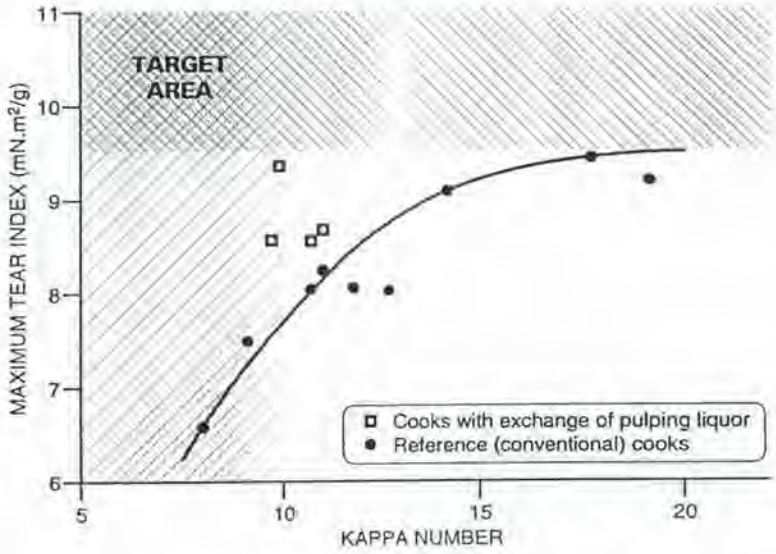


The pulps from the high sulfide cooks had a slightly higher tear index at a given Kappa number than those from the low sulfide cooks, consistent with a beneficial effect from the second principle of extended delignification.

Lignin removal

Figure 3 illustrates the results obtained when lignin is removed from the pulping liquor during the later half of an otherwise conventional cook by exchanging the pulping liquor for fresh liquor of a similar composition.

Figure 3
STRENGTH *vs* LIGNIN CONTENT



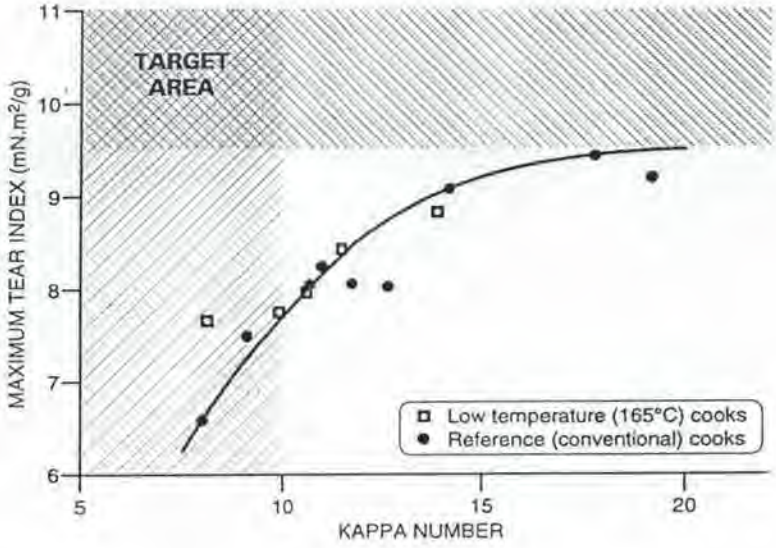
The procedure also appears to have resulted in an improved tear - Kappa number relationship, consistent with a beneficial effect from the third principle of extended delignification.

Temperature

Figure 4 illustrates the effect of reducing the temperature of a conventional cook from 170°C to 165°C, without reducing the H-factor.

No uniform improvement is apparent. Only the lowest Kappa number pulp of the low temperature series had a tear index higher than might have been expected. Given the inherent variability of the wood sample, this result may have arisen by chance. However, it may be that the 5°C decrease in temperature is too small to give a detectable improvement in pulp strength. Another series of cooks at 160°C will be carried out at a later date to test this hypothesis.

Figure 4
STRENGTH *vs* LIGNIN CONTENT

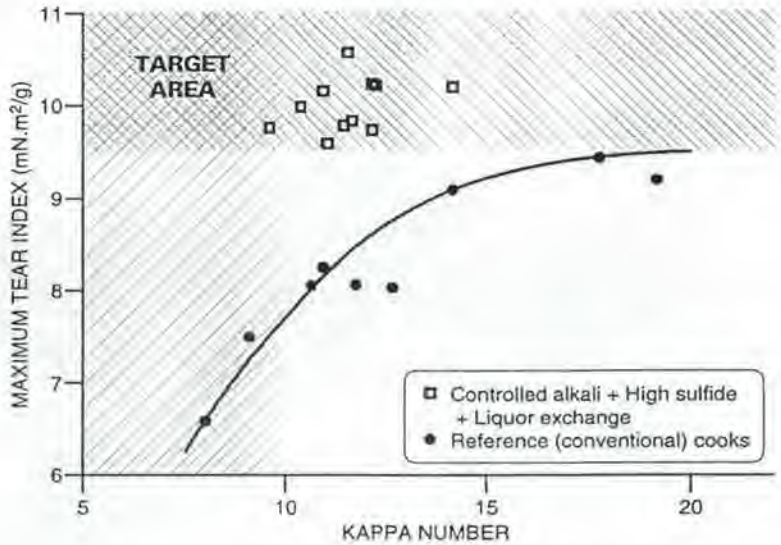


Combined effects

On an industrial scale, the principles of extended delignification would normally be used in combination. Batch processes such as RDH and SuperBatch use a combination of a levelled alkali profile and high sulfide pre-treatment, while the modern continuous pulping processes may use all four principles.

Figure 5 gives the results when controlled alkali, high sulfide, and lowered lignin are all applied at once. A substantial improvement in tear index at a given Kappa number is evident over the use of a single factor alone.

Figure 5
STRENGTH *vs* LIGNIN CONTENT



CONCLUSION

It was found that three of the four principles that are understood to apply to the extended delignification of northern hemisphere softwoods (level alkali profile, high initial hydrosulfide ion concentration and low dissolved lignin concentration) improved the tearing strength of the eucalypt pulp at a given Kappa number. However, no evidence was found for a beneficial effect of the fourth principle, lower cooking temperature, although further work is planned to confirm this point.

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ADDING VALUE TO SECONDARY TIMBER PRODUCTS USED IN HORTICULTURE BY LABORATORY ANALYSIS AND QUALITY CONTROL.

David P. Wraight
Forest Service - QDPI
PO Box 631 Indooroopilly Queensland 4068

ABSTRACT.

To the timber industry secondary timber products are largely a waste disposal problem and any way of being relieved of them at nil cost or small return is icing on the cake.

To the horticultural industry however secondary timber products are an important resource which is actively researched.

This paper explains to the producer of the secondary timber products how the horticultural industry uses the products and the nature of their commitment to them. It argues that to improve its returns from this resource the timber industry has to take more control and catch up with the horticultural industry in knowledge and understanding of the product.

It is proposed that a suitable starting point for this would be product characterisation and quality control aided by laboratory analysis. A set of tests for product characteristics is proposed and described and the relevance of these to the market is explained in the context of the uses to which the horticultural industry puts secondary timber products. The concept of quality assurance and the trend towards it is mentioned.

INTRODUCTION.

This paper addresses the issue of laboratory analysis of secondary timber products as sold to the horticultural industry for the purpose of product characterisation and quality control, and argues that this would be a value adding exercise. It has its origins in the coincidence of two events:

Firstly the author had begun work in the Chemistry and Wood Preservation Section of the QDPI Forest Service to analyse potting mixes and the components of potting mixes for QDPI Forest Research Institute Scientists, based on the Australian Standard AS3743-1989.

And secondly the author happened to see an episode of the television programme Burke's Backyard in which Don Burke reviewed mulching materials including were a number of forest residues and about which he passed comments to the effect that

i) some of the products offered for sale contain naturally occurring chemicals that leach out and kill plants.

ii) the products are highly variable and the industry has poor quality control.

So with this parentage the paper argues that improved returns for secondary timber products depend in part on the producers increasing their knowledge of the products and the uses to which they are put and also upon increased quality control.

IDENTIFYING THE SECONDARY TIMBER PRODUCTS IN QUESTION.

The products are:

SAWDUST, SHAVINGS, WOOD CHIPS, and BARK

OBSERVATIONS ABOUT THESE SECONDARY TIMBER PRODUCTS AND THEIR PRODUCTION

As an indication of the quantities of material available the following table has been adapted from the 1991-92 Annual Report of the Queensland Forest Service, and data gathered by TRADAC.

PRODUCTION OF SELECTED SECONDARY TIMBER PRODUCTS (QUEENSLAND 1991-92)

	PINE	HARDWOOD	CYPRESS
VOLUME REMOVED (m^3)	709930	608937	164356
SAWDUST	97970 (13.8%)	89514 (14.7%)	24325 (14.8%)
CHIPS[3]	199490 (28.1%)	27402 (4.5%)	
SHAVINGS	70993 (10.0%)	18268 (3.0%)	2630 (1.6%)
BARK	3.04%[2]	see note 1	see note 1

NOTE 1. Hardwood and Cypress bark are currently not separated in the normal sawmilling process. These products are generally included with the wings.
NOTE 2. Bark volumes are given as loose volumes rather than solid wood volumes.
NOTE 3. Wing, hearts and dockings are all used to produce chips. The percentage volumes given above reflect the current level of in-house processing of secondary products which exist within the three species groups.

In many cases these secondary timber products are regarded as waste by the miller and as such present a disposal problem. At the site of production they are often seen as mounds taking up valuable space and land and can present a dust and fire hazard. Large quantities of them have been used as land fill or burnt in an effort to dispose of them.

Some producers are fortunate in that somebody with a use for the material will buy it and usually supply the transport to remove it.

Before any of the arguments for the value-adding potential of quality control and associated lab testing can have effect the idea that this is waste needs to change. As long as this attitude prevails, the owner will not be inclined to invest in it any further.

OBSERVATIONS ABOUT THE HORTICULTURAL MARKET FOR THESE PRODUCTS.

The horticultural industry employs secondary timber products for three main purposes:

LANDSCAPING, MULCH, and GROWING MEDIA

Accurate data about the amounts and types used is not available. A survey by Dr K V Sharman of QDPI in 1992 however revealed widespread use of secondary timber products in a variety of horticultural contexts, but was unable to report quantities. Some undergoes a degree of processing to be resold as a commercial product - landscaping supplies or potting mix, but a lot finds its end use in the horticultural industry in the form of growth media. Many nurseries source it directly from the sawmiller and make they own potting mix with it.

DESCRIBING HOW AND WHY THE HORTICULTURAL INDUSTRY USES SECONDARY TIMBER PRODUCTS.

It is important to know why the product is sought after or valued because only with an understanding of this can it be improved and value added.

Landscaping aesthetics/construction

The material used for landscaping has two broad functions, one aesthetic, the other horticultural. Generally the secondary timber products used are bark pieces and wood chips. The aesthetic function is as an attractive ground cover with a natural appearance. The horticultural function is that as a ground cover they inhibit the growth of weeds, help the soil retain moisture by reducing evaporation and they insulate the soil from large changes in temperature.

Bark and wood chips are used because they are inexpensive, easy to obtain and easy to handle. They also resemble, more than any other material used, the naturally occuring organic litter. They allow the passage of water and of air unlike some of the alternatives.

The main competitors to the secondary timber products in this area are: pebbles, gravel and sheet plastic.

Mulch.

Mulches are applied to soil as a ground cover and a protection for the roots of freshly planted stock. They do not serve the aesthetic function of the ground covers mentioned before but do have the added benefits of improving soil texture and fertility by adding organic matter.

Mulches can be made partly or wholely from composted secondary timber products.

The main competitors to the secondary timber products in this area are mulches based on other organic material such as grass clippings, straw, baggasse, or peat ammended by mixing with manure or blood and bone or even seaweed.

Growing Media

Bark sawdust and shavings are used to make potting mixes by the manufacturers of commercial potting mix and by nurseries for their own use.

The smaller bark chips, wood shavings and sawdust are particularly valued for the way they affect such properties as the air filled porosity and bulk density of a growing medium. The roots of plants require exposure to air as well as moisture and this requirement differs from species to species. A growing medium therefore has to some extent to be tailored to the plant to be grown in it.

Often a user of potting mix will have a requirement for a medium of a certain density. For example, indoor landscapers and plant hire companies like low densities to keep pot weights down.

The main competitors to the secondary timber products in this area are: expanded polysyrene beads, vermiculite, bagasse, straw, coir, peanut shells, rice hulls, scoria, zeolite and perlite.

A DISCUSSION OF HORTICULTURAL PROBLEMS, RESEARCH, AND STANDARDS IN RELATION TO SECONDARY TIMBER PRODUCTS.

When using secondary timber products the horticultural industry has encountered three main problems.

- Acidity: Wood is quite acidic and this acidity can affect the growth of plants. For example acidic

components leaching from wood chips that have been spread as a ground cover can so change the soil pH that nutrient availablity is affected. Similarly the acidity caused by a wood component of a growth medium may lead to nutrient deficiencies in the plants growing in it.

▾ Phytotoxins: These are naturally occuring water extractable compounds in timber which are toxic to plants. In general they are polyphenolic compounds commonly known as tannins. They can be leached from bark, wood chips or sawdust by normal irrigation and will prevent germination, kill seedlings or inhibit the growth of plants. Not all barks or woods contain these compounds in sufficient quantities to be a problem. The barks of radiata pine (*Pinus radiata*) and slash pine (*Pinus elliottii*) are particularly bad in this respect whereas hoop pine (*Araucaria cunninghamii*) is very much less of a problem. Problematic levels of these toxins are found in most Australian hardwoods; notable exceptions are jarrah (*Eucalyptus marginata*) and karri (*E. diversicolor*).

▾ Nitrogen demand. Wood or bark is decomposed by the actions of microorganisms which consume inorganic forms of nitrogen in the process. This nitrogen is then no longer available to plants. In practice secondary timber products can consume so much of the inorganic nitrogen that plant growth is severly impared. This consumption of nitrogen is termed "drawdown".

ACIDITY AND POLYPHENOL CONTENT IN A RANGE OF COMMERCIAL TIMBERS.

Timber species Common name	Latin name	pH	Polyphenols % (tannic acid equivalent)
Blackbutt	*Eucalyptus pilularis*	3.12-3.25	4.6-13.5
Peppermint	*E. piperita*	3.15	11.0
Turpentine	*Syncarpia glomulifera*	3.21	15.2
White Mahogany	*Eucalyptus acmenioides*	3.24	8.72
Coastal Grey Box	*E. bosistoana*	3.43	15.8
Tallowwood	*E. microcorys*	3.55	17.0-17.3
Bangalay	*E. botryoides*	3.56	4.37
Mountain Grey Gum	*E. cypellocarpa*	3.57	12.1
Yellow Stringybark	*E. muellerana*	3.62	11.6
Sydney Blue Gum	*E. saligna*	3.65-3.80	5.78-10.3
Red Ironbark	*E. sideroxylon*	3.66	10.4-11.0
Flooded Gum	*E. grandis*	3.84	5.24
Spotted Gum	*E. maculata*	4.25-4.68	4.46-6.05
Grey Ironbark	*E. paniculata*	4.88	6.92
Brush Box	*Lephostemon confertus*	4.55	1.23
Hoop Pine	*Araucaria cunninghamii*		
Slash Pine	*Pinus elliottii*		
Radiata Pine	*Pinus radiata*	4.2-4.7	

The horticultural industry has long known that all of these problems can be aleviated by first ageing and/or composting the wood waste. This certainly has the desired effect of removing phytotoxins and moderating nitrogen drawdown but it also has the effect of changing the wood wastes such that they lose some of their desirable properties. This situation has lead to a considerable amount of horticultural research into the uses and performance of secondary timber products.

Composting is a major area of research. The horticultural industry has learnt how best to compost the various wood wastes and to overcome the problems associated with it.

Another area of research has been into the testing and quality control of potting mix of which the secondary timber products can form a large part. This has lead to the formulation of an Australian Standard for potting mix, AS3743-1989. This sets standards for the important parameters of

potting mix depending upon their intended use and more importantly describes methods of test.

It is important to realise that the standard applies only to finished potting mix and not the individual components that go into a mix. However the standard adopts an important practical principle in the design of the test methods which is important to the components as well. That principle is that the test methods approximate the practical conditions under which potting mix is used, the intention being that the results obtained from these testing methods have a truer relationship to the conditions of use and are not just highly reproducible but laboratory bound numbers.

The AS3743-1989 describes methods of test for the following parameters and chemical analytes:

Physical Properties:

Air filled porosity	Bulk density
Wettability	Large pieces
Total water holding capacity	

Chemical Properties:

pH	Sulfur	Iron
Electrical conductivity	Calcium	Copper
Nitrogen as ammonium	Calcium/Magnesium ratio	Zinc
Nitrogen as ammonium plus nitrate	Potassium/Magnesium ratio	Manganese
Phosphorus	Sodium	Boron
Potassium	Chloride	

Biochemical Indexes:

Toxicity	Nitrogen Drawdown Index

This is related because it emphasizes how seriously the horticulturalist takes this product and demonstrates the investment in terms of research and product support that they are prepared to make. By contrast the supplier of the raw materials is usually years behind.

COMPARING AND CONTRASTING THE ATTITUDES OF THE TIMBER INDUSTRY AND THE HORTICULTURAL INDUSTRY TOWARD SECONDARY TIMBER PRODUCTS.

In recent years the timber industry has increased its efforts to make more out of secondary timber products. There has however been little forthcoming in the form of investment in value-adding exercises by the industry itself. The usual sort of approach is typified by the publication "Business Opportunities with Secondary Timber Products: A Prospectus for Enterprising Business" which helps to spread awareness of the products but indicates that the timber industry is still relying on others to take it off their hands as is. It is clear that to the producer of secondary timber products they remain a waste problem and that while this attitude prevails the producer is not likely to invest in any value-adding exercise.

On the other hand the horticultural industry, which represent only a small subset of the uses identified for secondary timber products in the document mentioned, are able to add value to it. This industry has developed a considerable body of knowledge about the secondary timber products and actively invests in developing products made from them. They do this with very little input from the producer. The art, knowledge and science belongs to the value-adder and it is they who profit greatly by it.

For the timber industry to improve its returns from its secondary production it must first reclaim the property in an intellectual sense. It must regain control of the commodity through knowledge

of the potential value of the product. The message for the creators of the resource is "know thy product".

It is suggested that as the horticultural consumption of the product is the best established it provides the most likely starting place for this exercise and that product knowledge begins as product characterization by laboratory analysis.

It is proposed that by taking AS3743-1989 as a basis, the owner of the secondary timber product resource can gain valuable knowledge of the resource that will aid in getting higher returns.

NOMINATING AND DESCRIBING THE TESTS THE TIMBER INDUSTRY MAY EMPLOY WITH THE INTENTION OF ADDING VALUE TO SECONDARY TIMBER PRODUCTS.

It is suggested that only a subset of these are applicable to the materials we are concerned with here. It is argued that there is value in applying the following subset of tests to secondary timber products going to or intended for the horticultural market.

- pH
- Toxicity
- Nitrogen Drawdown Index

It is also suggested that a chemical determination of polyphenols may be substituted for the toxicity test as most of the phytotoxicity is caused by these compounds and it is quicker.

Briefly the tests comprise:

The pH test.

An aqueous extract is prepared using a particular ratio of solid material to water, in this case 1:5. The water phase if decanted or filtered off to separate it from the solid material and the pH of this water phase is measured.

Fresh wood material imparts reasonably high pH to the water because it contains soluble acidic components.

Nitrogen Drawdown Index.

This test measures the rate at which a substrate uses up soluble nitrogen. The substrate is leached with water then charged with a solution of potassium nitrate of known concentration (usually as 75mg(N)L^{-1}) and allowed to incubate for 4 days. After incubation the amount of nitrate remaining is measured and the ratio of this to that which was present initially is the nitrogen drawdown index.

All secondary timber products, particularly if fresh or near fresh, record low NDI i.e. they use up a large proportion of the soluble nitrogen. So much so in fact that Sharman recommends the use of 150mg(N)L^{-1} as the charging solution so that a measurable amount of nitrate is left after the incubation period.

Generally sawdust, bark, shavings and chips all yield NDI < 0.1 unless they have been significantly composted.

After phytotoxicity it is this nitrogen demand of wood which is responsible for poor plant growth in media which contain it. The phytotoxic effect disappears sooner with adequate leaching, as the chemicals are removed or polymerise under moist conditions. The nitrogen demand is a longer lasting phenomenon.

The Toxicity test.

The toxicity test is to measure the growth of a test organism (a rapidly growing seedling) in the substrate and compare this to a standard mixture.

Performing this test in a woody substrate provides a dramatic demonstration of the harmful and therefore undesirable effects of the leacheable phytotoxins present in wood. Radish seedlings for example will grow roots some 50mm long in the standard peat/perlite mixture but will average less than 5mm in a substrate of hardwood. This test has the disadvantage of requiring five days to perform.

Polyphenol test.

A more rapid estimate of phytotoxicity may be offered by a chemical determination of the leachable polyphenols in a wood sample. This is done by preparing a water leachate of the wood material in question and using a colorimetric reagent specific for polyphenols.

THE VALUE-ADDING SCENARIO.

It is proposed is that by investing in a few simple tests of the product the producer can gain an advantage in the market.

Creative use of the test results could be for example that a sawmiller has an aged pile of chips/bark that he wishes to sell to a landscaper, if he the sawmiller can show the landscaper that these chips have a low level of polyphenolic phytotoxins and a moderated nitrogen drawdown and pH because of the length of time that they have been piled up in his yard then he has a product more appealing to the landscaper who now does not need to tie up valuable space storing the chips till they are mature.

Similarly sawdust or shavings for use in potting mix could be shown to the nurseryman to be well on its way to being useable because it has already partially composted in the yard.

In fact the scenario continues because the sawmiller can do simple things by way of storing secondary products that will hasten their maturation to a more readily useable product. For example the shaping of the storage mound and watering the mound are ways of hastening the leaching of acid and phytotoxic components of the material and of promoting microbial growth which can moderate the nitrogen drawdown of this material. The sawmiller could quite easily cooperate with the horticultural client in achieving this. This makes sense considering that the miller probably has the space and heavy equipment to fulfil this task whereas the horticulturalist may not. Thus the sawmiller is able to put his captial to more uses.

A WORD ABOUT QUALITY ASSURANCE.

There is a growing acceptance, even demand for products and production methods of all kinds to conform to standards of quality. The Australian Standards 3900 series, which parallel the ISO9000 series, deals with quality. Suppliers and producers are able to obtain accreditation under these standards, accreditation that means for example that they are preferred over others by consumers such as the Queensland government - as stated in its purchasing policy and guidelines. Thus there is an all too real commercial consequence of these concepts.

The comment has been made that the industry has poor quality control. What was meant by that? This was taken to mean that the product was so variable that it was not fully reliable. Now there is probably little that the producer can do about the inherent variability of the resource but there is something, in fact a lot, that the producer can do about measuring the quality and therefore be more judicous about its sale. Currently no differentiation is made or attempted and the entire production is for sale at the same low price. If it can be demonstrated that some is superior to the

rest then the producer is in a position to ask a higher price for it.

By engaging in product testing and characterization the producer begins to practise quality control. By planning these activities, say along the lines of the AS3900 series, the producer begins to practise quality assurance.

CONCLUSIONS.

There appears to be an obvious starting point for value adding to secondary timber products and that is by the application of already established methods of test in the area of the horticultural end-use for these products.

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CHARACTERISATION OF THE CHLORINATED ORGANIC SUBSTANCES IN FILTRATES FROM BLEACHING EUCALYPT KRAFT PULP

Terrence J. Smith, Ross H. Wearne and Adrian F. A. Wallis

Division of Forest Products, CSIRO, Private Bag 10, Clayton, Victoria 3168

ABSTRACT

Oxygen-delignified kraft pulps from mature and young eucalypt woods were bleached with sequences involving chlorine (C), chlorine dioxide (D) and alkali-oxygen (EO). The bleaching filtrates were analysed for chlorinated organic compounds by gas chromatography with the use of a mass selective detector. Chlorinated compounds found included a range of chlorinated phenols, neutral compounds, aliphatic acids and phenolic acids. A total of 41 chlorinated phenols were identified, mostly in the EO filtrates following prebleaching with chlorine {(EO)[C]} and only few in the (EO)[D] filtrates. 2-Chlorosyringaldehyde was the only significant chlorinated phenol obtained after D prebleaching. There was no indication of differences in the types of chlorinated phenols obtained from the mature and young eucalypt samples, although there were higher levels of phenols in filtrates from the younger wood sample. The dominant chlorinated neutral compounds found in the filtrates were chloroform, chloroacetones and chlorodimethylsulfones. Most chloroform and chloroacetones were found in the C-stage filtrates, while chlorodimethylsulfones were found in both C and D-stage filtrates to the same extent. An abundant neutral compound, a chlorohydroxypypranone, was found in C-stage filtrates and in D-stage filtrates after acidification. The chloroacetic acids were the only aliphatic acids detected and were found in all filtrates examined. A method for the analysis of chlorinated phenolic acids involving sequential acetylation and methylation of the extracts was devised. Three chlorinated phenolic acids were identified in the filtrates as their methyl ester acetates. The total amount of chlorinated compounds analysed was consistently higher in the young eucalypt sample than in the mature sample, and correlated well with the generic parameters AOX and EOX.

INTRODUCTION

There is continuing interest in proposals for a new kraft pulp mill in Australia using eucalypt wood resources. The National Pulp Mills Research Program was set up following the demise of the Wesley Vale pulp mill project in 1989 to provide information for clarifying the Commonwealth Government environmental guidelines for new kraft pulp

mills (Nelson and Crossland, 1992). The focus of worldwide environmental attention related to kraft mills has been on the chlorinated organic substances in the effluents from bleaching of the pulps with chlorine-containing reagents. However, although certain chlorinated organic compounds are known to have biological effects, recent reports suggest that the biological effects of effluents from modern kraft pulp mills have little or nothing to do with chlorinated organic substances (Lehtinen,1992).

Although the chlorinated organic components of bleaching effluents have been extensively investigated, the studies have mainly involved effluents from softwoods using conventional bleaching sequences. Little is known about the chlorinated organic substances in effluents from bleaching eucalypt kraft pulps, particularly those from mature eucalypt woods. In addition, pulping and bleaching technology is undergoing rapid change in an effort to minimise the formation of chlorinated organic substances during bleaching (Berry *et al.*, 1991), and there is little information on the chlorinated substances in these effluents. Consequently, a study of the chlorinated components in effluents from bleaching of kraft pulps from commercial eucalypt woods using modern bleaching sequences was initiated under the auspices of the National Pulp Mills Research Program.

The eucalypt wood resource in Australia is slowly changing from mixed mature species to young plantation species. Thus both wood types were used in the present study. Woods from mature eucalypt species are generally rich in polyphenolic extractives, a portion of which may remain in the unbleached pulps after alkaline pulping (Gardner and Hillis, 1962). Following bleaching of the pulps, these polyphenolic residues may give rise to chlorinated organic compounds which have not previously been found in bleaching filtrates (Anon., 1989). Among these could be chlorinated phenols derived from condensed tannins (proanthocyanidins) and hydrolysable tannins (ellagitannins).

The chlorinated organic compounds occurring in bleaching effluents may be classified as chlorinated phenolic, neutral and acidic compounds (Carlberg, 1991; LaFleur, 1991). Chlorinated phenols in the bleaching effluents are typical chlorinated lignin degradation products containing methoxyl groups, *e.g.* guaiacols and syringols, and those products without methoxyl groups, *e.g.* phenols, catechols and pyrogallols, which may derive from either lignin or extractives. Chloroform, chloroacetones and chlorodimethyl-sulfones have been identified as dominant components of the neutral fraction, while minor amounts of additional chlorinated hydrocarbons, ethers, aldehydes, ketones, lactones and thiophenes have been noted. The chlorinated acidic compounds occurring in bleaching effluents are largely aliphatic acids, principally chloroacetic acids. This report describes the analysis of low molar mass chlorinated compounds present in filtrates from bleaching oxygen-delignified eucalypt kraft pulps with sequences involving chlorine and chlorine dioxide and subsequent oxygen-reinforced alkali extraction.

MATERIALS AND METHODS

Preparation of bleaching filtrates

Samples of woodchips from mature mixed eucalypt species and 10-year-old plantation *Eucalyptus globulus* trees were kraft pulped and oxygen delignified to a target Kappa number 9.5. The pulps were bleached with chlorine (C), chlorine dioxide (D) or a 70:30 D:C mixture (based on active chlorine) with an active chlorine multiple of 0.19. After removal of the residual chlorine by reaction with sodium sulfite, the filtrates were acidified to pH 1-2 with 18M sulfuric acid and stored at -12°C until required for analysis. The oxygen-reinforced alkali extraction of the pulps was carried out with 1.5% sodium hydroxide at 115°C for 30 min at 10% stock concentration and oxygen pressure 780 kPa. The filtrates were acidified and stored as above.

Generic organic halogen analyses

Adsorbable organic halogen (AOX) contents of the bleaching filtrates were obtained according to the SCAN-W 9:89 procedure, using the halogen analyser ECS 1000 manufactured by Euroglass BV, Delft, The Netherlands. Extractable organic halogen (EOX) contents of the bleaching liquors were determined by adjusting the bleaching filtrates to pH 1.5-2, and shaking aliquots of the filtrates (40 mL) with *n*-octanol (4 mL) at 20°C for 1 h. The extract was analysed on a halogen analyser as above.

Gas chromatography

Gas chromatography (gc) was carried out on a Hewlett Packard HP5890 series II chromatograph fitted with an autoinjector, a mass selective detector (msd) and an electron capture detector (ecd). The column used was a J&W bonded phase DB5 fused silica column (30 m x 0.25 mm id) with a phase thickness 0.25 μm. Purified helium was used as carrier gas with a linear velocity 30 cm/sec. Injector and detector temperatures were kept at 300°C and a variety of temperature programs, injection volumes and purge delays were employed depending on the nature of the analysis. Injections were splitless. Electron impact (70 eV) spectra were obtained for masses 40 to 450 amu, unless stated otherwise.

Determination of chlorinated phenols in bleaching filtrates

Chlorinated phenols were determined by a modification of an *in situ* acetylation method (Voss *et al.* 1981) involving acetylation of the phenols, extraction with hexane, and gc with the use of an electron capture detector (ecd). Analysis with the msd was used to verify the identity of the gc peaks. 2,3,6-Trichlorophenol was used as the internal standard.

Determination of chlorinated neutral compounds in bleaching filtrates

Chlorinated neutral compounds in the filtrates were determined by extraction followed by gc analysis. To filtrate samples (80 mL) aliquots of bromomethane in methanol were added as an internal standard, and the mixtures were continuously extracted for 16 h with dichloromethane (DCM) (75 mL). The extracts were dried with sodium sulfate, concentrated on a rotary evaporator at 20°C, then analysed by gc with the msd. Chloroform was analysed by gc-msd of pentane extracts, monitoring the mass fragment *m/z* 83.

Determination of chloroacetic acids in bleaching filtrates

Mono-, di- and trichloroacetic acids in the filtrates were determined by extraction followed by gc analysis. The filtrates (80 mL) were adjusted to pH 0.8, and aliquots of 2-bromopropanoic acid in methanol were added as an internal standard. The mixtures were continuously extracted with DCM (75 mL) for 6 h. The extracts were dried with sodium sulfate, concentrated by rotary evaporation at 20°C and methylated with diazomethane in diethyl ether [prepared from Diazald® (Robinson, 1974)]. The methylated extract was analysed by gc with the msd monitoring the ion fragment at *m/z* 59.

Determination of chlorinated phenolic acids in bleaching filtrates

Chlorinated phenolic acids were determined by extraction and derivatisation followed by gc analysis. Aliquots of the internal standard 5-chlorosalicylic acid in methanol were added to filtrate samples (80 mL) at pH 2 and the mixtures were continuously extracted for 16 h with DCM (75 mL). The extracts were dried with sodium sulfate and concentrated on a rotary evaporator at 20°C to *ca.* 0.5 mL. These were transferred to a centrifuge tube to give a final volume of *ca.* 1 mL. N-Methylimidazole (25 μL) and acetic anhydride (50 μL) were added and after standing for 60 min at 20°C, 0.5M sulfuric acid (1.0 mL) was added and the mixture was mixed on a vortex mixer for 0.5 min. The aqueous layer was removed with a pipette, and the DCM solution was dried with sodium sulfate. The extract was methylated for 5 min with an ethereal diazomethane solution. The volume was reduced to *ca.* 1 mL under a stream of nitrogen, and the mixture was analysed by gc with a msd.

RESULTS AND DISCUSSION

Bleaching filtrates

Commercial bleaching sequences outlined for new eucalypt kraft pulps have used technologies for minimising the chlorinated organic substances formed during bleaching, typically oxygen delignification and oxygen-reinforced alkali extraction. The sequence O(CD)(EO)DD was proposed for the Wesley Vale pulp mill project in 1989 (Jamieson, 1989). A current proposal for a bleached eucalypt kraft pulp mill in Australia involves

modified continuous cooking to extend the delignification, oxygen delignification and the molecular chlorine-free bleaching sequence ODEPoD(ED) (Allison and Sakai, 1992). As almost all chlorinated organic material is formed in the prebleaching stages and subsequent alkali extraction stages, filtrates from these stages were chosen for study. Kraft pulps from both a mature mixed species and a young plantation *E. globulus* wood were oxygen-delignified to Kappa number 9.5 and bleached with C, D and 70:30 D:C sequences with subsequent (EO) treatment. The bleaching filtrates were collected and analysed for chlorinated organic compounds.

Chlorinated phenols

The determination of chlorinated phenols in bleaching filtrates was carried out by a modified *in situ* acetylation procedure (Voss *et al.*, 1981). Initial inspection of the filtrates showed that 14 major chlorinated phenols were present; 3 catechols, 4 guaiacols, 1 syringol, 2 vanillins, 2 syringaldehydes and 2 acetosyringones. All 14 chlorinated phenols have been found previously as major chlorinated phenols in bleaching effluents with the exception of the chlorinated acetosyringones. The presence of 2-chloro and 2,6-dichloroacetosyringone in the filtrates was confirmed by synthesis of the reference compounds and comparison of gc retention times and mass spectra with those of the analytes.

TABLE 1 Total chlorinated phenols in filtrates from bleaching eucalypt kraft pulps

Bleaching filtrate	Chlorinated phenols ($g.tonne^{-1}$)	
	Mature wood	Young wood
C	2.90	2.72
(EO)[C]	25.3	47.0
(DC)	0.50	1.14
(EO)[DC]	9.31	31.7
D	0.05	0.06
(EO)[D]	4.29	19.0

The levels of chlorinated phenols in the bleaching filtrates from different prebleaching treatments decreased in the order C > (DC) > D (Table 1). Most chlorinated phenols occurred in the (EO) filtrates following the prebleaching. The Kappa number after the (EO) stage was 1.2 for C-prebleaching and 2.7 for D-treatment, and this difference was not sufficient to account for the large difference in chlorinated phenols levels. The major chlorinated phenol in the C(EO) filtrates was 2,6-dichlorosyringaldehyde, whereas 2-chlorosyringaldehyde occurred in the D(EO) filtrates almost to the exclusion of other

chlorinated phenols. These results contrast those of an earlier study of bleaching of oxygen-delignified eucalypt kraft pulps, in which the most prevalent chlorinated phenols in the bleaching filtrates were tetrachlorinated phenols, followed by trichlorophenols (Germgård and Vannfält, 1990; Asplund and Germgård, 1991). Syringaldehyde is a typical oxidation product of hardwood lignins, and the preponderance of the chlorinated syringaldehydes in the bleaching filtrates is probably a consequence of the oxidising conditions used in the bleaching. Analogously, chlorovanillins were found to be the major products of similar treatment of radiata pine kraft pulps (Allison *et al.*, 1992).

The levels of chlorinated phenols were higher in the filtrates from bleaching of the young eucalypt kraft pulp than the mature eucalypt pulp (Table 1). As pulps from both mature and young eucalypt woods were bleached to similar Kappa numbers, the difference in the chlorinated phenol levels is probably due to differences in the amounts or types of residual lignin in the oxygen-delignified pulps. The actual amounts of lignin in the pulps may vary if polyphenol residues are present in the pulps. Eucalypt lignin is well known for its variation in structure, as exemplified by the varying content of syringyl and guaiacyl structures (Sarkanen and Hergert, 1971).

In addition to the 14 major chlorinated phenols analysed in the bleaching filtrates, 27 minor chlorinated phenols were identified by gc-ms comparison with authentic samples. Many of the phenols have not been identified as filtrate components previously, and some are new compounds. The compounds identified were chloro derivatives of the following phenols (with the number of derivatives in parentheses): phenol (2), catechol (7), guaiacol (7), 3-methoxycatechol (4), syringol (2), 4-hydroxybenzaldehyde (2), vanillin (7), syringaldehyde (2), acetoguaiacone (3) and acetosyringone (2). A feature of the chlorinated phenols identified is the number which have a formyl or acetyl group *para* to the phenolic hydroxyl group, which is characteristic of lignin oxidation products. All of these chlorinated phenols may be formed from the residual lignin in the pulps, although the phenols without methoxyl groups may derived optionally from polyphenolic extractives. Three additional chlorinated phenols were identified; 2,4,6-trichlororesorcinol and 2-chloro and 2,6-dichloro-3,4,5-trimethoxybenzaldehyde, which are unlikely to derive from lignin and are more likely to be formed from residues from polyphenols originally present in the woods. There was no difference between the types of chlorinated phenols found in filtrates from bleaching pulps from the mature and young wood samples, and consequently there is no evidence for a significant influence of extractives on the levels and types of chlorinated phenols formed during bleaching.

Chlorinated neutral compounds

Chloroform is a major chlorinated organic compound formed during pulp bleaching with chlorine-containing reagents, and the amounts of chloroform generated have been

found to be dependent on the bleaching reagent, chlorine multiple and the pH of the spent bleaching liquor (Crawford and Stryker, 1988). For oxygen-delignified hardwood kraft pulps with chlorine dioxide substitution, chloroform levels in excess of 100 g per tonne of pulp have been reported (Crawford *et al.*, 1991). Most of the chloroform is generated in the prebleaching and extraction stages, and relatively small amounts are formed in the final D stages.

C and D-stage filtrates were adjusted to pH 8 before analysis for chloroform. Without this adjustment, much lower chloroform values were obtained for the C-stage filtrates, as earlier studies have shown. The chlorinated pulps were extracted with alkali without oxygen reinforcement due to the difficulty in analysing (EO)-stage filtrates for volatile compounds. A reduction in chloroform levels of greater than 90% resulted from the use of chlorine dioxide instead of chlorine in the prebleaching (Table 2). There were lower amounts of chloroform present in the E-stage filtrates than the filtrates from prebleaching. The kraft pulp from the mature eucalypt sample gave more chloroform than that from the young sample.

TABLE 2 Chlorinated neutral compounds in eucalypt kraft pulp bleaching filtrates

Bleaching filtrate	Chlorinated compounds (g.tonne^{-1})					
	Chloroform[a]		Chloroacetones		Chlorodimethylsulfones	
	Mature	Young	Mature	Young	Mature	Young
C	26.7	12.3	106	226	7.3	4.0
(EO)[C]	9.2	3.8	--	--	--	--
(DC)	2.3	3.7	14.0	12.8	3.6	5.7
(EO)[DC]	0.6	0.5	--	--	--	--
D	1.6	1.2	5.2	--	5.4	5.7
(EO)[D]	0.1	0.6	--	--	--	--

[a]E-stage extraction rather than (EO)

Three chloroacetones and two chlorodimethylsulfones were identified in the chlorination-stage bleaching filtrates. None of these analytes occurred in the (EO)-stage filtrates (Table 2). The chloroacetones analysed, 1,1,3-trichloroacetone (1,1,3A), 1,1,3,3-A and pentachloroacetone, were most prevalent in the C-stage filtrates, and were present in small amounts in the D-stage filtrate from the mature eucalypt kraft pulp. The C-stage filtrate from the young wood sample had significantly higher levels of chloroacetones, particularly 1,1,3,3A, than that of the mature eucalypt sample. The remaining tetrachloroacetone isomer, 1,1,1,3A, was detected in the bleaching filtrates, although no reference compound was available for confirmation of the mass spectral identification. When the chlorination

filtrates were extracted at pH 8, considerably lower amounts of chloroacetones were found. Stability tests carried out on chloroacetones at pH 8 showed that whereas 1,1A and 1,1,1A persisted in the aqueous solution at 20°C for several days, the analytes found in the bleaching filtrates were rapidly degraded. Chloroacetones have been found to lose their biological activity at neutral or alkaline pH (Nazar and Rapson, 1982). The three chloroacetones, 1,1,3A, 1,1,3,3A and pentachloroacetone, have been reported as the major components of a range of C-stage effluents from kraft pulp bleaching, and hexachloroacetone was present as a minor component (McKague *et al.*, 1990). The chloroacetones do not persist in bleaching filtrates due to their instability, and have not been identified in final mill effluents.

Of the two main chlorodimethylsulfones found in the chlorination filtrates, 1,1-dichlorodimethylsulfone (1,1DS) was more prevalent than 1,1,3DS. A tetrachlorosulfone (tentatively identified as 1,1,3,3DS) was present as a minor component of the filtrates, as has recently been reported (Pedersen-Bjergaard *et al.*, 1993). The levels of the chlorodimethylsulfones were similar in all three prebleaching stages (Table 2). When the chlorination filtrates were extracted at pH 8, levels of the chlorodimethylsulfones were almost unchanged. The chlorodimethylsulfones have been reported as moderately persistent and to be present as components of a range of biologically-treated kraft mill effluents (Voss, 1983).

An abundant neutral compound C-stage extracts and acidified D-stage extracts was identified as a chlorohydroxypyranone with a molecular ion [M^+] *m/z* 146. The compound was also found in acidified (DC)-stage filtrates but was not found in (EO) stages. The acetate of this compound was found in extracts where N-methylimidazole was used to effect acetylation but not in the *in situ* acetylation technique. The methyl ether is found in extracts used in the determination of acetic acids.

In addition to the neutral compounds described above, the dichloromethane extracts contained minor amounts of chlorinated hydrocarbons and a range of chlorinated phenols, which have been discussed above. Relatively few neutral compounds were identified in the bleaching filtrates, particularly in the D- and (EO)-stage filtrates. No chlorinated thiophenes were identified, although several chlorinated thiophenes in the effluents from bleaching of eucalypt kraft pulps have been previously reported (Carlberg, 1991; Lunde *et al.*, 1991). Lower amounts of these compounds were found in the effluents if the black liquor carryover was minimised.

Chlorinated acidic compounds

The analyses of chlorinated aliphatic and phenolic acids were considered separately due to differences in their physical and chemical characteristics. The aliphatic acids were analysed by extracting the filtrates at pH 0.8 with dichloromethane for 6 h. Extraction at higher pHs

resulted in lower recoveries of the acids. The sole chlorinated aliphatic acids identified in the filtrates were the three chloroacetic acids. Trichloroacetic acid was most abundant in the C-stage filtrate while the dichloro acid dominated the (DC)- and D-stage filtrates. More chloroacetic acids appeared in the chlorination filtrates than in the (EO) filtrates (Table 3), which is consistent with earlier results (Lindstrom and Österberg, 1986). All three chloroacetic acids were present in the filtrates tested except that the trichloro acid was absent in the (EO)-stage filtrates. A compound with a mass spectrum consistent with a monochlorofurancarboxylic acid was also identified as an effluent component. Chlorinated furancarboxylic acids have not been previously reported as bleaching effluent components.

TABLE 3 Chlorinated acidic compounds in eucalypt kraft bleaching filtrates

Bleaching filtrate	Chlorinated organic compounds ($g.tonne^{-1}$)			
	Chloroacetic acids		Chlorinated phenolic acids	
	Mature	Young	Mature	Young
C	71.0	125.1	0.3	2.2
(EO)[C]	4.1	19.4	2.5	6.5
(DC)	43.3	51.6	0.7	2.5
(EO)[DC]	4.8	10.7	1.1	3.7
D	49.6	62.1	0.4	0.7
(EO)[D]	14.6	7.2	0.6	0.9

The chlorinated phenolic acids were analysed as their methyl ester acetates by acetylation of the phenolic hydroxyl group and subsequent methylation of the carboxylic acid, rather than methylation alone to give methyl ester methyl ethers, as the former strategy offers greater structural information. It is based in part on a method for analysis of chlorinated phenols (Morales *et al.*, 1992) but the acetylation step with acetic anhydride was modified to use N-methylimidazole as a powerful acetylation catalyst rather than pyridine.

Three chlorinated phenolic acids were identified in the bleaching filtrates (Table 3). 5-Chlorovanillic acid was only found in the EO stage following chlorine bleaching and another chlorinated vanillic acid was also detected in this filtrate. Both the monochloro and dichlorosyringic acids (SAC) were detected. 2,6SAC was found in higher levels in the C-stage filtrates than the (DC) filtrates which follows the trend of the syringaldehydes. The chlorinated syringic and vanillic acids have been identified previously as components of bleaching filtrates (Kachi *et al.*, 1980). Additional phenolic acids were detected in the bleaching filtrates, although positive identification and determination could not be effected due to a lack of authentic standards.

Total extractable chlorinated organic compounds

The filtrates were tested for their content of lipophilic chlorinated organic substances by measuring their extractable organic halogen (EOX) content (Table 4). The EOX content of the filtrates was obtained on *n*-octanol extracts, as difficulty was encountered in obtaining consistent results with cyclohexane or light petroleum. Absorbable organic halogen (AOX) contents were also determined for comparison. The AOX contents of the combined prebleaching-extraction filtrates were well correlated with the EOX contents ($r^2 = 0.98$), as were both AOX and EOX contents with the total amount of chlorinated compounds analysed ($r^2 = 0.95$ and 0.98 respectively).

TABLE 4 Organic halogen and total chlorinated organics in bleaching filtrates

Bleaching filtrate	Chlorinated substances ($g.tonne^{-1}$)					
	AOX		EOX		Total analysed	
	Mature	Young	Mature	Young	Mature	Young
C	1028	1406	60.7	153.5	213.9	372.3
(EO)[C]	145	293	46.4	44.0	41.1	76.6
(DC)	679	714	30.6	56.4	64.3	77.4
(EO)[DC]	56	141	13.9	20.3	16.0	46.5
D	483	632	25.2	31.9	62.2	69.8
(EO)[D]	21	65	6.1	12.4	19.6	27.7

CONCLUSIONS

Chlorosyringaldehydes are the major chlorinated phenols in filtrates from bleaching oxygen-delignified eucalypt kraft pulps with chlorine-containing reagents. A total of 41 chlorinated phenols were identified in the bleaching filtrates, and three of the chlorinated phenols probably derive from polyphenolic extractives rather than lignin. There was no evidence for differences in the types of chlorinated phenols arising from the mature and young eucalypt wood samples. The major acidic and neutral chlorinated organic compounds identified were similar to those isolated in previous studies. The total amount of chlorinated compounds analysed was higher in the young eucalypt sample than from the mature sample, and correlated well with the generic parameters AOX and EOX.

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A QUANTITATIVE DESCRIPTION OF FIBRE DEVELOPMENT IN *EUCALYPTUS GLOBULUS*

Brad G. Ridoutt, Roger Sands
Cooperative Research Centre for Hardwood Fibre and Paper Science
School of Forestry, The University of Melbourne
Creswick, Victoria 3363, Australia
and
Geoffrey M. Downes
Cooperative Research Centre for Hardwood Fibre and Paper Science
CSIRO Division of Forest Products
Clayton, Victoria 3168, Australia

ABSTRACT

At 10 % of tree height in six-year-old plantation grown *Eucalyptus globulus* the average duration of the cell division cycle in the vascular cambium was 3.9 days, corresponding to an average rate of radial cell production of 3.5 cells per day. The duration of fibre expansion and secondary wall deposition averaged 6.0 days and 32.8 days respectively. Developing fibres elongated at an average rate of 99 µm per day and increased in radial diameter at an average rate of 1.8 µm per day.

INTRODUCTION

Secondary xylem fibres are formed by cell division in the vascular cambium. These cells subsequently undergo a sequence of developmental changes including cell enlargement with continued primary wall formation, secondary wall deposition and lignification. The final phase of development is the autolysis of cell contents and dissolution of non lignified parts of the wall such that mature fibres are not capable of further anatomical changes. Fibre dimensions are therefore determined in part by the dimensions of the meristematic cambial initials from which they are formed and in part by the rate and the duration of the processes involving fibre differentiation (Ridoutt, Sands 1993). However, little is known of the mechanisms that control these processes. The objective of this study was to provide a quantitative description of fibre development in *Eucalyptus globulus* that had been grown under intensive silvicultural management. It is the quantification of the processes of fibre development that renders the mechanisms that control these processes amenable to physiological investigation.

MATERIALS AND METHODS

Plant Material

Three six-year-old *Eucalyptus globulus* trees growing in a plantation in Gippsland, Victoria were chosen for this study. The average height was 12.6 m and the average stem diameter over bark at 10 % of tree height from the base was 18.2 cm. In January 1993, 550 µm diameter stainless steel needles were used to produce a series of minute injuries to the cambial zone at this height level. This technique has been demonstrated to produce a reliable and characteristic marker for determining the rate of radial cell production in hardwoods (Kuroda, Shimaji, 1984). In March, 74 days later, a wood sample with bark and intact cambium was removed from each tree. These samples were immediately fixed in FAA (formalin- acetic acid- ethanol- water, 10: 5: 50: 35 % volume) and dehydrated through an ethanol series. Where the needle had been inserted, suitably trimmed pieces were embedded in acrylic resin, sectioned at 4- 5 µm in transverse section through the injury and stained with toluidine blue (O'Brien et al. 1964). Similar pieces were trimmed at a distance of approximately 1 cm from where the needle had been inserted and prepared for microscopy in the same way except that tangential longitudinal sections through the cambial zone were also obtained. Also at approximately this distance from the needle insertion, thick (100 µm) sections of most recently differentiated xylem were macerated by gently boiling for 1 h in a mixture of equal quantities of glacial acetic acid and hydrogen peroxide. Macerates were stained with 1 % aqueous safranan.

Microscopy

All measurements were made using an image analysis system connected to a research microscope using a video camera. From the sections that contained the minute injury, the distance was measured from the cambial zone to the point in the injury that was deduced to be the site of the cambial initials at the time of needle insertion (Kuroda, Shimaji 1984). Measurements of cell dimensions were obtained from the sections that did not include the injury and showed no signs of abnormal growth. From the tangential sections the lengths of 100 randomly selected fusiform initials were measured for each tree. From the transverse sections the number of cells in each phase of development was counted in five radial files for each tree. The dividing phase was distinguished from the enlargement phase by the increasing radial diameter of the differentiating xylem and phloem cells. The commencement of secondary wall development was detected by the birefringence of the S1 wall layer when viewed through crossed polarising filters. The end of secondary wall deposition was defined by the ability to detect the S3 wall layer. This was observed to coincide closely with the disappearance of the cell contents as has

previously been reported by Wardrop and Harada (1965). Fibre elongation was assumed to occur in parallel with fibre radial enlargement as has been reported by Fujiwara (1993). The radial diameter of all the cells in these files regarded as being in the dividing phase were measured, as well as the radial diameter and lumen diameter of the 10 most recently differentiated fibres in each of these files. From temporarily mounted slides of the macerated xylem, the length of 100 randomly selected and intact fibres was measured.

Calculations

The rate of fibre production (cells day^{-1}) was calculated by dividing the measured radial increment from the time of needle insertion to the time the wood samples were collected by the average radial diameter of mature fibres in each tree and by the number of days between needle insertion and wood sample collection. For each tree the duration of the cell division cycle, the phase of fibre enlargement and the phase of secondary wall deposition were calculated by dividing the number of cells in each phase by the rate of cell production. This calculation is based on the assumption that the number of cells in each phase of development did not change significantly over the study period. The rates of fibre elongation and enlargement were calculated by dividing the difference between the mature fibre dimensions and the dimensions of the fusiform initials by the duration of each phase respectively.

RESULTS AND DISCUSSION

In the 74 days between needle insertion and collection of wood samples, the most rapidly growing stem produced 6.23 mm of radial growth (Table 1). This tree had an average of 21.2 cells in the cambial zone compared to an average of 5.8 cells in the cambial zone of the slowest growing stem that produced only 1.69 mm of radial growth over this period. The average number of cells in the enlargement phase ranged from 22.6 to 10.4 for the three trees and the average number of cells undergoing secondary wall development ranged between 134.4 and 51.0.

For the three trees combined, the average fusiform initial length and fibre length in the most recently differentiated xylem were 454 µm and 972 µm respectively. The ratio of average fibre length and average fusiform initial length represents the extent of elongation that developing fibres undergo during differentiation. Mature fibres were therefore an average of 2.14 times the length of the meristematic fusiform initials from which they were derived.

TABLE 1. MEASURED PARAMETERS OF FIBRE DEVELOPMENT AT 10 % OF TREE HEIGHT IN SIX-YEAR-OLD *EUCALYPTUS GLOBULUS*

Parameter	Tree		
	1	2	3
Width of xylem produced (mm)	3.16	6.23	1.69
Number of cells in			
-cambial zone	12.6	21.2	5.8
-enlargement phase	20.6	22.6	10.4
-secondary wall development	117.4	134.4	51.0
Mature fibre dimensions (µm)			
-length	945	1037	935
-radial diameter	15.5	13.1	15.6
-single tangential wall thickness	2.2	2.0	2.3
Fusiform initial dimensions (µm)			
-length	482	475	404
-radial diameter	4.9	4.5	5.1

Table 2 presents the calculated rate and duration of each of the phases of fibre development. The rate of fibre production ranged from 6.4 to 1.5 fibres per day. However the duration of the cell division cycle in the cambial zone was less variable and only ranged between 3.3 and 4.6 days. This suggests that differences in the rate of fibre production arise mostly from differences in the number of cells in the cambial zone rather than from differences in the duration of the cell division cycle in these cells. For the three trees combined, the duration of the phase of cell enlargement was 6.0 days with an average rate of cell elongation of 99 µm per day and an average rate of cell radial expansion of 1.8 µm per day. The duration of fibre secondary wall development ranged between 20.9 and 42.6 days.

TABLE 2. CALCULATED RATE AND DURATION OF THE PHASES OF FIBRE DEVELOPMENT AT 10 % OF TREE HEIGHT IN SIX-YEAR-OLD *EUCALYPTUS GLOBULUS*

Parameter	Tree			
	1	2	3	Mean
Duration (day)				
-cell division cycle	4.6	3.3	4.0	3.9
-fibre enlargement	7.5	3.5	7.1	6.0
-fibre secondary wall development	42.6	20.9	34.9	32.8
Rate				
-fibre production (fibre day^{-1})	2.8	6.4	1.5	3.5
-fibre elongation ($\mu m\ day^{-1}$)	62	160	74	99
-fibre radial enlargement ($\mu m\ day^{-1}$)	1.4	2.4	1.5	1.8

Similar measurements have previously only been obtained for softwoods and hardwood seedlings grown under controlled environment conditions. In these studies the rate of radial cell production was determined by reference either to a distinct growth ring boundary or to the pith. This study has demonstrated the use of small diameter needles to produce a marker of xylem growth in a diffuse porous species that does not form distinct nor reliable growth rings. This has thereby enabled the processes of fibre development to be quantified. These techniques are now being used to examine quantitatively the processes of fibre development under different experimental conditions as a means of investigating the mechanisms that control fibre development.

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CONDITION OF NATURAL DURABILITY SPECIMENS FROM THE CSIRO IN-GROUND FIELD TEST AFTER 23 YEARS OF EXPOSURE

John D. Thornton, Gary C. Johnson
CSIRO Division of Forest Products
Private Bag 10, Rosebank MDC, Clayton, Victoria 3169
and
Nam-Ky Nguyen
CSIRO Biometrics Unit
Private Bag 10, Rosebank MDC, Clayton, Victoria 3169

ABSTRACT

The condition of outer heartwood specimens of 77 timber species in the CSIRO natural durability field test is reported after 23 years' exposure at five sites (Innisfail, Brisbane, Sydney, Walpeup and Melbourne). For those timbers that have not yet biodeteriorated sufficiently to yield median specimen life (MEDSL) values at one or more of the sites, mean rating values against decay and termites are provided (including ratings for two preservative-treated sapwood controls). Where available, MEDSL values are given together with the first and third quartiles, Q_1 and Q_3, respectively.

Due to the requirement to gather data beyond 25 years in order to comply with the original definition of Class 2 and Class 1 timbers, no attempt was made to alter or confirm the "tentative" durability classes that have remained in use since before this test commenced. However, final MEDSL, Q_1 and Q_3 values for 26 of the timber species were included. Specimens in the best condition were tallowwood, grey ironbark, red box, red ironbark, wandoo and bull oak. At this stage wandoo appeared to be the best of the durables, but the CCA-treated (12 kg m^{-3}) radiata pine sapwood rated higher.

INTRODUCTION

Four publications have reported results from the CSIRO field test of natural durability of 77 timber species exposed in the ground at five Australian sites. These papers presented data on the condition of specimens after exposure for 10 years (Thornton *et al.* 1983b), 13 years (Thornton *et al.* 1983a), 15 years (Johnson *et al.* 1986) and 21 years (Thornton *et al.* 1991). This paper provides data on these species after 23 years' exposure.

In the first two papers, specimen life data were based on mean time to reach an unserviceable condition. The report after 21 years was the first to include the median (the second quartile) of the replicates as a measure of specimen life (MEDSL) and the first quartile (Q_1). This paper reports, for the first time from the test, values for the third quartile (Q_3). Q_1 and Q_3 act as lower and upper bounds for the MEDSL. For those timber species that have not yet biodeteriorated sufficiently to yield MEDSL values for one or more of the five sites, mean rating values against decay and termites are provided. Moreover, ratings for the two preservative-treated controls are given.

The purpose of the CSIRO natural durability test was to confirm or adjust the tentative durability ratings that were allocated by consensus of opinion of timber experts. In order to fulfil the definition of a Class 2 timber, these tentative ratings will not be changed *until* this test has run beyond 25 years.

MATERIALS AND METHODS

Despite all the relevant details having been previously published, a brief outline is included for the benefit of those attending this conference.

Timber species, treatment and specimen details

In this test Australian hardwoods were species of *Eucalyptus*, *Lophostemon* and *Syncarpia* (Myrtaceae), *Acacia*, *Allocasuarina*, *Litsea* and *Nothofagus* (non-myrtaceous). Exotic hardwoods were of *Anisoptera*, *Intsia*, *Pterocarpus*, *Quercus*, and *Tectona*. Australian softwood species were *Agathis*, *Athrotaxis*, *Callitris*, *Lagarostrobos*, *Phyllocladus* and *Prumnopitys* and the exotic ones were *Pinus*, *Pseudotsuga*, *Sequoia* and *Thuja*. The choice of most of the indigenous species was made following requests to heads of state forestry departments to supply timber species expected to be available in commercial quantities in the future.

As a comparison with the untreated heartwood, creosote-treated *Pinus radiata* sapwood (175-210 kg of creosote per m^3, conforming to AS K55-1965) and copper-chromium-arsenic-treated *P. radiata* sapwood (12 kg of dry salt per m^3) were also included.

Specimens were cut to give a finished, air-dry size of 50 x 50 mm cross-section and 450 mm length. Heartwood specimens were taken from outer heartwood of the butt log and where possible five trees of each species were represented.

Test site and exposure details

In Queensland: at Jolly's Lookout (near Brisbane), mean annual rainfall (m.a.r.) 1500 mm, and in the wet tropical rainforest at Innisfail (m.a.r. 3500 mm). In New South Wales: at Pennant Hills, Sydney (m.a.r. 950 mm). In Victoria: in the semi-arid Mallee at Walpeup(m.a.r. 340 mm), and at Mulgrave (Melbourne, m.a.r. 920 mm). The latter site was sold 18 years after the test was installed and the specimens were immediately moved to a nearby site at Rowville.

Specimens were installed in parallel rows. For most timber species 10 replicates (two from each of five trees) were allocated to each site, with 740 specimens installed per site. Specimens were installed, with 300 mm of the 450 mm length buried vertically in the ground, at four sites between May and July 1968, and at the Melbourne site in July 1969.

Inspection procedure and data analysis

Though inspections were infrequent in the early years of this test, in the last 14 years, four sites were inspected nearly every other year, with the fifth (Walpeup) inspected on a yearly basis. The same system for rating (Table 1) specimen condition was used throughout this test. Since the 11th year of exposure two inspectors were used, with each

inspector assessing alternate rows of specimens at successive inspections. A knife was used to determine the position on the specimen most affected by decay and, separately, the position most affected by termites.

TABLE 1. System for rating the condition of each specimen[a]

Rating of stake	Condition of specimen
8	No loss of cross-section
7	Any loss of cross-section up to 15% of cross-section
6	From slightly more than 15% up to 30% loss of cross-section
5	From slightly more than 30% up to 45% loss of cross-section
4	From slightly more than 45% up to 60% loss of cross-section
3	From slightly more than 60% up to 75% loss of cross-section
2	From slightly more than 75% up to 90% loss of cross-section
1	From slightly more than 90% and less than 100% loss of cross-section
0	Total loss of cross-section

a) Each stake is rated separately for condition with respect to microbial decay and insect attack, at the cross-section that is most destroyed by micro-organisms and also at the cross-section that is most destroyed by insects.

A replicate was considered unserviceable to decay or termites when a rating of 3 was reached. The time to reach this rating due to the more severe hazard (i.e. either decay or termites) was defined as being mid-way between an inspection at which the specimen rated >3 and the following inspection at which that specimen rated 3 or less. The median time for the replicates of that timber to become unserviceable (MEDSL) was determined (Table 2) as were the first (Q_1) and the third (Q_3) quartiles. The inter-quartile range, i.e. the difference between $Q_3$and Q_1, provides a measure of variation of performance. For those timber species not yet deteriorated sufficiently to yield MEDSL values, the mean rating at the most recent inspection against decay and against termites was computed.

RESULTS AND DISCUSSION

The mean condition of the replicates of a timber species, for each site where that species has not yet yielded a MEDSL value, is shown in Table 2. The relative magnitude of the mean ratings against decay and termites gives a good indication of site hazard. (The data in Table 2 are given simply to enable site hazards to be discussed at this stage. However, it should be understood that the results presented in Table 3 have to be obtained before making the choice of timber species to be included in Table 2). Accordingly, to the remaining specimens, decay is the major hazard at the Brisbane and Sydney sites, termites the main hazard at Innisfail, decay and termite hazards are often balanced at Walpeup, while termites have never been observed at either of the two Melbourne sites (Table 2).

TABLE 2. **Mean rating[a)] of heartwood specimens, of those timber species not yet yielding specimen life (MEDSL) values at one or more sites, with respect to decay and termites after 23 years of exposure**

Species	Site and Hazard									
	Brisbane		Innisfail		Sydney		Walpeup		Melbourne	
	Decay	Termites	Decay	Termites	Decay	Termites	Decay	Termites	Decay	Termites
Australian hardwoods (Myrtaceae)										
E. acmenoides (White mahogany)	-	-	-	-	(3.8)	7.4	4.7	5.5	5.3	8.0
E. astringens (Brown mallet)	-	-	-	-	-	-	-	-	(3.4)	8.0
E. bosistoana (Coast grey box)	-	-	-	-	-	-		-	(4.9)	8.0
E. camaldulensis (River red gum)	-	-	-	-	-	-	-	-	(3.8)	8.0
E. cladocalyx (Sugar gum)	-	-	4.4	(3.4)	(3.9)	6,6	4.1	4.6	5.0	8.0
E. cloeziana (Gympie messmate)	3.6	(5.4)	-	-	(3.3)	6.9	4.8	4.5	4.8	8.0
E. consideniana (Yertchuk)	-	-		-	-		3.6	(2.8)	-	-
E. cornuta (Yate)	-	-	-	-		-	-	-	(3.0)	8.0
E. gomphocephala (Tuart)	-	-	-	-	(2.9)	6.3	-	-	4.9	8.0
E. guilfoylei (Yellow tingle)	-	-	-	-	-	-	-	-	(3.7)	8.0
E. leucoxylon (Yellow gum)	-	-	-	-	-	-	4.2	4.8	5.6	8.0
E. longifolia (Woollybutt)	(2.6)	(4.7)	-	-	(3.6)	6.4	4.5	(3.8)	5.2	8.0
E. maculata (Spotted gum)	-	-	-	-	-	-	-	-	(4.0)	8.0
E. marginata (Jarrah)	-	-	-	-	-	-	-	-	(2.7)	8.0
E. melliodora (Yellow box)	-	-	(4.3)	(2.9)	4.6	7.0	4.8	5.3	5.7	8.0
E. microcorys (Tallowwood)	4.1	6.1	4.7	(3.4)	3.2	7.6	4.7	5.0	5.7	8.0
E. moluccana (Grey box)	(2.6)	(4.6)	-	-	(3.5)	6.0	4.6	4.2	(4.5)	8.0
E. paniculata (Grey ironbark)	(3.2)	(4.4)	4.8	(2.6)	5.3	6.9	3.5	3.8	(4.3)	8.0
E. patens (WA blackbutt)	-	-	-	-	(2.4)	7.0	4.3	4.4	-	-
E. pilularis (Blackbutt)	-	-	-	-	-	-	3.6	3.1	(2.4)	8.0
E. polyanthemos (Red box)	(4.5)	(5.7)	4.7	(3.0)	(3.5)	8.0	4.7	(6.5)	5.0	8.0
E. resinifera (Red mahogany)	-	-	-	-		-	3.2	4.3	5.2	8.0
E. salmonophloia (Salmon gum)	(3.0)	(4.6)	-	-	-	-	-	-	(4.4)	8.0
E. sideroxylon (Red ironbark)	(3.1)	(5.4)	4.9	(3.4)	(3.2)	7.3	4.2	4.8	5.6	8.0
E. tereticornis (Forest red gum)	-	-	-	-	(3.2)	7.7	3.8	4.2	5.2	8.0

E. wandoo (Wandoo)	4.4	5.9	4.8	4.1	5.7	7.7	4.4	4.8	5.8	8.0
L. suaveolens (Swamp box)	-	-	-	-	-	-	4.3	7.6	-	-
S. glomulifera (Turpentine)	-	-	-	-	-	-	3.6	4.0	(3.8)	8.0
S. hillii (Satinay)	-	-	-	-	-	-	3.9	5.2	4.2	8.0
Australian hardwoods other than Myrtaceae										
A. acuminata (Raspberry jam)	(2.9)	(5.2)	-	-	(3.8)	6.9	5.0	5.0	(4.7)	8.0
A. harpophylla (Brigalow)	(2.6)	7.3	-	-	2.8	7.7	3.7	4.1	5.2	8.0
A. luehmannii (Bull oak)	(3.3)	(7.5)	5.0	(5.5)	5.2	(7.0)	(3.0)	(3.7)	(4.2)	8.0
Exotic hardwoods										
I. bijuga (Kwila)	-	-	-	-	-	-	(2.6)	(3.2)	-	-
P. indicus (NG rosewood)	-	-	-	-	-	-	3.2	(4.4)	-	-
T. grandis (Burmese teak)	-	-	-	-	-	-	(3.8)	6.1	4.2	8.0
Australian softwoods										
A. selaginoides (King William pine)	-	-	-	-	-	-	(6.0)	(4.0)	-	-
C. columellaris (White cypress pine)	-	-	-	-	-	-	(2.9)	6.0	(4.0)	8.0
P. asplenifolius (Celery-top pine)	-	-	-	-	-	-	(3.7)	(3.0)	-	-
Exotic softwoods										
S. sempervirens (Redwood)	-	-	-	-	-	-	5.9	5.3	-	-
Preservative-treated *P. radiata* sapwood										
CCA at 12 kg m^{-3}	6.9	7.9	6.0	6.8	6.8	7.6	7.0	7.9	6.8	8.0
K55 creosote at 175-210 kg m^{-3}	5.4	6.4	4.6	(5.1)	5.7	6.9	6.7	7.1	5.6	8.0

a) Rating values range from 8 for a completely sound timber to 0 for a failed one, with 3 representing unserviceability. Figures in parentheses are means for which the length of the 95% confidence interval is 3.0 or greater. These values are, therefore, to be viewed as less reliable than the unbracketed values.

-, Indicates that a median specimen life (MEDSL) value is available, for this timber species at this site, see Table 3.

TABLE 3. Median specimen life (MEDSL), first and third quartile values[a] of heartwood specimens exposed for 23 years

Species	Brisbane			Innisfail			Sydney			Walpeup			Melbourne		
	Q_1	(MEDSL)	Q_3	Q_1	(MEDSL)	Q_3	Q_1	(MEDSL)	Q_3	Q_1	(MEDSL)	Q_3	Q_1	(MEDSL)	Q_3
Australian hardwoods (Myrtaceae)															
E. acmenoides (White mahogany)	13.9	(20.0)	22.0	18.1	(22.0)	-	20.2	(-)	-	-	(-)	-	-	(-)	-
E. amygdalina (Black peppermint)	3.1	(3.1)	8.5	1.1	(3.2)	3.2	8.6	(10.3)	12.0	8.8	(8.8)	15.8	4.3	(6.3)	8.3
E. astringens (Brown mallet)	8.5	(8.5)	12.0	3.2	(5.2)	8.6	15.6	(22.1)	-	8.8	(16.0)	22.5	-	(-)	-
E. bosistoana (Coast grey box)	8.5	(20.0)	-	3.2	(8.5)	13.9	12.0	(22.1)	-	12.4	(20.0)	-	-	(-)	-
E. botryoides (Southern mahogany)	3.1	(6.8)	8.5	1.1	(4.2)	8.5	12.0	(12.0)	12.0	14.8	(18.5)	19.5	12.3	(14.0)	19.6
E. calophylla (Marri)	3.1	(3.1)	5.2	1.1	(5.2)	5.2	12.0	(12.0)	14.6	8.8	(12.4)	14.8	8.3	(10.9)	19.6
E. camaldulensis (River red gum)	8.5	(8.5)	13.9	8.5	(11.9)	22.0	8.4	(15.6)	-	18.5	(22.0)	-	-	(-)	-
E. capitellata (Brown stringybark)	3.1	(5.2)	5.2	1.1	(1.1)	3.2	4.7	(8.6)	13.6	5.3	(8.8)	16.8	4.3	(12.3)	-
E. cladocalyx (Sugar gum)	12.0	(19.0)	-	16.0	(-)	-	-	(-)	-	-	(-)	-	-	(-)	-
E. cloeziana (Gympie messmate)	22.0	(-)	-	1.1	(13.9)	20.0	20.2	(-)	-	-	(-)	-	-	(-)	-
E. consideniana (Yertchuk)	8.5	(8.5)	12.0	1.1	(3.2)	8.5	8.6	(16.1)	-	12.4	(-)	-	14.0	(16.8)	-
E. cornuta (Yate)	8.5	(18.0)	-	1.1	(3.2)	8.5	14.6	(15.6)	20.2	8.8	(12.4)	16.5	12.3	(-)	-
E. cypellocarpa (Mountain grey gum)	2.0	(4.2)	6.8	1.1	(1.1)	1.1	8.6	(12.0)	12.0	8.8	(8.8)	14.8	8.3	(12.3)	12.3
E. diversicolor (Karri)	5.2	(6.8)	8.5	1.1	(1.1)	1.1	8.6	(12.0)	16.9	8.8	(8.8)	12.4	12.3	(15.5)	19.6
E. dives (Broad-leaved peppermint)	3.1	(5.2)	8.5	1.1	(2.2)	3.2	4.7	(10.3)	12.0	8.8	(14.8)	17.7	8.3	(10.9)	12.3
E. elata (River peppermint)	1.0	(1.0)	1.0	1.1	(1.1)	3.2	1.6	(4.7)	8.6	3.3	(5.3)	8.8	4.3	(4.3)	10.9
E. eugenioides (White stringybark)	2.0	(4.2)	6.8	3.2	(3.2)	5.2	4.7	(8.6)	20.2	12.4	(16.3)	-	10.9	(12.3)	15.5
E. eugenioides (Wilkinson's stringybark)	3.1	(8.5)	8.5	3.2	(5.2)	8.5	4.7	(10.3)	16.6	8.8	(10.6)	16.8	8.3	(8.3)	19.6
E. fastigata (Brownbarrel)	3.1	(4.2)	8.5	1.1	(1.1)	3.2	4.7	(8.6)	8.6	3.3	(8.8)	12.4	4.3	(4.3)	14.0
E. globulus (Tasmanian blue gum)	3.1	(6.8)	8.5	1.1	(1.1)	1.1	4.7	(12.0)	18.1	3.3	(8.8)	12.4	10.9	(12.3)	15.5
E. globulus (Maiden's gum)	3.1	(5.2)	8.5	1.1	(1.1)	3.2	8.6	(12.0)	20.2	12.4	(14.3)	19.5	8.3	(10.9)	-
E. gomphocephala (Tuart)	13.9	(20.0)	-	1.1	(4.2)	8.5	8.6	(-)	-	13.8	(18.5)	-	-	(-)	-
E. goniocalyx (Long-leaved box)	4.2	(8.5)	14.0	1.1	(3.2)	5.2	8.6	(10.3)	17.9	16.6	(21.5)	-	14.0	(15.5)	-
E. grandis (Rose gum)	3.1	(6.8)	8.5	3.2	(6.8)	8.5	8.6	(8.6)	16.6	12.4	(14.8)	22.5	4.3	(8.3)	-
E. guilfoylei (Yellow tingle)	5.8	(8.5)	11.2	1.1	(1.1)	8.5	12.0	(14.6)	-	12.4	(13.1)	21.0	13.9	(-)	-
E. haemastoma (Scribbly gum)	5.2	(5.2)	8.5	1.1	(2.2)	4.2	12.0	(12.0)	18.1	18.5	(19.5)	-	12.3	(14.0)	-
E. jacksonii (Red tingle)	3.1	(3.1)	5.2	1.1	(1.1)	1.1	4.7	(8.6)	12.0	5.3	(7.1)	8.8	8.3	(10.9)	10.9
E. leucoxylon (Yellow gum)	8.5	(15.0)	22.0	1.1	(10.2)	-	8.6	(8.6)	12.0	20.5	(-)	-	-	(-)	-
E. longifolia (Woollybutt)	8.5	(-)	-	3.2	(8.5)	11.9	13.6	(-)	-	-	(-)	-	-	(-)	-
E. macrorhyncha (Red stringybark)	8.5	(8.5)	12.0	3.2	(8.5)	-	8.6	(12.0)	22.1	18.5	(20.5)	-	8.3	(14.8)	-
E. maculata (Spotted gum)	8.5	(8.5)	12.0	1.1	(8.5)	22.0	8.6	(15.1)	-	14.8	(18.1)	-	-	(-)	-
E. marginata (Jarrah)	3.1	(6.8)	8.5	8.5	(8.5)	8.5	12.0	(12.0)	20.2	16.8	(20.5)	21.5	14.0	(-)	-
E. megacarpa (Bullich)	4.2	(6.8)	8.5	1.1	(1.1)	3.2	4.7	(12.0)	12.0	6.1	(8.8)	14.2	11.6	(13.9)	-
E. melliodora (Yellow box)	12.0	(19.0)	-	11.9	(-)	-	-	(-)	-	-	(-)	-	-	(-)	-

E. microcorys (Tallowwood)	-	(-)	-	18.1	(-)	-	15.6	(-)	-	-	(-)	-	-	(-)	-
E. moluccana (Grey box)	16.0	(-)	-	8.5	(8.5)	-	15.4	(-)	-	-	(-)	-	-	(-)	-
E. muelleriana (Yellow stringybark)	5.2	(5.2)	8.5	1.1	(1.1)	3.2	8.6	(8.6)	12.0	8.8	(14.8)	-	8.3	(15.5)	-
E. obliqua (Messmate)	1.0	(3.1)	8.5	1.1	(1.1)	2.2	4.7	(8.6)	8.6	8.8	(8.8)	16.8	4.3	(8.3)	10.9
E. paniculata (Grey ironbark)	13.9	(-)	-	11.9	(-)	-	-	(-)	-	20.5	(-)	-	-	(-)	-
E. patens (WA blackbutt)	5.2	(8.5)	12.0	1.1	(1.1)	5.2	12.0	(-)	-	22.5	(-)	-	14.0	(19.6)	-
E. pilularis (Blackbutt)	3.1	(5.2)	8.5	1.1	(3.2)	8.5	12.0	(15.1)	20.2	18.5	(-)	-	12.3	(-)	-
E. polyanthemos (Red box)	-	(-)	-	-	(-)	-	-	(-)	-	-	(-)	-	-	(-)	-
E. radiata (NSW messmate)	1.0	(3.1)	5.2	1.1	(1.1)	3.2	8.6	(8.6)	8.6	8.8	(12.4)	19.5	4.3	(8.3)	8.3
E. regnans (Mountain ash)	1.0	(2.0)	3.1	1.1	(1.1)	1.1	4.7	(8.6)	8.6	3.3	(5.3)	8.8	1.1	(6.3)	15.5
E. resinifera (Red mahogany)	8.5	(12.0)	13.9	8.5	(8.5)	11.9	12.0	(13.3)	-	18.5	(-)	-	-	(-)	-
E. rubida (Candlebark)	1.0	(1.0)	5.2	1.1	(1.1)	3.2	4.7	(4.7)	8.6	3.3	(6.1)	8.8	4.3	(4.3)	12.3
E. saligna (Sydney blue gum)	3.1	(4.2)	5.2	3.2	(5.2)	5.2	8.6	(12.0)	12.0	8.8	(13.8)	15.8	12.3	(14.0)	-
E. salmonophloia (Salmon gum)	20.0	(-)	-	1.1	(2.2)	10.7	12.0	(13.6)	22.1	12.4	(21.0)	-	-	(-)	-
E. sideroxylon (Red ironbark)	18.0	(-)	-	22.0	(-)	-	12.0	(-)	-	-	(-)	-	-	(-)	-
E. sieberi (Silvertop ash)	1.0	(5.2)	8.5	1.1	(1.1)	1.1	8.6	(12.0)	-	8.8	(13.8)	18.5	10.9	(13.2)	15.5
E. tereticornis (Forest red gum)	12.0	(13.0)	13.9	13.9	(18.1)	-	13.6	(-)	-	17.7	(-)	-	-	(-)	-
E. viminalis (Manna gum)	1.0	(1.0)	3.1	1.1	(1.1)	1.1	4.7	(4.7)	8.6	1.0	(5.3)	5.3	4.3	(4.3)	8.3
E. wandoo (Wandoo)	-	(-)	-	20.0	(-)	-	-	(-)	-	-	(-)	-	-	(-)	-
L. confertus (Brush box)	1.0	(3.1)	3.1	3.2	(3.2)	5.2	4.7	(8.6)	8.6	5.3	(13.8)	17.7	8.3	(8.3)	10.9
L. suaveolens (Swamp box)	8.5	(13.9)	13.9	8.5	(8.5)	8.5	12.0	(15.6)	18.1	-	(-)	-	10.9	(16.3)	-
S. glomulifera (Turpentine)	8.5	(10.3)	16.0	8.5	(8.5)	16.0	8.6	(16.1)	-	14.8	(-)	-	-	(-)	-
S. hillii (Satinay)	5.2	(6.8)	8.5	8.5	(8.5)	11.9	8.6	(12.0)	12.0	-	(-)	-	19.6	(-)	-
Australian hardwoods other than Myrtaceae															
A. acuminata (Raspberry jam)	16.0	(-)	-	11.2	(16.0)	20.1	20.2	(-)	-	-	(-)	-	-	(-)	-
A. harpophylla (Brigalow)	13.9	(-)	-	22.0	(22.0)	-	13.6	(-)	-	22.5	(-)	-	-	(-)	-
A. luehmannii (Bull oak)	16.0	(-)	-	-	(-)	-	-	(-)	-	8.9	(-)	-	-	(-)	-
L. reticulata (Bollywood)	3.1	(3.1)	5.2	1.1	(5.2)	5.2	4.7	(8.4)	12.0	8.8	(12.4)	16.8	8.3	(8.3)	12.3
N. cunninghamii (Myrtle beech)	1.0	(1.0)	3.1	1.1	(1.1)	1.1	1.6	(6.7)	8.6	1.0	(2.1)	3.3	8.3	(8.3)	10.9
Exotic hardwoods															
A. thyrifera (Garawa)	3.1	(4.2)	8.5	3.2	(8.5)	8.5	4.7	(8.6)	10.3	5.3	(8.8)	19.5	4.3	(6.3)	8.3
I. bijuga (Kwila)	5.2	(8.5)	8.5	5.2	(8.5)	11.9	4.7	(10.3)	13.6	17.7	(-)	-	10.9	(15.5)	-
P. indicus (NG rosewood)	5.2	(8.5)	8.5	3.2	(5.2)	8.5	8.6	(8.6)	12.0	16.8	(-)	-	12.3	(12.3)	14.0
Q. alba (American white oak)	1.0	(2.0)	4.2	1.1	(1.1)	3.2	8.6	(8.6)	10.3	7.1	(8.8)	10.6	4.3	(4.3)	6.3
T. grandis (Burmese teak)	8.5	(12.0)	18.0	5.2	(10.2)	13.9	12.0	(15.9)	-	22.5	(-)	-	-	(-)	-
Australian softwoods															
A. robusta (Kauri pine)	1.0	(1.0)	1.0	1.1	(1.1)	1.1	1.6	(1.6)	1.6	5.3	(8.8)	8.8	4.3	(4.3)	4.3

A. selaginoides (King William pine)	5.2	(6.8)	10.3	5.2	(8.5)	8.5	8.6	(8.6)	10.3	-	(-)	-	10.9	(10.9)	10.9
C. columellaris (White cypress pine)	8.5	(10.3)	13.0	4.2	(8.5)	10.2	8.6	(12.0)	12.0	13.8	(-)	-	-	(-)	-
L. franklinii (Huon pine)	6.8	(8.5)	10.3	3.2	(4.2)	5.2	8.6	(10.3)	12.0	8.8	(8.8)	8.8	10.9	(10.9)	10.9
P. asplenifolius (Celery-top pine)	6.8	(10.3)	12.0	3.2	(5.2)	5.2	4.7	(8.4)	12.0	8.8	(-)	-	10.9	(10.9)	11.6
P. amara (Black pine)	1.0	(1.0)	1.0	1.1	(1.1)	1.1	1.6	(3.2)	4.7	8.8	(12.4)	18.5	4.3	(4.3)	8.3
Exotic softwoods															
P. radiata (Radiata pine)	1.0	(1.0)	1.0	1.1	(1.1)	1.1	1.6	(1.6)	1.6	1.0	(1.0)	1.0	4.3	(6.3)	8.3
P. menziesii (Douglas fir)	3.1	(3.1)	5.2	1.1	(1.1)	1.1	4.7	(4.7)	4.7	1.0	(3.3)	5.3	8.3	(8.3)	10.9
S. sempervirens (Redwood)	3.1	(5.8)	8.5	2.2	(5.2)	5.2	8.6	(8.6)	12.0	-	(-)	-	8.3	(13.2)	19.6
T. plicata (Western red cedar)	5.2	(6.8)	8.5	3.2	(5.2)	5.2	4.7	(8.6)	8.6	13.8	(19.1)	-	10.9	(10.9)	12.3
Preservative treated *P. radiata* sapwood															
CCA at 12 kg m^{-3}	-	(-)	-	-	(-)	-	-	(-)	-	-	(-)	-	-	(-)	-
K55 Creosote at 175-210 kg m^{-3}	-	(-)	-	-	(-)	-	-	(-)	-	-	(-)	-	-	(-)	-

a) MEDSL values are the medians of the specimen life values of the replicates of each species. Each MEDSL value is preceded by the first quartile and followed by the third quartile.

-, not enough replicates unserviceable and, therefore, the value cannot be calculated for the particular timber species and site.

Only six naturally durable timbers have not yet yielded a MEDSL value at any of the sites (tallowwood, grey ironbark, red box, rred ironbark, wandoo and bull oak). Of these the best overall performer is wandoo (Table 2). However, the preservative-treated radiata pine sapwood controls, particularly the 12 kg m^{-3} CCA treatment, are in far better overall condition than the best of the naturally durables.

Median specimen life (MEDSL) values, together with the Q_1 and Q_3 of each timber species, are given in Table 3. All timber species originally in test are included in this table, even though some have not yet yielded Q_1 and MEDSL values, or in some cases even Q_1 values. However, for 26 timbers, the data in this table are now complete for all five sites. Such timbers are, of course, the poorest performers overall. On the other hand, neither of the treated controls yielded even a Q_1 value at any site. The only durable timbers rating similar to the treated controls are wandoo and red box, the former having yielded a single Q_1 value (20.0 years at Innisfail).

The next publication from this test will be based on data gathered at the inspection to be carried out after 25 years of specimen exposure. On completion of further inspections at either 26 or 27 years, the data will be used to confirm or adjust the original "tentative" durability ratings.

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THE IMPLICATIONS OF THE BUILDING ENVELOPE MICRO-CLIMATE TO THE DURABILITY AND SERVICEABILITY OF WOOD AND WOOD PRODUCTS

I.S. Cole
CSIRO Division of Building, Construction and Engineering
PO Box 56, Highett, Victoria 3190

ABSTRACT

Results from a recently completed study of the temperature and relative humidity in the wall cavities of houses sited in Melbourne, Brisbane and Darwin are used to calculate the moisture content of the cavity airspaces in this paper. For the wettest cavity in the Melbourne and Brisbane houses the equilibrium moisture content (EMC) within a softwood member is calculated. This calculation is made using a semi-infinite model assuming both side and edge grain diffusion. Data on the EMC levels required for growth of wood decay fungi, and the degradation of melamine-urea-formaldehyde adhesives is presented. This data is then combined with the calculated EMC levels to determine whether conditions suitable for either biodeterioration or adhesive decay exist.

INTRODUCTION

It has long been established that the durability of timber and wood products in buildings may be limited by environmental conditions. In particular, excessive humidity and humidity cycles may cause material breakdown. Further, research has defined the temperature and humidity cycles within buildings and established connections between these cycles and material damage (Nevander 1985; Rousseau 1983). However, in Australia little data has been published on the microclimate in the building envelopes. In the absence of this data, a systematic assessment of the effect of building envelope microclimate on damage of timber and wood products has not been possible.

To provide such data, a study of the microclimate in wall cavities of houses sited in a range of Australian climatic zones was undertaken (Cole 1992). This paper uses the results of this recently completed study to calculate the moisture content of the air in wall cavities and to estimate the equilibrium moisture content (EMC) at the surface and within typical softwood studs. The effect of EMC levels on the degradation of adhesives or the biodeterioration of timber is then addressed.

EXPERIMENTAL

In the micro-climate study, cavities in walls of different orientations were monitored for one year with temperature and relative humidity (RH) being recorded. Houses were monitored in Darwin, Brisbane and Melbourne which are in tropical, sub-tropical and temperate climates respectively. All houses were typical of modern Australian construction, being brick veneer slab on ground with tiled roofs. No insulation was used in the Darwin and Brisbane houses while sisalation was placed in wall cavities and sarking in the roof space of the Melbourne house. Absolute humidity (AH) was calculated from a knowledge of RH and temperature. The period monitored varied slightly for each house but was within the years 1990 and 1991.

The orientation of the monitored walls was as follows: Darwin north and west, and Brisbane and Melbourne north and south. The walls were defined as exposed or sheltered on the basis of wind direction during the wettest season (summer for Darwin and Brisbane, winter for Melbourne). In winter the southern bayside suburbs of Melbourne are subjected to predominantly northerly winds (Bureau of Meteorology 1988). In Darwin and Brisbane (river plain) the summer winds are predominantly from the north-west and south-west

respectively (Bureau of Meteorology 1988). Thus the Darwin west wall, Brisbane south wall and Melbourne north wall are defined as the exposed walls, and the Darwin north (faces open garage), Brisbane north and Melbourne south walls are defined as the sheltered walls. However, in the case of Darwin this definition is somewhat artificial as neither wall is either directly exposed to or completely sheltered from the prevailing summer winds.

SURFACE EMC

The original study detailed the variation in RH, and temperature in the airspace of the wall cavity. The moisture content of the airspace can be estimated using the technique derived by Bramhall (1979). Then, in order to estimate the EMC at the surface of wood components it has, following Leicester and Lu (1992), been assumed that the surface layer of the wood is in equilibrium with the temperature and RH of the surrounding air. The temporal variation in EMC of the airspace in a Brisbane south wall cavity is given in Fig. 1. An exceedence diagram of EMC for the Brisbane south wall cavity is given in Fig. 2. EMC is dependent both on the season and the wall orientation being highest for the south-orientated wall in summer.

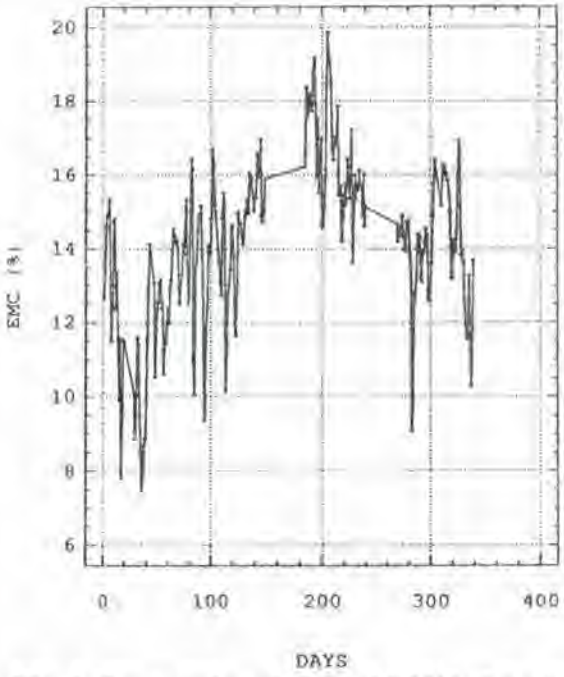

Fig. 1. Temporal variation of EMC of air in Brisbane exposed wall cavity.

EMC Within Timber Members

The EMC within timber members is calculated for the wettest wall of the houses in Brisbane (exposed wall) and Melbourne (sheltered wall). In order to calculate the EMC within a timber member, the temporal variation in the surface EMC must be simplified. An appropriate model of the variation in EMC is of the following form.

$$m_{air}(t) = m_{av} \sum \sin [2\pi (t + \Theta)/P] \quad (1)$$

where m_{av} is the mean, P is the period, and Θ is the phase difference. The parameters for the Melbourne and Brisbane wall cavities given in Tables 1 and 2 were derived using a modified Box-Cox seasonal decomposition algorithm (Box & Jenkins 1976). In the case of the daily cycle, significant variations occur in the mean cycle magnitude in the different seasons and thus in Tables 1 and 2 this value is given on a seasonal basis.

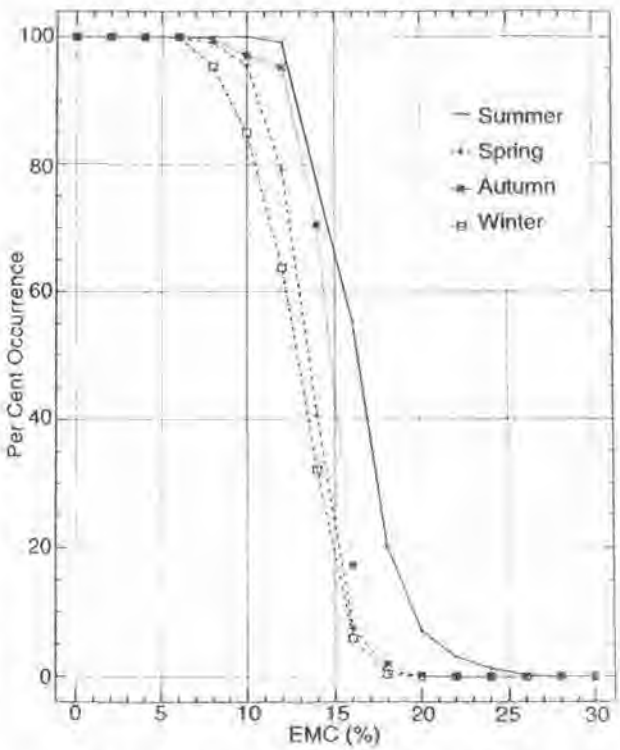

Fig. 2. Exceedence of EMC of air for Brisbane exposed wall cavity.

TABLE 1. PARAMETERS FOR MODEL OF AIRSPACE EMC VARIATION IN A MELBOURNE WALL CAVITY

Period (days)	Magnitude $2\,m_{av}$ (%)	Phase (days)	Season
1	5.7		Summer
1	4.9		Autumn
1	4.7		Winter
1	5.6		Spring
7	5.3	–1	
22	3.6	0	
55	2.7	15	
206	4.5	60	
365	3.8	–100	
mean	15.1		

TABLE 2. PARAMETERS FOR MODEL OF AIRSPACE EMC VARIATION IN A BRISBANE WALL CAVITY

Period (days)	Magnitude $2\,m_{av}$ (%)	Phase (days)	Season
1	4.9		Summer
1	3.0		Autumn
1	2.8		Winter
1	3.5		Spring
7	3.4	0	
22	2.8	–7	
63	1.5	0	
223	1.1	100	
365	5.6	–115	
mean	13		

The estimate of the moisture content in timber will be based on one-dimensional Ficks law:

$$\partial m/\partial t = D_x \partial^2 m/\partial x^2 \qquad (2)$$

where D_x denotes the diffusion constant.

The boundary conditions are defined by:

$$m\,(x = 0) = m_{air} \qquad (3)$$

However, as timber components may be of varying sizes, a model of a semi-infinite beam rather than model a specific geometry has been used. This has the advantage that the data is not specimen specific. It has the disadvantage that edge effects (with the exception of the front edge) are ignored and diffusion is assumed to be only in one direction. These assumptions should lead to lower values than if a finite specimen was modelled and multi-directional diffusion was allowed, and thus the results of this study may underestimate the EMC that occurs in the actual situation.

For a semi-infinite body, bounded by x = 0, the application of Eqs (3), (2) and (1) leads to the following:

$$m = m_{mean} + m_{av} \sum e^{-H_x x} \sin\,\{[2\pi\,(t + \Theta) + H_x x]/P\} \qquad (4)$$

where $H_x x = \sqrt{P/2D_x}$.

Equation (4) has been used to calculate the values of EMC within a semi-infinite piece of softwood. The value of the coefficient H_x has been calculated using a diffusion moisture coefficient as proposed by Droin-Josserand *et al.* (1989). Their diffusion relationships are developed from a study on Scots pine (*Pinus sylvestris*) sapwood, but give diffusion values typical for softwoods, as detailed below, where D units are cm^2/s:

$D = 1.5*10^{-6} \exp(0.0228*EMC)$ for side grain diffusion
$D = 304*10^{-6} \exp(-0.177*EMC)$ for end grain diffusion.

In Figs 3 and 4 the predicted variations in EMC at selected distances from the surface, assuming side grain diffusion, are given for semi-infinite softwood in Melbourne and Brisbane respectively. In Figs 5 and 6 the predicted variation in EMC, 5 and 20 mm from the surface, assuming end grain diffusion, are given for a semi infinite softwood in Melbourne. In the case of side grain diffusion, the daily cycle is not considered as it does

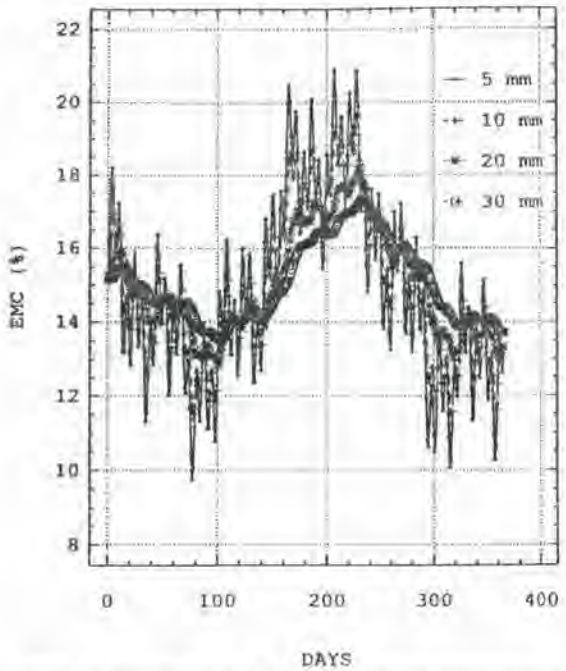

Fig. 3. Internal EMC (assuming side grain diffusion) for semi-infinite softwood in Melbourne wall cavity.

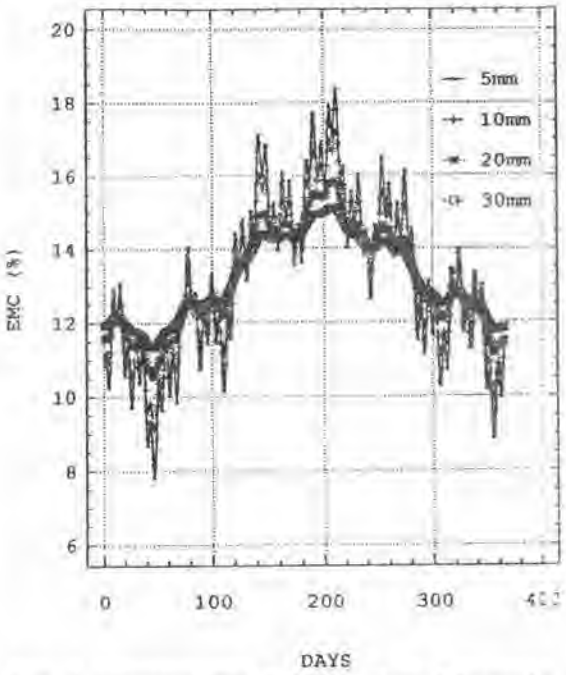

Fig. 4. Internal EMC (assuming side grain diffusion) for semi-infinite softwood in Brisbane wall cavity.

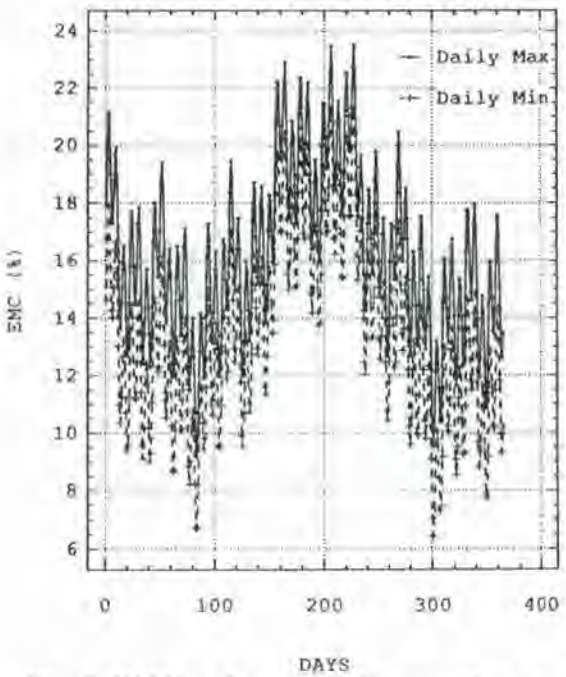

Fig. 5. EMC at 5 mm depth (assuming end grain diffusion) for semi-infinite softwood in Melbourne wall cavity.

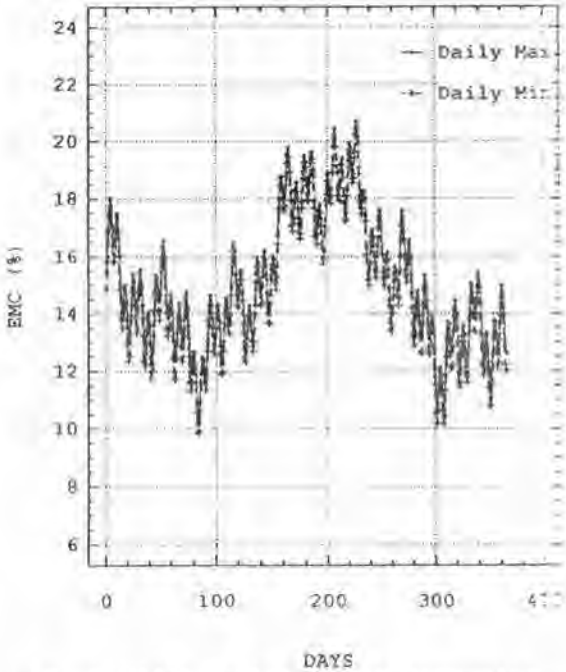

Fig. 6. EMC at 20 mm depth (assuming end grain diffusion) for semi-infinite softwood in Melbourne wall cavity.

not give rise to EMC variation at depths greater than approximately 2 mm, however it is included in the case of end grain diffusion. This is reflected in the figures so that the maximum and minimum in Figs 5 and 6 refer to the maximum and minimum of the EMC on any given day.

DEGRADATION

Excessive EMC may promote degradation in a number of ways. Two such ways and critical conditions for them are discussed below.

The comparative degradation of wood adhesives is of concern in Australia. Interest at present focuses on the use of melamine-urea-formaldehyde (MUF) adhesives instead of the traditional phenol or phenol resorcinol adhesives for finger-jointed studs in timber framing. In British and American standards the use of MUF adhesives is limited to specific moisture and temperature conditions. In the UK standard BS 4169 the EMC must not exceed 18% and the temperature 50°C, while in the US standard AITC 190.1, EMC should not exceed 16% and temperature 49°C. Australian wall cavities on the eastern/northern seaboard do not exhibit temperatures in excess of 49°C, so that EMC is the only limiting factor. The standards do not set time levels for MUF degradation. It is possible that short periods of high EMC may not promote degradation and thus it is assumed, in this paper, that degradation will occur if the time above the limit exceeds 10%.

A second degradation that timber members could potentially suffer in wall cavities is biodeterioration by wood decay fungi. The formation and growth of fungi is largely controlled by the EMC of the wood. Fungi will certainly form if the EMC exceeds 30% (Thornton 1991; Griffin 1977) which equates to fibre saturation point. However, EMC must be lower than 20% to guarantee that fungi will not form (Bootle 1980). Once formed, fungi may continue to grow at lower moisture contents. The exact limit at which growth will cease is open to conjecture. Thornton (1991) suggests that growth will cease around 18%. Fungi formation and growth requires EMC to be above the limit for significant periods of time and thus it is assumed in this paper that biodeterioration will occur only if the EMC limit is exceeded for greater than 10% of the time.

We can thus define four critical limits with reference to adhesive durability and biodeterioration. The lowest is 16% which reflects the US MUF limit. The next limit at 18% reflects the UK MUF limit and Thornton's (1991) limit for continued growth of wood decay fungi. A third limit is defined at 20% which is Bootle's (1980) value below which fungi formation will not occur, while a final limit is set at 30% above which, according to Thornton, fungi formation is highly likely. The percentage of time for each season that the wall cavity air EMC exceeds the first three of these limits is given in Table 3. The 30% EMC exceedence is not tabulated as all results were zero with the exception of the Melbourne south wall cavity where the EMC exceeded 30% for 0.3% of the summer. As stated above, decay is assumed to occur if EMC is above the relevant limit for 10% of the time.

TABLE 3. CRITICAL EMC EXCEEDENCE VALUES FOR ADHESIVE DECAY AND FUNGI GROWTH IN WALL CAVITY AIR

Location	EMC critical values (%)											
	Summer			Autumn			Winter			Spring		
	16	18	20	16	18	20	16	18	20	16	18	20
Melbourne exposed	7	2	0.5	12	5	2	27	13	4	22	13	6
Melbourne sheltered	16	7	5	42	17	4	58	29	10	18	6	2
Brisbane exposed	54	20	7	17	3	0	5	1	0	6	2	0
Brisbane sheltered	12	4	1	16	3	0	8	3	0	3	0	0
Darwin exposed	68	63	18	6	4	3	0	0	0	0	0	0
Darwin sheltered	72	46	8	7	3	0.5	1	0	0	0	0	0

Similarly the exceedence of EMC relative to the critical values can be calculated at various depths within the hypothetical semi-infinite softwood. This is done for such a softwood placed in a sheltered Melbourne and exposed Brisbane wall cavity under the assumptions of side grain and end grain diffusion in Tables 4 and 5 respectively.

TABLE 4. CRITICAL EMC EXCEEDENCE VALUES AT GIVEN DEPTHS IN HYPOTHETICAL SOFTWOOD IN MELBOURNE AND BRISBANE WALL CAVITIES ASSUMING SIDE GRAIN DIFFUSION

Loc.	Depth (mm)	EMC critical value (%)											
		Summer			Autumn			Winter			Spring		
		20	18	16	20	18	16	20	18	16	20	18	16
Melb.	5	0	1.1	12	2.2	11	27	8.7	31	81	0	0	5.5
	10	0	0	11	0	7.6	18	0	30	86	0	0	5
	20	0	0	0	0	0	7.6	0	5.4	92	0	0	3.3
	30	0	0	0	0	0	0	0	0	96	0	0	3.2
Bris.	5	0	2.2	41	0	0	5.4	0	0	0	0	0	0
	10	0	0	33	0	0	0	0	0	0	0	0	0
	20	0	0	0	0	0	0	0	0	0	0	0	0
	30	0	0	0	0	0	0	0	0	0	0	0	0

TABLE 5. CRITICAL EMC EXCEEDENCE VALUES AT GIVEN DEPTHS IN HYPOTHETICAL SOFTWOOD IN MELBOURNE AND BRISBANE WALL CAVITIES ASSUMING END GRAIN DIFFUSION

Loc.	Depth (mm)	EMC critical value (%)											
		Summer			Autumn			Winter			Spring		
		20	18	16	20	18	16	20	18	16	20	18	16
Melb.	5	1.7	6.7	14	6.6	18	35	20.7	46	71	1.1	3.3	14
	10	0	4.5	13	3.8	14	34	14.2	51	82	0	1.1	9.0
	20	0	0.6	12	0	10	22	5.4	43	84	0	0	7.7
	30	0	0	11	0	4.3	17	0	40	84	0	0	4.4
Bris.	5	2.8	20	48	0	1.7	11	0	0	0	0	0	0.6
	10	0	8.9	51	0	0	14	0	0	0	0	0	0
	20	0	2.8	37	0	0	8.6	0	0	0	0	0	0
	30	0	0	18	0	0	0	0	0	0	0	0	0

DISCUSSION

Estimates of the EMC of the airspace of wall cavities in brick-veneer buildings sited in three Australian cities have been made. For the wettest wall cavity in the Melbourne and Brisbane houses, estimates of the EMC within a hypothetical semi-infinite softwood have been made. These estimates are based on measurements carried out over one year in one house in each city and thus care must be taken in generalising the results. However, unpublished analysis indicated that the climatic variation in the year monitored was typical of the annual climatic variation normally experienced in each centre. In the case of the Melbourne house, a further study of the microclimatic in four brick-veneer houses has been completed. This study indicated that the wall cavity microclimate in the

Melbourne house presented in this paper was typical of the microclimate in the wall cavities of the larger group of houses. All houses were in sound condition and showed no evidence of moisture-induced problems.

The data presented thus provides an initial database to assess the impact of microclimate on material durability. The deterioration phenomena discussed are presented only to illustrate the importance of microclimate information to durability studies. The study indicates that the MUF adhesive at the timber surface would decay under the UK limits in Brisbane (exposed cavity) and Darwin (exposed and sheltered) and under the US limits in all wall cavities. In modelling moisture diffusion into timber components we have not used a specific model and thus it could be argued that the data is not directly applicable to the problem of finger joints. However the model, under the assumptions of side grain diffusion, is likely to be conservative with respect to finger joints and thus can provide a lower estimate of EMC in such joints. The study indicates that only in summer will the US limit be exceeded within (to a depth of between 10 and 20 mm) a softwood member in the wettest wall of the Brisbane house, while the UK limit is not exceeded for significant periods in any season. In contrast, in Melbourne the UK limit is exceeded to a depth greater than 5 mm in autumn and winter and to depths between 10 and 20 mm in winter. The US limit is exceeded to depths greater than 10 mm in all seasons but spring and at all calculated depths in winter. In finger joints if large fingers are used and the fingers are not completely sealed by adhesive then end grain may be exposed. Under such conditions moisture penetration into the joint is very significant (refer to Table 5) for joints in both Brisbane and Melbourne, with both the US and UK limits being excluded in a number of seasons to significant depths.

The formation of wood decay fungi on the surface of timber is not guaranteed at any location (i.e. 30% limit is not exceeded). On the other hand, the possibility that fungi can form cannot be ruled out (i.e. 20% limit exceeded) in Darwin summer (exposed wall) and Melbourne winter (exposed wall). Once initiated, growth (at the surface) could continue in Brisbane (exposed wall) and Darwin (exposed and sheltered walls) in summer, and in Melbourne in winter (sheltered wall) and spring (exposed wall). In cases where moisture ingress is controlled by side grain diffusion, fungi formation is improbable within timber members in both Brisbane and Melbourne. Growth of fungi formed on the timber surface into the timber is (considering EMC only) possible according to both the criteria derived from Thornton in Melbourne in autumn and spring. Such growth is not possible in Brisbane. However, in winter and spring in Darwin and Brisbane surface EMCs drop to very low values. The effect that this has on fungi has not been addressed. If end grain diffusion is possible then fungi growth into timber members is possible in both locations.

The above analysis is aimed at defining only when microclimatic variables are such that material deterioration is possible. It should not be considered that decay is inevitable if microclimatic variables are favourable as other factors may restrict the decay mechanisms.

CONCLUSIONS

The EMC of the airspace of wall cavities of houses sited in Melbourne, Brisbane and Darwin has been calculated. For the wettest wall cavity in Melbourne and Darwin the EMC within a hypothetical semi-infinite softwood has been calculated. The applicability of such data to the assessment of probable material durability was then illustrated by two examples. These are the deterioration of melamine-urea-formaldehyde adhesives in timber studs and the biodeterioration of wood by decay fungi. With respect to these decay mechanisms, it was concluded that:

(1) EMC levels are such that decay of MUF adhesive at the surface of finger jointed timber studs is possible in all monitored locations. Decay within the joints is possible in Melbourne according to both the UK and US criteria but only possible in Brisbane according to the US criteria.

(2) While the formation of wood by decay fungi is not guaranteed in any location, the possibility cannot be ruled out in Darwin and Melbourne. If wood decay fungi do form, periods in which conditions are suitable for growth exist in all locations.

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IMPROVING THE WEATHER RESISTANCE OF GLUE-LAMINATED KARRI & JARRAH

J. Balfas† and P.D. Evans

Department of Forestry, Australian National University, ACT 0200

ABSTRACT

Chemical modification (surface modification and dimensional stabilisation) significantly increased the dry and wet shear strength of karri and jarrah lap-shear specimens (laminates) bonded with resorcinol formaldehyde. The combination of surface modification (sanding/sodium hydroxide treatment), and furfurylation produced the highest dry and wet shear strengths. Acetylated laminates had the lowest dry bond strength, but the lowest loss of strength on wetting. In most cases karri showed higher dry, but lower wet shear strength than jarrah. Untreated laminates rapidly delaminated during artificial accelerated weathering, but surface modification and dimensional stabilisation significantly increased the resistance of specimens to delamination. Only a small proportion (<10%) of acetylated specimens delaminated during accelerated weathering and surface modified acetylated laminates showed no delamination during the weathering test. Laminates treated with a combination of surface modification and furfurylation showed less delamination than specimens treated by surface modification alone. Chemical modification treatments that increase both glue bond strength and dimensional stability appear to offer an effective means of improving the weathering resistance of glue-laminated karri and jarrah.

INTRODUCTION

In Australia some electricity authorities use solid wood cross-arms on power poles. Tallowwood (*Eucalyptus microcorys* F. Muell.) is the main species used in the Eastern states while jarrah (*E. marginata* ex Sm.) cross-arms are used in Western Australia (WA). In recent years the price of solid wood cross-arms has increased significantly and electricity authorities have started to use, or have shown interest in using cross-arms manufactured from steel, fibre-glass or glue-laminated timber. In WA, glue-laminated furniture blanks (Valwood panels) have been manufactured by edge and face gluing thin dried boards cut from regrowth karri (*Eucalyptus diversicolor* F. Muell.) and jarrah thinnings. Glue-laminated cross-arms have also been manufactured using a similar process, but using an exterior grade resorcinol formaldehyde adhesive. The bending strength of such cross-arms exceeded those of a small sample of solid jarrah cross-arms (Siemon 1991).

An important consideration in the use of glue-laminated cross-arms is their resistance to delamination during exterior exposure and therefore artificial accelerated weathering tests on glue-laminated karri and jarrah cross-arms, both untreated and treated with a variety of water repellent preservatives and coatings, were undertaken (Evans 1988). Untreated cross-arms

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† Forest Products Research and Development Centre, Bogor, Indonesia

showed rapid delamination during accelerated weathering and although some water repellent preservatives were effective in retarding the rate of delamination, after 1000 hours of accelerated weathering all treated cross-arms showed extensive delamination (Evans 1988). The inability of conventional water repellents or coatings to prevent delamination of glue-laminated regrowth karri and jarrah cross-arms led to the search for alternative approaches to improve their weather resistance. Since delamination of Scots pine (*Pinus sylvestris* L.) and Norway spruce (*Picea abies* Karst) glue-laminated specimens during cyclic wetting is reported to be significantly lower after acetylation of laminates (Larsson *et al.* 1992), chemical modification was selected as an alternative approach. The resistance of glue-laminated timber to delamination during weathering depends on glue bond strength between laminates and the dimensional stability of laminates (Chugg 1964), and therefore the chemical modification techniques chosen to improve weather resistance involved surface modification (sanding and sodium hydroxide treatment) of laminates to improve glue bonding and acetylation or furfurylation to improve their dimensional stability. The ability of these treatments to improve the glue bonding and dimensional stability of wood has been established previously (see reviews by Zavarin 1984 and Rowell 1983) and work also showed that they were effective treatments for regrowth karri and jarrah (Balfas 1993; Balfas *et al.* 1993). There have been few if any studies of the ability of chemical modification techniques to improve the weather resistance of glue-laminated regrowth eucalypt timber and it has not been clearly established whether the combination of surface modification and dimensional stabilisation can further increase the resistance of glue-laminated timber to delaminate during weathering.

In this paper the shear strength of chemically modified lap-shear specimens bonded with resorcinol formaldehyde was measured in the dry and wet conditions, and also after artificial accelerated weathering. The delamination of modified specimens during accelerated weathering was also assessed. The aim was to determine whether surface modification and dimensional stabilisation treatments can significantly improve the weather resistance of glue-laminated regrowth karri and jarrah.

MATERIALS AND METHODS

Preparation of wood samples

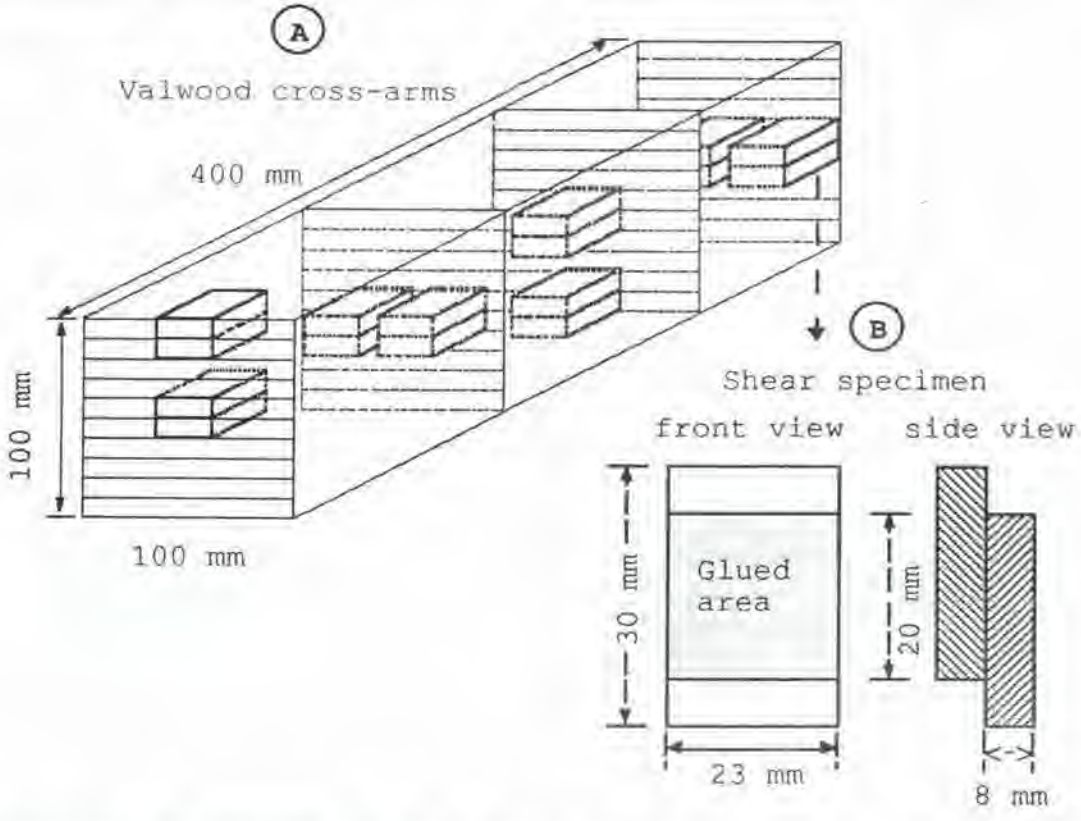
Defect-free, flat-sawn (back-sawn) regrowth karri and jarrah heartwood was used in this study. Fifty karri and 50 jarrah boards measuring 10mm x 100mm x 600mm were provided by the Department of Conservation and Land Management (CALM), Western Australia. The karri boards were relatively uniform in colour, but there were distinct differences in the colour of jarrah boards. Since the colour differences in jarrah boards were due to variation in extractive content which influenced wettability and glue bonding (Balfas 1993), jarrah boards were sub-divided into two groups of light and dark colour. All boards were re-planed on both sides to 8mm thickness to give fresh surfaces and then cut into small blocks measuring 8mm

(radial) x 25mm (longitudinal) x 100mm (tangential). The cutting pattern used to produce these samples has been described previously (Balfas *et al.* 1993). After cutting, blocks were conditioned to 10% moisture content in a conditioning room at 20 ± 1 °C and 65 ± 5% relative humidity for three weeks. One hundred wood blocks of each sample type were then selected at random, batched into 10 groups, i.e., 10 blocks per group, and for each sample type two groups of blocks were then allocated to the following five treatments;

A, untreated controls (Cntrl); B, surface modification using a combination of sanding and sodium hydroxide treatment (S-Na); C, chemical modification by acetylation (Ac); D, chemical modification by acetylation followed by surface modification (Ac-S-Na); E, surface modification followed by furfurylation (S-Na-Fur).

To compare modified laminates with unmodified exterior grade Valwood (Val), forty shear specimens for each species were cut from five laminated Valwood cross-arms, i.e., eight specimens were cut from each cross-arm. The cutting arrangement to produce these specimens is shown in Fig. 1. Karri and jarrah Valwood shear block specimens were then divided into two groups of 20 specimens.

Figure 1. Preparation of lap-shear specimens (B) from Valwood cross-arms (A)



Chemical modification and preparation of lap-shear specimens

Sanding involved manually rubbing one side of an air dry block with an 80 grit abrasive paper for 30 seconds. A previous study (Balfas *et al.* 1993) had shown that this significantly improved

the wettability and adhesive properties of regrowth karri and jarrah. Surface modification with sodium hydroxide (NaOH) involved smearing one side of an air dry block with 2.0 M aqueous solution of NaOH at a rate of 48mL/m^2. Specimens treated by acetylation were oven dried at 105 °C for 48h, and placed in a stainless steel pressure vessel which was pre-heated in an oven at 120 °C. Five wood blocks were loaded into the pressure vessel and 200mL of a 25% (v/v) solution of acetic anhydride in xylene was added. The pressure vessel was then sealed and placed in an oven at 120 °C for 24h. Excess acetic anhydride solution was removed from the specimens by drying them in a fume cupboard for 0.5h and then allowing them to dry in a conditioning room for seven days. Furfurylation was applied to laminates after glue bonding. A solution of furfuryl alcohol was prepared by dissolving one part by weight of zinc chloride ($ZnCl_2$; M & B, purity > 95%) in one part of distilled water. This was then added to 98 parts by weight of furfuryl alcohol (C_4CH_3O-CH_2OH, TCI chromatography reagent). Air dry laminates were soaked in 200 mL of this solution for 48h. The reaction was carried out in a 250 mL measuring cylinder at 20 °C, and wood laminates were kept below the level of the solution. After the reaction period was complete, treated specimens were wrapped in aluminium foil and then dried in an oven at 120 °C for 6h. Specimens were then conditioned for seven days. With the exception of Valwood specimens, lap-shear specimens were prepared from treated blocks. Ten small panels were made for each sample type and treatment group, by bonding 20 pairs of wood blocks parallel to the grain with resorcinol formaldehyde resin as described previously (Balfas *et al.* 1993).

Dry and wet shear tests and accelerated weathering

Five small panels per wood type and treatment were allocated to dry and wet shear tests and a similar number of panels were allocated to accelerated weathering. Each small panel was cut with a small band-saw (1mm kerf) into four shear test specimens of a similar size to those shown above (Fig. 1). Prepared lap-shear specimens remained in a conditioning room (as above) for seven days prior to testing. Two shear specimens per block were tested in the dry condition, and the remaining two shear specimens were tested after 24h immersion in tap water. Shear strength was determined as described previously (Balfas *et al.* 1993).

Shear specimens not tested for dry or wet shear strength were exposed to artificial accelerated weathering in a Weather-ometer (Atlas Electrical Devices Co. model 600/XW-WR). Twenty shear block specimens for each wood type and treatment were fixed with battery clips to radiata pine (*Pinus radiata* D. Don) panels, 230mm (height) x80 mm (width) x 7mm (thick) in size. Six blocks, one from each treatment and one cut from Valwood, were fixed to each panel. There were 57 panels and 340 blocks *in toto* exposed in the Weather-ometer. Panels were attached to the Weather-ometer carousel with the glue-line of the shear specimens located approximately 400mm away from the ultra-violet (UV) light source. A 6000W, water cooled xenon-arc lamp, with inner and outer borosilicate filters, was used as the radiation emitted by this lamp has a spectral distribution which closely resembles that of natural sunlight. To maintain the power

output of the lamp its Wattage was periodically increased at a standard rate every 400h. The temperature and relative humidity of the Weather-ometer chamber were set at 50 °C and 50% relative humidity. Each 24h period of weathering consisted of 24h of continuous light with a 1.8h period of water spray every 4.8h. The weathering resistance of laminates was assessed by observing specimen delamination during the exposure period, and by testing the dry shear strength of laminates that had maintained their integrity after 42 days of weathering.

Statistical analysis of data

An analysis of variance (ANOVA) was carried out to determine whether treatment, testing condition (dry v wet) and wood type significantly affected shear strength. An ANOVA was also carried out to determine whether treatment and wood type significantly affected dry shear strength of specimens after accelerated weathering. Wet and dry shear strength of laminates are presented graphically and least significant differences are presented for comparison of means. The residual dry shear strength of laminates after weathering are tabulated together with 95% confidence intervals.

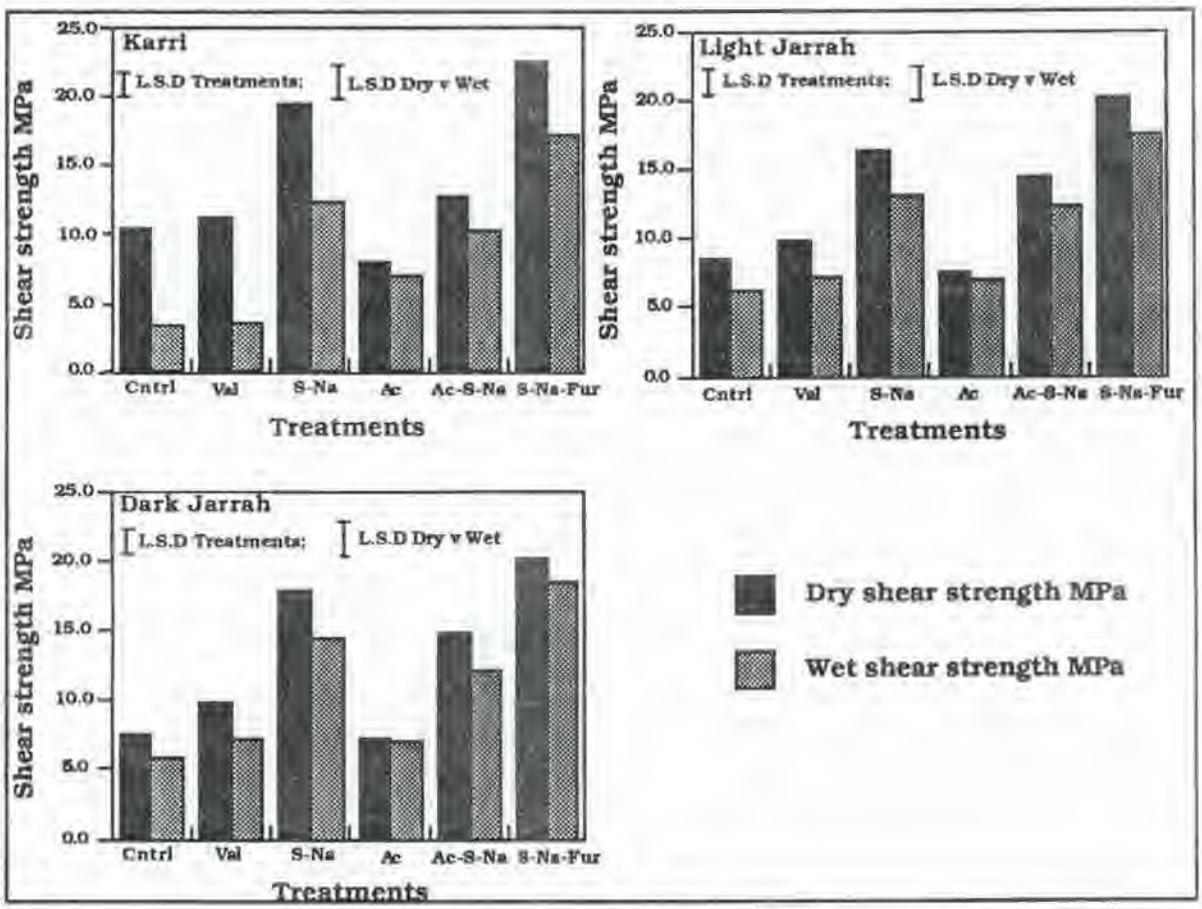
RESULTS AND DISCUSSION

There was a very highly significant ($p<0.001$) effect of treatment on shear strength of laminates. The shear strength of laminates from the different treatment groups are compared in Fig. 2. Irrespective of wood type, the dry shear strength of laminates treated by surface modification, acetylation/surface modification and surface modification/furfurylation was significantly ($p<0.05$) higher than for untreated controls. There was no significant difference ($p>0.05$) in dry shear strength of untreated controls, Valwood laminates and acetylated jarrah laminates, but acetylated karri laminates had a significantly ($p<0.05$) lower dry shear strength than untreated controls. The latter accords with a previous study (Larsson *et al.* 1992) in which it was observed that acetylation reduced the dry shear strength of Scots pine and Norway spruce laminates bonded with resorcinol formaldehyde. The lower dry shear strength of acetylated laminates is not surprising since acetylation blocks wood hydroxyl groups which participate in the formation of wood-adhesive bonds. The higher dry shear strength of acetylated specimens after surface modification may therefore be related to the ability of sodium hydroxide to deacetylate wood (alkali is very effective at deacetylating wood; Rowell *et al.* 1992) and hence increase the bonding of resorcinol formaldehyde to laminate surfaces.

Immersion of wood blocks in water and testing in the wet condition had a very highly significant ($p<0.001$) effect on shear strength and there was also a very highly significant ($p<0.001$) interaction of treatment and block condition on shear strength. All treated laminates show some loss of shear strength on wetting, but acetylated laminates and light and dark jarrah laminates treated by acetylation/surface modification and surface modification/furfurylation respectively showed no significant ($p>0.05$) loss of shear strength on wetting (Fig. 2). The remaining wood/treatment combinations showed significantly ($p<0.05$) lower shear strength when tested wet. Previous studies

(Vick and Rowell 1990; Larsson *et al.* 1992) have shown an increase in the shear strength of acetylated laminates after wetting, but this effect was not observed here. There were highly significant ($p<0.01$) interactions of treatment, wood type and treatment condition on shear strength. Thus, treated karri laminates showed greater strength losses on wetting than treated jarrah laminates. Untreated karri and Valwood laminates also showed significantly ($p<0.05$) lower shear strength when tested wet, whereas untreated jarrah and Valwood laminates showed no significant ($p>0.05$) loss of shear strength on wetting.

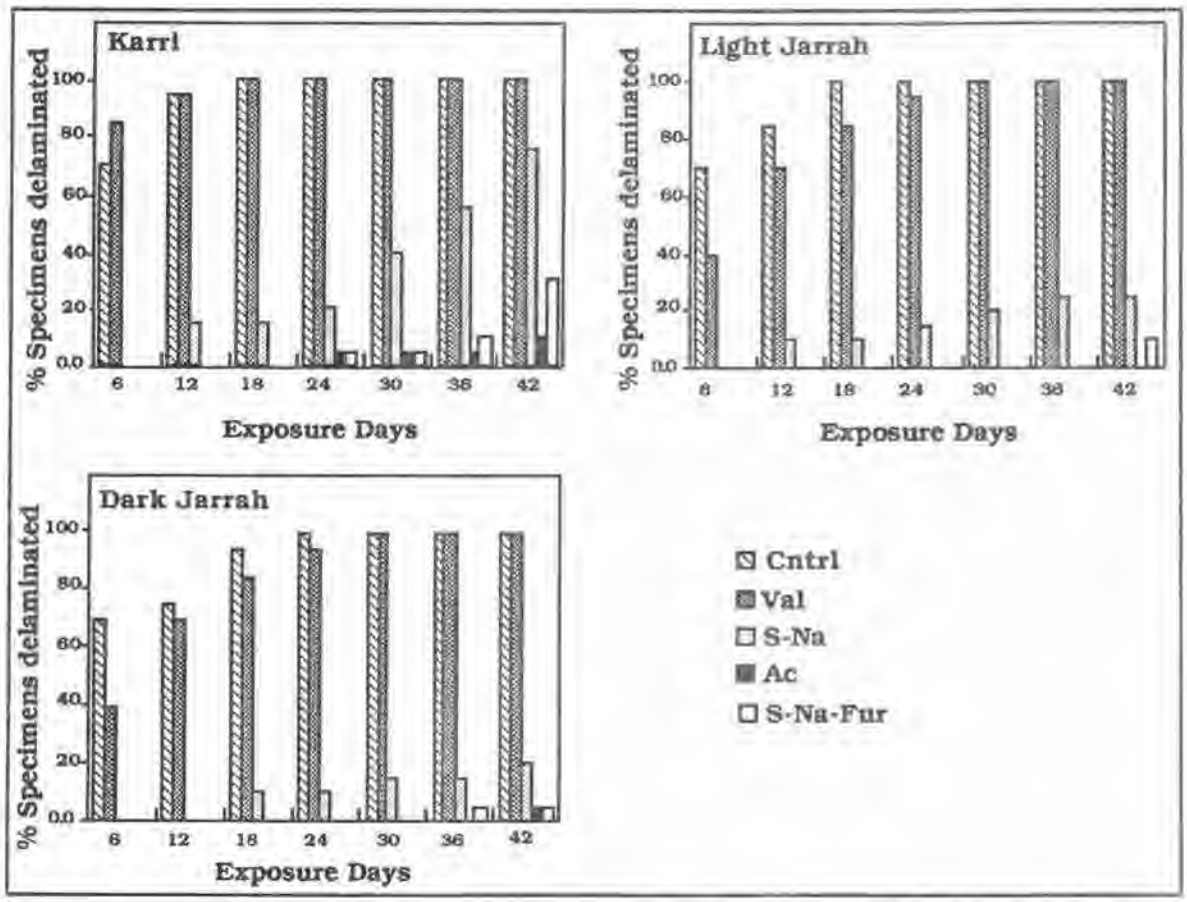
Figure 2. Dry and wet shear strength of laminates



Based on measurements of wet shear strength and loss of shear strength on wetting it appears that some of the treatments, particularly those that combine surface modification and dimensional stabilisation, may have potential to improve the weathering resistance of glue-laminated karri and jarrah. In this study treated laminates and controls were immersed in water for 24h and then tested for wet shear strength, but during exterior exposure glue-laminated timber is exposed to frequent cyclic wetting and drying and under such circumstances greater loss of adhesive strength between laminates may occur (Chugg 1964). Exposure of treated laminates to cyclic wetting, rather than simple immersion, followed by tests of glue bond strength between laminates is therefore a more realistic guide to the ability of treatments to improve weathering resistance. Hence in this study the ability of treatments to improve weathering resistance was assessed by observing the delamination of chemically modified lap-shear specimens during artificial

accelerated weathering. The latter involved both cyclic wetting and continuous UV exposure. Untreated and Valwood laminates showed rapid delamination on exposure to accelerated weathering (Fig. 3). Seventy percent of the karri controls and 85% of karri Valwood specimens delaminated within the first six days of exposure. After 18 days exposure all unmodified karri specimens were delaminated (Fig. 3). Laminated jarrah controls and jarrah Valwood specimens showed greater initial weathering resistance than karri, but all of the light and dark jarrah controls delaminated after 18 and 24 days exposure respectively and the jarrah Valwood specimens were all delaminated after 30 days exposure.

Figure 3. Delamination of laminates during accelerated weathering



A greater proportion of the chemically modified specimens maintained their integrity during the accelerated weathering test. Only a small proportion (<10%) of the acetylated specimens delaminated during accelerated weathering and surface modified acetylated laminates showed no delamination during the weathering test. Surface modification was effective in improving the weathering resistance of acetylated laminates and this may be related, as discussed above, to its ability to improve the glue bond strength of acetylated laminates.

Laminates treated with a combination of surface modification and furfurylation showed less delamination than specimens treated by surface modification alone, suggesting, in accord with previous work (Larsson *et al.* 1992), that dimensional stability is an important pre-requisite for the protection of

glue-laminated timber against delamination. Compared to the acetylated specimens, the furfurylated laminates showed a higher percentage (5-30%) of delamination. Differences in the ability of furfurylation and acetylation to dimensionally stabilise laminates (Balfas 1993) might be responsible for this.

There was a significant ($p<0.05$) effect of treatment and wood type on the dry shear strength of laminates after accelerated weathering. The shear strength of specimens after weathering are shown in Table 1. If the initial dry shear strength of treated specimens (Fig. 2) are compared with the residual dry shear strength (Table 1) it is clear that all treated specimens lost strength during the weathering test. Laminates lost greater strength when subjected to accelerated weathering than when exposed to 24h immersion in water and the more severe conditions during accelerated weathering, and in particular the effect of cyclic wetting and drying, may be responsible for this. Laminates treated with a combination of surface modification and furfurylation had the highest initial shear strength and also had the highest residual shear strength, but some of the specimens treated in this manner also delaminated during the weathering test, i.e., less than 20 complete specimens remained after weathering. The low residual strength of acetylated specimens after weathering compared to other treated specimens is probably related to their low initial strength.

Table 1. Residual dry shear strength (MPa) of modified specimens after accelerated weathering

Treatment	Wood type	Number of specimens	Shear strength	95% C.I.*
S-Na	Karri	5	6.0	3.4 - 8.6
S-Na	L. Jarrah	15	5.8	4.3 - 7.3
S-Na	D. Jarrah	16	7.5	6.1 - 9.0
Ac	Karri	18	2.6	1.2 - 4.0
Ac	L. Jarrah	20	5.4	4.1 - 6.7
Ac	D. Jarrah	20	6.3	5.0 - 7.6
Ac-S-Na	Karri	20	3.8	2.5 - 5.4
Ac-S-Na	L. Jarrah	20	9.5	8.2 - 10.8
Ac-S-Na	D. Jarrah	20	10.4	9.1 - 11.7
S-Na-Fur	Karri	14	6.4	4.8 - 9.4
S-Na-Fur	L. Jarrah	18	10.4	9.0 - 11.8
S-Na-Fur	D. Jarrah	19	11.4	10.0 - 12.8

*95% Confidence Interval

There was large variation in the residual strength of specimens treated by surface modification. For karri this may be related to the low number of shear specimens that remained intact after accelerated weathering (Table 1). Jarrah laminates treated by acetylation and surface modification had a relatively high residual dry shear strength and since they also showed no delamination during accelerated weathering this treatment may be an effective means of increasing their weather resistance.

In all cases, with the exception of surface modified karri where only five shear specimens remained intact after weathering, the residual bond strength of the modified jarrah specimens were higher than the modified karri specimens. Jarrah specimens also showed less delamination during weathering

indicating that jarrah is probably more suitable than karri for use in exterior glue-laminated products.

This study has shown that by chemically modifying wood to improve glue bond strength and dimensional stability, it is possible to greatly increase the weather resistance of Valwood/glue-laminated composites. If adopted in practice, such an approach may enable the production of weather resistant cross-arms and perhaps other exterior products from small, low grade regrowth karri and jarrah logs. Such an approach may also be feasible with other eucalypts and could also increase their potential to produce higher value exterior products.

CONCLUSIONS

Chemical modification treatments designed to increase glue bond strength and dimensional stability of regrowth karri and jarrah increased the dry and wet shear strength of small (lap-shear) glue-laminated specimens made from treated laminates. Acetylation reduced losses in shear strength on wetting, but acetylation and surface modification was more effective in reducing the delamination of glue-laminated specimens during accelerated weathering. Surface modification and furfurylation also reduced delamination during accelerated weathering. Surface modification significantly reduced the tendency of jarrah specimens to delaminate during accelerated weathering and may be a suitable means of improving the weather resistance of glue-laminated cross arms made from jarrah. Untreated and treated jarrah laminates showed greater weathering resistance than karri indicating that jarrah is probably more suitable than karri for use in exterior glue laminated products.

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ALTERNATIVES TO CHROMATED COPPER ARSENATE (CCA) PRESERVATIVES - INNOVATION, SACRIFICE OR COMMONSENSE

Jeanette A. Drysdale
Koppers-Hickson Timber Protection
P.O. Box 22-148, Auckland, New Zealand

ABSTRACT

Traditional wood preservative formulations including chromated copper arsenate (CCA) are under increasing scrutiny by society. The result is a greater awareness by the wood preservation industry of needing to deal with environmental problems. Legislation, regulations and Codes of Practice are being used to control or make recommendations for plant design, operation, and the treatment and handling of timber. These are the commonsense responses. Innovation is the research programmes being undertaken around the world to overcome areas of concern with existing formulations, e.g., disposal of redundant treated timber, and testing of new actives as potential wood preservatives. The distinction is made between new formulations as CCA alternatives for specific end-uses, and as outright replacements for CCA. Formulations researched in recent years are identified and data on the new copper azole formulations is presented. However the question is also asked as to whether we are sacrificing the proven long-term performance, safety and cost effectiveness of CCA in our search for an alternative with milder more 'environmentally friendly' actives without regard to the implications of product and public liability.

INTRODUCTION

There is a long history of proven performance for timber treated with the chromated copper arsenate (CCA) wood preservative formulations (e.g., Arsenault, 1975; Anon., 1989; Forest Research Institute, 1989; Connell, Nicholson, 1990; Thornton 1991). In 1988 it was estimated CCA consumption worldwide was 100,000 tonnes whereas other waterborne preservative usage was approximately 15,000 tonnes (Connell et al, 1990). However there is concern being expressed about protecting the environment from industrial activities and this has included an increasing focus and discussion on the use of pesticides including those applied as wood preservatives.

Some pressure on CCA in Europe has also been the direct result of companies seeking competitive advantage in the marketplace by introducing an alternative preservative. This type of "green opportunism" as described by Connell et al (1990) can create mistrust in the industry and may even encourage consumers to seek alternative materials to timber.

It is recognised that the environmental issues relating to wood preservation have arisen from concern or problems associated with disposal of chemical waste and treated timber, and the misuse of chemicals or mishandling of freshly treated timber which may have resulted in contaminated sites. The industry has responded positively to the challenge to meet societies needs but is faced with more stringent management of existing wood preservatives and industrial practices (Braithwaite,Drysdale,1993) and a comprehensive portfolio of legislation, regulations, guidelines and Codes of Good Practice (e.g., Anon, 1991 and 1992; Butler, 1993; Connell, Anderson, 1990; Das, Mathur, 1993; EEC, 1992 and 1993; TPAA/ANZECC, 1993).

In some European and Nordic countries legislative or regulatory changes have generated the demand for formulations that are outright CCA replacements rather than having the choice of using CCA alternatives for some specific timber end-uses. In Sweden a regulation change disallows use of CCA-treated timber for above-ground end-uses unless for structural applications after 1994 although up until 1991 all timber was treated under the Nordic Standard to a single CCA retention whether used in or out of ground contact.

The other major environmental issue is the safe disposal of redundant treated timber either as waste from the processing phase or on completion of the useful service life. Research results are being reported on the necessary criteria for the safe burning of CCA treated timber (Pasek, McIntyre, 1992) and for timber treated with alternatives (Cornfield et al, 1993). This work has included attention to the recovery of the copper, chromium and arsenic both from timber and from ash after burning.

Equally there is the challenge for innovative research in the quest for more 'environmentally friendly' milder actives as cost-effective formulations to be available in the future. Wood preservative formulations are not only assessed for effectiveness in preventing attack by wood-destroying insects, fungi and bacteria, but also more critically in terms of environmental impact, toxicity to the end-user and for other negative health and safety effects, e.g., from the handling of timber at treatment sites or by end-users. Additional data including phytotoxicity data for plants in contact with treated timber is also becoming increasingly important both to demonstrate the safe use of existing preservatives (e.g., Levi et al, 1974; Grant, Dobbs, 1977; Spier et al, 1992 a & b) and to generate confidence in alternative formulations (.eg., Jin, Preston, 1993). Although the chromium and arsenic in CCA are being scrutinised, even alternatives containing copper have been identified as remaining toxic to aquatic life (Wegen, 1990). Therefore changing the preservative formulation will not necessarily allow treaters to be any less careful with existing or new treatment designs or operation, nor to relax precautions to avoid soil contamination from storm-water or runoff from drip pads or freshly treated timber.

The issue of financial and product liability has yet to be widely debated in Australasia. Financial liability or "polluter pays" for site cleanup can make an industry unattractive for investment. Product liability for timber prematurely failing in service also requires clarification. It is up to the manufacturer/producer to prove the product is up to specification and to define a service life. If the latter is not specified the service life required may be deemed to be what the public perceive it to be or is used to. In Australasia this could mean any alternative preservative might need to match the in-service performance of CCA.

The primary objective of any new preservative is to provide durability to otherwise perishable timber. This requires proving a formulation is 'fit for purpose'. The question then arises of establishing how long the useful service life of treated timber needs to be. The New Zealand Building Industry Authority (B.I.A., 1992) has taken a lead in this area. Where building materials are used for structures e.g., floors, walls, which provide structural stability, the building must have life of not less than 50 years, and for services where access is difficult, for hidden fixings or for attached structures of a building, again a 50 years minimum is specified. However for fixings to the building envelope e.g., windows, doors, where there is no difficulty of access or replacement then 15 years is allowable. For linings, coatings etc., where there is ready access, 5 years life is acceptable. This means any treated timber used under the New Zealand Building Code must comply with these performance specifications. Testing must support or prove acceptability/performance to these criteria.

TESTING REQUIREMENTS AND METHODOLOGY

The challenge for the researcher's of today is to find and test new formulations in a time-frame which will reliably predict a realistic performance for treated timber. This is no easy task as timber in commercial use is a mixture of sapwood and heartwood, of different species and dimensions and is exposed to multiple variables of different biological, physical and climatic hazards. As an example three test sites used by the New Zealand Forest Research Institute (FRI) demonstrate different combinations of fungal and bacterial hazards to timber (Wakeling, 1991). This has also been demonstrated in Australian field test sites where both fungal and termites hazards can vary (Thornton 1991). Testing has to accommodate this variability.

At the present time, Australia and New Zealand do not have a protocol for the evaluation of new wood preservative formulations. However the Australasian Wood Preservation Committee is presently developing a protocol for this purpose (Hedley, 1993 a). The proposed protocol is described as being limited to specifying the minimum requirements for efficacy testing against wood-destroying microorganisms, and will not cover other important properties required for successful use as a wood preservative, e.g., corrosion, paintability, gluing, effect on timber strength, health and safety. This is a different approach to that adopted elsewhere, for example the American Wood Preservers' Association (AWPA), where the test protocol encompasses the chemical and physical properties of the preservative, treatment process attributes, and properties of the treated timber (AWPA,1992).

The Australasian proposal is also described as making provision for testing methodology to reflect the requirements of the end-uses for treated timber in each Hazard Class. It is a sensible approach to approve new formulations for specific Hazard Classes or even for use on limited commodities. This approach has been taken with the permethrin/alkylammonium treatment in Australia for plywood used in protected situations (H2) or exposed above ground but fixed vertically (H3). This situation also exists for other formulations with specific properties, e.g., boron salts or solvent-based treatments (LOSP). Boron salts are used around the world for Hazard Class 1 and 2 end-uses but would otherwise be

affected by the potential for leaching in-service adversely influencing long-term performance in other Hazard Classes. Hedley, Butcher (1985) and Hedley (1993b) again have also suggested any new preservative be first approved for lower risk Hazard Classes and once satisfactory commercial performance is verified, the approval be extended, e.g., to in-ground use.

Laboratory testing methods are undertaken under defined conditions so that results are repeatable. The standard test fungi and methodology have been developed around the existing formulations, e.g., CCA, and may not always be appropriate to validating new formulations.

Interpreting laboratory test results requires caution. For example if small test blocks are used this may allow chemicals with penetration problems to appear more effective than the commercial reality. This was demonstrated some years ago with AAC preservatives in 20 x 20 x 20mm soil blocks which once crosscut, decayed in the exposed internal zone, and was also shown to be a problem on partially seasoned (steam conditioned) timber (Butcher, 1983).

Accelerated test methods (fungus cellar, accelerated field test simulator) or field tests are more realistic but the results take longer to generate. However care must still be taken to ensure the variable biological exposures are represented. In recent years there have been examples of bacterial degradation and copper tolerant brown rot fungi in treated timber so new formulations must address these specific issues especially if the formulation is copper-based or relies on a single organic active which may be susceptible to degradation or chemical depletion over time by leaching.

DEVELOPMENTS IN THE SEARCH FOR CCA ALTERNATIVES

Potential alternatives which are now typically organic compounds can be sourced from actives already commercially available and used in other industries such as agriculture, or as new actives which tend to be organic compounds. Generally actives already available are chosen purely for reasons of availability, cost and most importantly because there is toxicological data to support a new product approval. It is estimated to now cost UK Pounds Sterling 600,000 for a toxicological package for a product in Europe (Connell, 1993). This can limit formulation innovation to product improvements by the addition of biocides to improve performance, by reformulation of existing actives, or substitution of one active for another. Therefore early in the research programme decisions are made on whether to screen existing actives, e.g., Hedley et al, 1979 combinations of existing actives e.g., Connell et al, 1993, or completely new novel actives.

The most recent reviews on the history and development of wood preservatives and identification of potential wood preservatives have been by Connell et al (1990), Butler (1993), and Barnes (1993).

In summary when arsenic was first put under the environmental spotlight, studies were carried out on modified CCA's and various products were subsequently used. The most well-known of these are copper-chromium (CC), copper-chromium-boron (CCB), copper-chromium fluoride (CFK), copper-chromium-fluoroborate (CCFB) and copper-chromium-phosphorus (CCP). Subsequently the use of chromium has also been challenged.

Other potential wood preservatives fit the broad categories of copper-based ammoniacal or amine systems, alkylammonium compounds, boron salts, and other organic compounds including copper/organic mixtures.

If chromium is removed from the formulation there is an immediate problem of ensuring that copper is still 'fixed'. Water insoluble copper compounds could be used e.g., copper naphthenate or an alternative method is to use an ammoniacal based system. (Jin, Archer, 1991).

Ammoniacal systems are established in some countries e.g., U.S.A., Canada and Nordic countries. Formulation actives include ammoniacal copper borates, ammoniacal copper arsenates, ammoniacal copper zinc arsenates and ammoniacal copper quaternary ammonium compounds. The major disadvantages of ammoniacal systems is the presence of corrosive ammonia vapour and the health and safety consideration of a maximum allowable prolonged exposure limit of 25ppm.

Other formulations are available which do not have the disadvantage of the ammonia odour. An example of one product is copper-bis (N-cyclohexyl diazonium dioxide) or Cu-HDO (Marx, 1987) which has been used in Europe.

A range of alkylammonium compounds (AAC's) have been extensively tested (e.g., Butcher et al, 1977; Nicholas and Preston, 1980; Butcher and Greaves, 1982; Tsunoda and Nishimoto, 1987) and in combination with copper, (e.g., Butcher et al, 1979; Drysdale, 1983). Copper fixation was a problem and not improved until ammoniacal systems were used (Sundman, 1984).

Boron-based preservatives have also been widely recognised and used commercially because of insecticidal and fungicidal efficacy (e.g., Barnes et al, 1989), but the major disadvantage of the boron salts is the chemical not being 'fixed' in wood which restricts the use of boron treated timber to non-leaching or protected from the weather end-uses.

Chlorothalonil is being investigated but as an oil-borne rather than water-borne formulation (Woods and Bell, 1990; Laks and Woods, 1992). Copper or zinc naphthenate have been widely used as oil-based systems with more recent formulation developments as water-based emulsion systems. Other organic chemicals that have been tested include 3-iodo-2-propynl butyl carbamate or IPBC (Hansen, 1984), 2-(thiocyanomethylthio) benzothiazole (TCMTB), dichlorofluanids, sulphamides and a number of organic copper compounds, e.g., Preston et al, 1987; Arsenault et al, 1991; Stokes et al, 1991.

Organics formulated as emulsions which includes the isothiazoline compounds have been evaluated (Preston, 1983; Nicholas et al, 1984; Greenley, 1986; Greenley and Hegarty, 1988) as have triazole compounds as azaconazole (Leclereq, 1983), propiconazole (Valcke, 1989; Goodwine, 1990) or tebuconazole (Exner, 1991). The combinations of tebuconazole or propiconazole with copper have also been identified as effective wood preservatives (Connell et al,1993; Fox et al, 1993). The requirement for a broad spectrum of effectiveness from 'milder' actives indicates there may be greater emphasis on mixtures in the future.

Sutter pure culture decay agar tests carried out at the New Zealand Forest Research Institute on radiata pine test blocks (35 x 35 x 7mm), and exposed as either leached or unleached blocks, have shown a copper:boron tebuconazole, (25:1, Cu:azole) formulation to be more effective than CCA against the copper tolerant fungus, Poria placenta (Table 1).

TABLE 1 : Summary of Sutter Test Results on Radiata Pine

Test Fungi	Toxic Values $\%^{m}/_{m}$ of Oven Dry Wood			
	TANALITH® C ($\%^{m}/_{m}$ Total Active Elements)		Copper : Tebuconazole (25:1) ($\%^{m}/_{m}$ Copper)	
	Unleached	Leached	Unleached	Leached
Coniophora puteana	< 0.22	0.22 - 0.44	< 0.2	0.2 - 0.4
Poria placenta	> 2.47	> 2.47	< 0.2	< 0.2
Coriolus versicolor	< 0.22	< 0.22	< 0.2	< 0.2

Furthermore the copper boron azole toxic values for leached blocks when expressed as kg/m^{-3} of product (C. puteana 6.5-13.0kg/m^{-3}, P. placenta < 6.5kg/m^{-3}, and C. versicolor < 6.5kg/m^{-3}) compare favourably with the toxic values obtained for Scots pine blocks after European Standard EN84 leaching and exposed according to EN113. Toxic values of 4.22-12.46 kg/m^{-3} were obtained for C. puteana, 4.27-9.0 kg/m^{-3} for P. placenta and <4.23 kg/m^{-3} for C. versicolor (Connell et al, 1993).

Fungus cellar soil bed results for radiata pine specimens (5 x 10 x 160mm) treated with a copper boron (Cu : BAE, 25:70) or a copper boron azole formulation (Cu : BAE : tebuconazole, 25:70:1), 'fixed', then leached, are given in Table 2.

These results show the increased protection by addition of the azole to the copper boron formulation. As an indication a two year effective performance in the fungus cellar is indicative of an out of ground contact preservative retention.

TABLE 2 : **Soil Bed Test Data from Leached Radiata Pine Exposed in New Zealand Forest Research Institute Fungus Cellar**

Formulation	Retention of Copper kgm^{-3}	Mean % Soundness		Number Failed	
		14 Months	17 Months	14 Months	17 Months
Copper, boron (Cu : BAE = 25:70)	0.73	63	47	3	5
	1.12	44	37	5	6
	1.90	78	82	1	1
	2.76	85	78	0	1
Copper, boron, azole (Cu : BAE : Tebuconazole = 25:70:1)	0.81	97	96	0	0
	1.18	100	100	0	0
	1.79	99	99	0	0
	2.25	100	100	0	0
CCA-B (Salts) (11 month data only)	0.09	11	-	-	-
	0.19	0	-	-	-
	0.38*	57	-	-	-
	0.76	98	-	-	-
	1.51	100	-	-	-
Untreated Controls	-	25	16	6	-
*Denotes the New Zealand Hazard Class 3 Approved Retention (NZS MP3640 : 1992)					

No-choice laboratory termite tests have also been undertaken at CSIRO, Clayton against Coptotermes acinaciformis. Specimens were treated with CCA-C or a copper boron azole formulation, 'fixed', but small radiata pine blocks (5 x 20 x 20mm) not hot leached. A single treated block was exposed in a number 16 plastic vial (70mm high; 35mm wide) containing 3g of termite mound material. This was moistened with 1.0ml of deionized water and 1.0g of C. acinaciformis (approximately 280 individuals) were added to each vial. Five replicate samples were used for each test variable. Vials were stored at 26°C and 70% RH and after 6 weeks the blocks were removed from the test and their weight losses determined.

The results are summarised in Table 3. If a value of 5% weight loss of the block is used as the criteria for adequate protection, the CCA treatment is effective at about $0.3kg/m^{-3}$ and the copper boron azole at about $0.8kg/m^3$.

TABLE 3 : **Amount of Wood Consumed (mg) by C. acinaciformis in a No-choice Laboratory Test**

Formulation	Retention of Copper kgm^{-3}	Wood Consumed (mg)
Copper, boron, azole (Cu : BAE : Tebuconazole = 25:10:1)	0.4	62.0
	0.72	54.2
	0.92	49.6
	1.2	48.8
	2.72	42.8
CCA-C (Salts) (Retention expressed as Copper)	0.16	64.0
	0.28	49.6
	0.40	49.2
	0.52	48.8
	0.76	35.4
Untreated Control	-	353.0
Water Only Control	-	324.4
Solvent Control	-	208.2

CONCLUSIONS

Environmental issues whether global, regional or local, have been the catalyst for change or at least have given impetus to the re-evaluation of all past and present industry practices and the timber preservation industry is no different. For our industry the political and industry responses have varied. Unfortunately some responses, in particular some legislation in Europe, and the resultant impact on the wood preservation industry have been extreme with CCA use being discontinued or restricted. Therefore a cautionary approach is advised before adopting other countries legislation, regulations or policies and there is a need to understand the reasons or motives behind the changes being made.

The unsuspecting consumer who is often remote from relevant technical information may see or hear of changes overseas and interpret these as innovation rather than a sacrifice of the benefit which may have supported their original decision to purchase CCA-treated timber, i.e., cost-effective long-term proven durability. Substitution for CCA-treated timber then becomes sacrifice rather than commonsense. Any decisions to restrict the use of CCA-treated timber or to change to alternative chemicals or substrates must be based on knowledge of the facts and a meaningful risk assessment of both the formulation and the treated timber.

The wood preservation industry will always need to be sensitive to environmental issues. In the longer term we can also anticipate a trend for moving away from traditional methods of wood preservation, e.g., to gaseous treatments or use of super critical fluids, or to different timber protection technology, e.g., wood modification. We also need to be aware of a predicted shortage of wood fibre. We should aim to not compromise on a significantly lesser service life for treated timber that is less than the replacement rotation time for the raw wood resource. Research for the future should also reflect the anticipated uses for timber which may be different to the present day.

The widespread failures of timber treated with alkylammonium compounds (AAC's) in New Zealand after just a few years use from the late 1970's to early 80's, was a lesson on why not to commercialise a new formulation almost exclusively on laboratory data and with only short-term field test data which may not reflect the risk of degradation of the chemical actives, presence of tolerant fungi, or be representative of timber from a commercial treatment. Claims for prematurely decayed AAC-treated timber is now estimated at NZ$9 million in the 10 years since commercial treatment was banned. Debate and clarification on product liability issues relating to alternative treatments is required.

The search for, testing and successful commercialisation of a CCA alternative requires more than a test programme that proves the biological efficacy of a formulation. CCA has set a precedent of being a safe cost effective multi-active wood preservative formulation which will be difficult to match. A multitude of formulations are under evaluation including the copper azole formulations. As yet none of the alternative 'milder' formulations being offered commercially have yet been confirmed to meet the long life cost effectiveness of CCA in the Australasian market.

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DECAY EVALUATION OF THE PENETRATION OF LOSP INTO *Eucalyptus regnans* HEARTWOOD

L.J. Cookson and E.F. Dougal

CSIRO, Division of Forest Products, Private Bag 10, Rosebank MDC, Clayton, Victoria 3169.
Forestry Section, The University of Melbourne, Parkville, Victoria 3052.

ABSTRACT

The penetration of a light organic solvent preservative into *Eucalyptus regnans* F. Muell. heartwood was examined using a fungal bioassay. Boards two metres long were treated, blocks cut from them, and the freshly cut endgrain sealed with epoxy. Some blocks had two millimetres of surface wood (treated envelope) shaved off. Most unshaved blocks resisted decay. However, almost half of the shaved blocks had decay, indicating limited penetration of preservative past the two mm depth. Treated shaved blocks had less decay than untreated shaved blocks. There was little difference in performance between blocks when they were cut from different positions along the original two metre board.

INTRODUCTION

The locally grown hardwood *Eucalyptus regnans* F. Muell. is being assessed for its use in window joinery as a replacement for the imported timbers meranti and western red cedar. Earlier work with 300 mm long blocks, showed that *E. regnans* heartwood could absorb light organic solvent (white spirit), using a range of different treatment schedules (Ladu *et al.*, in prep). For the pressure treatments, mean retentions ranging from 21.1 kg/m^3 (27.0 l/m^3) to 52.8 kg/m^3 (67.7 l/m^3) for this size of timber were achieved. In other countries and with other timbers, retentions of this order are considered acceptable for LOSP treated commodities (Taylor, 1980; Vinden, 1986; Smith and Orsler, 1992). However, the penetration pattern obtained with *E. regnans* was difficult to interpret. Penetration of the organic solvent was mainly through the end grain. Lateral penetration was shallow and patchy, as revealed by dye carried in the solvent. It was not clear if the lateral penetration would be sufficient to protect long lengths of timber from decay, especially for sections some distance away from the endgrain.

This paper describes the treatment of two metre long boards of *E. regnans* heartwood, with a commercial LOSP. Blocks were cut from the boards, and subjected to decay using a modified planeing test (Willeitner and Gersonde, 1981). Some blocks had the two millimetre outer envelope shaved off, to determine if there was sufficient penetration beyond this depth to prevent decay. Treatment was by a Lowry schedule, at a pressure higher than normally used by the LOSP industry, but which would establish the principle of whether regrowth *E. regnans* heartwood was capable of being penetrated at depth in the side grain.

MATERIALS AND METHODS

The *E. regnans* boards used in this test came from the same 1939 regrowth material from Toolangi, Victoria. The boards were dressed to dimensions 30 x 80 x 2000 mm. Thirty-five boards were treated, of which 5 contained sapwood and heartwood, and 30 contained only heartwood. A further 3 boards were left untreated. The boards were taken from 8 different trees. The sawing pattern for each board is listed in Table 1. One end of each board was sealed with 4 coats of epoxy resin. The preservative used was Protim 80 WR, which had a specific gravity of 0.80, and contained by weight, 1.77% pentachlorophenol, 0.44% TBTO and 0.40% aldrin, plus wax and resin, dissolved in white spirit.

For treatment, boards were flooded with preservative, an air pressure of 1380 kPa (200 psi) applied for 1 hour, preservative drained away, and a vacuum of -80 kPa pulled for 30 minutes. Boards were then weighed to determine preservative uptake. The boards were left to air dry for 4 months. Nine heartwood boards representing a range of retentions were collected, as well as one sapwood-heartwood board, and blocks cut from them for penetration and decay studies.

Penetration study
Thirty mm long blocks were cut from various positions in the boards. Not all of the white spirit had evaporated from all boards after 4 months, in which case there was rapid bleeding of preservative over the freshly cut endgrain. Therefore, the cut blocks were further dried in an oven for 2 days at 50°C. One endgrain face on each block (the face, 150, 275, 500, 750, 1000, 1250, 1500, 1750, 1975 mm from the uncoated end) was mechanically sanded to expose new endgrain, and there was no bleeding. The cupric acetate colorimetric test for pentachlorophenol, described in AS 1605-1974, was then applied. The non-ionic surfactant used was polyethyleneglycol 3000. Freshly mixed indicator solution was brushed on to the sanded surface of each block. Four further coats of indicator solution were applied after the previous coat had air dried.

Decay study
(i) Block designations
All blocks cut from the boards for the laboratory decay study were 30 mm long. Unlike blocks for the penetration study, these blocks were not oven dried or sanded. From each of the 10 selected boards were cut:
10 blocks for decay.
9 blocks for decay, after they had the outer 2 mm perimeter of the treated envelope shaved off (the original radial and tangential faces of the boards).
4 blocks for sterile controls (to determine if any mass loss was due to factors other than decay).
4 blocks for sterile controls, which had the outer 2 mm perimeter of the treated envelope shaved off.

Tables 2 and 3 give the distance from the uncoated end of the board, from which the blocks for decay were cut.

Three untreated boards were also cut into 30 mm long blocks, so that untreated controls could be included in the decay test. Half of the untreated blocks had the outer 2 mm shaved from each radial and tangential face.

(ii) Artificial weathering and block preparation
All blocks were artificially weathered. They were vacuum impregnated in jars with tap water, and leached in three times their volume of water, on a shaking water bath for five days at 35°C. Water in the jars was changed daily. Blocks were removed from the jars, drained overnight, and placed in vacuum ovens at 40°C for 5 days. Blocks were reconditioned to 12% moisture content, and weighed. Both endgrain faces on each block were then sealed with 3 coats of epoxy resin. Blocks were again weighed (at 12% MC), to determine the mass of epoxy. Prior to placing them into the decay or sterile tray chambers, blocks were sterilised by gamma-irradiation.

(iii) Bioassay method
The decay chambers were stainless steel trays, 320 x 250 x 105 mm deep. The decay fungus was the white-rot *Perenniporia tephropora* (Mont.) Ryv., DFP strain number 7904. Test tubes were laid on the floor of each tray, and molten malt agar poured into the trays to a depth 2-3 mm short of the height of the side-on test tubes. Each tray was then placed in an autoclave bag, and the whole autoclave sterilised. Some trays were left sterile, to house the sterile control blocks. The remainder were inoculated with fungus, and after 2 weeks of growth, a sterile plastic mesh mat was laid on the tubes, and the blocks planted. Blocks were held above the agar (preventing water logging) by the test tubes. This method was similar to that described by Thornton (1979), although the blocks needed to be nearer to the agar due to shorter mycelial growth height of the white-rot compared to *Serpula lacrymans*.

For each board, all blocks for decay (shaved and unshaved) were randomised between and within 2 trays, along with 6 untreated control blocks (3 shaved, 3 unshaved). Also for each board, all sterile control blocks (shaved and unshaved) were randomly placed within the one sterile tray, along with 6 sterile untreated control blocks.

Trays were placed in an incubation room at 25°C for 16 weeks. Blocks were then removed from the trays, weighed to determine moisture content, conditioned back to 12% MC, and weighed again to determine the mass of wood (excluding epoxy mass). The mass loss for each block was then determined, and adjusted to account for the mass change found in the sterile controls.

Besides mass loss, fungal activity was assessed in another way. Blocks were split with the grain across their shortest width, and examined for the presence of whitened wood. The depth of white-rotted wood, as seen from the top and bottom uncoated faces of the blocks, was measured in millimetres.

RESULTS

Treatment results

The mean retention of LOSP for the 30 boards containing just heartwood, was 63.9 kg/m^3 (standard deviation, 24.7), with a range of 25.6-138.3 kg/m^3 (Table 1). Results were similar for the five sapwood-heartwood boards, with a mean retention of 66.5 kg/m^3 (s.d. 37.2), and a range of 37.5-126.9 kg/^{3}.

The distribution of pentachlorophenol was examined using the cupric acetate colorimetric test. The colour reaction worked best on those blocks from boards with higher retentions, producing red areas due to the formation of copper pentachlorophenate. The reaction was absent or unclear, in most blocks from boards with lower retentions. For those blocks that showed a clear reaction, penetration was patchy and shallow. Penetration was mainly from the endgrain. Colour diminished with distance from the uncoated end. In several boards, colour appeared to follow the endgrain pathway for the full two metre length from the uncoated end to the coated end. Most boards had fine microscopic checks following rays, more visible after fine sanding. End grain penetration may have followed both checks, and vessels that lack tyloses. The lateral penetration or treatment envelope was mostly only 0.5-1.0 mm deep.

Decay results

Mass loss data

In the decay test, untreated unshaved blocks, had a mean mass loss of 8.1% (s.d. 4.3), with a range of 0.0-19.6%. The unshaved treated blocks with treatment envelope intact, from different board positions, had a mean mass loss ranging from 0.0-0.8% (Table 2). Only one out of 100 blocks had a mass loss of more than 1.5%, and its mass loss was 3.8%. This block came from nearest the coated end, from the board with the second highest preservative retention.

The shaved untreated blocks had a mean mass loss of 8.3% (s.d. 4.3), with a range of 0.8-14.4% (Table 3). This was similar to the unshaved blocks. However, the shaved treated blocks had significantly more decay than unshaved treated blocks, with means ranging from 1.6-4.0% (Table 3). Forty out of 90 blocks had mass losses above 3.0%, indicating that lateral penetration was often not sufficient beyond 2 mm depth to prevent decay. However, the means were lower than the mean mass loss for untreated blocks.

There was no clear trend of mass loss in relation to distance from the uncoated end grain in the original boards (Tables 2 & 3).

Depth of white-rotted wood

The depth of white-rotted wood found in blocks, was also useful in evaluating the effectiveness of the treatment. Splitting blocks revealed that decay was mainly localised to the bottom face nearest the agar, rather than being uniform throughout the block. There was a clear delineation between a bottom layer of white-rotted wood, and sound wood. This layer followed the grain, suggesting that decay could quickly colonise by following vessels, but was much slower moving through rays or through cell walls. Some blocks, mainly those that were untreated, were also attacked from the top and side faces.

The untreated unshaved blocks, had a mean decay depth of 12.3 mm (s.d. 5.7 mm), with a range of 2-19 mm (Table 4). This mean amounted to 41.0% of the cross-section being colonised and at least partially decayed by fungus (12.3 divided by 30 mm). In comparison, the treated unshaved blocks, with treatment envelope intact, had much less decay. For these blocks, the mean depth of white-rotted wood was only 0.45 mm, or 1.5% of the cross-section. The range was 0-7 mm. Eleven out of 100 blocks had white-rotted

wood of more than 1 mm depth, and these were all from blocks cut from boards with the lower retentions (Table 4).

The shaved untreated blocks had a mean decay depth of 10.7 mm (s.d. 4.9 mm), with a range of 2-20 mm (Table 5). This mean amounted to 41.1% of the cross-section being colonised and at least partially decayed by fungus (10.7 divided by 26 mm). This was similar to the unshaved blocks. However, the shaved treated blocks contained significantly more white-rotted wood than unshaved treated blocks. The mean depth of white-rotted wood was 4.2 mm, or 16.3% of the cross-section. The range was 0-19 mm. Sixty-nine out of 90 blocks had white-rotted wood of more than 1 mm depth (Table 5). The mean decay depth was still lower than for the untreated blocks. There was a tendency for shaved blocks from boards with high preservative retentions, to have less decayed wood. The 27 blocks from the three boards with lowest retentions, had a mean decay depth of 5.8 mm. The 27 blocks from the three boards with highest retentions, had a mean decay depth of 2.6 mm.

For both the shaved and unshaved treated blocks, there was no clear trend of decay depth in relation to distance from the uncoated end grain in the original boards (Tables 4 & 5).

DISCUSSION

P. tephropora DFP 7904 caused a mean mass loss of only 8% in the untreated *E. regnans* control blocks. This strain is one of our most active white-rotters in laboratory tests. It is often the most preservative tolerant species when tested against treated eucalypt (Cookson and Greaves, 1986; Johnson *et al.*, in prep). Perhaps the main reason for the low mass loss, was that blocks were end grain sealed on their transverse faces. This probably slowed the rate at which blocks became wet. However, the wood had reached fibre saturation point at least by the end of the test. The sterile controls had moisture contents of about 27%. This should be enough for fungi to begin decaying wood, after which the moisture content would increase. Decayed untreated blocks had moisture contents of about 38%. End grain sealing, also appeared to slow the rate of penetration of the fungus through the wood. There were fewer exposed vessels for it to move rapidly through. Additionally, the blocks were larger than often used in other bioassays. Nurmi (1988) end sealed blocks cut from spruce (*Picea abies*) and pine (*Pinus sylvestris*), and obtained lower than usual mass losses with certain brown-rot fungi. End-sealing was thought to slow the penetration of fungi through these softwoods.

Although mass losses were low, they were sufficient to allow a comparison between shaved and unshaved blocks. Also, the depth of fungal colonisation was often more extensive than suggested by the mass loss figures. Presumably, much of this bleached wood was still in the process of being decayed. A mean of 41% of the wood in untreated controls was whitened or fungal colonised, compared to the mean mass loss of 8%.

For those boards where the PCP indicator produced a red colour reaction, a trend was seen where colour reduced with greater distance from the uncoated end grain. However, this trend was not born out in the decay test. The level of fungal activity was fairly constant in blocks cut from over the length of the board.

LOSP treatment was able to protect most of the unshaved *E. regnans* heartwood blocks from decay. In fungal bioassays, mass loss below 3% is usually considered to be insignificant. Only one of the treated unshaved blocks had more than 3% mass loss. The treatment also prevented fungal colonisation in most blocks, with only 11 of the 100 unshaved blocks affected at depth more than one millimetre. Those blocks with more extensive colonisation than one millimetre, all came from boards where retentions were lower than the mean. It is not known if this low level of fungal colonisation would also occur during the normal service life of window joinery.

For *E. regnans* heartwood, the complete treatment envelope must be confined to the outer wood fibres, as decay was common when the outer two mm was shaved off. Standards call for five to six mm lateral penetration in non-durable timbers that are used externally and above ground (Australian Standard, 1604-1980; TPAA, 1979). The penetration results achieved for *E. regnans* would seem not to be sufficient to pass the standard for treated wood. The treated zone is normally determined by chemical means, which might give different results to this biological assessment. However, from the distribution of PCP found here, and from earlier work with Sudan Black (Ladu *et al.*, in prep), it seems unlikely that the standard would be met on this count. Whether these depths are necessary in an LOSP treated window frame, that was treated in final form, painted, and re-painted every five to seven years, is not known. It is unlikely that this depth of penetration is being reached in other timbers, especially meranti. Yet failure of LOSP treated window joinery in Victoria is rare.

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TABLE 1. Uptake of Protim 80 WR by 2 m long boards, sealed at one end, during a Lowry schedule of 1 hour at 1380 kPa.

Sawing pattern: f = flat, q = quarter sawn, i = intermediate, f-i = pattern on both ends between flat and intermediate, f+f-i = one end flat, other end between f and i.

Board number	Tree code	Untreated mass (gm)	Sawing pattern	Uptake kg/m^3	Cut for bioassay
36	6	2760	f-i	25.6	yes
43	?	3467	f-i	36.5	no
23	12	2389	q	40.2	yes
35	6	2497	f+f-i	40.2	no
12	5	2649	q	42.1	no
4	12	2436	f	43.5	no
37	6	2875	i	44.0	yes
5	12	2415	f	51.5	yes
18	10	2654	i	51.5	no
14	4	2524	f	52.7	no
11	4	2914	f	53.5	no
26	10	2610	i	56.3	no
16	4	2696	i	57.7	yes
28	10	2599	i	57.9	no
20	10	2561	q	59.2	no
19	10	2658	f-i+i	60.2	yes
21	1	2392	i	61.0	no
15	2	2457	q	61.0	no
3	12	2419	i	62.5	no
34	6	2603	f+f-i	64.6	no
9	12	2362	f+f-i	65.8	yes
13	4	2500	i+f-i	68.5	no
27	10	2265	q	69.6	no
30	10	2489	i	70.0	yes
6	5	2693	q-i	75.2	no
33	2	2665	i	85.4	no
29	10	2349	i	96.7	no
22	6	2727	f	100.4	yes
2	12	2447	f+i	124.6	no
7	12	2340	f	138.3	no
Mean				63.9	
Boards with a large proportion of sapwood					
42	8	3506	i+i-f	37.5	yes
41	8	3443	f	39.0	no
40	2	2711	f-i	52.9	no
39	5	2976	f	76.2	no
38	4	2786	f	126.9	no
Mean				66.5	

TABLE 2. Percentage mass loss of unshaved blocks cut from boards, after 16 weeks with *P. tephropora*.

Board number	Retn kg/m^3	Distance of furtherest edge of block from uncoated end (cm) 3	15	27	50	75	100	125	150	175	197
36	25.6	0.0	0.5	0.2	1.3	1.0	0.4	0.4	1.0	0.5	0.3
42(sap)	37.5	0.2	0.5	0.2	0.3	0.1	0.6	0.7	1.0	1.2	1.3
23	40.2	+0.2	0.2	1.0	1.0	+0.1	0.7	0.3	0.2	0.5	0.3
37	44.0	0.8	0.7	1.4	1.5	0.6	0.5	1.4	1.3	0.7	0.7
5	51.5	+0.1	0.1	0.1	0.4	0.0	0.3	0.3	0.6	0.5	0.4
16	57.7	0.1	+0.1	0.6	0.6	0.6	0.2	0.5	0.5	+0.1	0.6
19	60.6	+0.4	0.2	0.0	0.1	0.0	0.1	+0.2	+0.1	0.0	0.4
9	65.8	+0.3	0.0	0.3	0.3	0.0	0.3	0.5	0.1	0.0	0.3
30	70.0	+0.3	0.3	0.1	0.0	0.2	0.1	0.1	1.1	0.3	3.8
22	100.4	+0.2	0.1	0.3	0.1	0.2	+0.1	0.0	+0.2	+0.1	0.1
Mean	55.3	0.0	0.3	0.4	0.6	0.3	0.3	0.4	0.6	0.4	0.8
s.d.	21.0	0.3	0.3	0.5	0.5	0.4	0.3	0.4	0.5	0.4	1.1

Untreated controls: n = 30, mean = 8.1%, s.d. = 4.3, range = 0.0-19.6%

TABLE 3. Percentage mass loss of shaved blocks cut from boards, after 16 weeks with *P. tephropora*.

Board number	Retn kg/m^3	Distance of furtherest edge of block from uncoated end (cm) 12	24	47	72	97	122	147	172	194
36	25.6	3.1	1.0	1.6	12.6	5.2	3.0	2.2	2.5	6.5
42(sap)	37.5	0.9	3.0	1.4	2.8	1.2	3.5	3.1	5.0	2.7
23	40.2	1.6	1.8	1.6	3.9	2.3	3.8	4.3	1.1	3.1
37	44.0	0.9	4.5	4.8	5.4	4.8	6.5	6.5	10.0	7.4
5	51.5	1.5	0.8	0.9	5.5	7.1	0.7	7.1	1.1	0.8
16	57.7	5.0	5.6	0.2	3.8	1.9	1.7	5.3	5.7	1.8
19	60.6	3.2	6.4	4.2	1.1	4.0	2.6	2.2	1.4	4.7
9	65.8	1.3	0.2	0.2	0.1	4.2	0.6	1.3	3.1	+0.1
30	70.0	4.2	2.0	1.2	4.3	0.6	1.0	2.9	7.5	4.3
22	100.4	0.6	1.8	0.3	0.4	0.3	0.9	0.3	1.7	0.7
Mean	55.3	2.2	2.7	1.6	4.0	3.2	2.4	3.5	3.9	3.2
s.d.	21.0	1.5	2.1	1.6	3.6	2.2	1.9	2.2	3.1	2.5

Untreated controls: n = 30, mean = 8.3%, s.d. = 4.3, range = 0.8-14.4%

TABLE 4. Depth (mm) of whitened wood in sidegrain, of unshaved blocks cut from boards, after 16 weeks with *P. tephropora*.

Board number	Retn kg/m^3	Distance of furtherest edge of block from uncoated end (cm)									
		3	15	27	50	75	100	125	150	175	197
36	25.6	0.0	0.5	0.5	2.0	3.0	0.0	0.0	7.0	0.0	0.0
42(sap)	37.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	1.0	1.0
23	40.2	1.0	0.5	4.0	5.0	0.0	2.0	1.0	0.0	3.0	2.0
37	44.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.5	0.0	0.0
5	51.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	2.0	0.5
16	57.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19	60.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9	65.8	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0
30	70.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.5	0.0	1.0
22	100.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mean	55.3	0.1	0.1	0.5	0.7	0.4	0.2	0.2	1.2	0.6	0.5
s.d.	21.0	0.3	0.2	1.3	1.6	0.9	0.6	0.3	2.2	1.1	0.7

Combining all treated blocks: mean = 0.45mm, cross-section = 1.5%.

Untreated controls: n = 30, mean = 12.3mm, s.d. = 5.7, range = 2.0-19.0mm, % cross-section = 41.0%

TABLE 5. Depth (mm) of whitened wood in sidegrain, of shaved blocks cut from boards, after 16 weeks with *P. tephropora*.

Board number	Retn kg/m^3	Distance of furtherest edge of block from uncoated end (cm)								
		12	24	47	72	97	122	147	172	194
36	25.6	5.0	5.0	0.0	19.0	16.0	10.0	2.0	4.0	7.0
42(sap)	37.5	2.0	6.0	4.0	6.0	3.0	5.0	6.0	9.0	5.0
23	40.2	3.0	3.0	4.0	9.0	2.0	6.0	7.0	4.0	5.0
37	44.0	0.5	0.0	2.0	4.0	5.0	11.0	9.0	8.0	16.0
5	51.5	3.0	2.0	2.0	10.0	12.0	1.0	9.0	2.0	0.0
16	57.7	6.0	2.0	0.0	1.0	0.5	4.0	5.0	3.0	2.0
19	60.6	5.0	8.0	7.0	1.0	5.0	4.0	1.0	1.0	2.0
9	65.8	1.5	0.0	0.5	0.0	9.0	0.0	4.0	1.0	0.0
30	70.0	6.0	4.0	5.0	2.0	0.0	0.0	4.0	7.0	3.0
22	100.4	4.0	4.0	1.0	2.0	0.5	4.0	3.0	2.0	2.0
Mean	55.3	3.6	3.4	2.6	5.4	5.3	4.5	5.0	4.1	4.2
s.d.	21.0	1.9	2.5	2.4	5.9	5.4	3.8	2.7	2.9	4.7

Combining all treated blocks: mean = 4.23mm, cross-section = 16.3%.

Untreated controls: n = 30, mean = 10.7mm, s.d. = 4.9, range = 2.0-20.0mm, % cross-section = 41.1%

ACCELERATED FIELD SIMULATOR STUDIES

Laurie J. Cookson, James W. Creffield, John R.J. French, Harry Greaves,
Gary C. Johnson, Kevin McCarthy and John D. Thornton
CSIRO Division of Forest Products
Private Bag 10, Rosebank MDC, Clayton, Victoria 3169

ABSTRACT

Accelerated field simulator studies, whilst of longer duration than standard laboratory tests, can provide a greater range of biodeteriogens. Accelerated field simulator testing can generally yield results far quicker field testing, is far more secure and can be economically inspected with far greater frequency to yield measures of variation in performance. This paper provides a catalogue of studies that have been carried out in the accelerated field simulator at CSIRO, and the wide range of variables covered by such tests is highlighted.

INTRODUCTION

Standard laboratory testing, using small wooden blocks, can often give a rapid indication of preservative efficacy or natural durability. However, only a limited number of fungal species, and certainly only one species per test block, are normally included in such laboratory tests. Clearly the choice of appropriate test of fungi is difficult to make when considering a new preservative formulation. In practice, it is possible that one microbial species may be capable of detoxifying or modifying the chemical while another species may then destroy the substrate. Ideally, one would carry out a field test in the severest climate that the product under test would be used in. The field test may require as long as 25 years or more to produce final data.

In order to devise a much more rapid test than a field test while still providing a variety of (at least microbial) hazards, various attempts have been made around the world over the last 20 years, to "bring the field into the laboratory". Of course, it may be argued that access to a wet tropical field site can provide rapid results and therefore the need for the accelerated field simulator (AFS) would be reduced. However, such a tropical site must be secure against loss of tenure, theft and vandalism of specimens, loss through animals, floods, fire and damage by vehicles, cyclone, routine cleaning etc. Also, it must be

economically inspected as frequently, if not more frequently, than every six months. These requirements almost necessitate such a tropical field test site being within the grounds of the research organisation itself. However, no wood research institution in Australia has ever been, or is currently, so well situated.

CSIRO first constructed a room for AFS testing in 1979, followed by a purpose built building (both at Highett) in 1981. Tanks from these facilities were transferred into the one, fully insulated, new building at Clayton in July 1992. Much research has already been performed, and will be described in some detail in this paper, illustrating the breadth of the work and thereby indicating the usefulness of the AFS in past, present and future research at the Division of Forest Products.

MATERIALS AND METHODS

Because their objectives vary greatly, a number of approaches have been taken, by different authors of this paper, in running their various trials. Basic to all of them is the AFS facility which is maintained at 28°C and 80-85% RH, in darkness. Containers range from small to large, the most numerous being stainless steel tanks of dimension 1.8 x 0.77 x 0.65 m. Some smaller tanks are used, as well as a large concrete drainage culvert capable of easily holding stubs of commercial sized poles. With the exception of some out of ground contact work (e.g. of decaying western red cedar weatherboards), all studies to date have been ground contact studies using soil from various sources (clay and sandy loams, plus, on one occasion, an artificial substrate). Some studies feature reconstructed soil profiles (i.e. litter layer and upper two horizons) transported from the field separately, with all tanks having screenings in the bottom for drainage. Watering is done from above and ranges from routine weekly to infrequently, to as required, based on moisture content readings of timber. Inspection intervals vary from as frequently as every 4 or 8 weeks, to every 6 months, or even yearly (in one case after a 5 year interval), depending on whether the requirement is for accurate determination of variability of performance or simply to differentiate the survivors from the others.

Advantages and disadvantages of this type of research have been presented and discussed before (Johnson *et al.*, 1982).

EXPERIMENTS AND RESULTS

For brevity, a description of experiments and results will adhere to the following format:

- *Reasons for carrying out the experiment*
- *Substrate and size*
- *Preservative (where applicable)*
- *Duration*
- *Findings*
- *Publications and/or reports*
- *Collaborators (if any).*

The experiments will be divided into three groups: preservative, natural durability and miscellaneous research.

Preservative research

1. Effects of concrete collars on efficacy of CCA
   - *Reasons for carrying out the experiment*: **To see if concreted, CCA-treated poles were more susceptible to decay than those not concreted and to observe the effect of impervious barriers between the concrete and pole interface**
   - *Substrate and size*: **Radiata pine, pole stubs, commercial**
   - *Preservative (where applicable)*: **CCA at 20-40 kg dry salt m^{-3}**
   - *Duration*: **5 years, completed**
   - *Findings:* **A CCA-tolerant brown rot fungus was found in the soil; both concreted and non-concreted stubs were readily decayed; presence of barrier between concrete and pole reduced decay; bandage with TCMTB prevented any decay; limited decay occurred if TCMTB added to concrete**
   - *Publications and/or reports*: **Reported to Joint Wood Preservation Committee (responsible to this conference) with journal publication in preparation**
   - *Collaborators (if any):* **None.**

2. Yellow stringybark preservation
   - *Reasons for carrying out the experiment*: **To evaluate the performance of yellow stringybark as a pole timber**
   - *Substrate and size*: **Stakes 20 x 20 x 150 mm**
   - *Preservative (where applicable)*: **CCA at five retentions to 40 kg m^{-3} in sapwood, untreated sapwood, untreated heartwood**
   - *Duration*: **4 years, planned for a total of 5 to 10 years**
   - *Findings*: **No decay at retentions of 20 kg m^{-3} and above; untreated sapwood has failed; untreated heartwood has moderate decay**
   - *Publications and/or reports*: **Four Divisional Reports**
   - *Collaborators (if any)*: **SECWA.**

3. PEC additives
   - *Reasons for carrying out the experiment*: **Demands from certain unions for lower creosote content in Pigment Emulsified Creosote (PEC) led to test of biocide additives**
   - *Substrate and size*: **Sapwood stakes 20 x 20 x 150 mm cut from hardwood poles**

- *Preservative (where applicable)* **PEC, PEC plus TCMTB, Boracol 40, copper ethanolamine nonanoate (CEN), Quatramine 80, arsenic trioxide, troysan polyphase or CCA, vs HTC (High-temperature creosote), toluene and water controls**
- *Duration*: **8 years, completed**
- *Findings*: **PEC and PEC + additives perform well at high (120 kg PEC m^{-3}) and moderate (60 kg PEC m^{-3}) retentions; severe decay at 30 kg PEC m^{-3}. Considering PEC treatments have creosote content equivalent to 65% HTC, PEC has more than held its own against HTC**
- *Publications and/or reports*: **Greaves *et al.*, 1985 (for 3, 6, 12 month results)**
- *Collaborators (if any)*: **Koppers, SECV.**

4. Weathered HTC versus PEC
   - *Reasons for carrying out the experiment*: **To determine comparative efficacy of weathered HTC and PEC formulations**
   - *Substrate and size*: **Quadrants from commercial poles, non-durable ash-type eucalypts or durable "regal" species**
   - *Preservative (where applicable)*: **PEC and HTC, each treated at 60°C and 90°C, then 100 hours in weatherometer**
   - *Duration*: **9 years, completed**
   - *Findings*: **When creosote retentions are similar, PEC performs as well as HTC**
   - *Publications and/or reports*: **Divisional report in preparation**
   - *Collaborators (if any)*: **Koppers, SECV.**

5. Chlorothalonil
   - *Reasons for carrying out the experiment*: **To determine the efficacy of chlorothalonil as a wood preservative**
   - *Substrate and size*: **Radiata pine and mountain ash sapwoods 25 x 25 x 150 mm**
   - *Preservative (where applicable)*: **Chlorothalonil in oil vs CCA (Tanalith C)**
   - *Duration*: **4 years of at least 5 years**
   - *Findings*: **Oil controls performing well and chlorothalonil performing better than CCA at all equivalent retentions; better in pine than in eucalypt**
   - *Publications and/or reports*: **Laks and Woods, 1992**
   - *Collaborators (if any)*: **ISK Biotech Corporation.**

6. Cell wall penetrating formulations
   - *Reasons for carrying out the experiment*: **To determine the efficacy of copper-based formulations that swell wood cell wall (for better penetration)**
   - *Substrate and size*: **Radiata pine and messmate sapwoods 20 x 20 x 130 mm**
   - *Preservative (where applicable)*: **Tanalith C, CEN and various commercial water-based or organic solvent formulations of acypetac-copper**
   - *Duration*: **5½ years, completed**
   - *Findings*: **Although Tanalith C was best, two ammoniacal formulations and CEN performed well, while organic solvent acypetac-copper formulation performed poorly**
   - *Publications and/or reports*: **Cookson and Greaves, 1991**
   - *Collaborators (if any)*: **Cuprinol, UK.**

7. Diffusing remedial preservatives
   - *Reasons for carrying out the experiment*: **Assess diffusing commercial formulations for remedial treatment**
   - *Substrate and size*: **Messmate natural rounds, 40-50 mm x 500 mm**
   - *Preservative (where applicable)*: **B_2O_3, B_2O_3 + CuO, $Na_2B_8O_{13}$ + CuO, each as fused solid rods**
   - *Duration*: **20 months, completed**
   - *Findings*: **Boron diffused and protected wood against decay fungi introduced by predecayed dowels (with specimens in vermiculite rather than soil) whereas copper did not diffuse**
   - *Publications and/or reports*: **Greaves *et al.*, 1982**
   - *Collaborators (if any)*: **None.**

8. Decay in CCA-treated vineyard posts
   - *Reasons for carrying out the experiment*: **Determine cause of premature failure of CCA-treated vineyard posts**
   - *Substrate and size*: **Radiata pine rounds**
   - *Preservative (where applicable)*: **Tanalith C and fire retardant CCA formulation (3S), individual rounds placed in large plastic tubes containing soil with or without additives of fertiliser, gypsum etc. as practiced in vineyards**
   - *Duration*: **5 years, completed**
   - *Findings*: **Failures were rapid, due to a tolerant brown rot fungus, and confined to fire retardant formulation. The 3S formulation had a moisture content always higher than the Tanalith C-treated posts throughout this test**
   - *Publications and/or reports*: **Report in preparation**
   - *Collaborators (if any)*: **None.**

9. Beehive treatments
   - *Reasons for carrying out the experiment*: **To find preservatives for beehives that do not need overpainting, and are suitable for use in contact with food**
   - *Substrate and size*: **Radiata pine, mainly sapwood, 30 x 20 x 200 mm**
   - *Preservative (where applicable)*: **Dipped for 10 or 20 min. in benzalkonium chloride (Quatramine 80) or copper naphthenate (each at 4 concentrations)**
   - *Duration*: **12 months**
   - *Findings*: **Wax dip prior to a single coat of paint was considered the most practical do-it-yourself treatment**
   - *Publications and/or reports*: **Robinson and French, 1984,1988**
   - *Collaborators (if any)*: **None.**

10. Low temperature creosote treatments of sapwood and heartwood
    - *Reasons for carrying out the experiment*: **Determine relative performance of radiata pine sapwood and heartwood treated with creosote**
    - *Substrate and size*: **Specimens 50 x 50 mm cross-section, originally treated as being all sapwood, top 100 mm removed from tops of specimens after 10 years field exposure, split radially to produce 50 x 25 x 100 mm stakes (one for exposure, one for retention analysis)**
    - *Preservative (where applicable)*: **K55 Creosote originally averaging 175-210 kg m^{-3}**
    - *Duration*: **184 weeks (i.e. until all heartwood failed), completed**
    - *Findings*: **Most of sapwood still serviceable**
    - *Publications and/or reports*: **No report, may be used for calibration to remainder of specimens now in field for 24 years (Mulgrave/Rowville sites)**
    - *Collaborators (if any)*: **None.**

11. Pretreatment of hardwood
    - *Reasons for carrying out the experiment*: **To obtain better protection of hardwoods by pretreatment with $Na_2S_2O_5$ before treating with CCA or chromium compounds.**
    - *Substrate and size*: **Spotted gum sapwood 20 x 20 x 150 mm**
    - *Preservative (where applicable)*: **Pretreat $Na_2S_2O_5$ followed by CCA, various chromium compounds, plus various controls, prior to leaching**
    - *Duration*: **5 years, completed**
    - *Findings*: **CCA performance improved slightly by the pretreatment; chromium compounds whether the hardwood was pretreated or not performed poorly, being attacked mainly by brown rot fungi**
    - *Publications and or reports*: **Not yet prepared for publication**
    - *Collaborators (if any)*: **None.**

12. Novel formulations
    - *Reasons for carrying out the experiment*: **Testing of novel formulations and some agricultural formulations already tried overseas as wood preservatives, to see if they have potential in hardwoods**
    - *Substrate and size*: **Mountain ash sapwood, 20 x 20 x 150 mm**
    - *Preservative (where applicable)*: **16 fungicides each at 3 retentions, leached 5 years, ongoing**
    - *Findings*: **6 treatments continue to perform well**
    - *Publications and/or reports*: **No reports yet prepared**
    - *Collaborators (if any)*: **None.**

Natural Durability Research

13. Natural durability of selected timber species
    - *Reasons for carrying out the experiment*: **To determine the relative durability of 36 timbers, to determine variability both within and between different trees of the same timber species**
    - *Substrate and size*: **Specimens 20 x 20 x 100 mm, obtained from 50 x 50 x 100 mm tops removed from stakes exposed in field (Walpeup, Victoria) for 10 years; some fresh cut non-durable controls**
    - *Preservative (where applicable)*: **CCA control offcuts, 12 kg m^{-3}**
    - *Duration*: **5 years, completed**
    - *Findings*: **Variation between trees of same species greater than variation within a tree, median specimen lives obtained for all species and treatments except three (raspberry jam, brigalow and 12 kg m^{-3} CCA radiata sapwood control), Q3 obtained for all but a further two**
    - *Publications and/or reports*: **Thornton *et al.*, 1981, plus journal paper in preparation**
    - *Collaborators (if any)*: **None.**

14. Natural durability
    - *Reasons for carrying out the experiment*: **To determine the relative durability of more than 70 timber spp.**
    - *Substrate and size*: **Specimens 20 x 20 x 100 mm, again obtained from 50 x 50 x 100 mm tops removed from stakes in field (Mulgrave, Victoria) for 13 years; fresh cut specimens (as in 13)**

- *Preservative (where applicable)*: **CCA control offcuts, 12 kg m^{-3}**
- *Duration*: **5 years for decay only, 2½ years exposure of both predecayed and non-predecayed specimens to termites**
- *Findings*: **Complete range of decay failures (brown rot, white rot, soft rot) occurring at either groundline, base or top of specimen; termite attack extremely rapid, reliable and reproducible; all completed**
- *Publications and/or reports*: **Johnson *et al.*, 1983 and accompanying Divisional Video, Johnson *et al.*, 1988, further journal publication planned**
- *Collaborators (if any)*: **None.**

15. A comparison of the durability of old growth and regrowth timbers
    - *Reasons for carrying out the experiment*: **A comparison of heartwood durability of timbers from different resources, i.e. regrowth or plantation against old growth**
    - *Substrate and size*: **Range of commercial timbers, 20 x 20 x 100 mm outer heartwood**
    - *Preservative (where applicable)*: **Some preservative (CCA), controls**
    - *Duration*: **3½ years, ongoing**
    - *Findings*: **See Paper 2/21 (Johnson *et al.*, 1993) at this Conference**
    - *Publications and/or reports*: **4 Divisional reports, paper 2/21 this Conference**
    - *Collaborators (if any)*: **Department of CALM, WA.**

16. Comparison of Malas and Hopea for PNG poles
    - *Reasons for carrying out the experiment*: **Assist PNG in choice of pole timbers**
    - *Substrate and size*: **Malas and hopea; outer heart, inner heart, and sapwood; 20 x 20 x 100 mm**
    - *Preservative (where applicable)*: **No preservatives**
    - *Duration*: **4 years, completed**
    - *Findings*: **Large variation between and within trees of each species; malas more durable than hopea; malas sapwood has considerable durability**
    - *Publications and/or reports*: **7 Divisional reports, may be published with or without data on penetration and resultant CCA loadings obtained using same trees**
    - *Collaborators (if any)*: **PNG ELCOM.**

Miscellaneous Research

17. Decay resistance of composite sheet products
    - *Reasons for carrying out the experiment*: **Compare decay resistance of cellulose fibre reinforced cement with the previously used asbestos fibre reinforced cement**
    - *Substrate and size*: **Small sheets, three-quarters buried in soil with added decay fungi and litter**
    - *Preservative (where applicable)*: **No preservative**
    - *Duration*: **1, 5 and 10 year harvests, completed**
    - *Findings*: **Variation in both moisture content and (due to carbonisation) mass gain between the two products; returned to collaborator for strength and carbon content determinations compared to unexposed controls**
    - *Publications and/or reports*: **3 Divisional reports**
    - *Collaborators (if any)*: **James Hardie.**

18. Methane emission from termites
    - *Reasons for carrying out the experiment*: **To estimate the amount of methane produced by termites in a *Coptotermes lacteus* mound.**
    - *Substrate and size*: **As for study number 14.**
    - *Preservative (where applicable)*: **No preservatives.**
    - *Duration*: **several days, completed.**
    - *Findings*: **Average methane flux was 0.7 mg per kg of termites per hour.**
    - *Publications and/or reports*: **Fraser *et al.*, 1986.**
    - *Collaborators (if any)*: **None.**

19. Position of termite attack
    - *Reasons for carrying out the experiment*: **To determine the effect of position of untreated hardwood specimens in the tank on attack by termites.**
    - *Substrate and size*: **Mountain ash sapwood, 20 x 20 x 100 mm.**
    - *Preservative (where applicable)*: **None.**
    - *Duration*: **2 months, completed.**
    - *Findings*: **Specimens placed in rows at the end of the tank were attacked to a greater extent (p<1%) than those in the middle of the tank.**
    - *Publications and/or reports*: **None.**
    - *Collaborators (if any)*: **None.**

20. Monitoring soil biology
    - *Reasons for carrying out the experiment*: **To determine the changes over time in the number of soil bacteria, fungi and Actinomycetes. Soil moisture content and pH recorded at isolation times.**
    - *Substrate and size*: **None.**
    - *Preservative (where applicable)*: **None.**
    - *Duration*: **84 days.**
    - *Findings*: **No reduction in the number of propagules of bacteria or fungi were noted.**
    - *Publications and/or reports*: **None.**
    - *Collaborators (if any)*: **None.**

21. Biodegradation of Stramit Space Board
    - *Reasons for carrying out the experiment*: **To accelerate the biodegradation of this panel product by addition of nitrogen and inoculum.**
    - *Substrate and size*: **Segment of panel, 50 x 100 x 100 mm.**
    - *Preservative (where applicable)*: **None.**
    - *Duration*: **12 weeks, completed.**
    - *Findings*: **The specimen in contact with the soil was more readily attached. Neither chicken manure nor fungal inoculum enhanced degradation.**
    - *Publications and/or reports*: **Divisional report.**
    - *Collaborators (if any)*: **Stramit Industries.**

22. Other studies

    In addition: Decaying specimens are kept active for teaching/display purposes; litter from field test sites is AFS-predecayed until ready for transfer to soil surface of ongoing tests; brown-rotting CCA treated posts are kept active so that soil will contain such fungi; assessments of microbial propagules in soil at start of tests; non-durable species are predecayed for use as attractant baits in field, and as baits for use in buildings to detect subterranean termites (with or without subsequent insecticide addition); biodegradable plastic products have been

exposed in one soil type; attempts are being made to reproduce the actual succession of decay types influencing natural durability in the field; means of selecting likely tolerant organisms for new preservatives can be studied. Finally calibration tests of natural durability, AFS to field, have just been completed (against decay and termites) in the field using AFS-sized specimens (20 x 20 x 100 mm) that were matched with the fresh cut non-durable controls used in studies 13, 14 and 15. The latter field exposure was inspected more frequently than a normal field test (i.e. three times per year) and the last specimen became unserviceable after just under eight years.

Summary of AFS testing

Our work has shown that durability of a wide range of timber species and efficacy of preservatives (water-borne, oil-borne or solvent-borne) can be determined in the AFS. Specimens with cross-sections ranging from 20 x 20 mm (sawn) to commercial pole rounds have been successfully used. New preservatives are compared, against well known comparative control timbers/preservatives. While all tests are carried out at 28°C and around 85% RH, various soils (often with amendments from rotting specimens, decaying litter, etc.) have been used as well as artificial media. For some overseas institutions, their fungal cellar or soil-bed methodology (often using smaller test chambers, shallow soils and with resultant soil-drainage difficulties) apparently become almost exclusively a soft rot facility. However, AFS testing in CSIRO has provided the full range of decay hazards because the conditions are suited to the activity of brown rot and white rot decay (as evidenced not only by rot type, but also by fruit-body production, on both specimens and litter that occurs frequently in the course of some of our studies), as well as soft rot attack. Additionally, natural durability determinations have included the provision of a complete active termite colony over a 2½ year period.

Research to calibrate the AFS against some field sites has been underway for some time. One approach is to expose AFS-size specimens in both the field and the AFS, and inspect them frequently for decay or termite attack. Also, for two series of natural durability tests (against decay and termites), the AFS specimens were prepared from sound tops removed from the stakes after 10 to 13 years in the ongoing field tests. Deterioration in the stake tops in the AFS after 2½ years (termites) and 5 years (decay) was much more severe than in the field test specimens exposed in ground for around 25 years, even at the tropical and subtropical sites. Calibration will be attempted when biodeterioration of specimens the field test is somewhat further advanced, and publication considered at that time.

Although this paper only deals in general with advantages and disadvantages of AFS testing, it is clear that its economy and suitability for frequent inspection yields data

that can be more extensive than that obtainable from field sites. The altered timber resource, or new preservatives, can be evaluated directly and precisely against known controls to give comparative results.

Publications: Complete list including Forest Products Conference (FPRC), International Research Group on Wood Preservation (IRG), as well as journal papers.

Cookson, L.J. and Greaves, H. (1991). An accelerated field simulator trial of metal soaps. Holzforschung 45, 19-22.

Fraser, P.J., Rasmussen, R.A., Creffield, J.W., French, J.R. and Kahlil, M.A.K. (1986). Termites and global methane - another assessment. Journal of Atmospheric Chemistry 4: 295-310.

Greaves, H., Chin, C.W. and Watkins, J.B. (1985). Improved PEC preservatives with added biocides. IRG Document No. IRG/WP/3322, 7 pp.

Greaves, H., McCarthy, R. and Cookson, L.J. (1982). An accelerated field simulator trial of fused preservative rods. International Journal of Wood Preservation 2(2), 69-76.

Laks, P.E. and Woods, T.L. (1992). Chlorothalonil: A new ground contact wood preservative. IRG Document No. IRG/WP/3712-92, pp 5 and 6.

Johnson, G.C., Thornton, J.D., Creffield, J.W. and Howick, C.D. (1983). Natural durability studies in an accelerated field simulator - A novel approach. IRG Document No. IRG/WP/2197, 7 pp.

Johnson, G.C., Thornton, J.D., Creffield, J.W. and Howick, C.D. (1988). Assessing timber durability using an accelerated field simulator. I. Initiation of decay and termite studies. Material und Organismen 23(2), 97-114.

Johnson, G.C., Thornton, J.D. and Greaves, H. (1982). The accelerated field simulator (= fungal cellar). IRG Document No. IRG/WP/2170, 9 pp.

Johnson, G.C., Thornton, J.D. and Nguyen, N-K. (1993). An accelerated field simulator study of the natural durability of heartwood from mature and regrowth trees. Proceedings 24th FPRC. Topic 2/21, 9 pp.

Robinson, P.J. and French, J.R.J. (1984). Beekeeping and wood preservation in Australia. Proceedings 21st. FPRC, Topic B12, 7 pp.

Robinson, P.J. and French, J.R.J. (1988). Wood preservation in the Australian beekeeping industry. IRG Document No. IRG/WP/3473, 7 pp.

Thornton, J.D., Johnson, G.C. and Saunders, I.W. (1981). Accelerated "fungal cellar" testing of the natural durability of the heartwood of Australian timbers in ground contact. Proceedings 20th FPRC, Topic WP6, 7 pp.

TERMITE PHYSICAL BARRIER PROTECTING FOREST PRODUCTS.

By

B. AHMED and J.R.J. FRENCH

CSIRO, Division of Forest Products
Bayview Ave., Clayton, Vic., 3168, Australia

ABSTRACT

Granite particles of different sizes were tested against laboratory and field populations of subterranean termites as a suitable alternative to soil chemical barriers. Currently, there is increasing environmental awareness, with the health and safety aspects of using persistant insecticides against termites. Many house-holders would like to avoid treating their properties with insecticides such as cyclodienes (OC's),(chlordane and heptachlor) and the organophosphate , Dursban. At present there are no consistently satisfactory methods to eliminate or detoxify cyclodiene insecticides from soils. Suitable alternatives that are environmentally safe and can be used to substitute for these chemicals are physical barriers such as granite particles (Granitgard) and fine stainless steel mesh (Termi-mesh).

Workers of subterranean termites were tested in laboratory and field bioassays for their ability to penetrate barriers of granite particles of three different sizes. The results indicated that laboratory and field populations of subterranean termites of the genus *Coptotermes* were unable to penetrate granite particles of 2.4 - 1.7 mm diam..

1. INTRODUCTION

About 360 species of termites have been recorded from the Australian region, but, only about 20 species attack timber-in-service, and are of economic importance. The damage attributed to termites every year is in the vicinity of AUD$100 million (French, 1986). *Coptotermes. acinaciformis* is by far Australia's most destructive termite, due mainly to its cosmopolitan distribution. , *Mastotermes darwiniensis* is probably even more voracious but is confined to the area north of Tropic of Capricorn (Ratcliffe et al 1952). Since the second World War, termiticides, mainly cyclodienes, have been used as a soil chemical barrier against subterranean termites. These chemicals were applied on soil to form a continuous and persistant chemical barrier and to exclude subterranean termites from entering building structures.

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In 1957, Ebeling and Pence tested the relationship between sand and cinder particles (2.4 - 1.7 mm) and the penetration of subterranean termites through these barriers, and discovered that termites were not able to penetrate the barrier. They described the ability of the termites in moving the particles with their heads and mandibles to either side of the wall, the smaller sand particles are taken into the buccal cavity and mixed with gluey substance in the mouth of the termites and then placed along the walls of the galleries to make tightly sealed gallery surfaces. Termites transport smaller soil particles with their buccal cavity and the larger particles with their external surface mandibles. Recently, Tamashiro et al (1987) discovered that the subterranean termites, *Coptotermes formosanus*, was unable to penetrate barriers of basalt particles (2.4-1.7 mm). The basalt particles were too large and heavy for termites to carry and hard for them to chew due to the functions of mass and hardness. Similarly the space between the basaltic particles are too small for the termites to crawl through. In the light of mounting concern over the environmental safety of insecticides, such a technique shows great potential as an alternative to soil chemical barriers.

2 Material and Methods:

2.1. Laboratory bioassay

2.1.1 Granite substrate

E.B. Masons & Sons P/L, Cohuna, Victoria supplied the granite particles, which have a specific gravity of 2.8. The particles were fairly uniform in size, varying from less than 1.7, 2.4 to 1.7 mm and greater than 2.4 mm in diameter and used in laboratory and field tests.

2.1.2 Termites Used:

Termites used in laboratory bioassay were mainly *Coptotermes acinaciformis* This species of termite is congeneric with the Hawaiian termite *(Coptotermes formosanus). C. acinaciformis* is the most economically important subterranean termite with respect to timber-in-service and widely distributed in mainland Australia. Freshly orphaned workers and soldiers of *C. acinaciformis* termites were collected from the Northern territory near Darwin. Other termites included in the test were *Coptotermes lacteus, C. frenchi*, and *Nasutitermes exitiosus.*

2.1.3 Experiment 1 -Preparation of experimental units for upward tunnelling

The experimental units consisted of a circular plastic container (380 ml), in which was placed 20 gm of moistened river sand, containing three times the volume of water as of sand, and 1.5 gms of *C. acinaciformis* . Into each container a plastic cylinder (160 mm long, 25 mm diam.) containing 150 mm of the granite substrate in test was inserted vertically, and a small piece of cork placed on the surface of the substrate. The container was sealed with a lid that had a 26 mm diameter hole cut in the surface of the lid to allow the cyclinder to remain vertical (see Fig 1 (i)). To enhance the activity of penetration of the termites at the glass granite interface a black plastic cover (sleeve) was slipped over the container. rates and moisture content were recorded daily. The experimental units with the termites were then placed in a conditioning room, at a temperature of 27 °C and 75% R.H.. The penetration distance, termite activity, mortality

2.1.4 Experiment 1 -Preparation of experimental units for downwards tunnelling

The experimental units were similar to the Experiment 1 above (2.1.3) except that the circular container with the sand and termites was positioned on top of the vertically held plastic cylinder (see Fig 1 (ii)).

2.2.0 Field Bioassays

Field experiments were conducted on active above ground colonies of *Coptotermes* termites. The mounds were located (1) In the Boola Boola State forest in East Gippsland forest.(150 Km south-east of Melbourne). The termite species found are *C. lacteus,* which are congeneric to the *C. acinaciformis* and, (2) Townsville area, Queensland, where active above ground mounds of *C. acinaciformis* are found. The principal impetus of utilizing active above ground mounds was to place test materials in a situation of high termite activity.

The three main types of bioassays were as follows:-

2.2.1 Plastic containers connected to mounds

Rectangular plastic containers (250 x 120 x 90 mm) filled with different sizes granite particles and connected in the mounds with conduits (100 mm long and 25 mm wide) and wet corrugated cardboard rolled inside, to enhance termite activity in the box. Decayed wood bait blocks (50 x 50 x 20 mm) were placed on the surface of the granite substrate. Termites that were able to penetrate the substrate were observed feeding on the bait blocks.

2.2.2 Conduits connected to mounds

Conduits (90 mm diam. and 200 mm length) were filled with different granite sizes and connected to active mounds similar to the rectangular plastic containers.

2.2.3 Trenches outside mounds

Trenches (260 mm depth and 200 mm square) were dug around active mounds and the trenches were connected to the mounds by conduits with corrugated cardboard inserts (Fig. 2). The trenches were filled with granite particles. Small specimens of wood were placed at the centre of the trenches, and completely surrounded by granite substrate, while cork specimen were placed on the surface of the substrate.

3 RESULT

3.1 Laboratory results:

In both experiments namely upward and downwards penetration bioassays termites were unable to penetrate the 2.4 - 1.7 mm granite substrate. Although termites attempted to tunnel through the barrier, the substrate remained intact for the whole period of the bioassay.

Unlike the 2.4 -1.7 mm granite substrate sized particles, the fine granite particles (<.1.7 mm) were easily penetrated within the first 24hrs of the bioassay. Termites could take the

particles into their buccal cavities and place them along the walls of gallaries or carry the individual particles down to the container. Similarly the coarser granite particles (>2.4 mm) were penetrated as the termites were able crawl through the voids between granite particles, but unable to carry or move the granite particles.

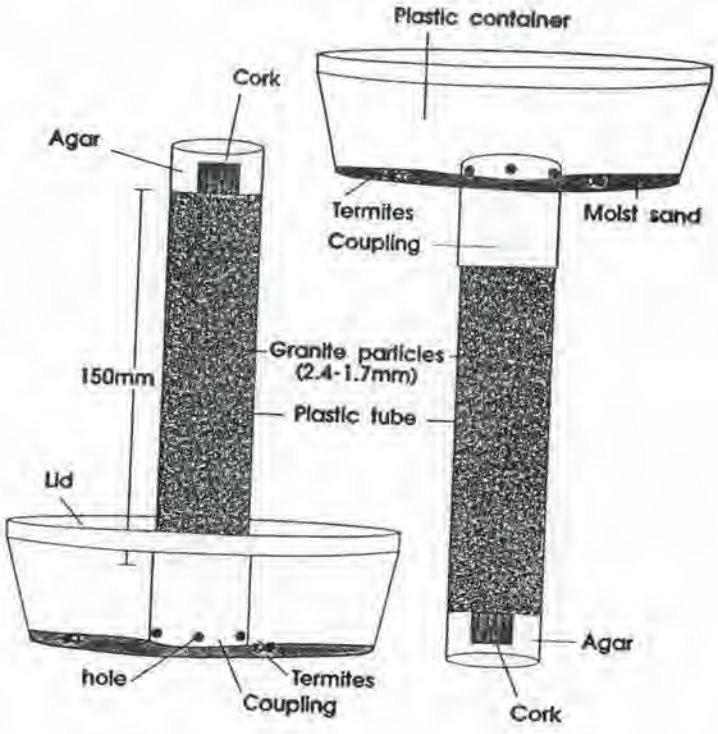

Fig. 1 Diagrammatic representation of the experimental layout in laboratory tests to evaluate (i) upwards and (ii) downward tunnelling ability of the termites.

3.2 Field results

3.2.1 Plastic containers connected to mounds

Termites were able to penetrate all the barriers except the 2.4 -1.7 mm granite substrate.

3.2.2 Conduits connected to mounds:

After four weeks there was no penetration in the 2.4 - 1.7 mm diam. substrate. Whereas the fine and coarse granite substrate were penetrated and termites were feeding on the bait blocks.

3.2.3 Trenches outside mounds:

Termites were found attacking both bait blocks (top and centre bait) on the untreated control, fine and coarse granite particles after four weeks. However, bait blocks on the

surface of the 2.4 - 1.7 mm granite particles were attacked by termites. They were able to construct shelter-tube across the surface of the substrate.

Table 1: *Coptotermes lacteus* workers tunnelling through granite substrate after 4 weeks.
Mean of five replicates.

Granite substrate				
Termite mound	>1.7mm	2.4- 1.7 mm	<2.4 mm	Soil control
1	TA	NA	TA	TA
2	TA	NA	TA	TA
3	TA	TA*	TA	TA
4	TA	TA*	TA	TA

Key: TA= Termite activity NA= No activity
TA*= Termite attack by walking across the substrate

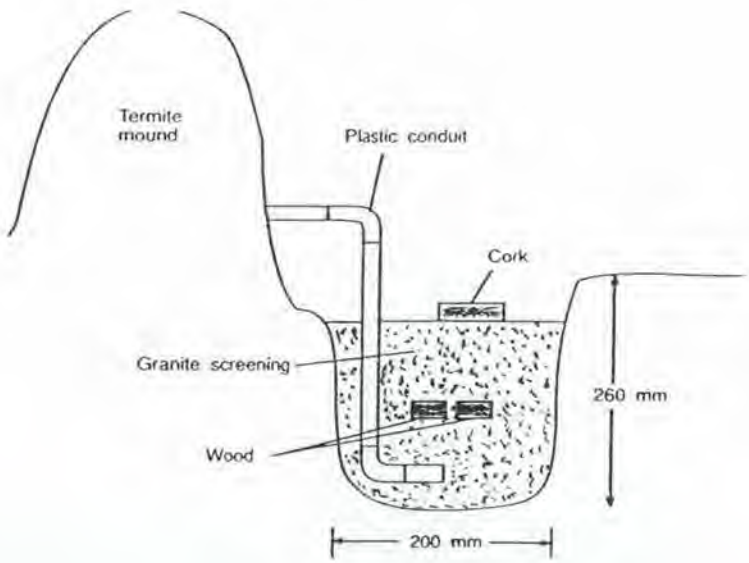

Fig.2. Diagrammatic layout of field experiment of bait blocks on the surface and middle of the granite screenings within each trench.

2/7

4.0 Conclusion:

It seems timely to explore the use of a physical barriers to protect wood and wood products from subterranean termites. Both laboratory and field results have shown that subterranean termites can not penetrate granite particles 2.4 - 1.7 mm diam..The main features of the physical barrier are the acceptability by the community and the pest control industry that this system is a more environmentally acceptable method of protecting timber-in-service. The field results showed that termites can walk across the surface of the barriers by building shelter tubes. However, the nature of termites egress into buildings is usually cryptic. If termites were to expose themselves, their presence could easily be detected and a suitable prophylactic treatment could be used.

Since these experiments were so successful, field experiments on retrofitting granite particles (now commercially available under the Trade Name of Granitgard, and produced as a 2.4 - 1.7 mm diam. substrate) are in progress to examine whether or not such a physical barrier can protect an existing building from termites attack when a trench of Granitgard is placed around the perimeter of the building. The result of retrofitting field bioassay at a site in northern Victoria (Walpeup), after 18 months indicated that all the species of termites present were unable to penetrate the Granitgard trenches.

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Borate protection of slash pine (*Pinus elliottii*) sapwood from attack by subterranean termites (*Coptotermes* sp., Isoptera: Rhinotermitidae)

B.C. Peters and P.J. Allen

Timber Research

Queensland Department of Primary Industries

Forest Service

PO Box 631, Indooroopilly, Qld. 4068

Summary

A field bioassay was undertaken with *Coptotermes acinaciformis* (Froggatt) in summer to determine protection of slash pine (*Pinus elliottii* Engelm.) sapwood afforded by borate compounds. Sapwood blocks were placed in plastic containers and attached to infested trees. Termite response was determined by mass loss over five weeks and modelled. For 1.0 and 5.0 percent mass loss, mean borate retentions of 0.58 and 0.14 percent m/m boric acid equivalent (BAE), respectively were derived. Marked variation in termite response, between infested trees, was demonstrated. The need for long term field exposure trials is indicated. For comparison, termite response to white cypress (*Callitris glaucophylla* Thompson and Johnson), is also reported.

Introduction

The two main strategies used to protect buildings from subterranean termite attack, in Australia, are prevention (excluding infestations) and cure (eradicating infestations). Preventative measures have included the installation of physical barriers and/or chemically-treated soil barriers during building construction. Curative measures usually involve the use of chemicals. Traditional physical barriers (shaped metal sheeting) have become unpopular because modern building practices, such as those involving slab on ground construction, do not facilitate their easy incorporation. Chemical soil barriers, involving highly effective cyclodiene termiticides, are commonly used (Lenz *et al.* 1990). These chemicals are quite toxic to animals and persist in the environment. Consequently, it seems likely that these chemicals will be withdrawn from use in Australia in the near future (Verkerk 1990, Watson 1990, National Health and Medical Research Council 1992).

Softwood timbers are extensively used in building construction and are increasing their hold on the market in Australia (Greve 1988, Aust. For. Council 1989). Most Australian softwoods are non-durable and highly susceptible to attack by termites. The use of preservative-treated softwoods in building construction may provide an acceptable alternative. Wood treated with borates has no aesthetic drawbacks, is considered to have low mammalian toxicity and has been demonstrated to be toxic to termites (Tamblyn *et al.* 1968, Johanson and Howick 1975, Grace *et al.* 1992).

Peters and Allen (in press) conducted field bioassays with two Australian *Coptotermes* species to determine protection of hoop pine sapwood afforded by borate compounds. Termite response was assessed using mass loss over five weeks and described in terms of borate concentration using logarithmic models. With *Coptotermes acinaciformis* (Froggatt), for 1.0 and 5.0 percent mass loss, retentions ranged from 0.49 and 0.25 percent m/m boric acid equivalent (BAE), respectively, in late winter, to 0.76 and 0.47 percent BAE, respectively in late summer. These results support conclusions from earlier laboratory studies conducted elsewhere (Gay *et al.* 1958). Peters and Allen (in press) concluded that higher borate retentions than those given could be necessary in midsummer for comparable levels of protection, because of a seasonal effect.

There is, however, a lack of field evidence that borate compounds can protect timber against termite attack in Australia. Field evaluation of *C. acinaciformis* to borate-treated slash pine (*Pinus elliottii* Engelm.) sapwood, during summer, and resultant protective values are reported in this paper. For comparison, termite response to white cypress (*Callitris glaucophylla* Thompson and Johnson) is also reported.

Materials and Methods

Termites

Trees of *Eucalyptus signata* F. Muell. (scribbly gum) infested with *C. acinaciformis* were selected adjacent to Compartment 47, State Forest 589, Twins Logging Area at Beerburrum (26° 58 S., 152° 54 E.), Queensland. These trees were drilled to the centre at breast height, with a 20 mm diameter auger. Dowels (each 300 mm × 19 mm diam.) of termite susceptible timber (*Eucalyptus obliqua* L'Herit) were inserted into each tree and plugged with moist soil to prevent entry by ants. These dowels were removed weekly and inspected for termite attack. Dowels inserted into these trees were sealed in place by the termites and attacked.

Timber samples

Slash pine timber (30 × 30 × 2400 mm) at equilibrium moisture content were selected for sapwood content, straightness of grain, and minimal knots. A vacuum pressure impregnation process with Polybor®, a sodium polyborate complex, was used to produce nominal retention concentrations of 0.00, 0.20, 0.40, 0.60, 0.80, 1.00 and 1.20 percent m/m boric acid equivalent (BAE) in oven dry timber. The timber treatment was a Bethell (Wilkinson 1979) process using a dry vacuum of -95 kPa for 60 minutes, pressurising to 1400 kPa until refusal with a final empty cylinder vacuum of -85 kPa for 30 minutes. About 60 pieces of timber were treated in each charge.

After treatment, each charge was allowed to air dry under cover to equilibrium moisture content. Several lengths were then selected at random from each charge to be used for termite bioassay. The faces of the timber were rough-sanded on all faces to remove surface crystallised boron compounds. End sections of at least 50 mm were discarded from each length of treated timber. Knots and timber surrounding the knots were also excluded. The remainder of each length was then cut into blocks (100 mm long) and labelled. Six representative blocks from each length were selected for moisture content and boron analyses.

Boron determinations were obtained using the outer 6 mm analytical zone of the samples because it was considered that this zone, which contains the highest concentration, would be encountered by the termites first. The analytical zone was cut from each block, dried at 70°C for 24 hours, and ground in a cross-beater mill through a 1.0 mm mesh. Boron was determined by UV-visible spectrophotometry using azo methine-H on extracts obtained by diffusing borates from the ground analytical zone using 1.8 M sulphuric acid for 2 hours at 70°C. These determinations were completed before the bioassays.

Untreated timber was used to prepare controls. Lengths of white cypress containing heartwood and sapwood were also cut into blocks in a similar manner. The initial mass of each bioassay block was determined. An estimated oven dry mass was then calculated using the initial mass and the moisture content of the full length of timber.

Bioassay technique

Response of termites to treated sapwood blocks was tested using a random multiple choice method (French *et al.* 1987) which was adapted from La Fage *et al.* (1983). Rectangular plastic containers (lunch boxes, 200 × 130 × 70 mm deep) were used as bioassay chambers. A 19 mm hole was drilled into each of the the two longest sides of each container and a 300 mm long, 19 mm plastic conduit attached through the

holes. Four 10 mm diameter holes were also drilled in the conduit to allow the termites to enter the box.

Dry quartz sand was used to cover the bottom of the container to a depth of 30 mm. A piece of single backed corrugated cardboard (175 × 120 mm, with corrugations undermost and in the longitudinal direction) was placed on the sand and the conduit. Five blocks, from the same treatment charge, were then placed in the container and covered with a plastic lid. A piece of single backed corrugated cardboard (350 mm long; 45 mm wide with the corrugations facing inwards) was placed in the conduit. A heavy duty black plastic bag was placed over the container, with the conduit protruding. The opening of the plastic bag was rolled and taped. Each assembly was then connected to a colony by inserting the plastic conduit into a 20 mm diameter hole drilled in the side of the tree. The containers were inspected periodically for the first five days after connection to verify termite entry.

The termites packed the entire length of conduit with moist soil within a day, and usually packed the container to the lid within three days. An assembly was repositioned with new conduit if termites did not enter the container. Termite feeding responses were assessed for all blocks after exposure for five weeks by determining the mass of wood consumed by the termites.

Experimental design

The experiment, which was conducted at Beerburrum during summer, involved 10 trees infested with *C. acinaciformis*. Each container had five blocks treated to the same nominal level of boron. Blocks within a container were randomly assigned to five positions. The blocks within each container were cut from five different lengths of timber from the same treatment charge. Each tree had one block from each length in a container. Seven containers each with a different nominal boron level were inserted into each tree. The nominal levels of boron were 0.0, 0.2, 0.4, 0.6, 0.8, 1.0 and 1.2 percent m/m BAE. Two other containers were also inserted. These containers had five untreated control blocks or five white cypress blocks containing both heartwood and sapwood.

Statistical analyses

The natural logarithm of the mass loss data for individual blocks were subjected to a regression analysis to partition the variation attributable to boron, tree, position in container and to the interactions involving these variables. Mass loss data were also averaged to provide a mean value for the blocks cut from the same lengths of timber. Thus, termite responses were averaged across the ten trees for each length.

The following model was fitted using least squares regression.

$$Mass\ loss = e^{(b_0 + b_1 \times boron\ concentration + b_2 \times \log(boron\ concentration + 0.1))}$$

where b_0, b_1 and b_2 are constants.

This empirical model was based on the work of Link and DeGroot (1987) and Williams *et al.* (1990).

Results and Discussion

Termites were usually present at the end of the bioassay period in containers with blocks of white cypress. Only the sapwood was attacked. For ten of the white cypress blocks, the mass loss exceeded one percent, but none lost more than five percent (mean estimated initial oven dry mass = 71.4 g, standard deviation = 7.2, number of blocks = 50). White cypress heartwood is known to be resistant to termite attack but the sapwood is susceptible (Australian Standard AS 1604-1980). However, we found that the sapwood of white cypress was less susceptible to termite attack than the sapwood of slash pine.

Mean mass loss data (averaged across trees) for each length of treated timber are shown in Figure 1. These data reflect primarily the effects of boron on wood consumption by *C. acinaciformis*. Actual borate retentions differed markedly from nominal borate retentions, especially at the higher concentrations. Termites were often absent at the end of the bioassay period from containers with blocks treated above 0.50 percent m/m BAE. The fitted regression lines for the mean, highest and lowest termite responses are also shown in Figure 1.

Statistical comparison between the untreated controls and the water (solvent) controls indicated no significant differences. Thus, the water (solvent) controls were used as standards because termite response to these lengths of timber was more homogeneous.

Results of the analysis of variance for the regression of the natural logarithm of the mass loss data for individual blocks are presented in Table 1. Most of the variation for the dependent variable could be explained by boron levels. Tree differences were also statistically significant ($p < 0.001$). Position differences were not significant. Boron levels and tree interactions were statistically significant ($p < 0.001$). Other interactions were not significant and were therefore included in the residual error.

Borate retentions corresponding to predicted mass loss values for *C. acinaciformis* attacking treated slash pine sapwood are shown in Table 2. The ranges in borate retentions, determined using the curves fitted to the data from the highest and lowest termite responses, are also presented. Borate retentions required for the various predicted mass loss values differ appreciably between trees. Since the mean mass loss for the controls was about 25 percent, the borate retentions corresponding to predicted mass loss values are probably underestimates. Longer exposure would have increased the mass loss for the controls and the blocks with low borate retentions, thereby changing the shape of the fitted model.

Lenz and Creffield (1993) offered test specimens together with a concentrated supply of susceptible timber below the soil surface to provide an attractive food source and an environment that is conducive to sustained foraging by termites. A field experiment incorporating test specimens and susceptible timber together in plastic containers has been established. Facility for longer exposure to the termites has been included in the design. Results will be reported in due course.

Acknowledgements

Mr A. Moffatt treated the timber and performed the chemical analyses. Messrs J. Kennedy and C. Fitzgerald assisted with field and laboratory work for the bioassays. Drs J.A.L. Watson and W.V. Brown identified the termites. Timber Research and Development Advisory Council of Queensland (TRADAC) provided financial support. All assistance is gratefully acknowledged.

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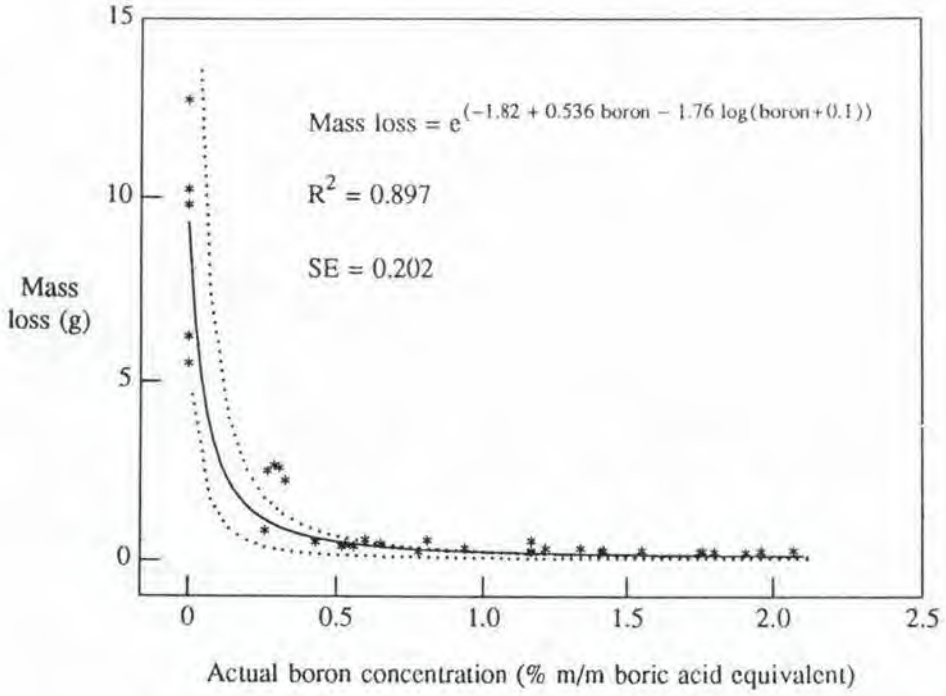

Figure 1. Dosage response curve for *C. acinaciformis* termites (in trees) to borate-treated *P. elliottii* (slash pine) sapwood. The solid line indicates the model fitted to the mean mass loss averaged across infested trees for each length of timber. The dotted lines indicate the models fitted to the highest and lowest termite responses.

Table 1. Analysis of variance for the regression of the natural logarithm of mass loss.

Source	Degrees of freedom	Mean squares	F-ratio
Boron	1	808.54	832.8 ***
Log(Boron+0.1)	1	189.17	190.8 ***
Tree	9	18.23	18.4 ***
Position	4	0.30	0.3 ns
Boron × Tree	9	4.95	5.0 ***
Log(Boron+0.1) × Tree	9	3.28	3.3 ***
Residual	316	0.99	
Total	349	4.44	

ns = not significant; *** = $P < 0.001$

Table 2. Borate retentions (% m/m boric acid equivalent) and predicted percent wood mass loss values for *Coptotermes acinaciformis* with treated *P. elliottii* (slash pine) sapwood blocks (Mean estimated initial oven dry mass = 43.6 g, Standard deviation = 5.3, Number of blocks = 350).

Percent mass loss	Mean	Range
1.0	0.58	0.21 - 0.63
2.5	0.26	0.10 - 0.34
5.0	0.14	0.04 - 0.20

ESTABLISHMENT AND PRELIMINARY (5 YR) RESULTS OF A MAJOR ABOVE-GROUND TIMBER DURABILITY TRIAL IN EASTERN AUSTRALIA

Myron Cause
Timber Research, DPI Forest Service
PO Box 631, Indooroopilly Qld 4068

ABSTRACT

Despite a widespread need for above-ground timber durability data in Australia, there has been little research work undertaken in this area. In 1987 the Queensland DPI Forest Service established a comprehensive trial testing 39 local and imported timber species. The importance of good replication was emphasised, and the trial involved the preparation of almost 6 200 painted and unpainted mortise and tenon 'L' shaped test pieces, and their exposure at eleven different sites in Queensland, New South Wales, Victoria, and the Australian Capital Territory.

This paper describes the nature of the trial, and presents preliminary results following five years of weather exposure. The trial is a unique and invaluable data source in Australia. The need is noted for further work to maximise the potential for relevance to building and timber engineering design. To achieve this, it is critical that continuous and guaranteed funding of the trial on a national industry basis be secured.

1. INTRODUCTION

Timber utilisation in Australia has always been disadvantaged by an absence of good research information on the performance of timber in above-ground, weather exposed situations. The durability of various species of timber against decay is economically important for builders, timber engineers, and owners – who pay for the completed product and expect a long service life. It is important to have accurate information on service life when selecting species to be used in external building applications such as windows, doors, cladding and similar applications. Additionally, timber engineering in Australia is developing to the stage where data is required for designers to calibrate prediction models for performance of weather exposed engineered timber structures such as bridges and large dimension external building applications.

Although Beesley *et al.* (1983) established a small CSIRO above-ground trial which is continuing today (Creffield *et al.* 1992) inherent design restrictions mean the data from that work may be of limited value in assessing variability of timber performance at a given site. Until now, timber durability classifications above-ground in Australia have basically been inferred from historical anecdotes, and from results of a single CSIRO in-ground trial which has now reached 25 years of service (Thornton *et al.* 1991). However, above-ground extrapolations were never the intention of that trial, and there are serious limitations in attempting to do this. The decay potential of timber in-ground (in the presence of termites) is quite different from the situation above-ground, where the suite of decay organisms and the hazard levels are demonstrably different.

The Queensland DPI Forest Service had long recognised the widespread need for above-ground timber durability data. In an ambitious move, a detailed workplan (Cause 1985) was prepared, and in 1987 Australia's first comprehensive above-ground durability trial testing a number of local and imported timber species was established. The importance of good replication of test pieces was

emphasised, and the trial involved the preparation of almost 6 200 painted and unpainted mortise and tenon 'L' shaped test pieces, and their exposure at eleven different sites in Queensland, New South Wales, Victoria, and the Australian Capital Territory.

The stated objectives of the trial were as follows:

(i) To determine the relative durability of a number (39) of timber species* at a main site in south-east Queensland;
(ii) To determine the relative durability of a set of 9 reference species at each of 11 sites in eastern Australia;
(iii) To determine the relative durability of painted and unpainted test species at each of 11 sites in eastern Australia;
(iv) To provide a measure of differences in decay hazard between 11 sites in eastern Australia;
(v) To provide data on the relationship between timber durability and climatic factors; and
(vi) To provide data to compare the results of this trial with those obtained from other above-ground and in-ground trials.

These objectives may obviously be supplemented by further outcomes *e.g.* the provision of timber engineering design data. In particular, the provision of adequate replication in this trial will allow future presentation of meaningful performance variability and lower percentiles of service life – information of great importance to design engineers.

2. MATERIALS AND METHOD

2.1 Test Sites

The study utilises eleven (11) exposure test sites (Figure 1) in eastern Australia. The sites have generally been chosen to represent a range of climatic environments. Seven (7) of the sites coincide with those used for concurrent CSIRO work (Beesley *et. al.* 1983), and this may be advantageous in interpreting the relationships between timber durabilities and climatic factors.

Site	Approx. Mean Precip. mm January	July
Beerburrum	106	59
Rockhampton	89	35
Hay Point	230	29
Townsville	117	18
Sth. Johnstone	417	104
Toowoomba	116	54
Dalby	98	41
Mt. Isa	60	1
Sydney	94	61
Canberra	53	64
Melbourne	50	47

Figure 1 — Above-ground durability trial exposure sites.

* actually 32 species in 39 configurations e.g. sapwood and heartwood

Main site: Beerburrum

The main site is located 50 km north of Brisbane at Beerburrum.

The main site tests nine (9) reference species and thirty (30) other species configurations.

Other sites: South Johnstone; Townsville; Hay Point; Rockhampton; Toowoomba; Dalby; Mt Isa; Sydney; Canberra; Melbourne.

These sites test the nine (9) reference species only, relating results in local climate conditions to those at the main site.

Site Attributes

Specific locations for the erection of test units at the 11 test sites was dependant on presence of certain attributes such as long term security and availability of relevant meteorological data. Minimum meteorological data required was daily maximum and minimum temperature (°C); and daily precipitation (mm). It was very desirable that these data be collected from the actual exposure test sites, or at least from close nearby.

2.2 Timber Species

(a) Reference species (at Main site and all other sites)

Nine (9) species were chosen as references to relate results between sites. The basis of selection was principally to provide an anticipated range of durabilities from low to very high, with additional consideration to their use as a standard or reference to other studies, and to their relative economic significance.

Reference Species	Codes
• radiata pine *Pinus radiata* (untreated sapwood)	radiata sap
• white cypress *Callitris glaucophylla* (untreated sapwood)	cypress sap
• Douglas fir *Pseudotsuga menziesii* (fast growth heartwood North America)	D.fir fast
• northern silky oak *Cardwellia sublimis*	NSO
• brush box *Lophostemon confertus* (outer heartwood)	BBX
• western red cedar *Thuja plicata* (slow growth heartwood North America)	WRC
• spotted gum *Eucalyptus maculata*	SPG
• grey ironbark *Eucalyptus drepanophylla*	GRI
• radiata pine *Pinus radiata* (CCA treated sapwood above-ground H3)	CCA rad

(b) Other Species (at Main site only)

Twenty-seven (27) species in thirty (30) configurations were chosen for additional relative durability analysis at the Main site. The basis of selection was perceived present and future market significance, but included some instances where long-standing utilisation questions may be answered. A few known high and low durability species were included to provide an additional source of relative durability information between all species being tested.

Main Site Species

Australian Softwoods:	Codes
• hoop pine *Araucaria cunninghamii* (heartwood plantation)	hoop P
• hoop pine *Araucaria cunninghamii* (heartwood native)	hoop N
• slash pine *Pinus elliottii* (heartwood plantation)	slash
• Caribbean pine *Pinus caribaea* (heartwood plantation)	Carib
• white cypress *Callitris glaucophylla* (heartwood – no sapwood present)	cypress H
• black cypress *Callitris endlicheri* (untreated sapwood)	blkcyp sap
Imported Softwoods:	
• radiata pine *Pinus radiata* (heartwood plantation)	radiata H
• Douglas fir *Pseudotsuga menziesii* (slow growth heartwood North America)	D.fir slow

Australian Hardwoods:	Codes
• spotted gum *Eucalyptus citriodora*	SPG c
• spotted gum *Eucalyptus henryi*	SPG h
• forest red gum *Eucalyptus tereticornis*	FRG
• blackbutt *Eucalyptus pilularis* (regrowth heartwood)	BBT r
• blackbutt *Eucalyptus pilularis* (mature inner heartwood)	BBT i
• blackbutt *Eucalyptus pilularis* (mature outer heartwood)	BBT o
• brush box *Lophostemon confertus* (inner heartwood)	BBX i
• red mahogany *Eucalyptus resinifera*	RMH
• rose gum *Eucalyptus grandis*	RSG
• Sydney blue gum *Eucalyptus saligna*	SBG
• mountain ash *Eucalyptus regnans*	Mtn ash
• alpine ash *Eucalyptus delegatensis*	Alp ash
• messmate *Eucalyptus obliqua*	messmate
• fishtail silky oak *Neorites kevediana*	FSO
• white Eungella satinash *Syzygium wesa*	WESA
• Queensland maple *Flindersia brayleyana*	Q maple
• Johnstone River hardwood *Backhousia bancroftii*	JRH
• rose alder *Caldcluvia paniculosa*	rose alder
Imported Hardwoods:	
• meranti, light red *Shorea* spp.	meranti
• kapur *Dryobalanops* spp.	kapur
• red balau *Shorea* spp.	red balau
• kamarere *Eucalyptus deglupta*	kamarere

2.3 Test Pieces and Units

L shaped test pieces with a machined mortise and tenon joint are used (Figure 2). The tenon member is the test piece that is subjected to periodic assessment, while the purpose of the mortise member is to complete the joint during outdoor exposure.

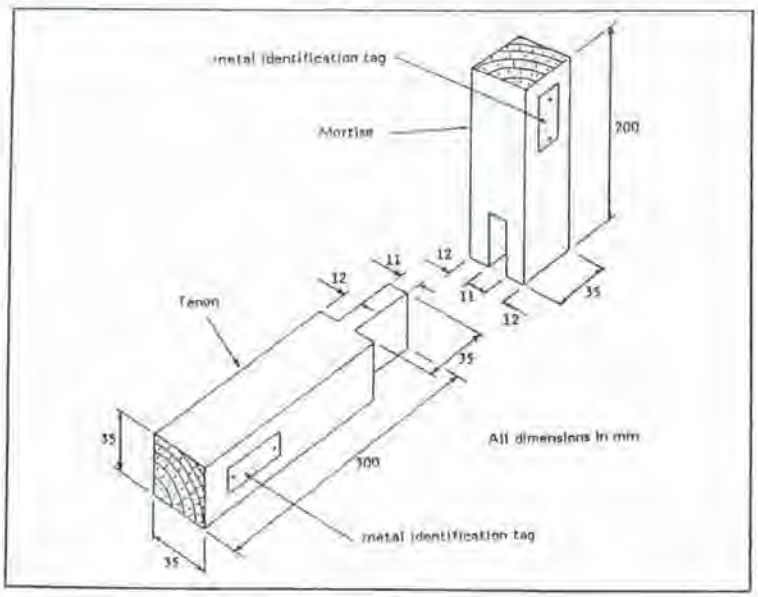

Figure 2 — The L-joint specification.

All timber was seasoned (10-15% moisture content) prior to preparation of the test pieces, and only clear grade material was used. For each test piece, the mortise and tenon were machined into either end of a single 640 mm long member, and this permitted a central section (with matching number to the L-joint) to be subsequently retained in the laboratory for all 6 200 L-joints in this trial. These sections are available for valuable material characterisation if required in interpretation of results *e.g.* wood density, sapwood/heartwood determinations, or other characteristics.

The L-joints are orientated 10° backwards from vertical in a plywood rack to form a **test unit** simulating a high decay hazard. The test units are based on the fundamentals of testing procedure adopted by the International Research Group on Wood Preservation (Carey *et al.* 1981), but with a slight modification in arrangement to provide limited air circulation around both the mortise and tenon members. The backward slope of the unit ensures liquid water is channelled into the joint, and provides a (drained) water trap at the junction of the plywood shelf and back. A plastic angle incorporating spacing blocks is attached to the back to separate the L-joints and maintain the mortise position during exposure. Two thin plastic strips support the tenon and keep it from contacting the plywood shelf.

The trial incorporates both unpainted test pieces and those finished with a conventional acrylic paint system. Painting involved an acrylic primer and two (white) acrylic top coats over the outside of each assembled test piece, leaving the internal joint as bare wood. The distal ends of all test pieces are sealed to prevent access of moisture and micro-organisms, but the test joint itself is not sealed. Upon exposure, the test joints were not glued or mechanically fastened together, and the tolerance of the joint was a firm to tight push fit. To ensure uniformity of hazard, the paint finish coating over the joint was broken by pulling the joint apart and reassembling prior to exposure of the test unit. The test unit (L-joint and exposure rack) thus closely simulates the more extreme actual ecological conditions confronting weather exposed timber *e.g.* the lower joint of an external window frame; window or door jambs scribed over sills; solid timber doors with panel or glass inserts; the junction of end stops with timber cladding; and various styles of engineered jointed structures.

The majority of material in the trial was collected from three different sources throughout each species geographic range. Computer generated schedules were used to randomly allocate L-joints to sites, ensuring that all three collection sources were evenly represented at each site. L-joints were fully randomised on exposure racks. Exposure racks were facing North at all test sites.

Every test piece (both painted and unpainted) was replicated 24 times at every site. Provision was made for random harvesting of L-joints for destructive moisture content and laboratory pathology examination after 1 and 3 years exposure, and currently 18 replicates remain of all test pieces at all sites.

2.4 Assessment Methodology

All L-joints were inspected visually on site at each assessment time by careful knife probing for decay. The area subject to assessment was the (unpainted) internal surfaces of the tenon member exposed when the L-joint was broken open (Figure 3).

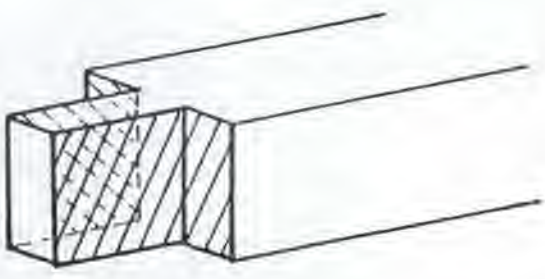

Figure 3 — Area of tenon joint surface (hatched) subjected to visual decay assessment.

An arbitrary rating system (modified from Carey *et. al.* 1981 to improve quantification and to provide a performance index) was employed as follows:

Decay Score	Condition of internal tenon joint surface
4	Sound
3	Signs of slight surface decay (incipient/fruit bodies present)
2	Small zones of obvious decay (<25% of surface area affected)
1	Extensive decay (>25% of surface area affected)
0	Failed (completely decayed through cross section of tenon joint). As a component in practice it would have to be replaced at this point.

The mean decay score for each species was divided by four and expressed as a percentage **performance rating**. The performance ratings will thus range from 100 percent (all sound) to 0 percent (all failed).

3. PRELIMINARY RESULTS AND DISCUSSION

3.1 General

Field assessments of all sites were undertaken in 1990 (3 years exposure) and in 1992 (5 years exposure). Because of differences in original setout times, the Melbourne, Canberra, and Sydney sites fall due for inspection in May/June, whereas the Queensland sites fall due in the period September-December.

Details of the 5 year results are presented in Section 3.2 (space limitations prevent the earlier 3 year figures being included in this paper). On the 5 year inspection, it was noticed that some of the white cypress L-joints had decay becoming established in the heartwood zone, when heartwood is present in these joints in addition to sapwood. To monitor this occurrence, both white and black cypress L-joints were given two decay scores, one for sapwood and one for heartwood. This effectively means there are now ten sets of reference data at each site.

3.2 Decay Scores (5 years exposure)

Tables 1-12 present 5 year results for all exposure sites in this trial. In fact there are 11 sites, but the twelfth table presents the additional non-reference species at the main site. For convenience in direct comparison, the main site reference species (Table 1) are included again in the Table 12 data.

Results are presented as mean decay scores, and relative performance ratings, and these are ranked in the tables from good to poor. Results are presented separately for painted and unpainted test pieces at each site. Also presented is the standard error for the mean decay scores, which provides a useful indication of the relative variability within species at each site.

It will be noted that the simple ranking of relative species performance as presented in Tables 1-12 varies with site as well as with finish coating, and this reflects changes in local decay hazards. While the percentage performance rating is a useful tool in comparing species within and between sites, it should be noted that the rating has not been calibrated to denote unserviceability in timber structures.

The results presented are tentative for the softwood species (excluding cypress and CCA radiata) until sapwood/heartwood determinations are undertaken to clarify the exact nature of some of this material.

It will be noted that the decay scores are usually worse for painted material than for equivalent unpainted material at the same site. As the painted joints were broken open prior to exposure to

ensure moisture is channeled directly into the joint, this situation means the paint film effectively traps moisture inside the joint to create a higher decay hazard for a longer time. This reduces the time to failure, and gives an alternative look at species ranking and performance under more extreme exposure conditions.

The codes used for species in Tables 1-12 are as listed in Section 2.2 above. Additional codes are for white and black cypress heartwood in the presence of sapwood, and these are Cypress h/s and blkcyp h/s respectively.

B'BURRUM UNPAINTED 18 reps					B'BURRUM PAINTED 18 reps				
Rank	Species	Mean Score	Std Error	Perform %	Rank	Species	Mean Score	Std Error	Perform %
1	CCA rad	4.00	0.00	100.0	1	CCA rad	4.00	0.00	100.0
1	GRI	4.00	0.00	100.0	2	GRI	3.83	0.12	95.8
2	SPG	3.94	0.06	98.5	3	SPG	3.61	0.17	90.3
3	WRC	3.83	0.17	95.8	4	WRC	3.56	0.22	89.0
4	BBX	3.78	0.22	94.5	5	BBX	3.33	0.20	83.3
5	Cypress h/s	3.39	0.26	84.8	6	Cypress h/s	2.67	0.28	66.8
6	NSO	2.56	0.28	64.0	7	NSO	1.12	0.30	28.0
7	D.fir fast	1.72	0.32	43.0	8	D.fir fast	0.61	0.26	15.3
8	radiata sap	0.50	0.20	12.5	9	radiata sap	0.11	0.08	2.8
9	cypress sap	0.33	0.11	8.3	9	cypress sap	0.11	0.08	2.8

Table 1 — Beerburrum (main site) reference species after 5 years exposure.

ROCKHAMPTON UNPAINTED 18 reps					ROCKHAMPTON PAINTED 18 reps				
Rank	Species	Mean Score	Std Error	Perform %	Rank	Species	Mean Score	Std Error	Perform %
1	CCA rad	4.00	0.00	100.0	1	CCA rad	4.00	0.00	100.0
1	GRI	4.00	0.00	100.0	1	WRC	4.00	0.00	100.0
1	SPG	4.00	0.00	100.0	2	GRI	3.89	0.11	97.2
1	WRC	4.00	0.00	100.0	3	BBX	3.83	0.12	95.8
1	BBX	4.00	0.00	100.0	4	SPG	3.61	0.17	90.3
2	NSO	3.94	0.06	98.6	5	Cypress h/s	3.33	0.24	83.3
3	Cypress h/s	3.78	0.13	94.5	6	NSO	2.50	0.39	62.5
4	radiata sap	1.94	0.41	48.5	7	D.fir fast	1.17	0.39	29.3
5	D.fir fast	1.78	0.30	44.5	7	cypress sap	1.17	0.41	29.3
6	cypress sap	0.39	0.23	9.7	8	radiata sap	0.39	0.17	9.7

Table 2 — Rockhampton reference species after 5 years exposure.

HAY POINT UNPAINTED 18 reps					HAY POINT PAINTED 18 reps				
Rank	Species	Mean Score	Std Error	Perform %	Rank	Species	Mean Score	Std Error	Perform %
1	CCA rad	4.00	0.00	100.0	1	CCA rad	4.00	0.00	100.0
1	GRI	4.00	0.00	100.0	2	WRC	3.89	0.11	97.3
1	SPG	4.00	0.00	100.0	3	BBX	3.78	0.13	94.5
2	WRC	3.94	0.06	98.5	4	Cypress h/s	3.56	0.22	89.0
2	BBX	3.94	0.06	98.5	5	GRI	3.50	0.15	87.5
3	Cypress h/s	3.61	0.27	90.3	6	SPG	3.22	0.21	80.5
4	NSO	3.28	0.30	82.0	7	NSO	2.33	0.29	58.3
5	D.fir fast	2.94	0.33	73.5	8	D.fir fast	1.67	0.35	41.8
6	radiata sap	2.72	0.34	68.0	9	cypress sap	1.11	0.34	27.8
7	cypress sap	1.56	0.35	39.0	10	radiata sap	0.78	0.21	19.5

Table 3 — Hay Point reference species after 5 years exposure.

TOWNSVILLE UNPAINTED 18 reps					TOWNSVILLE PAINTED 18 reps				
Rank	Species	Mean Score	Std Error	Perform %	Rank	Species	Mean Score	Std Error	Perform %
1	CCA rad	4.00	0.00	100.0	1	CCA rad	4.00	0.00	100.0
1	GRI	4.00	0.00	100.0	1	WRC	4.00	0.00	100.0
1	SPG	4.00	0.00	100.0	1	BBX	4.00	0.00	100.0
1	WRC	4.00	0.00	100.0	2	GRI	3.78	0.22	94.5
1	BBX	4.00	0.00	100.0	3	SPG	3.72	0.14	93.0
1	NSO	4.00	0.00	100.0	4	NSO	3.56	0.25	89.0
2	Cypress h/s	3.72	0.18	93.0	5	Cypress h/s	3.17	0.27	79.3
3	D.fir fast	3.28	0.30	82.0	6	D.fir fast	2.72	0.41	68.0
4	radiata sap	3.11	0.34	77.8	7	cypress sap	0.67	0.24	16.8
5	cypress sap	1.72	0.38	43.0	8	radiata sap	0.39	0.14	9.8

Table 4 — Townsville reference species after 5 years exposure.

STH. JOHNSTONE UNPAINTED 18 reps					STH. JOHNSTONE PAINTED 18 reps				
Rank	Species	Mean Score	Std Error	Perform %	Rank	Species	Mean Score	Std Error	Perform %
1	CCA rad	4.00	0.00	100.0	1	CCA rad	4.00	0.00	100.0
1	WRC	4.00	0.00	100.0	2	GRI	2.94	0.19	73.5
2	GRI	3.39	0.20	84.8	2	WRC	2.94	0.34	73.5
3	BBX	3.17	0.19	79.3	3	SPG	2.61	0.22	65.0
4	SPG	2.94	0.22	73.5	4	Cypress h/s	2.06	0.32	51.5
5	NSO	2.33	0.36	58.3	5	NSO	1.94	0.30	48.5
6	Cypress h/s	1.89	0.30	47.3	6	BBX	1.50	0.15	37.5
7	D.fir fast	1.10	0.33	26.5	7	D.fir fast	0.67	0.11	16.8
8	radiata sap	0.94	0.31	23.6	8	radiata sap	0.56	0.25	14.0
9	cypress sap	0.00	0.00	0.0	9	cypress sap	0.44	0.25	11.0

Table 5 — South Johnstone reference species after 5 years exposure.

TOOWOOMBA UNPAINTED 18 reps					TOOWOOMBA PAINTED 18 reps				
Rank	Species	Mean Score	Std Error	Perform %	Rank	Species	Mean Score	Std Error	Perform %
1	CCA rad	4.00	0.00	100.0	1	CCA rad	4.00	0.00	100.0
1	GRI	4.00	0.00	100.0	1	WRC	4.00	0.00	100.0
1	SPG	4.00	0.00	100.0	2	GRI	3.89	0.11	97.3
1	WRC	4.00	0.00	100.0	3	BBX	3.67	0.14	91.8
1	BBX	4.00	0.00	100.0	4	SPG	3.56	0.15	89.0
2	Cypress h/s	3.89	0.08	97.3	5	Cypress h/s	3.17	0.22	79.3
3	NSO	3.39	0.23	84.8	6	NSO	1.11	0.21	27.8
4	D.fir fast	1.72	0.30	43.0	7	D.fir fast	1.00	0.40	25.0
5	radiata sap	1.22	0.31	30.5	8	cypress sap	0.22	0.22	5.5
9	cypress sap	0.17	0.12	4.3	9	radiata sap	0.00	0.00	0.0

Table 6 — Toowoomba reference species after 5 years exposure.

DALBY UNPAINTED 18 reps					DALBY PAINTED 18 reps				
Rank	Species	Mean Score	Std Error	Perform %	Rank	Species	Mean Score	Std Error	Perform %
1	CCA rad	4.00	0.00	100.0	1	CCA rad	4.00	0.00	100.0
1	GRI	4.00	0.00	100.0	1	WRC	4.00	0.00	100.0
1	SPG	4.00	0.00	100.0	2	Cypress h/s	3.94	0.06	98.5
1	WRC	4.00	0.00	100.0	3	BBX	3.78	0.15	94.5
1	BBX	4.00	0.00	100.0	4	GRI	3.72	0.14	93.0
2	Cypress h/s	3.94	0.06	98.5	5	SPG	3.28	0.18	82.3
2	NSO	3.94	0.06	98.5	6	NSO	1.78	0.21	44.5
3	D.fir fast	2.50	0.34	62.5	7	D.fir fast	1.00	0.40	25.0
4	cypress sap	1.89	0.37	47.3	8	cypress sap	0.61	0.29	15.3
5	radiata sap	1.06	0.29	26.5	9	radiata sap	0.06	0.06	1.5

Table 7 — Dalby reference species after 5 years exposure.

MT. ISA UNPAINTED 18 reps					MT. ISA PAINTED 18 reps				
Rank	Species	Mean Score	Std Error	Perform %	Rank	Species	Mean Score	Std Error	Perform %
1	CCA rad	4.00	0.00	100.0	1	CCA rad	4.00	0.00	100.0
1	GRI	4.00	0.00	100.0	1	GRI	4.00	0.00	100.0
1	SPG	4.00	0.00	100.0	1	SPG	4.00	0.00	100.0
1	WRC	4.00	0.00	100.0	1	WRC	4.00	0.00	100.0
1	Cypress h/s	4.00	0.00	100.0	1	Cypress h/s	4.00	0.00	100.0
1	BBX	4.00	0.00	100.0	1	BBX	4.00	0.00	100.0
1	NSO	4.00	0.00	100.0	1	NSO	4.00	0.00	100.0
1	D.fir fast	4.00	0.00	100.0	1	D.fir fast	4.00	0.00	100.0
1	radiata sap	4.00	0.00	100.0	1	radiata sap	4.00	0.00	100.0
1	cypress sap	4.00	0.00	100.0	2	cypress sap	3.39	0.28	84.8

Table 8 — Mt Isa reference species after 5 years exposure.

SYDNEY UNPAINTED 18 reps					SYDNEY PAINTED 18 reps				
Rank	Species	Mean Score	Std Error	Perform %	Rank	Species	Mean Score	Std Error	Perform %
1	CCA rad	4.00	0.00	100.0	1	CCA rad	4.00	0.00	100.0
1	Cypress h/s	4.00	0.00	100.0	1	Cypress h/s	4.00	0.00	100.0
1	SPG	4.00	0.00	100.0	2	GRI	3.78	0.13	94.5
1	BBX	4.00	0.00	100.0	2	WRC	3.78	0.15	94.5
2	GRI	3.94	0.06	98.5	2	SPG	3.78	0.13	94.5
3	WRC	3.83	0.17	95.8	3	BBX	3.39	0.20	84.8
4	D.fir fast	3.44	0.23	86.0	4	D.fir fast	3.18	0.31	79.5
5	NSO	3.28	0.29	82.0	5	NSO	3.17	0.27	79.3
6	radiata sap	2.72	0.40	68.0	6	radiata sap	2.06	0.39	51.5
7	cypress sap	1.61	0.29	40.3	7	cypress sap	1.44	0.32	36.0

Table 9 — Sydney reference species after 5 years exposure.

CANBERRA UNPAINTED 18 reps					CANBERRA PAINTED 18 reps				
Rank	Species	Mean Score	Std Error	Perform %	Rank	Species	Mean Score	Std Error	Perform %
1	CCA rad	4.00	0.00	100.0	1	CCA rad	4.00	0.00	100.0
1	GRI	4.00	0.00	100.0	1	GRI	4.00	0.00	100.0
1	SPG	4.00	0.00	100.0	1	Cypress h/s	4.00	0.00	100.0
1	WRC	4.00	0.00	100.0	1	WRC	4.00	0.00	100.0
1	Cypress h/s	4.00	0.00	100.0	2	BBX	3.94	0.06	98.6
2	BBX	3.94	0.06	98.6	2	SPG	3.94	0.06	98.6
2	NSO	3.94	0.06	98.6	3	NSO	3.56	0.20	89.0
3	D.fir fast	3.47	0.29	86.8	4	D.fir fast	3.28	0.29	82.0
4	radiata sap	3.33	0.29	83.3	5	cypress sap	2.50	0.36	62.5
5	cypress sap	2.72	0.36	68.0	6	radiata sap	2.44	0.37	61.0

Table 10 — Canberra reference species after 5 years exposure.

MELBOURNE UNPAINTED 18 reps					MELBOURNE PAINTED 18 reps				
Rank	Species	Mean Score	Std Error	Perform %	Rank	Species	Mean Score	Std Error	Perform %
1	CCA rad	4.00	0.00	100.0	1	CCA rad	4.00	0.00	100.0
1	GRI	4.00	0.00	100.0	1	WRC	4.00	0.00	100.0
1	SPG	4.00	0.00	100.0	1	Cypress h/s	3.89	0.11	97.3
1	WRC	4.00	0.00	100.0	3	GRI	3.78	0.10	94.5
1	Cypress h/s	4.00	0.00	100.0	4	SPG	3.67	0.14	91.8
1	BBX	4.00	0.00	100.0	5	BBX	3.56	0.19	89.0
2	NSO	3.22	0.28	80.5	6	cypress sap	3.17	0.38	79.3
3	D.fir fast	2.61	0.35	65.3	6	D.fir fast	3.17	0.33	79.3
4	cypress sap	1.94	0.42	48.5	7	NSO	2.67	0.30	66.8
5	radiata sap	1.33	0.29	33.3	8	radiata sap	1.56	0.39	39.0

Table 11 — Melbourne reference species after 5 years exposure.

B'BURRUM UNPAINTED 18 reps					B'BURRUM PAINTED 18 reps				
Rank	Species	Mean Score	Std Error	Perform %	Rank	Species	Mean Score	Std Error	Perform %
1	CCA rad*	4.00	0.00	100.0	1	CCA rad*	4.00	0.00	100.0
1	GRI*	4.00	0.00	100.0	1	cypress H	4.00	0.00	100.0
1	cypress H	4.00	0.00	100.0	2	RMH	3.92	0.08	98.0
1	FRG	4.00	0.00	100.0	3	GRI*	3.83	0.12	95.8
1	BBT r	4.00	0.00	100.0	4	kapur	3.78	0.13	94.5
1	RMH	4.00	0.00	100.0	4	red balau	3.78	0.13	94.5
1	RSG	4.00	0.00	100.0	5	SPG c	3.72	0.14	93.0
1	FSO	4.00	0.00	100.0	5	BBT i	3.72	0.14	93.0
1	JRH	4.00	0.00	100.0	6	FRG	3.61	0.14	90.3
1	kapur	4.00	0.00	100.0	6	SPG*	3.61	0.17	90.3
1	red balau	4.00	0.00	100.0	6	BBT r	3.61	0.17	90.3
2	SPG*	3.94	0.06	98.5	7	WRC*	3.56	0.22	89.0
2	SBG	3.94	0.06	98.5	7	RSG	3.56	0.19	89.0
3	SPG c	3.89	0.11	97.3	7	SBG	3.56	0.19	89.0
3	BBT o	3.89	0.08	97.3	7	BBT o	3.56	0.19	89.0
3	WESA	3.89	0.08	97.3	8	FSO	3.33	0.20	87.5
4	WRC*	3.83	0.17	95.8	8	BBX*	3.33	0.20	83.3
4	SPG h	3.83	0.12	95.8	9	JRH	3.22	0.31	80.5
5	BBX*	3.78	0.22	94.5	10	kamarere	2.78	0.36	69.5
5	BBT i	3.78	0.13	94.5	11	SPG h	2.72	0.23	68.0
6	D.fir slow	3.50	0.25	87.5	12	Cypress h/s*	2.67	0.28	66.8
6	kamarere	3.50	0.28	87.5	13	WESA	2.61	0.23	65.3
7	Q. maple	3.44	0.23	86.0	13	D.fir slow	2.61	0.41	65.2
7	Alp ash	3.44	0.23	86.0	14	messmate	2.56	0.22	64.0
8	Cypress h/s*	3.39	0.26	84.8	15	blk cyp h/s	2.17	0.31	54.3
9	meranti	3.33	0.23	83.3	16	BBX i	2.08	0.29	52.0
10	rose alder	3.28	0.23	82.0	17	Alp ash	1.94	0.24	48.5
11	BBX i	3.25	0.35	81.3	18	Q. maple	1.50	0.15	37.5
12	blkcyp h/s	3.06	0.27	76.5	19	hoop N	1.33	0.46	33.2
13	messmate	2.94	0.34	73.5	20	rose alder	1.28	0.11	32.0
14	Mtn ash	2.78	0.35	69.5	21	NSO*	1.12	0.30	28.0
15	NSO*	2.56	0.28	64.0	22	radiata H	1.11	0.39	27.7
16	D.fir fast*	1.72	0.32	43.0	23	Carib	1.00	0.66	25.0
16	radiata H	1.72	0.41	43.0	24	slash	0.89	0.30	22.2
17	Carib	1.67	0.53	41.7	25	blkcyp sap	0.82	0.32	20.5
18	slash	1.44	0.33	36.0	26	meranti	0.73	0.18	18.3
19	hoop N	1.22	0.42	30.5	27	Mtn. ash	0.71	0.26	17.8
20	blkcyp sap	1.06	0.34	26.5	28	D.fir fast*	0.61	0.25	15.3
21	radiata sap*	0.50	0.20	12.5	29	radiata sap*	0.11	0.08	2.8
22	cypress sap*	0.33	0.11	8.3	29	cypress sap*	0.11	0.08	2.8
23	hoop P	0.00	0.00	0.0	30	hoop P	0.00	0.00	0.0

* = main site reference species (from Table 1) included again for convenience in comparison.

Table 12 — Beerburrum (main site) other species after 5 years exposure.

3.3 Discussion

This trial is intended to continue for 20-25 years. Results to date provide good information on the lower durability species, but are 'early days' for the more durable ones. There are numerous results of interest in the Tables with different species performing better or not as well as anticipated. Space restrictions in this paper limit specific comment to only a few results at the main site.

(a) Some hardwoods *e.g.* rose gum, red mahogany, performed above initial expectations.

(b) Cypress heartwood sawn free of sapwood was showing 100% performance (all joints sound) after 5 years, regardless of whether joints were unpainted or painted. However, heartwood in direct contact with sapwood had a performance rating of 85% (unpainted) and 67% (painted). This is presumably due to some localised increase in decay hazard where heartwood is directly contacting sapwood containing high moisture content and wood decay fungi levels.

(c) The Douglas fir slow growth material (close growth rings) performed substantially better than fast growth material (wide growth rings), regardless of whether unpainted or painted.

(d) The native hoop pine material was doing substantially better (around 32% performance) than plantation material (zero percent performance). Interpretation of these results should await laboratory determinations of sapwood/heartwood presence in all softwood L-joints.

4. CONCLUSION

This above ground timber durability trial is a unique and invaluable data source in Australia. Cause (1993) has identified further work that should be undertaken, including the following:

- Installation of a second set of reference and test pieces to capture an alternative climate period, and to calibrate new test material.
- Limited setout of alternative test pieces *e.g.* primed and/or bolted joints.
- Review of frequency of field inspections to undertake every two years for the life of the trial.
- Investigation of durability/climate relationships *e.g.* mapping of decay hazards.
- Use of results to calibrate engineering performance design models for weather exposed timber structures.

It is critical that the trial be consolidated now so that the maximum potential for relevance to building and timber engineering design is achieved. **An important factor in this will be securing continuous and guaranteed funding of the trial on a national industry basis.**

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PERFORMANCE OF TIMBER DECKING AT A BRISBANE SITE AFTER 5½ YEARS WEATHER EXPOSURE

Myron Cause
Timber Research, DPI Forest Service
PO Box 631, Indooroopilly Qld 4068

and

Geoff Stringer
Hyne and Son Pty Ltd
160 Kent Street, Maryborough Qld 4650

ABSTRACT

The relative serviceability of four timber decking species (white cypress, brush box, CCA treated slash pine, and CCA treated hoop pine) was assessed at a Brisbane site. A total of 96 decking panels were constructed with various parameters such as finish systems, board orientation, and sun exposure. Results are presented for decay performance following 5½ years of weather exposure.

Cypress decking coated with a water repellent preservative (WRP)followed by an oil-based stain finish gave superior decay resistance under all conditions, followed by the acrylic paint finish, and the nil finish control. Furthermore, trend analysis shows that the WRP/stain finished decks are virtually maintaining their good performance, while the painted and nil finished decking is deteriorating at an increasing rate. Board orientation of cypress with heartwood up (sapwood down) also consistently gave superior performance.

Brush box decking finished with acrylic paint exhibited a relatively high level of slight surface decay associated with moisture entry through board checks. Again the WRP/stain finish provided superior performance for brush box.

No decay was present in CCA-treated plantation slash pine or hoop pine decking.

1. INTRODUCTION

This paper reports results from a decay evaluation carried out in 1992 on a timber decking trial after 5½ years of weather exposure. The timber decking trial was established at the Queensland Department of Primary Industries Forest Service Brisbane test site in January 1987. The trial is a cooperative one developed by Timber Research of DPI FS and the Timber Research and Development Advisory Council (TRADAC).

The objectives of the trial were:

(i) To assess the relative serviceability of the following four species as weather exposed decking in a Brisbane environment –
white cypress
brush box
CCA treated slash pine
CCA treated hoop pine.

(ii) To provide information about the influence of various treatments on deck performance. These treatment factors are summarized in Table 1.

Treatment	Details	Species
gap width between boards	3 mm, 6 mm	all species
finish system	paint, WRP/stain, nil (control)	all species
sealing joist/board interface	preservative emulsion, board finish	all species
board orientation	sapwood up, heartwood up	cypress only
nail type	ring shank, plain shank	CCA-slash only
sun exposure	full sun, shade	cypress only

Table 1 — Summary of treatments.

The trial involves the weather exposure and monitoring of deck panels constructed from full size industry standard decking boards laid over joists at 450 mm centres. Figure 1 and Plate 1 illustrates the configuration of the test panels, which were constructed in sets of three to facilitate handling. A total of 96 panels (32 sets of three) were assembled. All species (72 panels) were installed in an open sunny location, while a further 24 panels of one species (white cypress) were installed at a nearby well-shaded location.

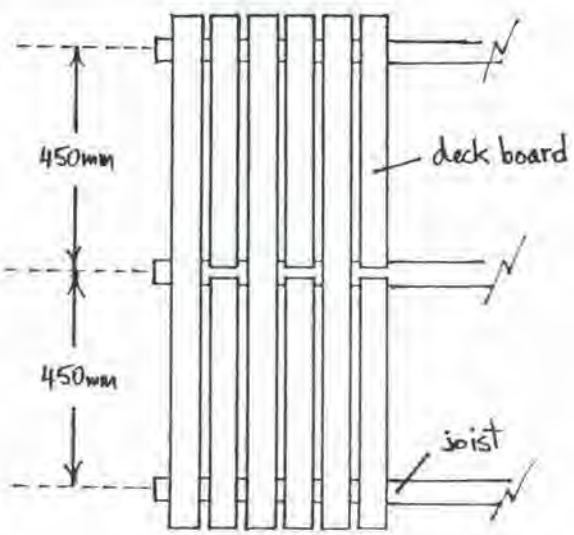

Figure 1 — Configuration of decking test panels.

Finish coatings were applied according to paint manufacturer recommendations. The stain finish system used was a first coat of Zinc Napthenate water repellent preservative (WRP), followed by two coats of an oil based stain. The paint finish system was a first coat of oil-based wood primer, followed by two coats of an acrylic decking paint.

Complete details of the design and establishment of the trial are available in other DPI FS reports (Cause 1986, 1987). Assessments have been made and reported at 12 months (Cause 1988), 24 months (Cause 1989), 36 months (Cause 1990), and 5½ years (Cause and Stringer 1992). The early assessments were based on comparative detailed measurements of checking, cupping, nail proudness and other features. The 5½ year assessment as reported here was limited to decay incidence only. Following the 36 month evaluation, decking maintenance was carried out by TRADAC at the sun site. This involved cleaning the painted and stained panels and refinishing the top surface only with another coat of paint or WRP/stain as appropriate.

2. METHOD

2.1 Field Measure Criteria

Each individual board was assessed for decay by careful probing with a knife at both topside and underside surfaces. Presence or absence of decay was recorded separately for sapwood and heartwood in three zones defined previously (Cause and Stringer 1992) as butt joins over joists, joist interfaces (no joins), and midspans of boards.

To provide a method of numerically quantifying deck performance, the severity of decay was recorded (for each of the three defined zones) on a scale of 1 to 5 as defined in Table 2. Additionally, the location of the decay in each zone was recorded as topside, underside, or both sides of the board.

Decay Score	Descriptive basis
5	nil decay
4	slight (incipient/fruit bodies present)
3	moderate (small zones of obvious decay <25% of defined surface area)
2	severe (obvious decay >25% of defined surface area)
1	destroyed (completely decayed through cross section in defined area)

Table 2 — Decay scores recorded.

After each board had been assessed, an effective 'performance score' was produced for each whole deck by summing the individual board scores. Table 3 illustrates an extract from a field data sheet to show how the maximum possible decay performance score of 240 is derived. Higher panel decay scores indicate better performance (less decay) than lower scores. Thus a deck with a panel score of 240 has no apparent decay at all, whereas (for example) a deck with a panel score of 215 would be exhibiting severe decay in many boards.

DECK BOARD NO.	DECAY						BOARD TOTALS
	BUTT JOINS		JOIST INTERFACE		MID SPANS		
	Sap	Heart	Sap	Heart	Sap	Heart	
1	—	—	5	5	5	5	20
2a	5	5	5	5	5	5	30
2b	5	5	5	5	5	5	30
3	—	—	5	5	5	5	20
4a	5	5	5	5	5	5	30
4b	5	5	5	5	5	5	30
5	—	—	5	5	5	5	20
6a	5	5	5	5	5	5	30
6b	5	5	5	5	5	5	30
Panel Totals	30	30	45	45	45	45	240

Table 3 — Derivation of Panel Decay Score (maximum 240).

2.2 Data Presentation

The results of the 5½ year assessment are presented for each species as follows:

(a) Changes in panel decay scores over time during the life of the trial; and

(b) Changes in percentage of decayed boards over time during the life of the trial.

The percentage of boards affected by decay has been arbitrarily reported at the following three levels.

(i) Percentage of boards with some level of decay (i.e. scores 4–1 as defined in Table 2).

(ii) Percentage of boards containing 'aesthetic' failure. For the purposes of this report, this appearance failure has been arbitrarily taken as those boards with scores 2 or 1 anywhere on the topside surface. **These 'aesthetic' failures are intended to represent boards that most consumers would find visually unacceptable in the deck.**

(iii) Percentage of boards containing 'structural' failure. For the purposes of this report, this failure has been arbitrarily taken as those boards with scores of 1 anywhere in the board, on either topside or underside surfaces. **These 'structural' failures are intended to represent boards that most consumers would seek to replace in the deck for both safety and appearance reasons.**

3. RESULTS

3.1 Cypress

3.1.1. Panel Decay Scores (changes over time)

Table 4 presents changes in mean panel decay scores over time for the three finish systems and two board orientations used in the cypress decking.

Species	Finish	Board orientations	Mean Panel Decay Scores		
			1 yr	3 yrs	5½ yrs
Cypress sun site	Paint	Sapwood up	240.0	234.5	229.3
	Paint	Heartwood up	240.0	237.0	231.0
	WRP/Stain	Sapwood up	240.0	239.5	238.0
	WRP/Stain	Heartwood up	240.0	239.5	239.5
	nil	Sapwood up	240.0	232.8	215.3
	nil	Heartwood up	240.0	237.0	230.3
Cypress shade site	Paint	Sapwood up	240.0	238.5	235.5
	Paint	Heartwood up	240.0	239.5	239.0
	WRP/Stain	Sapwood up	240.0	239.8	239.8
	WRP/Stain	Heartwood up	240.0	240.0	240.0
	nil	Sapwood up	240.0	239.0	235.5
	nil	Heartwood up	240.0	237.5	229.8

Table 4 — Tabulated changes over time in mean panel decay scores for cypress decking in Brisbane.

Figure 2 graphs the changes over time in mean panel decay scores (cypress sun site) for sapwood up board orientation and the three finish systems used. Heartwood up board orientation is not graphed separately, as the trends are the same, but with less marked differences between finishes. Figure 3 graphs the same details for the cypress shade site decking.

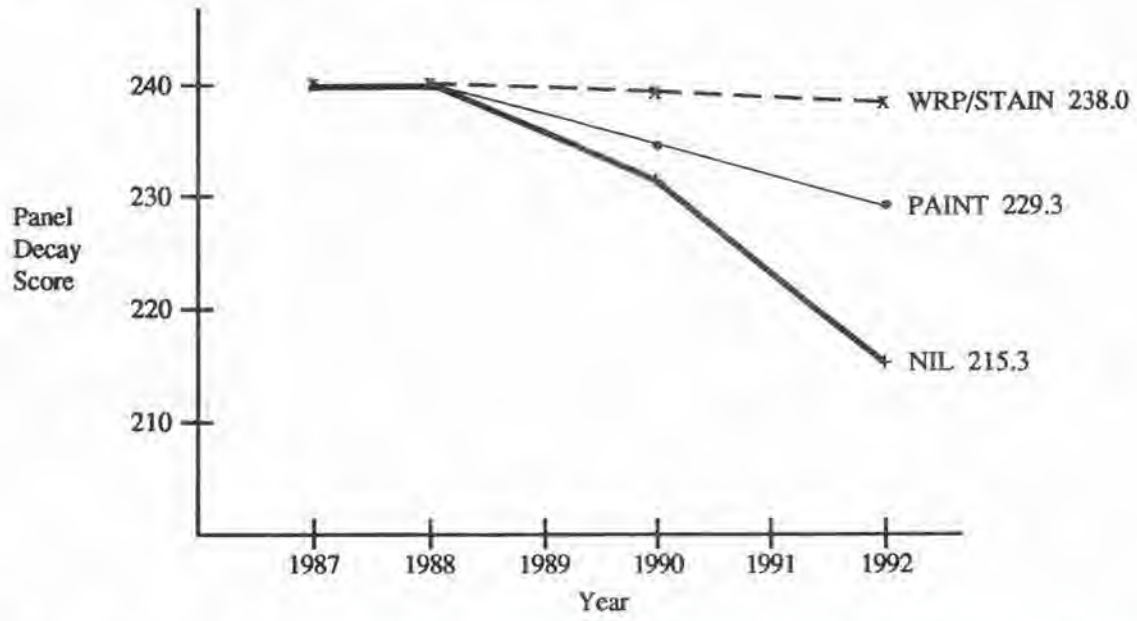

Figure 2 — Plotted changes over time in mean panel decay scores for cypress decking with sapwood up board orientation for the three finish regimes (sun site).

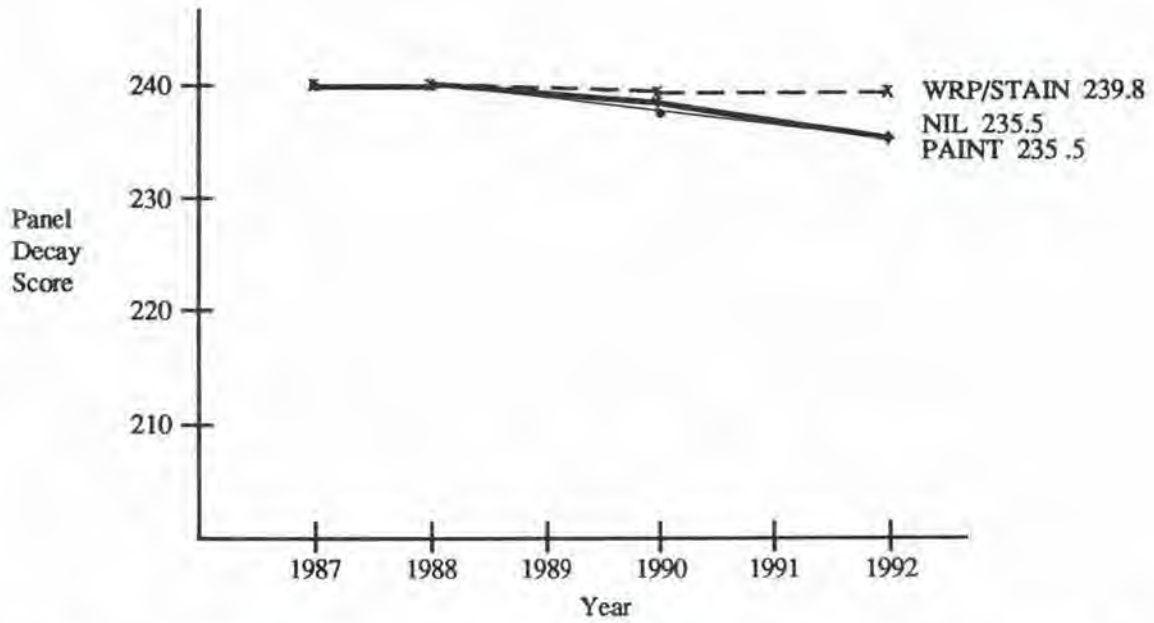

Figure 3 — Plotted changes over time in mean panel decay scores for cypress decking with sapwood up board orientation for the three finish regimes (shade site).

3.1.2 Percentage of decayed boards (changes over time)

Table 5 presents changes over time in percentage of decayed boards for the cypress decking. The three levels of decay ('some', 'aesthetic', 'structural') were defined for the purposes of this report in Section 2.2(b) above.

Species	Finish	Board Orientation	Percentage of Boards								
			Some Decay			'Aesthetic' failure			'Structural' failure		
			1 yr	3 yr	5½ yr	1 yr	3 yr	5½ yr	1 yr	3 yr	5½ yr
Cypress sun site	Paint	Sapwood up	nil	19.4	19.4	nil	8.3	19.4	nil	2.8	13.9
	Paint	Heartwood up	nil	13.9	16.7	nil	nil	2.8	nil	nil	11.1
	WRP/Stain	Sapwood up	nil	2.8	2.8	nil	nil	2.8	nil	nil	2.8
	WRP/Stain	Heartwood up	nil	2.8	2.8	nil	nil	nil	nil	nil	nil
	nil	Sapwood up	nil	30.6	50.0	nil	nil	33.3	nil	nil	27.8
	nil	Heartwood up	nil	8.3	19.4	nil	2.8	8.3	nil	nil	5.6
Cypress shade site	Paint	Sapwood up	nil	8.3	11.1	nil	nil	5.6	nil	nil	2.8
	Paint	Heartwood up	nil	2.8	5.6	nil	nil	2.8	nil	nil	nil
	WRP/Stain	Sapwood up	nil	2.8	2.8	nil	nil	nil	nil	nil	nil
	WRP/Stain	Heartwood up	nil	nil	nil	nil	nil	nil	nil	nil	nil
	nil	Sapwood up	nil	11.1	19.4	nil	nil	2.8	nil	nil	nil
		Heartwood up	nil	11.1	33.3	nil	nil	2.8	nil	nil	nil

Table 5 — Tabulated changes over time in percentage of decayed boards (3 levels of decay) for cypress decking in Brisbane.

Figure 4 graphs the changes over time in the percentage of decayed boards for cypress decking, sun site, nil finish and heartwood orientated upwards. This figure indicates the progressive nature of the three failure levels and the relative time lag between failure levels.

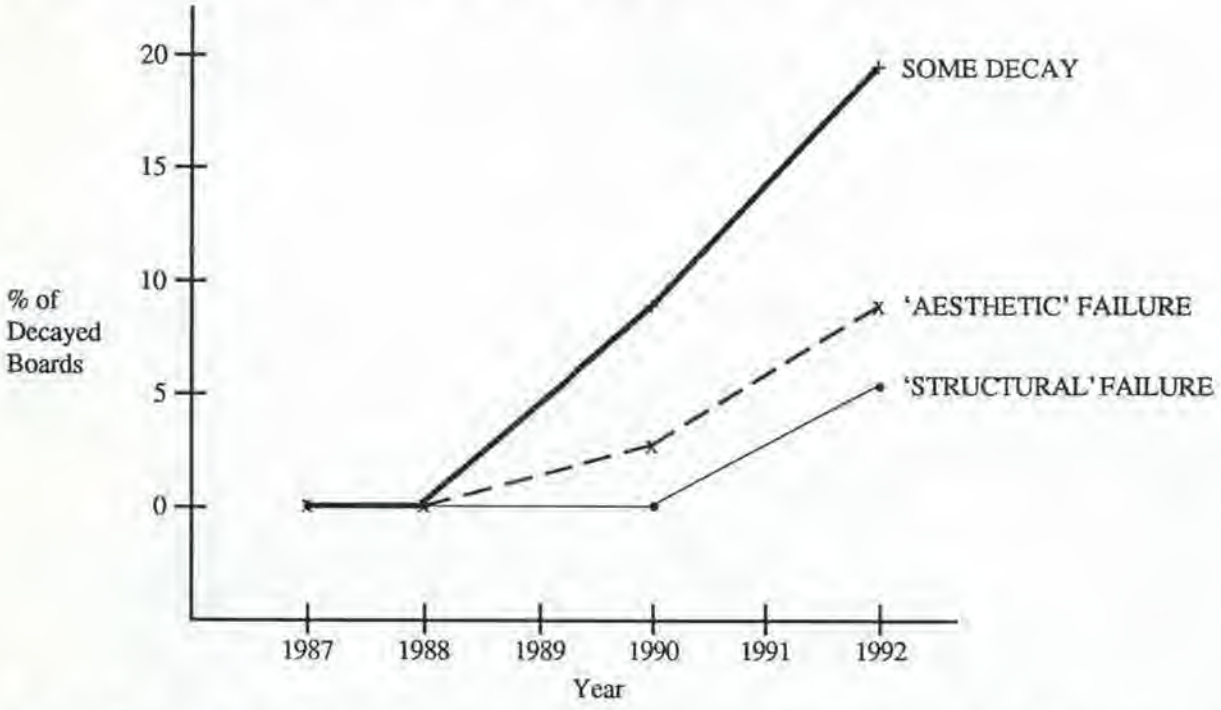

Figure 4 — Plotted changes over time in percentage of decayed boards for cypress decking, sun site, nil finish, heartwood up board orientation.

3.2 Brush Box

3.2.1 Panel decay scores (changes over time)

Table 6 presents changes in mean panel scores over time for the three finish systems used.

Finish	Mean Panel Decay Scores		
	1 yr	3 yrs	5½ yrs
Paint	240.0	235.5	236.0
WRP/Stain	240.0	240.0	240.0
nil	240.0	240.0	240.0

Table 6 – Tabulated changes over time in mean panel decay scores for brush box decking in Brisbane.

3.2.2 Percentage of decayed boards (changes over time)

Table 7 presents changes over time in the percentage of boards with some decay for the three finish systems used. This level of decay was defined in Section 2.2(b)(i) above.

Finish	Percentage boards with some decay		
	1 yr	3 yrs	5½ yrs
Paint	nil	19.4%	30.6%
WRP/Stain	nil	nil	nil
nil	nil	nil	nil

Table 7 – Tabulated changes over time in percentage of decayed boards (1 level of decay only) for brush box decking in Brisbane.

3.3 CCA Slash and CCA Hoop

No decay was observed in CCA treated slash pine or CCA treated hoop pine decking, although each species had a few boards containing small zones of untreatable heartwood. All these decks scored the maximum panel decay score of 240, and are not considered further in this report.

4. DISCUSSION

4.1 General

This discussion is limited to those species (white cypress and brush box) that had some level of decay present in the decking panels and concentrates on the overall trends in decay, and probable explanations for those trends.

4.2 White cypress

4.2.1 Finish type

After 5½ years exposure, the results showed that the water repellent preservative/stain finish gave markedly superior decay resistance under all conditions, followed by the paint finish, and then the nil finish control. Furthermore, the graph of changes over time in the more severe sun site (Figure 2) shows that the WRP/stain finished decks are virtually maintaining their good performance, while the painted and nil finished decks are deteriorating at an increasing rate.

An explanation for these results is as follows.

This trial has (previously) shown that the surface checks that develop in white cypress are maximised in nil-finished boards. It is likely that these checks allow free entry of moisture into the non-durable sapwood zone, with subsequent substantial occurrence of decay. In contrast, painted decking reduces the incidence of surface checking, and for this reason subsequent decay as a result of water entry into the non-durable sapwood zone is not as extensive as in the nil-

finished decking. In the case of the WRP/stain finished decking, the trial has previously shown that surface checking is less than nil finished decks, but more severe than in painted decks. Despite this level of surface checking, apparently the preservative benefit of the brush applied water repellent has been sufficient to provide substantial ongoing decay protection to the non-durable sapwood zone in these above-ground exposure conditions. Plate 1 clearly illustrates the superior decay performance of the WRP/stain finish after 5½ years exposure.

4.2.2. Board orientation

Prior to establishment of this trial, limited field investigations of white cypress decking by TRADAC had suggested that sapwood on the underside of boards in contact with the joist was the most adverse orientation for development of decay. However, after 5½ years exposure the results of this trial indicate that installation of boards with heartwood up (i.e. sapwood down) will consistently give superior performance.

The reason for heartwood up decking providing overall superior performance is again believed to be associated with surface checking in the boards. Surface checking is more extensive on the top surface than the bottom surface of boards. Where such checks occur they penetrate any finish system and provide a cavity where water is held. The heartwood of cypress has high natural durability, and surface checking into this material does not produce the decay hazard that results from similar checking into the non-durable sapwood zone when it is on the top surface.

4.2.3 Exposure conditions

When the shade site was initially included in the trial design, it was assumed that it would represent a more severe decay hazard than the sun site, because of increased vegetable litter on the deck and potentially reduced air circulation. However, the shade site used in the trial actually resulted in reduced decay incidence for all finish regimes compared to the sun site.

There are two aspects that contribute to an explanation for these results - temperature and rainfall intercept.

Temperature

This trial has previously shown that the milder temperatures and exposure of the shade site has resulted in markedly reduced surface checking. In the same way as discussed above for finish type and board orientation, reduced surface checking in the shade site panels can be expected to directly reduce the incidence of sapwood decay. Another possible temperature influence is that the consistently lower temperatures on the shade site decking may provide less optimum growth conditions for fungal activity, and thus contribute to a lower decay hazard there.

Rainfall intercept

It is likely that the partly overhanging trees at the shade site may intercept a considerable amount of rainfall and either redirect it along branches, or facilitate direct evaporation off the foliage. Consequently, the decay hazard may be lower at the shade site because the decking is not receiving the same direct rainfall as the sun site.

It is of interest to note that the shade site decking has a noticeable surface mould on the boards, and this is not present on any of the sun site decking. Presumably water that does get onto the shade site decking can maintain damp surface conditions for a longer period than at the sun site. Despite the conditions suiting this mould growth, they have evidently not created a high enough hazard to produce substantial sapwood decay at this site.

It is intended to install additional rain gauges at the shade site to accurately monitor what rainfall is reaching the decking, compared to the nearby sun site.

4.2.4 Summary

The most severe sapwood decay in white cypress occurred in the sun site panels with sapwood up board orientation. It is important that industry recommendations on use of cypress decking be targeted at practical solutions for this 'worst case' scenario. In particular, Plate 1 and the data on incidence of 'structural' failure provided in Table 5 clearly indicates the superior decay protection provided by the WRP/stain finish, and the heartwood up board orientation.

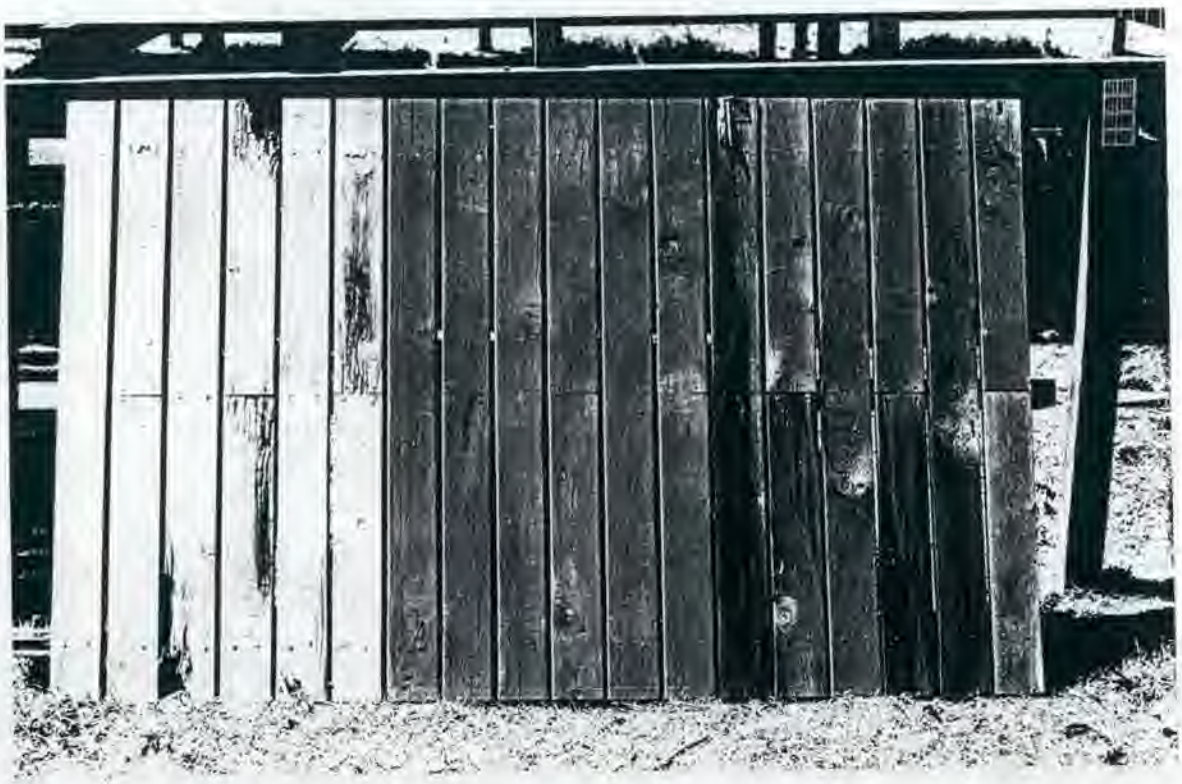

Plate 1 — White cypress decking panels after 5½ years exposure in Brisbane. The superior decay performance of the WRP/stain finished panel (centre) is clearly evident compared to the acrylic paint finished panel (left), and the nil finished panel (right). Decayed sapwood zones usually have associated dark mould growth on the surface.

4.3 Brush box

After 5½ years exposure, the results generally show that brush box decking is performing well, with no incidence of either 'aesthetic' or 'structural' decay failure. However, it should be noted that there was a relatively high level of slight surface decay associated with moisture entry through surface checks in the acrylic painted boards, and the extent of this surface decay has increased over time. Under the conditions of this trial, the WRP/stain finish also provides superior performance in brush box decking.

5. Conclusion

After 5½ years exposure to the weather, the results from this decking trial indicate that installation factors such as finish type and sapwood orientation can have a substantial influence on the durability performance of timber decking.

This trial has basically focussed on these installation factors, rather than the traditional aspects of natural durability and preservation retention. In the case of white cypress, this is an important approach, as the sapwood of this species cannot be CCA treated in the conventional sense.

This non-traditional focus has provided an important result for the two species that have exhibited some level of decay i.e. white cypress and brush box. For both these species, the trial has demonstrated that choice of finish is a very important influence on performance, with the water repellent preservative/stain finish providing vastly superior decay protection over the acrylic paint finish system. In the case of white cypress, the design of the trial also allowed other positive influences to be identified. In particular, both orientation of boards with heartwood up, and provision of shade over the decking has improved sapwood protection.

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TREATABILITY OF MESSMATE (Eucalyptus obliqua L'Herit) WITH TRIMETHYL BORATE

Francisco J. Romero
Peter Vinden
and
Peter Kho
The University of Melbourne
Faculty of Agriculture and Forestry
Forestry Section
Creswick, Victoria 3363

ABSTRACT

A novel method to treat the sapwood of messmate (Eucalyptus obliqua L'Herit) with trimethyl borate (TMB) has been investigated. The objective is to achieve treatment that complies to the specifications in hazard class, H1. The moisture content of wood at the time of treatment was found to have a significant effect on sapwood penetration. Penetration at 6 % moisture content (70 %) was higher than in blocks treated at 9 and 12 %. There was no difference in the boric acid equivalent of the samples at the 3 levels of moisture content studied (6, 9 and 12 %). Although the boric acid equivalent of 1.0 % wt/wt obtained at 6 % m.c. satisfies the specifications of hazard class H1 of the Australian Standards, the 70.0 % penetration does not. Further research is needed to overcome this problem.

INTRODUCTION

Trimethyl borate is an organometallic compound. The treatment of wood with trimethyl borate is based on hydrolysis. Its reaction with wood moisture is shown below :

$$\underset{\text{Trimethyl borate}}{B(OCH_3)_3} + 3\,H_2O \rightarrow H_3BO_3 + 3\,CH_3OH \quad (1)$$

Water — Boric acid — Methanol

This reaction is reversible. Depending on the relative concentrations of the chemicals, the reaction can generate either boric acid or trimethyl borate. Trimethyl borate has a low boiling point of 65°C and a low surface tension of 22.5 dynes/cm. The low boiling point is important for the vapour phase treatment. Other boric acid esters react similarly but their alcohol radicals have higher boiling points. This makes the vaporisation more difficult (Steinberg & Hunter, 1955). It is colourless and has a relatively low oral toxicity LD50 (CRC, 1976; Sax, 1979).

There are several methods of applying trimethyl borate to timber. These are summarised by Hislop (1955). Vapour phase application has been studied extensively. The Forest Research Institute of New Zealand has developed an integrated drying and treatment process using trimethyl borate in the vapour phase (Bergervoet *et al.*, 1992a). Trimethyl borate can also be applied to panel products in the vapour phase. Murphy and Turner (1989) and Bergervoet *et al.* (1992b) obtained very encouraging results for the treatment of different wood panel products.

Vinden *et al.* (1991) have identified five main factors which influence the depth of chemical penetration and treatment variability. These are wood substrate permeability, wood moisture content at the time of treatment, treatment vessel pressure, effectiveness of vapour generation and distribution, and the treatment temperature.

Vinden *et al.* (1985) concluded that temperature and moisture content were the two most important parameters affecting treatment with trimethyl borate. When heating radiata pine (Pinus radiata D. Don) to 70°C, they found that the retention (BAE % wt/wt) in the cross section and core to be 0.24 and 0.18 respectively. At 100°C, the cross section retention was 1.04 whereas the core retention was 0.58. When wood wool was used, they found that the amount of retention increased with the moisture content of sample. Wood at 12 % moisture content was found to be superficially penetrated, whereas, wood at 6 % moisture content had a more even penetration, with a core:cross section ratio of 0.7 for radiata pine. The data obtained by Vinden *et al.* (1985) showed a tendency for retention to increase with exposure time at temperatures over 70°C.

The penetration pathway of the vapour varies according to the type of wood, species or wood product. In the sapwood of radiata pine, the main penetration pathway is through the rays and the pits to the lumens of the tracheids. In hardwood the main flow path is through the relatively large vessels and from these vessels to the cell cavities. In panel products the gas penetrates through the matrix first rather than through the fibre and then diffuses into the cell wall. (Vinden *et al.*, 1991). They had concentrated primarily on the sapwood of radiata pine and panel products made from radiata pine. There is not much information available on the treatability of other species, including the eucalypts. Table 1 gives an indication of treatability of some species (Bergervoet *et al.*, 1992a).

The heartwood of messmate (Eucalypts obliqua L'Herit) is moderately durable - class H3 (seldom lasts more than 15 years and often considerably less) and the sapwood is susceptible to lyctid borer attack (Bootle, 1985). The objective of this trial is to study the treatability of heartwood and sapwood of messmate (Eucalyptus obliqua L'Herit) and determine if the treatment meet the requirements of the Australian Standards for hazard class H1.

TABLE 1: INDICATION OF THE TREATABILITY OF DIFFERENT SPECIES WITH TRIMETHYL BORATE

Species	Sapwood	Heartwood
Pinus sylvestris	√	√
Pinus ponderosa	√	√
Pseudotsuga menziesii	√	√
Chamaecyparis lawsoniana	√	?
Eucalyptus deglupta	√	?
Shorea sp.	√	?
Larix decidua	absent	?
Cupressus lusitanica	√	x
Eucalyptus fastigata	√	x
Eucalyptus regnans	√	x
Nothofagus menziensii	√	x
Eucalyptus delegatensis	absent	x
Swietenia sp.	absent	x

√ easy to treat x Not treatable ? Variable results

From Bergervoet *et al.* (1992a).

MATERIALS AND METHODS

The wood used in this study is messmate (Eucalyptus obliqua L'Herit) collected from Black Forest sawmill in Victoria. Twelve blocks of 20 mm x 70 mm x 150 mm were randomly obtained from boards and dried to three different moisture contents; 6, 9 and 12 %. The ends of these blocks were then sealed with an epoxy resin.

The blocks were treated by momentary immersion as described by Hislop (1955). After 7 days samples were cut from the centre of the blocks. These samples were analysed for boric acid equivalent in the cross section, core, heartwood and sapwood. Samples were analysed for boron using the azomethine-H method (John *et al.*, 1975) and the boric acid equivalent retentions (kg/m^3) calculated. Penetration was measured using the curcumin/salysilic acid spot test (AS 1604). The dimensions of the blocks were measured before and after the treatment to determine changes in dimension due to the treatment.

RESULTS AND DISCUSSION

Table 2 shows the values of boric acid equivalent (BAE % wt/wt) and retention (kg/m^3) for the cross section, core, sapwood and heartwood of messmate blocks treated with TMB at different moisture contents. Cross section samples from blocks at 6 % moisture content had 0.49 % wt/wt BAE and a retention of 3.17 kg/m^3. These values were higher than those for 9 and 12 % moisture content. However, there were no significant differences (0.05 level) in % wt/wt BAE and retention between cross section samples at different moisture content. Boric acid equivalent and retention values of cross section samples were higher than the values for the core samples. This was confirmed statistically at 0.05 level. The average level of boric acid in the core were found to be very low - 0.05 % wt/wt BAE.

Sapwood samples showed the highest uptake of all samples. Sapwood samples at 6 % moisture content had 1.0 % wt/wt BAE. Samples at 9 and 12 % moisture content achieved 0.65 and 0.68 % wt/wt BAE respectively. However, the difference in BAE % wt/wt between sapwood samples treated at 6 % moisture content and the higher moisture contents was not significantly different at the 0.05 level. Heartwood samples did not show the same levels of BAE % wt/wt values as the sapwood samples. Statistical differences between BAE % wt/wt of sapwood and heartwood were found at the 0.05 level.

TABLE 2: BORIC ACID EQUIVALENT (% wt/wt) AND RETENTION (kg/m³) OF TREATED MESSMATE (Eucalyptus obliqua L'Herit) WITH TMB AT 3 DIFFERENT MOISTURE CONTENT LEVELS

Sample	Wood moisture content %	Replicates	Boric Ac. Equivalent %			Retention kg/m³		
			Mean	S.D.	C.V., %	Mean	S.D.	C.V., %
Cross section	6±0.5	3	0.49	0.15	30.61	3.17	0.94	29.65
	9±0.5	3	0.27	0.17	62.96	1.75	0.10	57.14
	12±0.5	3	0.38	0.10	26.32	2.53	0.60	23.72
Core	6±0.5	3	0.06	0.05	83.30	0.37	0.33	89.19
	9±0.5	3	0.05	0.01	20.00	0.31	0.08	25.80
	12±0.5	3	0.04	0.15	37.50	0.46	0.72	47.82
Sapwood	6±0.5	3	1.01	0.28	27.72	6.56	1.85	28.20
	9±0.5	3	0.65	0.45	69.23	4.22	2.74	64.90
	12±0.5	3	0.68	0.06	8.82	4.44	0.35	7.88
Heartwood	6±0.5	3	0.16	0.80	50.00	1.04	0.51	49.04
	9±0.5	3	0.33	0.20	60.60	2.15	1.31	60.93
	12±0.5	3	0.31	0.13	41.94	1.98	0.84	42.42

TABLE 3: SAPWOOD AND HEARTWOOD PENETRATION IN MESSMATE (Eucalyptus obliqua L'Herit)

Sample	Wood moisture content %	Replicates	Penetration mm			Penetration %		
			Mean	S.D.	C.V., %	Mean	S.D.	C.V., %
Sapwood	6±0.5	3	5.39	1.26	23.37	70.00	17.11	24.42
	9±0.5	3	2.22	0.16	7.21	41.00	12.90	31.46
	12±0.5	3	1.93	0.65	27.68	22.30	0.64	2.87
Heartwood	6±0.5	3	1.09	0.49	23.37	N/A	N/A	N/A
	9±0.5	3	0.10	0.09	7.21	N/A	N/A	N/A
	12±0.5	3	0.55	0.09	33.68	N/A	N/A	N/A

Table 3 shows the depth of penetration in sapwood and heartwood of messmate samples treated with TMB at three different moisture content levels. Sapwood samples show deeper penetration at lower wood moisture contents. At 6 % moisture content boric acid was detected at 5 mm from the surface. At 9 and 12 % moisture content, the penetration was approximately 2 mm. There is a direct relationship between depth of penetration and moisture content. Differences in sapwood penetration in samples treated at 6 and 9 %, and between samples treated at 6 % and 12 % moisture content were significant at the 0.05 level. The depth of penetration in heartwood is less than that in sapwood . There is no significant difference between samples at different moisture contents at the 0.05 level. Preservative penetration in sapwood was approximately 70 % in blocks at 6 % moisture content. Penetration in blocks at 9 and 12 % moisture were 41 % and 22 % respectively. The results were significantly different at the 0.05 level. Although, there is a remarkable improvement in penetration at low levels of moisture content (6 %), the penetration of the sapwood is not total. AS 1604 specifies a requirement for total penetration of sapwood, and a preservative retention of 0.2 % wt/wt BAE.

The effect of treatment on the swelling of wood samples indicated virtually no change in dimension. The mean percentage swelling of wood samples was approximately 0.06 % for mean charge retentions of just under 1% wt/wt BAE. Preservative retention analysis agreed with calculated retentions based on weight increases and the losses of chemical incurred during the treatment process.

CONCLUSION

Preservative retention analysis demonstrated that the heartwood and core of messmate samples are not fully treated in this process. A higher retention is found in the sapwood of messmate with values ranging from 0.65 and 1.01 % wt/wt BAE. Penetration in sapwood improved with decreasing moisture content. Sapwood samples achieved approximately 5 mm penetration or 70 % of the sapwood cross-sectional area. Swelling after the treatment was not significant. Retention values for BAE % wt/wt comply with those specified by the Australian Standards (0.2 % wt/wt BAE). However, penetration was inadequate. Total penetration is required to protect sapwood against Lyctus sp. in hazard class H1. Further refinement of the process is necessary to meet treatment specifications.

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DIMENSIONAL STABILITY OF PARTICLE BOARD AND RADIATA PINE WOOD (*Pinus radiata* D. Don) TREATED WITH DIFFERENT RESINS

Nellie Ndegwa
Peter Vinden
and
Peter Kho
The University of Melbourne
Faculty of Agriculture and Forestry
Forestry Section
Creswick, Victoria 3363

ABSTRACT

Particleboard and solid wood stakes were treated with either an isocyanate or phenol formaldehyde resin and exposed in soil beds comprising three different soil types and two moisture contents. The treatments resulted in a marked improvement in the dimensional stability of particleboard but had no effect on solid wood. Higher moisture uptakes in stakes exposed in sandy soils indicated that the technique used for measuring soil water holding capacity needs to be reviewed.

INTRODUCTION

Wood is a very hygroscopic material and swells to a great extent when placed in contact with water. It is also an extremely anisotropic material. Internal stresses build up following moisture pick-up, causing dimensional changes. This property or attribute of wood compromises it's performance in humid enviroments.

A number of chemical compounds have been investigated for dimensional stabilization of wood. The most studied treatments for wood have been acetylation (Clermont and Bender, 1957; Risi and Arseneau, 1957a; Rowell, 1975; 1982;1985). Other chemicals include alkyl chlorides (Risi and Arseneau, 1957b), lactones (Goldstein *et al.*, 1959), aldehydes (Tarkow and Stamm, 1953), nitriles (Baechler, 1959; Goldstein *et al.*, 1959), epoxides (McMillin, 1963); Ellis and Rowell, 1984; Rowell and Ellis, 1984a;1984b) and phenolic resins (Goldstein *et al.*, 1959).

Chemical modification is defined as "a chemical reaction between some reactive part of a wood cell wall component and a single chemical reagent, with or without a catalyst, to form a covalent bond between the two" (Rowell, 1982).

Examples of covalent bonds are esterification, etherification, acetal formation, crosslinking and bulking (Stevens *et al.*, 1979). This excludes all impregnation treatments which do not form covalent bonds, polymer inclusions, coatings, and heat treatments (Rowell, 1975).

Dimensional instability is greater in reconstituted wood products, such as waferboard, flakeboard, and particleboard, than in solid wood products. There is need to conduct extensive research into applying the principals of chemical modification to these products. In theory, the chemical modification of panel products can be carried out at three stages during the manufacturing process:

- Chemical treatment of the wood particles or fibres prior to manufacture. This can be carried out either before or after drying of the furnish; e.g. acetylation of particles.
- During board manufacture.
- Post board manufacturing- for instance when all trimming and sanding has been completed.

The advantages of post manufacture treatment include:

- Treatment is on final product (independent of the manufacturing stage), thus eliminating problems associated with disposal of contaminated residues.
- Treatment levels can easily be adjusted to allow market requirements to be met on demand.
- The use of more toxic chemicals can be facilitated because of the containment possible in a pressure treatment vessel.

The research outlined in this paper investigates post board manufacture, dimensional stabilisation using isocyanate and phenol formaldehyde resins. The objectives were:

(i) To determine both the dimensional stability and decay resistance of boards treated with these resins

(ii)To evaluate soil-bed techniques as a method for evaluating dimensional stability and decay resistance.

This paper summarises the results for dimensional stability.

EXPERIMENTAL PROCEDURE

Preparation of the soil beds

Three different types of agricultural soil were selected from the Creswick region in Victoria. These included a sandy loam, a red clay-loam and black clay soil. The soils were air dried and then sieved through a two-millimeter mesh. Previous studies - for example, Vinden *et al.* (1982) have shown that drying the soil increases the virility of the soil and aids the process of sieving.

Nine plastic containers each measuring 45 cms x 28 cms x 20 cms deep were filled with each soil type to within 4 cms of the top of the container. Distilled water was then added to achieve the required water holding capacities of 98% and 102% using the proceedure outlined in BS 1982: Part 2 (1990). The soil beds were then thoroughly mixed to ensure uniform moisture distribution. Water holding capacity (WHC) (the water availability of the soil.) was measured using the technique described by Savory (1971). He defines WHC as "the moisture content of saturated soil after exposure to the suction exerted by a vacuum pump for ten minutes".

Preparation of the test specimens

Two types of stake were used in the experiment. Timber stakes measuring 5 mm x 10 mm x 150 mm were cut from clear Radiata pine sapwood. Particleboard stakes had dimensions of 10 mm x 20 mm x 150 mm. The stakes were sanded, the width, thickness and length measured and their weights recorded. The moisture content of these stakes were calculated from representative samples using the oven-drying method. The stakes were then vacuum impregnated with isocyanate and phenol formaldehyde resins. The viscocity of each resin was modified by adding a low boiling point solvent to each of the resins.

Treatment schedules involved using a pressure of -0.70 kPa (guage) for 30 seconds for particleboard stakes and a 2-minutes soak for the timber samples. Loadings of 21% were achieved. These stakes were then cured at 50°C for 24 hours to prevent resin bleed. The dimensions and weights of the stakes were then recorded.

The samples were leached according to the procedure described in BS 5761 : Part 2. and then dried in an oven at 60°C to constant weight. The weight, dimensions, deflection values and intial moisture contents of the control stakes were determined prior to the exposure trials.

Planting the test specimens

Both the treated and the control stakes were planted in rows, leaving approximately 20 mm of the length of the stake protruding above the surface of the substrate. Stakes were placed 20 mm apart and 20 mm from the sides of the containers. They were assigned positions in the containers according to a randomized block experimental design. These containers were then sealed tightly using ducting tape to prevent moisture loss. Prior to putting them into a fungal cellar, the weights of these containers were recorded.

Incubation

The tightly-sealed containers were then placed in an incubator maintained at 28°C. The weights, dimensions and deflections of the stakes were noted after 3, 6, 9, 16, 45 and 72 days exposure.

RESULTS AND DISCUSSION

Figure 1 shows the percentage swelling against exposure time in days for untreated and treated particle board and timber samples in the three different soil beds. There is a significant difference in swelling between the untreated and treated particleboard samples at the 0.05 level. However, in the first six days there was no significant difference between the treatments (0.05 level). Resin treatments reduced swelling in samples, improving their dimensional stability. The rates of swelling illustrate a large increase in the first days of exposure. This is followed by a slower rate of swelling between the 6^{th} and 16^{th} day. After this period an increase in the rate of swelling of particleboards was observed. This could be due to moisture penetrating to the centre of the board through pathways created by the release of residual compressive stresses imparted to the particle board during the pressing process. Phenol formaldehyde treatments provided greater dimensional stability than samples treated with isocyanate resin.

Swelling values for all solid wood treated samples were not significantly different from the controls (0.05 level). However isocyanate wood samples placed in red soil were significantly different (0.05 level) after 3 and 16 days exposure. Likewise the phenol formaldehyde treated samples were different (0.05 level) in sandy soils after 9 days exposure. There were no significant differences in swelling between isocyanate and phenol formaldehyde resins.

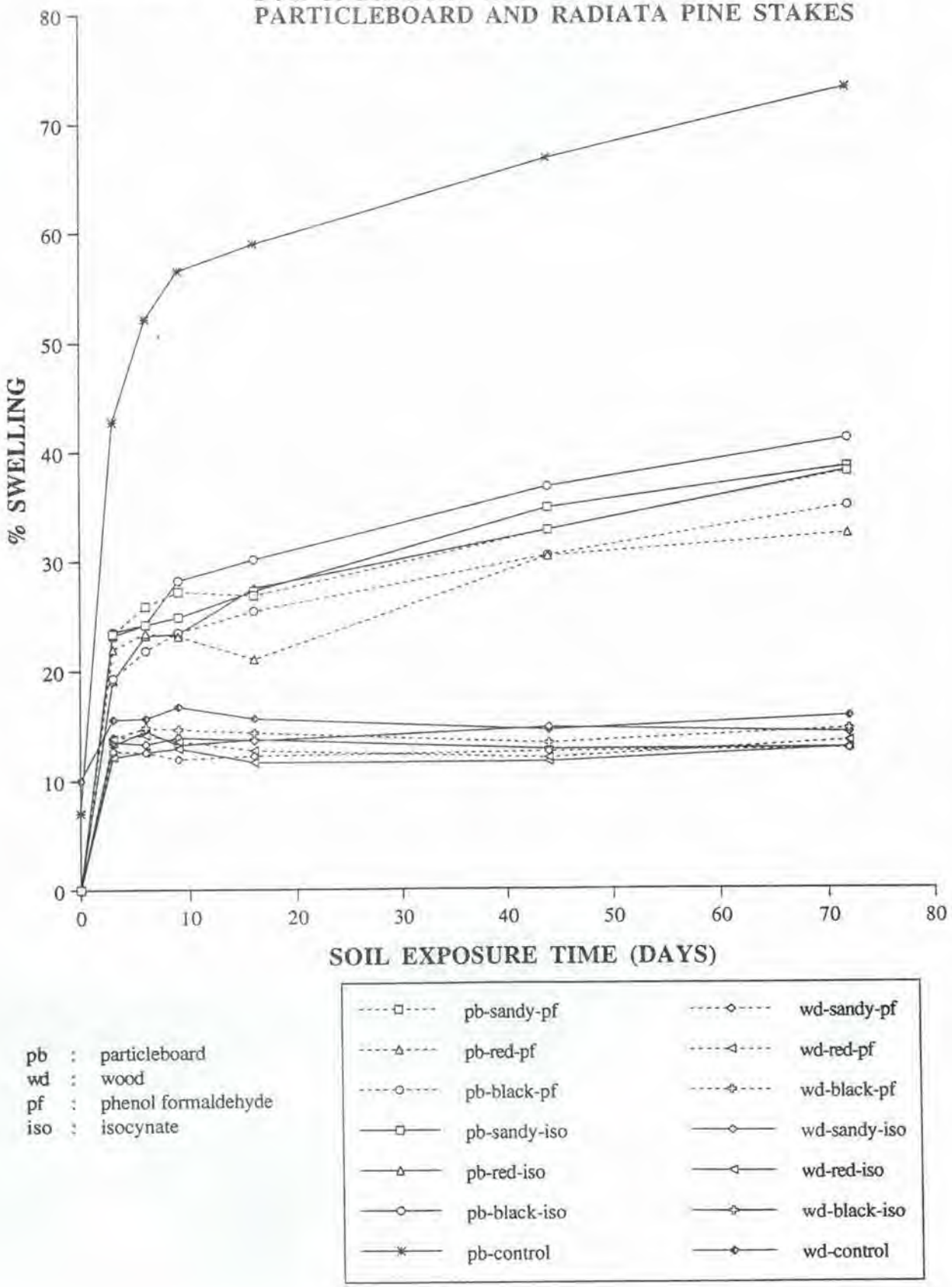
Figures 2 shows the percentage weight gain against exposure time for untreated and treated particleboard in diferent soil beds. Samples in the sandy soils had significantly higher weight gains than those in red and black soils. The weights of these samples increased rapidly after two weeks.

Figure 3 shows the percentage weight gain against exposure time for untreated and treated wood samples in different soils. There were significant differences (0.05 level) between the controls and treated samples. Samples placed in sandy soils exhibited higher weight gains than samples placed in other soil beds. This tendency is similar to the one shown in figure 2 for particleboard samples.

CONCLUSION

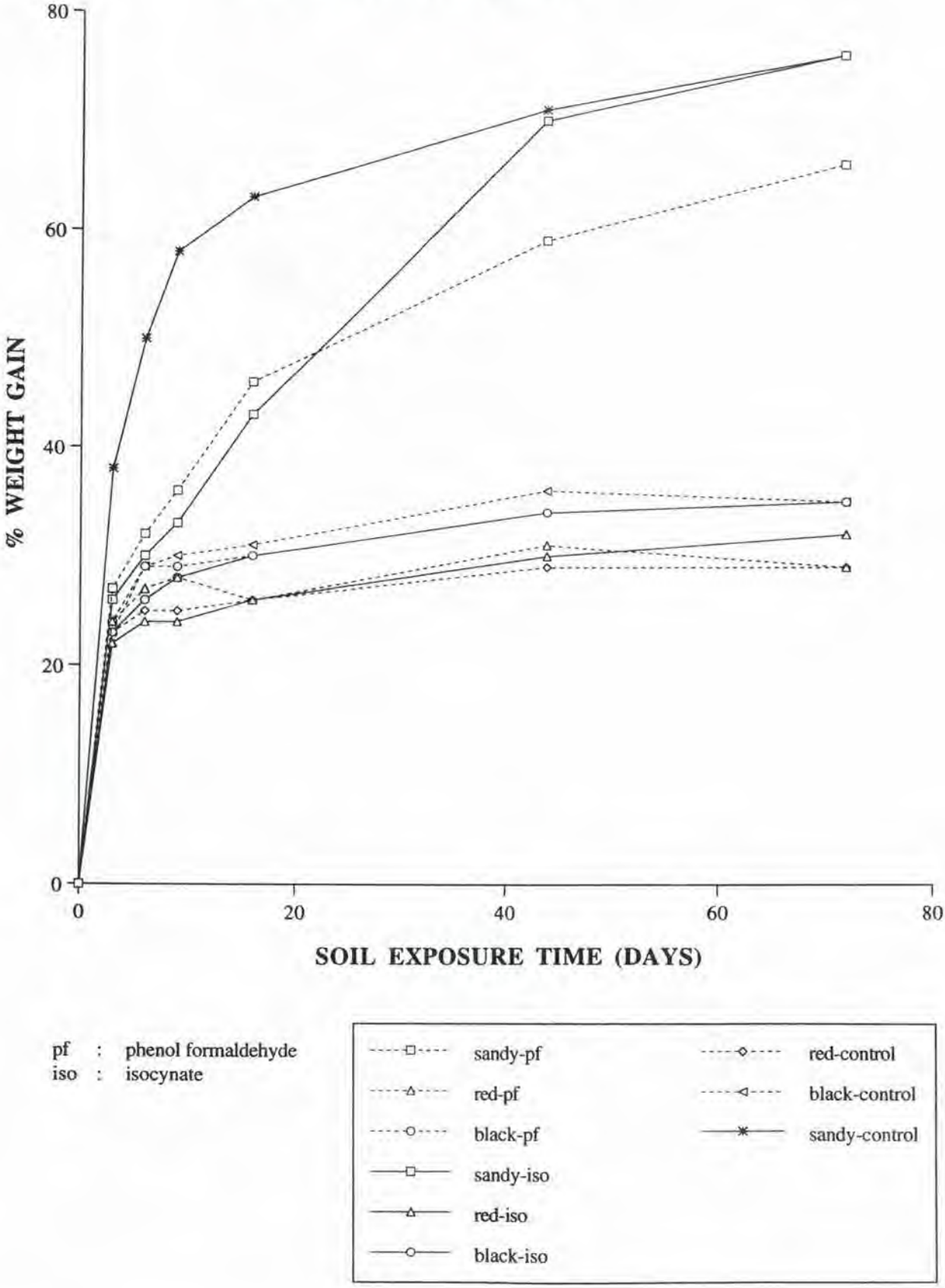
Particleboard samples treated with isocyanate and phenol formaldehyde resins had lower volumetric swelling and weight gains than untreated controls.

FIGURE 1 : % SWELLING vs TIME OF EXPOSURE (DAYS) FOR UNTREATED AND TREATED PARTICLEBOARD AND RADIATA PINE STAKES



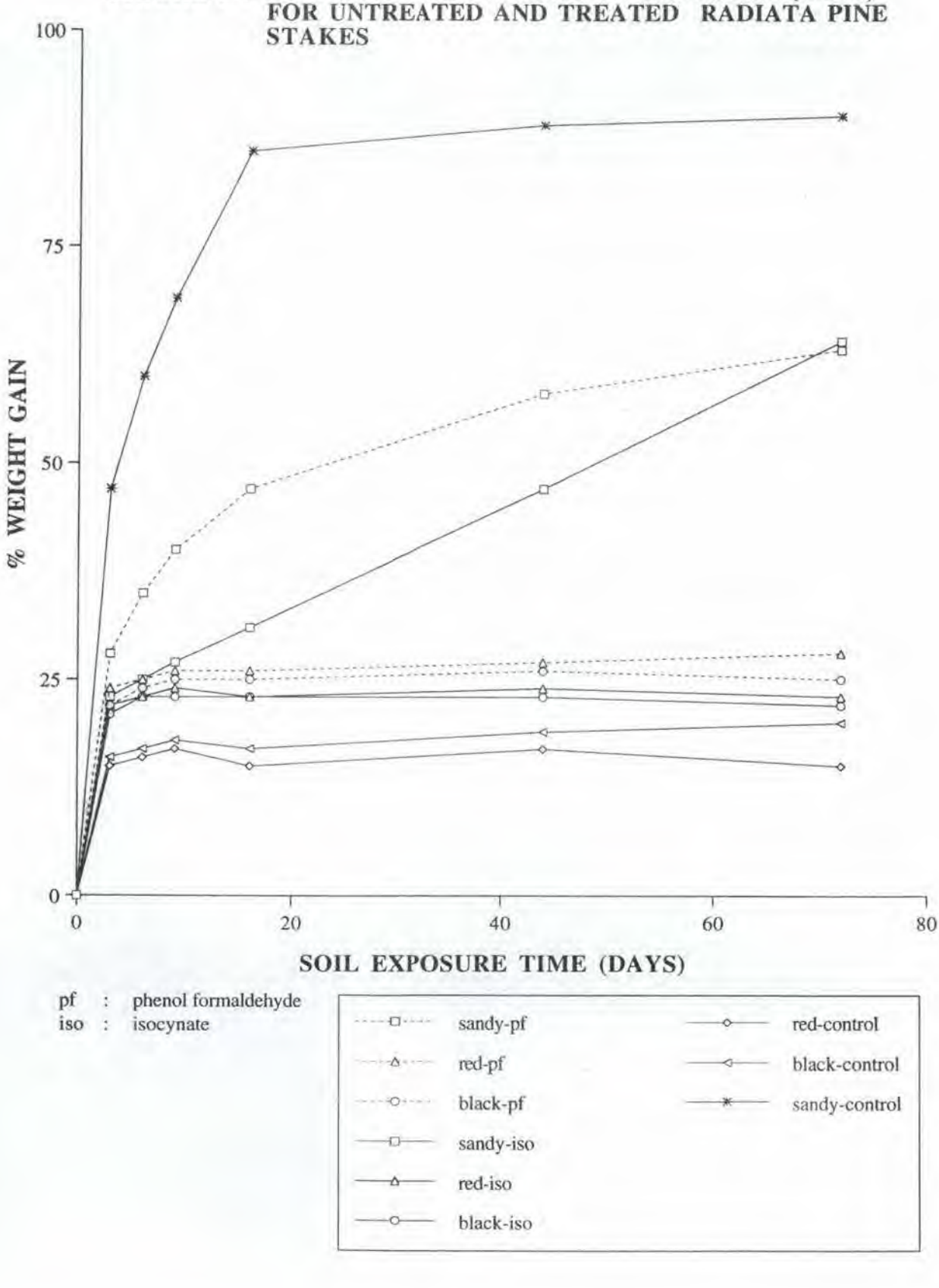
pb : particleboard
wd : wood
pf : phenol formaldehyde
iso : isocynate

FIGURE 2 : %WEIGHT GAIN vs TIME OF EXPOSURE (DAYS) FOR UNTREATED AND TREATED PARTICLEBOARD STAKES



pf : phenol formaldehyde
iso : isocynate

FIGURE 3 : %WEIGHT GAIN vs TIME OF EXPOSURE (DAYS) FOR UNTREATED AND TREATED RADIATA PINE STAKES



pf : phenol formaldehyde
iso : isocynate

Thus the treatments improved the dimensional stability of particleboard samples. There was also a significant difference in swelling between samples treated with isocyanate and phenol frormaldehyde. There were no significantly different weight gains between treated samples and controls.

Wood samples showed different swelling trends to particleboard samples. There were no significant difference in swelling between treated samples and controls. Thus, treatments with isocyanate and phenol formaldehyde did not improve the dimensional stability of solid wood samples. However, there were significant differences in weight gain between treated samples and controls.

Despite the different soil types being conditioned to the same water holding capacity, the stakes exposed in sandy soils tended to take up more moisture than the other soils. This indicates greater availability of free moisture in sandy soils and raises questions regarding the validity of the method for measuring water holding capacity.

Other techniques are being investigated for measuring water holding capacity. The rates of decay of stakes exposed in the soil-bed will also be reported in later publications.

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DIFFUSION AND TOXICITY EVALUATION OF A SOLID REMEDIAL PRESERVATIVE CONTAINING BORON AND FLUORINE

Kevin McCarthy
CSIRO Division of Forest Products
Private Bag 10, Rosebank MDC Clayton, Victoria, 3169

ABSTRACT

The diffusibility and toxicity of a new rod form of diffusible remedial wood preservative, containing disodium octaborate tetrahydrate/sodium fluoride and marketed as Polesaver Rods, and Rail Rods was evaluated in laboratory and field tests. Laboratory slab diffusion tests on several species of eucalypt hardwoods have confirmed the capability of the preservatives active ingredients to diffuse through both heartwood and sapwood in concentrations toxic enough to inhibit fungal growth. In addition, field testing has shown that significant radial and longitudinal diffusion of boron and fluorine was achieved from rods introduced into *Eucalyptus obliqua* pole stubs and *Eucalyptus maculata* and *Eucalyptus teriticornis* sleepers. Samples taken with the diffusion zone of the pole stubs indicated loadings of up to 4.1 kg/m^3 of boron and 5.2 kg/m^3 of fluoride.

INTRODUCTION

In Australia there is a wide variety of remedial treatments aimed at protecting the critical zone of structural timbers such as poles from biodeterioration. These treatments have been reviewed by McCarthy and Greaves (1990) where it is suggested that the majority of current practices leave much to be desired in their ability to control biodeterioration.

Traditionally, remedial formulations are introduced as flowable preparations, however inappropriate viscosity characteristics can lead to loss of preservative through checks and splits, predominantly in Australian eucalypts.

More recently, solid diffusion preservatives have been used. These were first assessed in Australia in the early 1980s (Greaves *et al.* 1982). Impel preservative rods, with boron as the sole active ingredient became available in Australia soon after and were targeted at the pole and heavy engineering timber markets.

Further development solid preservative principal has continued. One company has introduced Polesaver Rods and Rail Rods, which contain boron (124 g/kg) and fluorine (110 g/kg) as their active ingredients. Past experiences with boron and fluorine has documented their ability as proven wood preservatives (Gay *et al.* 195888, Becker 1973, Cockcroft and Levy 1973) and exhibiting good diffusion characteristics within the wood (McEvoy *et al.* 1985).

In this paper results of diffusion and toxicity trials of Polesaver Rods and Rail Rods are described.

MATERIALS AND METHODS

I. Slab Diffusion Bioassay

A novel method of testing both the toxicity and diffusibility of a formulation was developed by Da Costa of CSIRO and modified and reported by Da Costa and Greaves (1975).

A water-saturated slab measuring 50 x 50 x 6 mm with the edges sealed by dipping in Vaseline and paraffin wax is placed on top of the candidate chemical in a Petri dish. Diffusion of toxicant through the slab is assessed by placing a strip of inoculated agar on top of the slab at right angles to the grain direction of the slab. Inhibition of fungal growth on the strip of inoculated medium will occur if the toxicant diffuses through the slab and attains a sufficiently high concentration.

Slabs of heartwood and sapwood, 50 x 50 x 6 mm were cut from three different pole timbers: *Eucalyptus drepanophylla* F. Muell, ex Benth. (grey ironbark); *Eucalyptus marginata* Donn. ex Sm. (jarrah); and *Eucalyptus obliqua* L'Herit. (messmate). The timbers were representative of durability classes 1, 2 and 3 with basic densities of 1105 kg/m^3, 835 kg/m^3 and 770 kg/m^3, respectively.

Six replicate slabs of both heartwood and sapwood for each species were saturated under vacuum with water prior to use, then edge-sealed. Either 0.25, 0.5 or 1.0 g of Polesaver Rod was placed on moistened filter paper within a Petri dish. The bottom surface of the slab was then placed in direct contact with the upper surface of the chemical. After a pre-diffusion period of two days, the upper surface of the slab was inoculated with an agar strip infected with a mixed inoculum. The same procedure was carried out for the untreated controls. The slabs were then incubated at 28°C and 85% RH, and scored for fungal activity after 7, 14 and 28 days.

II. Stub Diffusion Trial

Stubs of *E. obliqua*, with diameters ranging from 150 to 250 mm and 500 mm long were cut from trees felled in the Cobaw State Forest, near Macedon, Victoria. Care was taken to ensure that each stub had intact, tightly adhering bark and contained no gross defects such as branch stubs or large kino pockets. Each stub was individually placed in a plastic bag immediately after cutting to minimise moisture loss during transport and storage.

In the laboratory, stubs were fitted with tensioned steel straps 18 mm wide by 0.7 mm thick placed about 20-30 mm from the cut ends. The steel straps served to minimise end checking and splitting during the trial duration.

Seven stubs were selected for the trial and a 16 mm diameter hole was axially drilled to a depth of 150 mm. A Polesaver Rod was inserted into each hole and the hole sealed with a screw-in plastic plug. The treated stubs were vertically stacked under cover.

After eight months the stubs were split longitudinally. Extreme care was taken to minimise formulation smearing of the freshly split faces. The split surfaces were sprayed with boron and fluorine indicators to determine the extent of radial and longitudinal diffusion of preservative from the point of application.

A sample was taken from the split surface to analyse the concentration of fluorine and boron in the radial diffusion zone. Analysis of fluoride was determined using an ion specific electrode, and boron using the Inductively Coupled Plasma/Atomic Emission Spectrometer.

III. Sleeper Diffusion Trial

Sleepers of *Eucalyptus maculata* (spotted gum) and *Eucalyptus tetericornis* (forest red gum) were obtained from a local supplier. Both sleepers were drilled on either side of the rail plate area and a Rail Rod was inserted in the holes as shown in Figure 1. The holes were sealed with a plastic plug and the sleepers were placed on a concrete slab and left in the open.

After 12 months the sleepers were dissected at the treatment areas for diffusion studies. Slabs (20 mm thick) were cut at the rail plate areas as shown in Figure 2 and sprayed with boron and fluorine indicators to detect the radial and longitudinal diffusion distances from the treatment point.

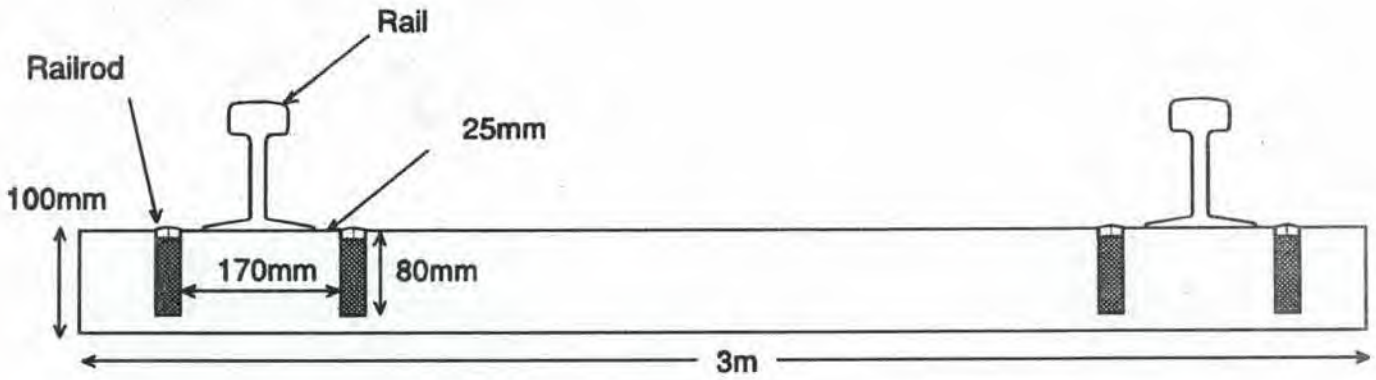

Figure 1. Treatment of sleepers with Rail Rods.

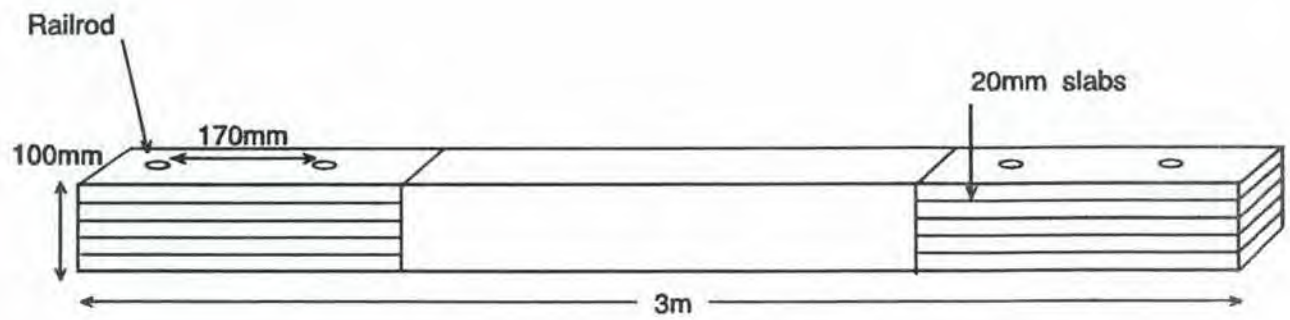

Figure 2. Sleepers cut into 20 mm slabs at treatment area.

RESULTS AND DISCUSSION

I. Slab Diffusion Bioassay

Table 1 summarises the slab diffusion results of Polesaver Rods using the heartwood and sapwood of three different timber substrates.

Table 1. Slab diffusion results of Polesaver Rods

Substrate	Treatment (g of rod)	Diffusion period (days*) 7	14	28
E. drepanophylla sapwood (grey ironbark)	0.25	0	0	0
	0.5	0	0	0
	1.0	0	0	0
	control	3.0	3.0	2.3
E. drepanophylla heartwood	0.25	0	0	0
	0.5	0	0	0
	1.0	0	0	0
	control	3.0	2.8	2.5
E. marginata sapwood (jarrah)	0.25	0	0	0
	0.5	0	0	0
	1.0	0	0	0
	control	3.0	3.0	2.8
E. marginata heartwood	0.25	0	0	0
	0.5	0	0	0
	1.0	0	0	0
	control	3.0	2.5	2.3
E. obliqua sapwood (messmate)	0.25	0	0	0
	0.5	0	0	0
	1.0	0	0	0
	control	3.0	3.0	2.5
E. obliqua heartwood	0.25	0	0	0
	0.5	0	0	0
	1.0	0	0	0
	control	3.0	2.5	2.5

*Mean of six replicate slabs.

0 - no evidence of fungal growth
1 - slight mycelium development
2 - moderate fungal growth
3 - good fungal growth

It is clearly evident that the Polesaver Rod is capable of diffusion through the heartwood and sapwood of the substrates used. Diffusion of the biologically active ingredients of the rod was sufficient to deliver a fungitoxic level of boron and/or fluorine on the upper surface of the slabs regardless of the treatment level.

Good mycelium growth was evident in the control slabs, indicating the mixed inoculum used was quite active. However, the scores have appeared to indicate slight drying of the inoculum over the course of the incubation period.

II. Stub Diffusion Trial

The radial and longitudinal diffusion depth of elemental components using colorimetric indicators are shown in Table 2. Table 3 presents the concentrations of fluoride and boron at the sampling point.

Table 2. Diffusion depths of elemental components after eight months

Stub No.	Depth of diffusion from preservative reservoir (mm)			
	Fluoride		Boron	
	Radial	Longitudinal	Radial	Longitudinal
1	50	360	60	380
2	40	300	65	410
3	40	250	50	470
4	40	400	60	500
5	50	300	60	350
6	45	320	50	400
7	35	340	45	320

Table 3. Concentrations of elemental components at sampling point after eight months

Stub No.	Concentration at sampling point (kg/m^3)		
	Fluoride	Boron	Total
1	2.4	1.5	3.9
2	2.0	1.3	3.3
3	2.9	3.0	5.9
4	15.9*	4.9*	20.8*
5	4.3	2.4	6.7
6	5.2	4.1	9.3
7	2.2	2.4	4.6
	$\bar{x} = 3.2$	$\bar{x} = 2.5$	$\bar{x} = 5.7$

*suspected sample contamination from preservative reservoir. Excluded from the mean.

Good radial and longitudinal diffusion depths were achieved for both elements. The boron component diffused furthest with distances of up to 65 mm in the radial direction and the full length of the stub (500 mm) longitudinally. Fluoride diffusion distances of up to 50 mm radially and 400 mm longitudinally were achieved.

The concentrations of fluoride and boron at the sampling point where quite high with loadings of up to 5.2 kg/m^3 and 4.1 kg/m^3 respectively. The total concentration of active ingredients were well above documented toxic threshold values against a wide range of decay fungi and termite species (Becker 1973, Cockcroft and Levy 1973).

III. Sleeper Diffusion Trial

The average radial and longitudinal diffusion distances from the application points are presented in Table 4.

Table 4. Average diffusion distances of elemental components

Sleeper	Sleeper depth (mm)	Radial diffusion (mm)*		Longitudinal diffusion (mm)*	
		Fluoride	Boron	Fluoride	Boron
E. maculata (spotted gum)	0	11 (10-15)	26 (30-35)	43 (40-45)	58 (55-65)
	20	15 (10-20)	38 (25-45)	49 (30-60)	75 (65-85)
	40	16 (15-20)	34 (20-45)	69 (55-80)	81 (75-85)
	60	20 (15-25)	36 (35-40)	63 (55-70)	74 (60-85)
	80	23 (20-25)	34 (30-40)	56 (50-60)	61 (55-70)
E. teriticornis (forest red gum)	0	9 (5-10)	16 (15-20)	29 (25-30)	46 (40-60)
	20	6 (5-10)	18 (15-20)	35 (30-40)	41 (40-45)
	40	13 (10-25)	20 (15-25)	36 (30-40)	61 (50-75)
	60	14 (10-15)	24 (20-30)	38 (30-45)	55 (45-60)
	80	13 (10-15)	25 (20-30)	33 (30-35)	51 (44-45)

*Mean (and range) of 4 readings.

Good diffusion distances were achieved with both active elements in all directions after 12 months. The boron component diffused furthest with full penetration between the two application points in some of the spotted gum slabs. Moisture content readings taken at the time of analysis were higher in the spotted gum sleeper which appears to be responsible for the longer diffusion distances of fluoride and boron achieved in that species.

As positive results obtained by the elemental indicators detect loadings of boron and fluoride above the toxic threshold for a wide range of decay fungi and termite species, the results have shown a significant proportion of the rail plate area would be protected against biodeterioration.

CONCLUSIONS

Polesaver Rods containing fluorine and boron as active ingredients are capable of diffusing through the heartwood and sapwood of eucalypt hardwoods in toxic enough concentrations to inhibit fungal growth. Diffusion distances of up to 60 mm radially and 500 mm longitudinally from the preservative reservoir were achieved in *E. obliqua* stubs. Samples taken within the diffusion zone are well above documented toxic threshold values. In addition, Rail Rods have clearly displayed their diffusibility in spotted gum and forest red gum sleepers.

The technical results achieved by this study have demonstrated that Polesaver Rods and Rail Rods would be effective in protecting wooden poles railway sleepers and other structural timbers from biodeterioration.

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DIFFUSION AND TOXICITY EVALUATION OF COMMERCIAL AND NON COMMERCIAL REMEDIAL PRESERVATIVES IN JARRAH STUBS

Kevin McCarthy
CSIRO Division of Forest Products
Private Bag 10, Rosebank MDC, Clayton, Vic. 3169

ABSTRACT

Stubs of *Eucalyptus marginata* (jarrah) were installed at the CSIRO Highett Pole Test Site and abaxially bored from 150 mm above ground-line to 450 mm below ground-line. Six remedial preservative formulations, Blue-7, CN Protective, Busan Pole Preservative Gel, Boracol 40, Boracol 40 + Impel Boron Rod, and CSIRO fluoroborate paste, were injected into the pre-drilled holes.

One, two and three years after application, two replicate stubs were removed and split longitudinally. Using colourimetric indicators the extent of radial diffusion of each elemental component from the abaxial hole was recorded. In addition, the stubs were bioassayed 100 mm below ground-line to determine the radial depth of effective fungitoxicant.

At three years, radial diffusion depths of effective fungitoxicants of up to 72 mm and 76 mm were recorded in stubs treated with CSIRO fluoroborate paste and Boracol 40 + Impel boron rod combination respectively. Busan Pole Preservative Gel recorded a diffusion depths up to 56 mm, while Blue-7 decreased slightly from year 2 to year 3 to achieve up to 34 mm of effective fungitoxicant. Boracol 40, while satisfactory at one year, recorded only 14 mm after three years. Negligible diffusion depths of copper naphthenate paste were achieved at any period.

INTRODUCTION

There are currently over 700,000 wooden poles in the State Energy Commission of Western Australia (SECWA) network. Of these approximately 85% are untreated jarrah species, all of which may be subject to biodeterioration at some stage during their service lives.

Records collected by SECWA show a high incidence of internal deterioration, primarily from decay fungi, in their wood pole population. This internal fungal attack or centre-rot as it is commonly known is claimed to be one of Australia's principal causes of pole deterioration (McEvoy *et al.* 1985) and generally occurs without warning or any visible external signs. Basidiomycetes producing brown-rot and white-rot are responsible for centre-rot. It normally occurs with the establishment of these fungi in the low durability pith region. Under favourable conditions decay extends rapidly outwards from this inner-heartwood pith zone to the relatively more durable outer-heartwood region.

The most effective method of controlling centre-rot in eucalypt poles is the use of preservatives which are capable of diffusing from the site of application. In Australia there is a wide variety of remedial treatments aimed at protecting the critical zone of in-service poles. Most of these treatments have been reviewed from time-to-time (e.g. Greaves and McCarthy 1985) and are applicable, though not necessarily effective in controlling centre-rot in poles.

Because of SECWA's need to protect their valuable asset, in particular from centre-rot fungi, they sought CSIRO's assistance in a collaborative project to investigate the problem and to carry out remedial preservation research on their untreated jarrah pole population.

In this paper results of a jarrah pole stub diffusion trial, incorporating the most widely used commercial remedial preservatives and a CSIRO developed non-commercial remedial preservative, is described.

MATERIALS AND METHODS

Commercial Formulations

Five commercial formulations; Blue-7, Busan Pole Preservative Gel (Busan P.P.G.), Boracol 40, Impel Boron Rods and CN Protective were used in the trial.

Blue-7, a copper fluoroborate, and Busan P.P.G., an organic fungicide, have been used quite extensively by pole using authorities throughout Australia. They were both included in a bandage trial designed to control soft-rot, where they were shown to diffuse through the sapwood of CCA-treated *Eucalyptus maculata* (spotted gum) poles (Chin *et al.* 1982). In addition, laboratory diffusion trials indicate that Blue-7 and Busan P.P.G.

have the ability to diffuse through the heartwood and sapwood of jarrah slabs in toxic enough concentrations to inhibit fungal growth (Johnson and McCarthy 1986).

Boracol 40 and Impel Boron Rods are water-diffusible borates which are highly effective and well established remedial wood preservatives (Greaves *et al.* 1982). Boracol 40 is a clear solution while Impel Rods are solid, having an appearance similar to glass. Due to the slow dissolving nature of the Impel Rods it was decided to use them in combination with the Boracol 40 solution which diffuses rapidly.

The use of CN Protective (copper naphthenate emulsion) as a remedial wood preservative is quite extensive, particularly in New South Wales where it is used for control of external deterioration of poles. As claims had been made CN Protective was capable of diffusing through eucalypts it was included.

Non-Commercial Formulation

A remedial preservative paste, containing fluorine and boron as its active ingredients was formulated by CSIRO. Past experiences with fluorine and boron has documented their ability as proven wood preservatives (Gay *et al.* 1958, Becker 1973, Cockcroft and Levy 1973) and exhibiting good diffusion characteristics within the wood (McEvoy *et al.* 1985). The formulation will be referred to as CSIRO fluoroborate paste.

Experimental

Stubs of *Eucalyptus marginata* (jarrah) each 1.8 m long with diameters ranging from 200 to 250 mm were cut from new full length poles. The stubs were installed at the Highett Pole Test Site, Victoria. They were left for 12 months in an attempt to stabilise the moisture content and bring about a microbiological conditioning.

After this time each stub was bored abaxially from 150 mm above ground-line to 450 mm below it in three equidistant positions around the pole (Figure 1) and the preservative formulations injected into the holes. Once introduced the holes were sealed with a screw-in plastic plug. A total of 36 stubs comprising six replicates for each preservative were treated.

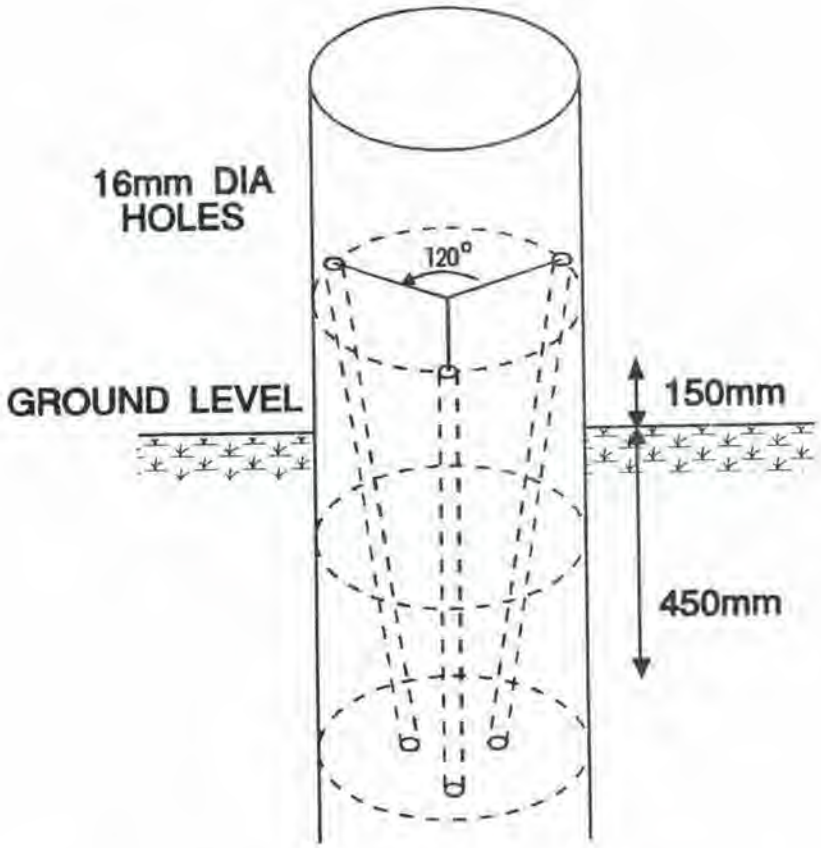

Figure 1. Internal treatment of stubs.

One, two and three years after preservative application two replicate stubs were removed and split longitudinally using a steel wedge to minimise formulation smearing of the freshly split faces. The remains of the preservative were carefully removed and the split surfaces planed smooth with a power plane.

The planed surfaces were sprayed with spot test reagents (as described in AS 1604-1974 Methods for sampling and Analysis of Wood Preservatives and Preservative-Treated Wood) to indicate the extent of radial diffusion of elemental preservative from the abaxial hole.

When only two active elements were present, one element was measured on one face of the split stub and the other on the opposing face. In the case of Blue-7 where three elements were present, one of the previously tested faces was re-planed (the indicator had penetrated the wood to less than one millimetre depth) and the clean face sprayed for the third element. The extent of diffusion of Busan P.P.G. could not be determined using this method.

As the spot test is only a measure of the preservatives elemental diffusion and not its fungitoxicity, a bioassay technique, which is a modification of that used by Greaves 1978, was used to determine the radial diffusion depth of effective fungitoxicant from the preservative reservoir.

A 100 mm long sample was taken in the radial direction from the abaxial hole approximately 100 mm below ground-line. The sample was sliced into consecutive 2 mm increments which were inoculated with ground-up centre-rot inoculum. The slices were incubated at 28°C and 85% relative humidity for 28 days. After this time the amount of growth on each slice was recorded. No growth indicates a sufficient concentration of preservative is present to inhibit activity of centre-rot fungi. Using this technique the diffusion depths of effective fungitoxicant were obtained.

RESULTS AND DISCUSSION

The average radial diffusion depths of elemental preservative and effective fungitoxicant over the three year period are presented in Tables 1 and 2.

TABLE 1. Average radial diffusion depth using elemental indicators

Preservative treatment	Diffusion period (mths)	Average radial diffusion depth of elemental preservative (mm)		
		Copper	Fluoride	Boron
Blue-7	12	2	24	32
	24	2	37	42
	36	2	40	46
CN Protective	12	2		
	24	2		
	36	4		
Boracol 40	12			35
	24			56
	36			32
CSIRO fluoroborate paste	12		29	42
	24		54	64
	36		62	74
Boracol + Impel Rod	12			42
	24			65
	36			79

TABLE 2 Average radial diffusion depth of effective fungitoxicant using the bioassay technique

Preservative treatment	Diffusion period (mths)	Average radial diffusion depth of effective fungitoxicant (mm)
Blue-7	12	25
	24	37
	36	33
CN-Protective	12	2
	24	2
	36	4
Busan Pole Preservative Gel	12	29
	24	50
	36	54
Boracol 40	12	23
	24	25
	36	14
CSIRO fluoroborate paste	12	31
	24	61
	36	70
Boracol 40 + Impel Rod	12	29
	24	60
	36	73

Colourimetric assessment

Over the three year period a steady increase in elemental fluoride and boron diffusion was observed in stubs treated with the CSIRO fluoroborate paste. An increase in both elements was also recorded with Blue-7, however, the rate of increase and overall diffusion distance was less than CSIRO fluoroborate paste. In both preservatives boron diffusion was greater than fluoride at each assessment interval.

Good diffusion distances of elemental boron were recorded with Boracol 40 after the first two years, while, a marked decrease occurred in the final year. The combination of Boracol 40 and Impel Rod treatment achieved the greatest diffusion distances of elemental boron of all treatments, and a steady increase was observed from year to year.

Copper diffusion in stubs treated with Blue-7 and CN Protective were negligible at each assessment.

Bioassay assessment

An increase from year-to-year in radial diffusion distances of effective fungitoxicant were recorded in stubs treated with CSIRO fluoroborate paste, Busan P.P.G. and Boracol 40 + Impel Rod combination. Blue-7 and Boracol 40 both increased over the first two years, however, a decrease was observed in the final year. The decrease being quite dramatic in stubs treated with Boracol 40. Stubs treated with CN Protective were unable to inhibit fungal growth beyond 4 mm from the preservative reservoir.

CSIRO fluoroborate paste and Boracol 40 + Impel rod combination achieved the furthest diffusion depth of effective fungitoxicant over the three years, and their rate of increase outperformed the other treatments. Trends observed in the results obtained with the bioassay technique were consistent with those of the elemental indicators.

CONCLUSION

After three years, radial diffusion distances of effective fungitoxicant of up to 72 and 76 mm were recorded in stubs treated with CSIRO fluoroborate paste and Boracol 40 + Impel Rod combination respectively. Diffusion of these distances from the preservative reservoir will provide a large proportion of the heartwood in the treatment zone with protection against decay fungi. Furthermore, when stubs with these two treatments were split it was noticed that an adequate amount of treatment was still present in the holes and a further re-treatment would not have been necessary.

A satisfactory diffusion distance of effective fungitoxicant of up to 56 mm was recorded with Busan P.P.G. and a further re-treatment would not be required. Blue-7 recorded distances of up to 34 mm after three years, a slight decrease on that recorded after two years. It was noticed at the final assessment that no Blue-7 was present in any of the abaxial holes, thus a further re-treatment would have been required sometime during the final year to keep the level of diffusing fungicide above the toxic threshold.

While diffusion of Boracol 40 was rapid in initial stages due to its high water solubility and low viscosity, the effective fungitoxicant distances decreased noticeably. After the three years only a small proportion of the heartwood would be protected. Examination of the preservative reservoir showed no Boracol 40 present after two and three years, thus a re-treatment would be required each year for it to be an effective treatment.

The use of CN Protective as an internal remedial treatment was clearly ineffective. The high molecular weight and low water solubility of copper naphthenate appears to be responsible for the negligible diffusion distances achieved.

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"QUALITY ASSURANCE AND TREATED TIMBERS HAS AUSTRALIAN BUSINESS FAILED IT'S CUSTOMERS? "

Marshall Segan
Managing Director - THE PINE CENTRE
127-131 Bakers Road, North Coburg, Victoria 3058

ABSTRACT

Australian producers of sawn treated timbers, with a few notable exceptions, have not dedicated themselves to a true customer focus over the past decade, particularly in the Victorian and South Australian markets. Producers have been largely " production driven " and concentrated on the domestic framing and housing markets, allowing themselves to be largely dominated by overseas producers, particularly from New Zealand and the United States/Canada. Admittedly, " dumping " was a claim that could well have been proven in the past, but in the absence of any serious market development work, this claim must be discounted somewhat.

Today, with a global shortage developing in overall timber supply, there exists a unique opportunity for Australian Timber producers to take back the control of their domestic markets and ensure in future cyclical movements that overseas producers do not have the degree of influence that existed in the past.

However, unless the Australian Industry as a whole, becomes truly committed to a real **Customer focus** (which entails a dedicated approach to all aspects of production/planning/dispatch and marketing, together with some serious planning to ensure market development), the present " window of opportunity " will be lost and arguably **export possibilities** will be greatly diminished, as a result.

True **Total Quality Management**, if adopted at the top of a particular organisation, will certainly enable market development to occur, and can be accompanied by growing profit margins and a wider, more loyal customer base.

DIFFERING APPROACHES TO PRODUCTION AND MARKETING

There are three basic approaches to the production and marketing of Treated Timbers that can be summarised a follows:-

1. High quality grades only
2. Average quality grades only
3. Low quality grades

There exists considerable controversy on the "correct" approach, but it can be strongly argued that pursuing a " High grade " option will have a number of advantages guaranteeing greater market development and long term profit than other possible strategies.

THE MARKET POSITION IN VICTORIA

The past decade has seen the emergence of "Wet after Treatment" CCA Pine becoming the mass market product, dominated by New Zealand and a number of local producers. Some Australian producers such as Hardys (formerly Dunstans) departed permanently from the market, while other locals scaled down their output and concentrated on other markets. Price became the dominant selling feature - Treated Pine became a commodity no different from supermarket bread "on special".
Dubious practices on the part of several producers turned into outright fraudulent behaviour and such practices are *not unknown today.*
It would be fair to state that the majority of producers abdicated their responsibility to consumers of timber and were content to allow "market forces" to reign.

A groundswell of activity has led to substantial industry support for a **National Treated Timber Quality Assurance Scheme**, and work is well under way to implement such a scheme - if momentum falters, a more limited program will be commenced in Victoria and South Australia by the Southern Timber Treaters Group Incorporated.

Despite the immense price discounting and unethical practices found in the market place, a number of Treated Pine producers and resellers managed to maintain high standards and at the same time increase their market share and profitability.

OUR COMPETITORS - OVERSEAS TIMBER & LOCAL SUBSTITUTES

Despite the recent evidence of growing world wide timber shortages, there is a reasonable likelihood that competitors to treated timbers will capitalise on average or poor quality products and continue to dominate the market.
Australian labour rates are unlikely to be as low as Chile or South Africa, and one can only speculate as to the potential of Eastern Europe timber supplies in the near future. In any event, it is certain that overseas producers will be quite happy to invade Australian markets targeting both on price and quality advantages.
Even if the immense world wood shortages do not actually develop as forecast, it is certain that non timber competitors will continue to take market share or prevent profitable market development by timber producers. That big Australian - BHP, will surely continue spending large amounts on research, and the building /renovation markets will be a primary focus for BHP and other well run non-timber companies. Successful products such as "Hardiflex" (developed by Dr. Bob Coutts of the CSIRO) have, without doubt taken markets that could well have been dominated by timber products produced by Australian companies.
Hence, it can be strongly asserted that "loose" practices of the past **will not be totally adequate nor profitable** for the future health and profitability of the timber industry.

THE JAPANESE EXPERIENCE

If there are any doubts that product quality and better delivery standards is not a profitable path to follow, one can only point to the staggering success of Japanese industry, particularly over the last decade or two. Household names such as Fujitsu General, NEC, Sanyo, Sony, JVC and a score of others are good examples of companies following a "TOTAL QUALITY MANAGEMENT" approach with a true customer focus driving all areas of corporate activity.

Of course, this line of argument will come up against our "cultural differences", the Japanese Ministry of Industry (MITI) involvement in industry, the "laziness of Australian workers", the size of our domestic markets, and a host of other traditional "red herrings".
Unfortunately, the lack of productivity, overseas market successes and other Australian "disgraces" can only be sheeted home to Australian managers and proprietors. Some Australian successes (such as the Cochlear ear implant) are creating their own international markets, and are clear evidence that occasionally, Australian industry can "get it right" and become market leaders.

A DEFINITION OF QUALITY
Quality can mean many different things.
For the purposes of this paper, quality will be considered as attaining a recognised degree of excellence or reliability. Such "excellence" will depend on a number of characteristics, but due to limitations of space, a lengthy examination is not possible.
It is contended that *there is a direct relationship between customer loyalty and the perceived quality of a particular product or service*
No statistical or research data has been produced to support this view, but several successful years of market and product development clearly supports this viewpoint. Perhaps one can put it down to "good luck"?

SOME CRUCIAL DEFINITIONS
A *Customer* is a person or firm that buys *regularly* from a particular store or business
The key word is *regular*:-

* Long term potential flow of sales and profits can flow
* Lower cost to service than a *new* customer

QUALITY has been defined earlier and in the opinion of the writer has a crucial link to profitability and long term sales growth.
QUALITY ASSURANCE - Please refer to Page 6
QUALITY CONTROL is a system for ensuring quality of output involving:-

* Inspection
* *Analysis* based on standards
* *Action* to make required changes

All of the above require a **true commitment** to meeting customer needs and requirements.

RELIABILITY - is the state of quality which ensures reliability in service over a stated period (in the eyes of ultimate customer)

KEY PREMISE

Those companies or businesses that truly concentrate on genuinely meeting customer needs and requirements with quality (reliable) products that are delivered on time, will ensure a steady flow of increasing profits, and will be able to avoid having to compete on price and fight in the gutter of the lowest acceptable common denominator of poor or average quality.

QUALITY OF TREATED TIMBER - WHO CARES?

Many timber producers argue strongly (and may believe) that the mass market is only concerned with the lowest possible price and that issues of quality, longevity and overall reliability do not influence purchases between seemingly similar products.
It can be quite easily demonstrated that although this approach may apply to a portion of all timber users, the inescapable fact remains that if a particular consumer is aware of the risk of timber failure or poor performance, he or she (particularly she!!) will generally opt for higher priced and higher quality material. Anecdotal evidence is available from a number of sources, to support the quality approach.
The writer of this paper challenges all those who read it, to remember all those incidents as a consumer, that were experienced in relation to poor or rude service, shoddy or unreliable goods, or overall unpleasant experiences. Did you willingly revisit a business with unpleasant memories? *The answer must be a resounding NO!*

FOREST PRODUCTS - SOME CUSTOMER GROUPINGS

Forest product customers reach into all areas of commerce, the home, our school system and government. All timber producers effectively share the same diverse customer base, and it is a little strange that large producers regard their target markets as only " timber merchants", " truss manufacturers" or other large volume resellers or fabricators. This narrow focus allows an abdication of concern or responsibility for real standards of quality assurance and the real needs of the wider market. Producers concern themselves with bare adherence to "Australian Standards" which may broadly mean the framing, flooring and lining markets.
It is this narrow focus that stifles innovation, market development in the true sense and obviously export potential.

THE SECRET TO SUCCESS?

It is clearly evident to the writer, that satisfied customers who appreciate high service levels and "value for money" will return again and again to a given business, despite high prices and cheap alternatives at close quarters.
Satisfied customers not only return - they willingly refer friends, work mates and family to businesses that dedicate their supply to include high quality and reliable *services.*
Advertising *that is free has no "pay back"* - arguably it has a "snow-ball " effect and continues to work for years. Free advertising seems a reasonable benefit for a high quality regime!
An unhappy customer on the other hand, will (according to Kodak Australia's research), *lead to a potential loss of* 12 - 14 *future sales* !
Unhappy customers willingly tell the world of their recent unpleasant retail experiences, and the flow on cannot lead to booming sales or long term goodwill and growing profit.

Conclusion: Lost customers, due to poor service or poor quality, will definitely lead to a substantial loss of long term business and potential profits.

SOME WELL PRESERVED MYTHS ON CUSTOMER INTELLIGENCE

One hears frequently the same old line: " The customer cares only about price" Arguably, it can be demonstrated that although this approach applies to a portion of the market, well educated consumers will not willingly buy defective or unreliable timber.
"We must get the order out at all costs"
This approach is common in many Australian businesses - it leads to product failures, legal suits and long term costs not imagined by short sighted suppliers. The writer knows of one well known Australian Radiata producer who presently "allows" its treated timber to be delivered after 8 weeks air-drying *irrespective of the timber size or season.* To make matters worse, the material is sold as "Perma-Pine" inferring that all the relevant Australian Standards are adhered to.
The Timber industry does itself little credit in allowing these practices to continue unchecked. Customer education (together with concerted and long term marketing) not short cuts at the production level, is the answer. Today's consumer is better educated as to their legal rights and powers than ever before- consumers will respond very favourably given a clear choice between good and poor quality timber products. Most customers also respect honesty in relation to delays, stock shortages and other disruptions.
Short sighted, low quality product regimes can only lead to poor returns and disaster.

TOTAL QUALITY MANAGEMENT

Philip Crosby, an internationally recognised authority on TQM defines it as: "*The system for causing quality, not appraisal*".
Mr. Crosby who is not exactly highly favoured by eminent bodies such as Standards Australia (perhaps due to his lack of focus on excessive statistical analysis), continually emphasises that all producers/suppliers of goods and services must " do it right the first time". The Pine Centre believe in addition that **" it costs a lot to do it twice".**
Crosby stresses that the standard to aim for must be "Zero Defect". No doubt the timber industry will recoil in horror - " perfect timber - we'll all be ruined "!

DEFINITION OF QUALITY ASSURANCE

Quality assurance does not merely mean the latest fad of ISO 9000 or the AS 3900 accreditation series - it means preventing defects from occurring *at* the point of production, *not once the material reaches the merchant's yard or the ultimate customer.*

MEASURING QUALITY

Crosby believes quality can easily be measured, calling it the *price of non-conformance (ie: correction).*
Crosby, Deming and other world experts, may differ as to the exact costs of "non-conformance", but it can be strongly argued that such "non-conformance" varies between 20% (manufacturing) and 35% (service companies) of gross sales revenue. Such figures will cause a howl of derision, as the magnitude cannot **seem** to be correct.

One can only assume that the Japanese defect figures of 1-2 per million in certain components, must be based on an understanding by the Japanese, that the cost of "non-conformance" can indeed be very high. Successful American giants such as Motorola have now achieved defect rates of one per million.

In any business, the price of non-conformance will include the following:-

1. Receptionist's time in taking a complaint
2. Complaints department in processing
3. Production/works supervisor time preparing replacement material
4. Delivery/collection costs
5. Putting back into stock or re-work
6. Lost revenue forgone due to points 1-5 above
7. Future costs associated with loss of sales and goodwill?

BALANCE SHEET MYOPIA/FIXATION

Large companies (and also small) are more often than not driven by the " bottom line " when making plans for production, market development or other longer term considerations.

Managers generally dislike change - the human race seem to prefer routine. Continuous improvement requires a constant and critical assessment of all activities of a company's operations. Change is often "put on the back burner", discounted as being " impractical ", " excessively expensive" or "not suited to our company".

This dislike of continual improvement and change, has led to IBM 's enormous and continuing losses, while nimbler rivals such as Texas Instruments and the "clone makers" of Korea and Taiwan have taken over significant market share and at the same time ending the existing profitability of the once mighty " Big Blue ". A decade ago, who would have thought that one of America's wealthiest companies would be overtaken by Microsoft?

The present difficulties facing the CSIRO and other world class research bodies in terms of funding, can once again be sheeted home to the myopic vision of many company managers and our political leaders. At precisely the time CSIRO should be flooded with funding, we are witnessing a mighty and worthwhile organisation languishing for resources in many areas.

Australia is certainly *not* becoming the clever country - we seem to despise success, and one could conclude that we are becoming the stupid country.

The outstanding work of **Johnson and Thornton in the ongoing studies of CCA treated timbers**, is a potential **gold mine** for all producers of treated radiata pine, *if only they were clever enough to pour further funding into product research , marketing and development* ***together****, instead of operating on traditional lines of jealousy and narrow corporate lines.*

The potential world class status of Treated Radiata Pine, as is being demonstrated by the continuing studies of Johnson and Thornton, can only be highly commended and supported by the Forest Products industries - God forbid that the work is not allowed to continue, until the last bit of long term data can be wrung from these tests. The ongoing results must be used relentlessly by industry to improve local quality standards while at the same time developing better profit margins and heaven help us - export markets!!

LACK OF A TRUE COMMITMENT TO THE CUSTOMER ON THE PART OF MANY MAJOR PRODUCERS, RETAILER GROUPS AND INDEPENDENT TIMBER MERCHANTS

The ignorance on the part of resellers of timber products is absolutely incredible, to say the least.

Timber merchants, who continue to fight with each other for share of the builder market, seem almost totally disinterested in training their staff in the different qualities of various timbers, and allow deliberately misleading information to be fed to the buying public.

One hilarious incident that springs to mind is that of a prominent Timber Retail group in the Northern suburbs of Melbourne. A well informed timber authority (not the writer) telephoned the outlet to find if the store had Treated Pine in redried(seasoned) material in the size of 100 x 100mm for post applications. The timber manager stated that the material was not currently stocked, and that Oregon (Douglas Fir) was actually **more durable than treated pine for ground contact " because of the natural oils present in the Oregon "** . Such claims are commonly made over the telephone.

Another such incident involved a 40 year guarantee on treated pine lattice " because such thin timber (10mm), has probably been correctly and totally penetrated " while pickets (19mm thick) were "only guaranteed for 10 years due to the greater thickness "!

While timber resellers indulge in such ignorant or fraudulent activities, the producers can only influence the correction of these practices *by becoming committed to genuine industry and market education. Ongoing market education would be a powerful tool for the timber industry, provided such education was well planned and not the result of irregular and uncommitted individual company efforts.*

THE PINE CENTRE STORY

The Pine Centre's history is well known within the timber industry.

In the early 1980's, the group (Emerald Trading) was involved directly in sawmilling, wine importation and wholesaling, timber retail and wholesale, furniture industry supply and a range of other diverse activities.

Management controls were lacking to say the least, and quality was not a major consideration. A major crisis involving incorrectly dried pine flooring resulted in heavy losses lasting some 5 years, and forced a major re-examination of the business direction and focus.

The support of creditors, plus an outstandingly dedicated staff enabled the business to continue trading, and finally all outstanding debts were paid in full.

The experience of running and rebuilding a business that could only have been termed "substantially insolvent" can be likened to completing an MBA course in a war zone.

Hence, the absolute commitment to quality and service was born from a desperate need to continue trading while building up a retail business. Customer needs were closely met , and today the service/quality commitment is still followed, even more fervently!

Fortunately, all financial problems were overcome, but only because the business was able to tap valuable niche markets which were there for the taking.

Those market exist today, and are growing in all sectors.

WHY A 40 YEAR GUARANTEE ?

In the late 1980's, it was clear most timber users could not tell the difference between one piece of treated timber and another. THE PINE CENTRE's now well known 40 Year Guarantee was a copy of another system operating interstate. The 40 year period was based on New Zealand warranty systems and applies specifically to rotting and insect attack. It does not cover twisting, cracking or other cosmetic (ie: appearance) degradation.

The Pine Centre staff are continuously encouraged to inform all potential and existing customers of the crucial need to protect **all exterior timbers** irrespective of specie, from the effects of Ultra violet and heat exposure. Careful consideration as to the correct stain or paint is constantly stressed to customers - merchant and public alike.

In addition, recognising the difficulty in ensuring that all timbers are correctly treated, The Pine Centre has insisted that " in ground " retention levels (12kg/m3 plus a loading) be produced by its suppliers and hence, the 40 year guarantee "system" was not merely a slick marketing trick. The suppliers to The Pine Centre sometimes wish that they did not have such a difficult customer to contend with!!

The Pine Centre management funded and organised the Structural Timber Update '91 Conference which aimed to promote the value of correctly produced and true to grade treated and other structural timbers, as it appeared that no other initiatives would be forthcoming from within the timber industry to highlight the often deficient practices operating which have allowed low grade timbers to be distributed to the market place.

CONCLUSIONS

The Australian Forest Products sector has enormous strengths that are presently largely untapped.

Quality Assurance and a true commitment to all customers, is a little like pregnancy - one cannot be a " little bit pregnant ".

In the past, timber producers and resellers have been reluctant to attack areas of deficiency on the grounds of either the high level (ie : " we are busy, so why worry?") of demand, or the low level of activity (" we cannot afford the damned quality business"). Philip Crosby's marvellous book (published by McGraw Hill - "Quality without tears") has a sentence that applies more than ever to the Australian economy and more particularly the Forest Products sector:

> " Yet - we who are in Management know that the good old days are gone. No-one can afford to blunder along any more ".

Although no effective studies have been undertaken in the treated timber markets, as to the possible linkage between poor quality material, market development and general price levels, it is well accepted by a number of well informed participants and Industry bodies (such as the Victorian Timber Merchants Association) that there is a wide-spread distrust in the community of the reliability of treated timber generally, and indeed one has only to drive through Melbourne's suburbs to see first hand the number of twisted and misformed fences, to conclude that " all is not well " in the Treated timber markets.

For Australian producers and resellers alike, the answer can only be a high quality commitment that unconditionally focuses on customer needs, wants and fears -plus a concerted **joint effort** in the areas of **marketing, consumer and trade education.** If these parameters are followed, the future will be dynamic and exciting. Ignoring market needs will enable overseas producers to continue to control our local markets and prevent a successful long term export effort.

A number of Timber Industry companies have come to appreciate greatly, the key work being carried out by leading CSIRO scientists such as the ongoing studies of **Thornton, Johnson and Nguyen .** The writer appeals to CSIRO management to ensure that the ongoing studies on CCA continue to be fully funded, **as it is without doubt that such a study is unlikely to be commenced again in the future, and it is very clear that the long term data which will continue to flow from these studies will have national significance as a substantive and documented competitive advantage to assist the Australian softwood industry to develop local and international markets.**

The writer also challenges the Australian Timber Industry to fully utilise and harness the data being made available by the aforementioned studies, so that if improved timber quality and reliability can be achieved by the majority of producers, **a long term marketing and education effort can be implemented to benefit both consumers of timber products and the profit margins of the suppliers to those consumers.**

The views outlined in the body of this paper will not be shared by a number of Industry participants, on the grounds of " competition ", " meeting the market " and a fear of change, which people may feel is beyond them. A high quality approach to all aspects of business is demonstrably effective for all businesses large and small, and **perhaps many of the problems facing Australia can be solved by focusing on the customer rather than blaming outside influences for our present economic problems.**

The work of outspoken and long-time critics such as Peter Campbell (whom the writer has never met), must be understood as constructive rather than destructive criticism. Our vital Forest Products industry must finally get it's house in order to thrive and truly prosper.

It is clear to the writer that a determined commitment to quality by timber producers will **ensure long term benefits** to the companies concerned **and their customers.**

It would seem appropriate to conclude with a repeat of Philip Crosby's delightful comment:

> " Yet - we who are in Management know that the good old days are gone. No-one can afford to blunder along any more ".

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AN ACCELERATED FIELD SIMULATOR STUDY OF THE NATURAL DURABILITY OF HEARTWOOD FROM MATURE AND REGROWTH TREES

Gary C. Johnson, John D. Thornton
CSIRO Division of Forest Products
Private Bag 10, Rosebank MDC, Clayton, Victoria 3169
and
Nam-Ky Nguyen
Biometrics Unit, CSIRO Institute of Animal Production and Processing
Private Bag 10, Rosebank MDC, Clayton, Victoria 3169

Introduction

The primary aim of this study is to determine whether the durability, with respect to decay, of specimens cut from the outer heartwood of regrowth trees is the same as the durability of samples collected from the identical zone of mature trees. It might be considered that any difference in heartwood durability of regrowth and mature trees of the same species is due to rate of growth or age of tree. Da Costa *et al.* (1961), Da Costa (1975) and Wilkes (1984) stated that heartwood from slow-grown trees is widely believed to be more durable than that from fast-grown trees. The evidence from studies of eucalypts is rather sparse, but does not support this believe. Rudman (1964) reported no significant difference in decay resistance between trees (*E. marginata* Donn: Sm.) of the same age (>45 years) but different growth rates. Bamber *et al.* (1969) could not relate polyphenol, i.e. one of the group of compounds that confer durability (Rudman 1964), content of plantation trees (*E. grandis*) to rate of growth. Wilkes (1984, 1985) found that faster-grown coppiced eucalypts (*E. albens* Benth., *E. bancroftii* (Maiden) Maiden, *E. dealbata* A. Cunn.:Schau., *E. goniocalyx* F. Muell.:Miq. and *E. macrorhyncha* F. Muell.: Benth.) produced more extractives than did the slower-grown species of the same age (40 years). Despite this relationship, the effect of growth rate on heartwood resistance to deterioration was negligible.

Age of tree is documented to have an effect on eucalypt durability. Juvenile wood, which is produced by eucalypts for eight to 12 years (Nelson and Heather 1972, Hillis pers. comm.), has a low basic density, short fibre length, thin cell walls and, most importantly in this discussion, low content of extractives. Because the extractives confer durability and juvenile wood is low in them, heartwood from trees still producing juvenile wood is of lower durability. Furthermore, fully mature heartwood may not be produced until the tree is up to 35 years of age (Bamber and Curtin 1974, Wilkes 1984).

A secondary aim of this study is to determine whether samples from certain timber species, with outer heartwood affected in the living tree by one or more fungi, are less durable than similar trees of the same species but not affected by these fungi. We are comparing *E. marginata* material pencilled with *Fistulina spiculifera* (Cooke) Reid with that without pencilling. Also, *E. diversicolor* F. Muell. with "brown wood" (Davison and Tay 1990) is being compared with a sample free of "brown wood".

Materials and Methods

1. Types of material tested

Throughout this report, timbers are grouped into the following four categories:

(i) regrowth timbers from Western Australia to compare with mature timbers from Western Australia,

(ii) plantation grown timbers from Western Australia to compare with native forest timbers from Queensland, New South Wales and Victoria,

(iii) timber affected by fungi to compare with unaffected material of the same species from category i, and

(iv) various timbers or treatments included as yardsticks.

The regrowth or plantation specimens were cut from trees with estimated ages of 14 to 70 years as compared with estimated ages of 100 to more than 450 years for the mature trees (Table 1). Also given is the range of air-dry densities of the regrowth and mature outer heartwood used in this study.

2. Preparation of specimens

Billets were collected from the butt log of five trees chosen to be representative of the commercial timber now present in mature or regrowth forests of selected regions or, in some cases, from Western Australian plantations. The heartwood test specimens were cut from a zone 25 mm closer to the pith than the apparent sapwood-heartwood boundary. The sapwood-heartwood boundary of the hardwoods was located by the use of dimethyl yellow stain.

The green specimens were cut to a size of 25 x 25 x 120 mm. After air-drying to equilibrium moisture content, they were machined to 20 x 20 x 100 mm.

3. Exposure in the Accelerated Field Simulator (AFS)

Test specimens were installed with three-quarters of their length in a sandy loam soil collected from Walpeup, Victoria (Newell, 1961). Litter from the same site was distributed over the soil surface and augmented at intervals. The specimens were installed in seven rows of 25 specimens in a completely random design. Five trees of each species contributed an outer heartwood specimen to this study. Five *E. regnans* F. Muell. and five *P. radiata* D. Don trees contributed the untreated yardstick timbers. CCA-treated sapwood specimens from the two species were exposed.

The AFS was maintained in the darkness at 27-28°C and at approximately 85% relative humidity.

4. Inspection method

Each specimen was removed from the soil and probed with a scalpel to determine the location and amount of decay present. Each specimen was rated, for cross-section lost to decay, on a scale ranging from 8 (sound) down to 0, in unit steps. A score of 3 or less was considered to indicate that the specimen was unserviceable. Inspections were carried out at eight-weekly intervals for 184 weeks.

5. Statistical analysis

The mean condition and standard deviation of these untreated timber species and two preservative-treated species were calculated. The Duncan's multiple range test was used to compare the mean condition of each species rating greater than 2 out of 8.

When sufficient specimens had reached unserviceability, median specimen life (MEDSL) values for a species were determined. The specimen life, recorded for each replicate, was the time to reach unserviceability, and was defined as being halfway between the inspection at which the specimen was serviceable (8 to 4) and the next inspection when it was unserviceable (3 to 0). The MEDSL value for a species is the statistic for which 50% of the specimen values, when arranged in order of magnitude, lie on each side. The reasons for adopting this statistic are given in Link and De Groot (1990) and Thornton *et al.* (1991).

Result and Discussion

The mean ratings of specimens cut from outer heartwood of *regrowth* and *mature* trees of eight of the 10 species in Tables 2 and 3 were not significantly different after 184 weeks of in-ground exposure. This finding supports the limited published data indicating no difference in durability of outer heartwood from faster-grown, regrowth eucalypts versus that from slower-grown, mature trees. The two exceptions to the above were *E. muelleriana* and *E. resinifera* with mean ratings of specimens cut from regrowth (plantation) significantly less than those of the mature (native forest) trees of the same species.

Three species (*A. fraserana, E. maculata, E. microcorys*) rated at least one unit higher for the mature specimens than for the regrowth ones. *E. marginata*, on the other hand, showed a higher mean rating for the regrowth than for the mature specimens. However, it should be emphasised that the difference between regrowth and mature is not significant.

The effect of fungal colonisation of heartwood in the living tree on the condition of specimens cut from the affected heartwood of two species of eucalypt can be seen in Table 4. Pencilling caused by *F. spiculifera* (formerly thought to be *F. hepatica* Schaeffer:Fr.) in mature heartwood specimens did not significantly affect the rating relative to that of mature heartwood unaffected by *F. spiculifera*. However, the mean rating of the specimens from mature trees, although not significantly different, was much less than that of the unaffected regrowth specimens.

The microorganisms and wounding that induced "brown wood" in *E. diversicolor* had a dramatic effect on the rating of *E. diversicolor* specimens. Whereas the "brown wood"

specimens failed well before the 184 week inspection, the unaffected regrowth specimens were rating a mean of 4.2 (Table 4). It is apparent that the organisms that caused or are associated with "brown wood" formation, some of which have been identified by Davison and Tay (1990), have a significant effect on that timber's durability, probably through oxidation of the polyphenolic extractives.

From Table 5 it is possible to determine which timber species or treatments are significantly different from one another at the 5% level by the Duncan's multiple range test. The specimens rating highest in condition, and not different from one another at the 5% level, include regrowth and mature *E. maculata, E. wandoo, E. microcorys* and *E. patens* as well as mature *E. resinifera* and *E. camaldulensis*. The latter and CCA-treated *P. radiata* sapwood were included as yardsticks against which to gauge the performance of other species.

The MEDSL values presented in Table 6 indicate the number of weeks of exposure required before the median specimen life of each species or treatment can be calculated. Regrowth *E. regnans* and regrowth *E. diversicolor* with "brown wood" were the first (at 44 weeks) to contribute MEDSL values. Treating *E. regnans* with CCA only increased the MEDSL by eight weeks. All of the untreated softwoods were registering MEDSL values by 84 weeks and by 172 weeks four hardwoods (regrowth *E. muelleriana* and *E. resinifera*; mature *E. marginata* both affected and not affected by *F. spiculifera*) which have a reputation for being durable were also listed.

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Table 1. Range of estimated ages of the trees included in this study and of the air-dry densities of the outer heartwood[1]

Species	Regrowth		Mature	
	Est. age (yrs)	Air-dry density (kg/m^3)	Est. age (yrs)	Air-dry density (kg/m^3)
Allocasuarina fraserana (Miq.) L. Johnson	25-50	651-763	100-125	708-798
Eucalyptus calophylla R.Br.:Lindl.	35-60	728-995	150-300	705-1000
E. camaldulensis Dehnh.	NA	NA	340->450	823-1000
E. diversicolor F. Muell.	15-20	858-900	100-200	806-919
E. diversicolor "brown wood"	15-20	659-867	NA	NA
E. maculata Hook.	21-45	704-967	>100	1060-1120
E. marginata Donn:Sm.	30-50	530-710	200-300	772-1050
E. marginata, Fistulina-affected	NA	NA	>200	734-856
E. microcorys F. Muell.	21-52	764-980	>100	919-1030
E. muelleriana Howitt	19-28	649-739	>100	641-932
E. patens Benth.	40-60	687-1070	150-300	877-1020
E. regnans F. Muell.	50	539-642	NA	NA
E. resinifera Sm.	21-52	631-883	>100	940-1100
E. wandoo Blakely	50-70	1010-1110	150-300	1080-1130
Pinus pinaster Ait.	28-57	609-747	NA	NA
P. radiata D. Don	14-34	421-779	NA	NA

[1] NA = not applicable; density is range of six replicates.

Table 2. Condition, after 184 weeks' exposure in the AFS, of heartwood specimens cut from regrowth and mature trees grown in Western Australia

Species	Mean rating[1] and standard deviation	
	regrowth	mature
A. fraserana	2.8 ± 2.2	3.8 ± 0.4
E. calophylla	4.2 ± 1.8	3.8 ± 1.6
E. diversicolor	4.2 ± 1.1	3.8 ± 1.1
E. marginata	4.2 ± 0.8	2.6 ± 2.8
E. patens	4.8 ± 1.1	4.6 ± 0.5
E. wandoo	6.4 ± 0.5	6.4 ± 0.5

[1]A rating of 8 indicates that the specimen is undecayed; 0 indicates that the whole cross-section is decayed.

Table 3. Condition, after 184 weeks' exposure in the AFS, of heartwood specimens cut from plantation trees grown in Western Australia and native forest trees grown in eastern Australia

Species	Mean rating[1] and standard deviation	
	regrowth (plantation)	mature (native forest)
E. maculata	5.6 ± 0.5	6.6 ± 0.5
E. microcorys	5.0± 1.4	6.0± 0
E. muelleriana[2]	0	4.4 ± 2.5
*E. resinifera**	2.2 ± 2.3	6.2 ± 0.4

[1]A rating of 8 indicates that the specimen is undecayed; 0 indicates that the whole cross-section is decayed.

*Mean ratings of regrowth specimens and mature specimens are significantly different at the 5% level by the Duncan's multiple range test.

[2]Species and treatments with mean ratings of less than 2 were excluded from the analysis.

Table 4. Condition, after 184 weeks' exposure in the AFS, of heartwood specimens cut from unaffected and fungus-affected *E. diversicolor* and *E. marginata*

Species	Mean rating[1] and standard deviation of			
	fungus-affected specimens		unaffected specimens	
	regrowth	mature	regrowth	mature
E. diversicolor[2]	0	NA	4.2 ± 1.1	NA
E. marginata	NA	2.8 ± 1.6	4.2± 0.8	2.6 ± 2.8

[1]A rating of 8 indicates that the specimen is undecayed; 0 indicates that the whole cross-section is decayed. NA = not applicable.

[2]Species and treatments with mean ratings of less than 2 were excluded from the analysis.

Table 5. Separation of means, by Duncan's multiple range test (DMRT), of timber species and treatments after 184 weeks' exposure in the AFS

Species and treatment	Means[2,3,4]	DMRT
E. maculata, mature	6.6	
E. wandoo, mature	6.4	
E. wandoo, regrowth	6.4	
E. resinifera, mature	6.2	
E. microcorys, mature	6.0	
E. maculata, regrowth	5.6	
E. microcorys, regrowth	5.0	
E. camaldulensis, mature	5.0	
E. patens, regrowth	4.8	
E. patens, mature	4.6	
E. muelleriana, mature	4.4	
E. calophylla, regrowth	4.2	
E. marginata, regrowth	4.2	
E. diversicolor, regrowth	4.2	
P. radiata sapwood, 8-10 kg/m^3 CCA	4.2	
E. diversicolor, mature	3.8	
A. fraserana, mature	3.8	
E. calophylla, mature	3.8	
A. fraserana, regrowth	2.8	
E. marginata, *Fistulina*-affected	2.8	
E. marginata, mature	2.6	
E. resinifera, regrowth	2.2	

[1]All specimens are heartwood unless otherwise indicated.

[2]Means joined by the same line are not significantly different at the 5% level.

[3]Species and treatments with mean ratings of less than 2 were excluded from the analysis.

[4]Mean of five replicates.

Table 6. MEDSL values determined from heartwood specimens exposed 184 weeks in the AFS

Species/treatment	MEDSL (weeks)
E. diversicolor (regrowth with "brown wood")	44
E. regnans (regrowth)	44
E. regnans (CCA-treated sapwood, 8-10 kg/m^3)	52
P. radiata (regrowth)	56
P. pinaster (regrowth)	84
E. muelleriana (regrowth)	124
E. resinifera (regrowth)	148
E. marginata (mature)	164
E. marginata (mature, *Fistulina*-affected)	172

SOFT ROT PREVENTION IN CCA-TREATED SPOTTED GUM POLES USING KOPPERS CN EMULSION

Alan Moffat
Timber Research QDPIFS
PO Box 631 Indooroopilly QLD 4068
and
Peter Carruthers
Koppers-Hickson Timber Protection Pty Ltd
PO Box 2122 North Sydney NSW 2059

ABSTRACT

End matched pairs of copper chrome arsenic treated spotted gum pole sections were installed in a high hazard field site in tropical north Queensland. One of each pair was coated with a copper naphthenate based preservative paste at groundline and the development of soft rot monitored annually by both field inspections and microscopic examinations. Two levels of CCA retentions were used to trial the added protection provided by the prophylactic treatment. The timber surfaces treated with the emulsified preservative had no fungal degrade after three years while CCA only timber surfaces were exhibiting soft rot attack. Non-CCA pole stubs with and without the paste treatments were also included.

INTRODUCTION

Traditional pole maintenance methods involve remedial practices after a pole has been attacked by bio-organisms. Chemical treatments applied to the surface of decayed poles rely on toxicant diffusion to control degrade within the affected zone. Tests were designed and implemented to prevent the onset of soft rot (SR) degradation by applying a surface treatment to copper chrome arsenic (CCA) treated pole size material at installation.

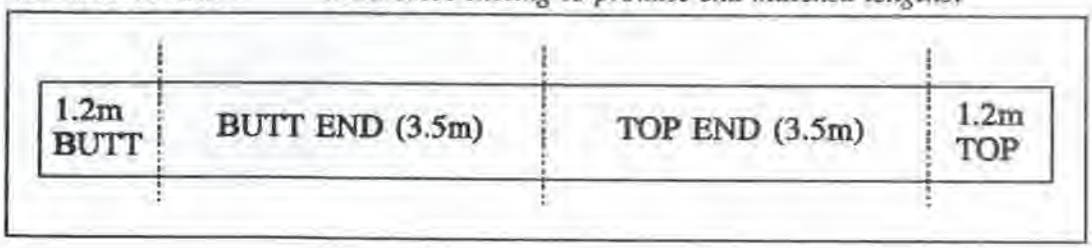
Exposure data for the first three years of a long term field trial were collected to examine the effect on SR attack in CCA treated spotted gum (*Eucalyptus maculata* Hook.). The test involved end matched pairs of pole stubs, with and without a groundline application of CN Timber Protective Emulsion (CN Emulsion), a Copper Naphthenate based remedial preservative paste manufactured by Koppers-Hickson Timber Protection. The trial was installed at the Queensland Department of Primary Industry Forest Service (QDPIFS) Canal Creek Experimental Field Site in 1989. Two retentions of CCA preservative were used in the trial, a low level to enhance SR attack and a commercial treatment satisfying Queensland legislative requirements for preservative treatment of power poles, Hazard 5 use, in accordance with *The Timber Utilisation and Marketing Act 1987-1990* (TUMA).

METHOD AND MATERIALS

POLE STUBS

Eight (8) spotted gum (SPG) trees were selected from the Maryborough district to produce stems 9.5 m long, with a butt diameter approximately 350mm and a minimum taper to the head. After debarking and pre-treatment seasoning at Koppers' Takura treatment facility, each stem was cross-cut to produce a set of two x 1.2M lengths and two x 3.5M lengths of end matched material- see Cutting Diagram 1.

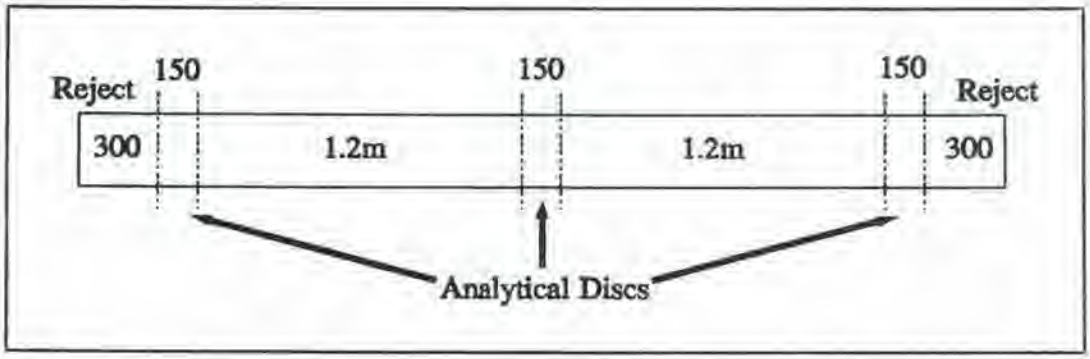
CUTTING DIAGRAM 1 *Stem cross-cutting to produce end matched lengths.*



One 3.5M length from each of the 8 stems, comprising 4 butt ends and 4 top ends, were then Vacuum Pressure Impregnated (VPI) with CCA to Queensland H3 hazard level. The matching 3.5M lengths were similarly VPI treated to Queensland H5 hazard level. The two 1.2M lengths from each stem were put aside as non - CCA end matched replicates.

Following further seasoning, each 3.5M length was cut to produce 2 x 1.2M end matched CCA treated specimens and 3 discs, 150mm long, from which analytical samples were produced - see Cutting Diagram 2. Two end sections, 300mm long , were cut and discarded from each end of all 3.5M lengths to remove any chance of CCA treatment anomalies from excessive end penetration into the sapwood.

CUTTING DIAGRAM 2 *3.5M Length cross-cutting to produce treated , matched specimens and analytical sampling discs.*



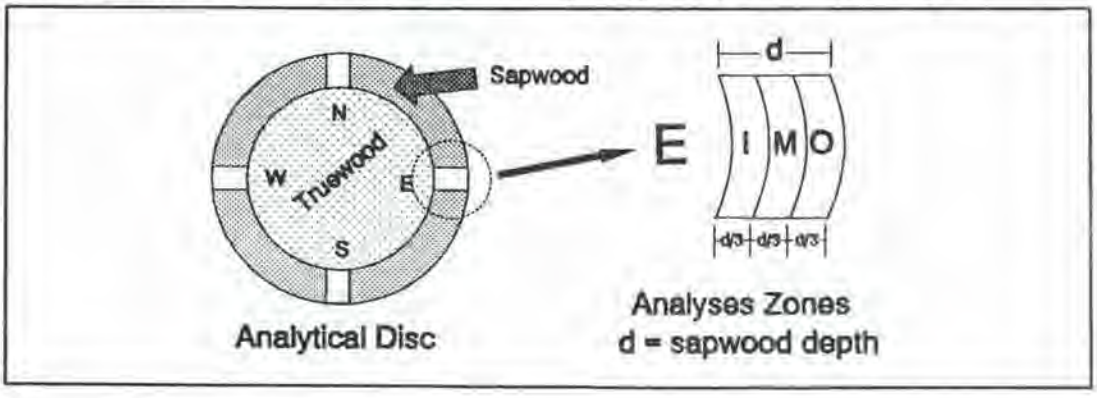
Each of the eight stems produced 6 exposure specimens consisting of:

2 x 1.2M lengths, of non CCA treatment
2 x 1.2M lengths, CCA treatment H3
2 x 1.2M lengths, CCA treatment H5

Thus 48 specimens were produced for the trial.
Each of the three discs from each 3.5M length treated with CCA preservative was sampled at four cardinal points around the disc to the full sapwood depth. The samples were then cut into three analytical zones comprised of the outer 1/3, middle 1/3 and inner 1/3 of the sapwood depth - see Cutting Diagram 3.

Each analytical zone was then analysed by atomic absorption techniques at the Koppers-Hickson analytical laboratory, to determine the percentage of Copper (Cu), Chromium (Cr) and Arsenic (As) in each analytical zone, based on a moisture free mass of timber (% m/m element in oven dried (O.D.) timber).

CUTTING DIAGRAM 3 *Analytical disc sampling for Cu, Cr and As analyses.*



Sample Summary
8 tree stems produced 8 x 3.5M lengths of H3 CCA and 8 x 3.5M lengths H5 CCA.
Each 3.5M length produced 3 discs
Each disc produced 4 sampling points
Each sampling point produced 3 analytical zones
Each analytical zone was analysed for 3 elements; Cu, Cr and As

Thus 8x2x3x4x3x3 = 1728 individual elemental determinations were carried out.

INSTALLATION

Six (6) specimens 1.2M long (2 x 3 treatments) from each stem were installed in September 1989 in random order in rows, producing 8 rows of specimens at 2M spacings in the tropical wet coastal QDPIFS Canal Creek Experimental Exposure Site. Each specimen was buried to a depth of 900 mm, and a metal cap fixed to the top.

KOPPERS CN EMULSION TREATMENT

Koppers CN Emulsion was applied to one of each matched pair of specimens. A 6mm thick layer of emulsion was applied to the surface of the pole stubs to be treated, from 100mm above ground line to a depth 300mm below groundline. Prior to backfilling, the CN Emulsion was covered with a layer of Rag-on-a-Roll (ROAR) industrial wiper produced by Kimberley-Clark Australia Pty. Ltd. (product number 4193) to maintain the emulsion layer on the pole stub specimen after backfilling and ramming.

INSPECTIONS

The trial was inspected 1, 2 and 3 years after installation.

After 1 year

The NO CCA WITH CN EMULSION replicates were excavated in the east quadrant and treatment product remaining on the surface was noted. Core samples were removed to beyond the sapwood zone with a plug cutter from four 'horizons'.

100mm above ground level
At ground line
100mm below ground level
200mm below ground level

The NO CCA WITHOUT CN EMULSION specimens were excavated in the same relative quadrant as the matching pair specimen and a core removed at ground level only, as advanced decay (white rot) was observed in the sapwood of these specimens.

After visual inspection and core sampling the specimens, the residual Koppers CN was reinstated and the stubs backfilled and the soil rammed.

The copper penetration and retention in the CN Emulsion treated specimens were determined after the plug samples were examined microscopically for biodeterioration.

After 2 years

The CCA TREATED H3 level specimens were excavated at the east quadrant and treatment product remaining on the surface was noted. The pole surface exposed was examined for SR attack. A specimen approximately 4mm deep was excised by a wad punch at a position 100mm below ground level for microscopic evaluation.

After 3 years

All the CCA TREATED specimens were excavated in the south quadrant. The pole surface exposed was examined for SR attack. Ratings for SR were graded:-

Severity	Rating
No degrade	1
Slight degrade	2
Moderate degrade	3
Severe degrade	4
Complete failure	5

An average sample approximately 4mm deep from the surface of each pole stub excavated was removed with a 12mm diameter wad punch for microscopic examination. Each field specimen was reinstated to its condition before inspection.

RESULTS

CHEMICAL ANALYSES OF SAMPLED ZONES

Table 1 gives the results of chemical analyses for Cu, Cr and As expressed as percent mass/mass (m/m) total elements (% TE) in oven dry timber from the three zones sampled within the sapwood band of each sampling point. Figures in brackets are standard deviations for the respective results.

AFTER 1 YEAR - NO CCA SPECIMENS

The ***NO CCA+CN Emulsion*** treated specimens contained sound sapwood to a depth of 4 to 5mm which coincided with the extent of copper penetration, in the zone where the product was applied. Some 2-3mm thickness of product remained on the surface of the specimens sampled. In the sapwood below the penetrated CN there was white rot decay.

Copper spot testing the 4 cores from each of the 8 CN Emulsion treated specimens showed a copper penetration average of 4mm, range 2-6mm. Mean retention of copper in the cross-section of the penetrated zone for each sampling zone determined by chemical analyses is shown in Table 2.

Analysis of variance of the copper retention data showed no significant differences between the sample zones.

The ***NO CCA NO CN*** specimens were severely decayed in the sapwood by a white rot. Core samples removed from these specimens were so badly decayed that the outer section, from the surface to 4-6mm depth, disintegrated during sampling.

AFTER 2 YEARS

The field and laboratory measurements for each of the eight pairs of *H3* pole stubs are given in Table 3.

In the table, 4000 microns (4mm) has been used as the standard thickness of each wad punched specimen for microscopic examination. This is an approximation to enable comparison in tabulation of the results; 0-4000 represents the average thickness of the wad punched samples which ranged from 3.5 to 4.5 mm thick.

AFTER 3 YEARS

The results of the laboratory examinations of the removed sapwood samples are given in Table 4 for each pair of stubs from each stem, *with* and *without* CN application. Where more than one rating is given, the degree of SR varied from the outer to the inner zone of the specimen with the rating from left to right.

TABLE 1 *CCA chemical analyses of sampled sapwood zones*

STEM NO	SAPWOOD DEPTH (mm)	POSN (1)	AVERAGE % TE m/m H3 level	STEM NO	SAPWOOD DEPTH (mm)	POSN (1)	AVERAGE % TE m/m H5 level
1T[2]	34 (1)	O M I	0.27 (0.04) 0.26 (0.05) 0.23 (0.06)	1B[3]	34 (1)	O M I	1.11 (0.08) 1.00 (0.12) 0.97 (0.14)
2T	28 (3)	O M I	0.32 (0.04) 0.28 (0.05) 0.29 (0.05)	2B	28 (3)	O M I	1.20 (0.19) 1.03 (0.17) 0.98 (0.18)
3T	35 (3)	O M I	0.28 (0.04) 0.25 (0.04) 0.24 (0.03)	3B	35 (3)	O M I	1.23 (0.09) 1.08 (0.07) 1.03 (0.10)
4T	31 (3)	O M I	0.37 (0.04) 0.34 (0.04) 0.33 (0.05)	4B	33 (3)	O M I	1.26 (0.13) 1.30 (0.10) 1.24 (0.14)
5B	26 (6)	O M I	0.34 (0.05) 0.30 (0.03) 0.34 (0.05)	5T	24 (3)	O M I	1.22 (0.17) 1.16 (0.14) 1.32 (0.22)
6B	20 (1)	O M I	0.44 (0.08) 0.36 (0.05) 0.33 (0.05)	6T	21 (2)	O M I	1.73 (0.16) 1.26 (0.10) 1.09 (0.15)
7B	32 (3)	O M I	0.30 (0.03) 0.26 (0.05) 0.21 (0.03)	7T	32 (2)	O M I	1.12 (0.10) 0.99 (0.09) 0.88 (0.12)
8B	31 (2)	O M I	0.30 (0.06) 0.30 (0.06) 0.30 (0.07)	8T	29 (3)	O M I	1.29 (0.15) 1.27 (0.13) 1.16 (0.13)

(1) O = Outer ⅓ of sapwood depth
M = Middle ⅓ of sapwood depth
I = Inner ⅓ of sapwood depth

(2) T = From **top** 3.5m length of stem

(3) B = From **butt** 3.5m length of stem.

Current retentions of CCA in TUMA for H3 and H5 levels in hardwoods in the inner ⅓ of sapwood are 0.3% and 0.7% TE m/m.

TABLE 2 *Mean copper retention in penetrated zone.*

SAMPLE ZONE	MEAN COPPER RETENTION % Cu m/m in Oven Dried Timber	STANDARD DEVIATION
A (+100mm)	0.20	.03
B (G-Line)	0.26	.07
C (-100mm)	0.24	.06
D (-200mm)	0.26	.07

TABLE 3 *Results from 2 nd. year sampling*

POLE STUB NUMBER	CN EMULSION TREATED				NO TREATMENT		
	FIELD[a] SOFT ROT	SURFACE CN RESIDUE	MICROSCOPIC EXAMINATION		FIELD[a] SOFT ROT	MICROSCOPIC EXAMINATION	
			DEPTH[b]	S.R.GRADE[c]		DEPTH[b]	S.R.GRADE[c]
1	Nil	Nil	0-4000	0	1	0-420 420-2100 2100-4000	3 1 0
2	Nil	Nil	0-4000	0	1	0-350 350-1330 1330-2830 2830-4000	5 2 1 0
3	Nil	Slight	0-4000	0	<1	0-700 700-4000	1 0
4	Nil	Slight	0-4000	0	<1	0-2030 2030-4000	2 0
5	Nil	10 mm	0-1120 1120-2170 2170-4000	0 2 0	2	0-980 980-4000	5 2
6	Nil	Slight	0-4000	0	2	0-1260 1260-4000	5 0-1
7	Nil	Slight	0-4000	0	1.5	0-1400 1400-2100 2100-4000	4 2 0
8	Nil	Slight	0-4000	0	2	0-1050 1050-2380 2380-4000	3 1 0

[a] = depth in mm

[b] = depth in microns from surface; 1000 microns = 1 mm

[c] = Soft Rot Grade; 0 to 5, nil to severe

TABLE 4 *Soft Rot Rating results from 3 rd year sampling*

Stem No	CCA Level H3		CCA Level H5	
	No CN	CN	No CN	CN
1	4	1	3	1
2	3-2	1	3-2	1
3	2-3	1	1	1
4	4	1	1	1
5	4	4	4-2-1	1
6	4-2	1	2-1	1
7	4	1	3-2	1
8	4	1	1	1

DISCUSSION AND CONCLUSIONS

After 1 year, Koppers CN Emulsion had penetrated untreated sapwood of the spotted gum pole stubs and prevented all fungal degrade in the penetrated zone. This zone was, on average 4mm deep. Beyond the penetrated zone white rot had attacked the sapwood.

All the low level (H3) CCA treated pole stubs **WITHOUT CN** had been colonised by soft rot at the timber/ground interface. The retention of CCA in these stubs is inappropriate for the end use of ***in ground contact*** according to Queensland TUMA. These levels were included in the trial to produce SR susceptible CCA treated spotted gum sapwood for testing the CN Emulsion efficacy.

Half the high level (H3) CCA treated pole stubs **WITHOUT CN** had been colonised by soft rot. The retention of CCA in these specimens satisfies with the minium retention of CCA required in the September 1993 draft of AS 2209, Timber poles for overhead lines, which is 1.10%m/m total active element in the analytical zone from 2mm below the surface of the pole to the full sapwood depth.

After 3 years the Koppers CN Emulsion had prevented soft rot from becoming establishedg on the surface of CCA treated poles of both H3 and H5 treatments tested.

Prevention of SR in new poles should be preferred to the eradication of SR from infected poles after the onset of the fungal degrade.

Eradication of SR in infected poles depends on two important criteria:

1. SR degrade in poles has to be accurately detected by field inspectorial staff for every pole.

2. The remedial treatments must overtake ingress of SR into the pole.

Errors in field identification and the time lag between remediation treatment and full fungitoxic or fungistatic effects, result in a net loss of pole strength due to SR degrade of wood material.

For low durability pole species, current eradication policy results in a loss of dimension in the annulus of supposedly high durability treated sapwood, required to support the pole and structures if/when the heartwood degrades.

Prevention of SR, from installation onwards, ensures that the full treated annulus remains intact for the life of the pole and ensures a safer pole in the ground.

The future of this trial should include the re-treatment of some replicates with CN Emulsion after a fixed period - for example every 5 years. Other replicates should not receive any further treatments so that a ***once only*** initial treatment performance may be monitored.

RECENT SAWING AND MACHINING RESEARCH, WORLD-WIDE

W.M. McKenzie
3 Bowles Avenue, Caulfield North, Victoria 3161

INTRODUCTION

World-wide and in Australia, wood sawing and machining research flowered in the period 1950-70, and largely faded in the 1970's. In the 80's there has been a revival of sawing and machining research in the northern hemisphere at least, as illustrated by the frequency of international meetings and the number of high quality papers from Japan, North America, Europe, eastern European countries and Russia. It is interesting, however, that there is still no appropriate section in Forest Products Society Annual Conferences, and no dedicated research unit in Australia.

Since I retired from CSIRO in 1985, I have had the opportunity to resume research wood cutting research in California and attend international meetings in that field. Thus I am able to provide a broad world-wide view of recent research aimed at improving mechanical processing of wood. Detail can be obtained from the proceedings and papers cited.

Possible reasons for the revival of wood cutting research in the 1980's are economic pressures (including competition from other materials), increasing use of wood composites and laminates, pressures to conserve resources and energy, smaller logs, technical developments such as computers, better instrumentation, automation and new materials.

World-wide, wood-use faces intense pressure from conservation movements which want to preserve old-growth forests and reduce energy use. As part of its response the wood industries should make better use of the trees that they cut. One approach is to add value to residues, and another, the main topic of this paper, is to improve mechanical processing in order to reduce residues and energy use, add value to products, and reduce costs.

UPGRADING RESIDUES

Under this heading I confine my remarks to Scrimber because I want to make a suggestion involving cutting. Developed by CSIRO, the process uses residual logs by crushing, adding glue and moulding them into rectangular sections. I would like to see this process elaborated to reduce the crushed mat to splinters, to be aligned in moulding various bulky products, one of which might be beams to replace imports of douglas fir for the purpose. Production of the splinters would be an interesting cutting problem, and alignment of them has a precedent in oriented strand board.

IMPROVING MECHANICAL PROCESSING

In mechanical wood processing, a number of objectives may be entertained. It is commonly desired to obtain high yield, accuracy, surface quality, production rate, profit, and quality of the the

environment in and around the plant (e.g. reduce noise). These objectives conflict, in that any one of them can be approached at the expense of one or more of the others. For instance, a narrower kerf can be, and sometimes is, achieved by reducing the feed rate. So, for each operation, management must consciously or tacitly set a policy based on the weight they attach to each of these objectives. Research can provide technical input to decisions as to priorities, and themes of current research tend to be related to dominant priorities which have changed over the years.

CURRENT TRENDS IN SAWING AND MACHINING RESEARCH

My account is organized under headings indicating the principal focus of the research, as follows:

Formation and quality of the wood surface and chip
Tool and machine precision
Tool edge deterioration
Noise
New cutting processes

These topics are not independent, of course, since findings in one area may have implications for other areas. In my view existing basic types of cutting processes will continue to dominate in the foreseeable future, but some new processes will be discussed.

FORMATION AND QUALITY OF THE WOOD SURFACE AND CHIP

Research under this heading is concerned with aspects of the cutting process that govern the character of the surface produced, for instance in sawing or planing, or the chip produced, for instance in veneer or pulp chip production. Such research has been revived by the need to complement automatic computer-controlled production with closer control of the cutting process to increase yield or provide adequate accuracy and surface or chip quality.

Some of the studies in this area are of a basic nature in the sense that they focus on tool-wood interactions during formation of a chip. Such studies are much more easily made at slow speed, and the value of the findings for operations at normal speeds was established years ago by Kivimaa and by McKenzie. Early slow-cutting experiments used single edges, and so does an experiment by Kimura and Yockochi (1993), who with chipless cutting in mind, developed and experimentally confirmed a model for the lateral force on an edge forced through a work-piece at various angles to the fibre direction. Also, Okumura *et al* (1993) have obtained finely resolved temperature measurements in the chip as well as the tool during slow cutting. Axelsson *et al* (1991, 1992) cut with a single edge in a transverse plane as in band-sawing, but at speeds in the operating range, achieving fine resolution by recording forces, texture and density as grey-scale images.

Loehnetz and Patzer (1988) in Madison and Thibaut (1991), in France, report studies of veneer cutting with the aim of optimizing knife and nosebar configurations in relation to wood properties. Cutting green wood, Thibaut found some effects, presumably hydrological, of cutting speed.

The advantages of slow-speed cutting and advanced technology have enabled McKenzie (1988a, 1988b, 1991a, 1991b, 1992b, 1993) to go

beyond study of single edges and observe the action of normal sawteeth cutting within the kerf in linear and circular paths. A picture of the cutting action and digitally displayed force components in three dimensions are recorded simultaneously by video and computer for close cross-reference. Results include elucidation of the nature of oscillations in force within and between tooth cuts during sawing, and the relationships between friction coefficient, force components and dulling. This work has provided recommendations for plants and sawshops to help them optimize sawtooth variables such as clearance angle and dulling and operating variables such as feed speed, in relation to wood variables such as species, heartwood/sapwood, moisture content, ring spacing and orientation, friction coefficient and density.

Sales (1991) has analysed surface quality of wood and wood-based materials, and Edvardsen (1993) has used a scanning electron microscope to observe the effects of knife dulling on surface appearance and gluing properties. The planing properties of species have been investigated by Jerger (1993) (red oak) and Mosteiro and Mendoza (1993) (coconut palm).

The value of lasers for characterizing sawn and machined surfaces has been assessed by De Vries and Lemaster (1991a) at the University of California Forest Products Laboratory, in the hope that they might be used for on-line monitoring in plants.

Quality of the chip, in this case for pulp, has been of interest in Quebec, where Hernandez and Quirion (1993) demonstrated gains in yield by optimizing knife clamp angle and position for winter and other times of the year.

TOOL AND MACHINE PRECISION

THe precision with which a tool acts is a vital factor governing surface accuracy and quality. The major kinds of tools studied have been sawblades and planing/moulding heads.

Saws

Mote and his students at Berkeley have conducted research on vibrations in circular and band sawblades since 1960, defining the effects of blade geometry, running speed up to and beyond the normal critical range, internal and externally-applied stresses, heating and on-line control (Parker anf Mote 1988; S.M. Yang and Mote 1988; B. Yang and Mote 1988; D'Angelo and Mote 1988; Shen and Mote 1988). The University of British Columbia has another very active centre. Yang and Hutton (1991) and Hutton (1991) have studied behaviour of circular saws at supercritical speed. Hutton and Lehmann (1991, 1993) Lehmann and Hutton (1991) have experimentally confirmed a detailed model of vibrational and cutting behaviour of band machines and saws. Finite element stress analysis of bandsaw blades has been used by Gassander (1993), concerned with gullet cracking, and Fuji, Noguchi and Sawada (1993), concerned with stability.

Such research has greatly expanded the basic knowledge required for increasing the precision of sawing, providing valuable information on blade design, tensioning regimes, appropriate saw speeds, and design of saw guides.

In Japan, new methods of tensioning are being sought. For instance shot peening has been tried successfully by Noguchi (1988), who suggests its value for tensioning large saws. In Madison, sawblade

materials less sensitive to temperature gradients have been tested (Danielson and Worzala 1991).

At a more practical level, Lister and Shajer (1991, 1993) have sought to evaluate present sawshop light-gap methods for assessing flatness and tension in circular and band saws. Holøgen in Norway has also developed a method inspecting saws using non-contact probes and computer acquisition. In its sawshop, the California Cedar Products Company has developed very accurate methods of assessing flatness (by converting probe measurements to color maps), and using natural frequencies to assess tension (Szymani 1991). Schultz (1991) described his company's experience in applying the scientific findings successfully to the manufacture and operation of thin saws. However, there should be much wider development and application of the information available.

There is an opportunity for Australian companies to develop instruments, tools and guides for improving saw performance, and market them locally and overseas.

In North America the saws of spline arbor edgers are supported by guides, usually water-fed. The mechanical system has been extensively investigated using modelling and experimentation by Tan and Mote (1985), Schajer (1991), Hutton and Lehmann (1988), Hutton and Kishimoto (1993) and Fenart, Auger and Snieg in France (1993). The results from all this work have enabled manufacturers (e.g. Valadez 1991), Bird 1993), in cooperation with enterprising plant operators, to refine sawblade-guide system and markedly reduce saw kerf width. In order to avoid wetting, Pleau and Love (1993) have designed and introduced a dry low-friction guide in Eastern Canadian sawmills and Nishio (1993) is investigating air-fed guides, which unfortunately are subject to instability (hammering) problems.

Reducing Saw Kerf Width

Reducing width of saw kerf is an obvious and important goal, but not a simple matter, because it conflicts with other goals of sawing as discussed in general terms earlier. It should also be noted that if a saw is so thin that it tends to wander, surface accuracy suffers, and wood may be lost in flattening the sawn surface. With very thin blades, secure attachment of braised teeth is a problem. I do not see prospects of much advance beyond the present frontiers explored by a few companies such as the California Cedar Products Company and some operators of spline arbor saws, which are operating well beyond common practice.

One question needing closer technical and economic investigation is, which kind of saw is potentially capable of cutting the thinnest kerf under practical conditions? Currently circular saws appear to lead the field. However, frame and band saws appear to have the potential for narrower kerfs because they can be tensioned by external force and the toothline span between guides can be less. Mechanically, frame saws can probably have the narrowest kerf, but because of their reciprocating action, are relatively slow. Hence practically, band saws have, I think, potentially the narrowest kerf, and as raw material becomes more
expensive will probably become more common, in spite of their cost. I would like to see evidence to test this conclusion.

Planer/Moulder Heads

Machined surface quality and the costs of subsequent processing and material loss are vitally dependent on head precision, but only recently has such close attentiona been paid to this subject as is now evident in Europe and USA. Heiermann (1993) of the Weinig company in Germany has reported a thorough analysis leading to a diagnostic model relating knife marks and related defects to spindle vibrations. Another manufacturer, SKF, has conducted research on machine performance monitoring and maintenance (Barclay 1992 and Herzog 1992). The University of North Carolina Engineering and Wood Technology departments are co-operating in extensive research on stability of planer and moulder heads (Stewart 1992). Thus much improved guidelines for design, manufacture, selection, operation and maintenance of planers and moulders are becoming available.

TOOL EDGE DETERIORATION

Interest in edge deterioration has been enhanced by increased use of wood composites and laminates, the needs being to maintain surface quality and accuracy and minimize down-time of expensive high-production equipment. The term edge deterioration is used here to include wear, or gradual abrasion, and brittle (catastrophic) failure, that is, crumbling or chipping.

Most attention has been paid to wear as defined above. One problem in monitoring wear is the geometrical definition of wear in relation to performance. Edge radius and edge retraction are still popular measures (e.g. Szymani 1993; Axelsson 1993; Porankiewicz 1993a; Kirbach 1993) in spite of early findings by Pahlitzsch and by McKenzie that clearance loss is better and no more difficult to measure.

In another relatively new field of wood cutting research, aimed at non-contact monitoring of cutting performance, Kato and Lemaster (1991) recorded acoustic emissions (AE) in relation to chip form as the tool dulled, and Tanaka (1991) has reported on the relation between surface quality and AE rate, feed rate and wood texture in sawing. Lemaster and Dornfield (1993) found that, in sanding, AE showed promising sensitivity to wood texture, machining parameters and belt condition. Fuji *et al* (1993), applied pattern recognition methods to the AE record in an attempt to infer significant changes in the dulling and cutting processes. Such studies may well lead to on-line monitoring of edge deterioration.

Knowledge of the mechanisms of wear at operating speeds has been greatly advanced by the work of Stewart (1991) and (Stewart *et al* 1993) showing that, at the high temperatures associated with normal speeds, electrolytic corrosion involves products from breakdown of wood constituents, considerably accelerating wear. Porankiewicz *et al* (1993) also found similar processes in machining melamine laminated particle board.

Wear tests of new tipping materials are continuing. Kirbach (1992) found some stellites to be much more durable than tungsten carbide in cutting green lumber. Szymani and Trinchera (1993) found Tantung, a cast alloy containing cobalt, chromium, tungsten, columbium and carbon to wear at half the rate of tungsten carbide. Clarke (1993) of de Beers cited particular cases where polycrystalline diamond (PCD), in spite of high first cost, has greatly reduced operating costs because of its much longer run times in sawing, moulding and

drilling laminated particle board, medium and high density fibre board and even plywood. Even greater savings and wider applicability are promised by efforts to use relatively thin layers of PCD, embedding PCD slices within tungsten carbide tips and vapour deposition of very thin layers of diamond. In testing the durablity of these very hard tipping materials wear cannot serve as the only criterion because in practice brittle failure or some other factor may become limiting. Nevertheless, one of the few workers reporting research on brittle failure is Porankiewicz (1993b) in Poland, who has examined the relationship between sand size classes in particle board and incidence of catastrophic failure.

The difficulty of attaching tips or coatings securely to the tool substrate is a formidable impediment to success with this approach, particularly for narrow-kerf sawing. C. Kato (1991) has demonstrated the benefits of attaching a very thin layer of chromium to a steel tool, but the problems of attaching a layer of new durable materials to tungsten carbide remain.

NOISE

Government regulation has stimulated increased research interest in noise produced by cutting tools processes. Kimura (1991) and Rhemrev and Cano (1988) have studied the basic fluid dynamics of noise from teeth, and Berolzheimer and Rhemrev (1993) report substantial reduction in noise produced by ripsaws, crosscut saws and debarkers through changes in head design and speed. In Japan, Hattori *et al* (1992) found that sawblades of a new high-damping material were free from idling noises (singing or screaming).

NEW PROCESSES

New cutting processes have been developed with the aim of overcoming inevitable limitations of conventional sawing, particularly kerf loss and the impossibility of turning sharp corners.

Slicing

In peeling and slicing there is no kerf. Conventional rotary peeling is fast, but with centre chucking of logs, peeling checks are inevitable and thickness limited. Longitudinal slicing machines have been developed in Japan and elsewhere, and can produce thicker material without checks, but they are slow and warping is a problem. Further, as in peeling, knots and grit damage the very sharp edge required, seemingly an insuperable problem in many applications.

Jet and Laser Cutting

Jets and lasers can produce very narrow kerfs, can start cutting within the work-piece, and make sharp turns. However they are costly and energy intensive. Investigation of jet and laser cutting of wood began in the 1960's at the University of Michigan. Water jets have been applied successfully for valuable materials, mainly non-wood, of limited thickness.

Lasers are non-wetting, but blacken the surface. They are used mainly for valuable non-wood materials, but in USA about 100 machines are being used for making die boards and fancy furniture parts and for specialty engraving. Laser cutting devices are being developed at

Michigan State University for obtaining dimension parts from lumber under computer control, taking advantage of their narrow kerf and cornering ability (Manetsch and Huber 1993). Westkamper (1991) found pulse-type laser jets promising, and Kitiyama *et al* (1993) are investigating their use for incising large sections before preservation.

CONCLUSION

Throughout the northern hemisphere in the last seven years there has been active research in many aspects of sawing and machining technology, aimed at increasing product quality, reducing waste and reducing costs of material, operation and maintenance. These aims are just as relevant for Australian wood industries, but in general will not be achieved here without local research and development effort.

I would emphasize the desirability of the following lines of research and development:

- Extension of the Scrimber process to produce large structural members to replace imports.
- Development of systems for precise narrow-kerf sawing in both primary and secondary operations to conserve timber resources, in conjunction with development of instruments, tools and saw guide systems for local use and export.
- Durable coatings adequately integrated with the substrate, will prove to be a necessary ingredient in obtaining narrower saw kerfs.
- Development of durable tipping materials for processing difficult woods of Australia and Asia.

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EQUILIBRIUM MOISTURE CONTENTS OF TIMBERS COMMONLY USED IN WESTERN AUSTRALIA

Gary K. Brennan and Judith A. Pitcher
Department of Conservation and Land Management, Harvey W.A. 6220

ABSTRACT

An equilibrium moisture content (EMC) survey was undertaken throughout Western Australia over two years. A range of species commonly used in W.A. was assessed indoors and outdoors (under cover) in locations ranging from the Kimberleys to the South Coast. Species assessed at all sites were ; jarrah, karri, Tasmanian blue gum, radiata pine and Douglas fir. EMC curves of the different species closely follow the EMC curves based on ambient conditions, indicating how sensitive timber is to changes in the ambient conditions of the surroundings. Mean EMCs of the five species exposed to indoor conditions were lower than the EMCs for outside conditions at a given location, except Karratha where the indoor EMC was 0.3 per cent higher. Seasonal variations occur in the moisture content of timber in normal use as furniture and panelling and that this will be accompanied by an approximately proportional change in dimension. Furniture should be designed to allow some movement due to shrinkage and expansion of timber components.

INTRODUCTION

Problems can arise when a wood product is used in widely varying humidity and temperature conditions, if the design and application of that product have not anticipated changes in dimension. For satisfactory performance of timber in-service, it is essential to use timber with moisture contents close to the EMC in use. Shrinkage can result in checking and warping of timber, and swelling in humid conditions can result in jammed doors and windows and buckled table tops.

This paper presents results of an EMC survey which was undertaken throughout Western Australia over two years. A range of species commonly used in W.A. was assessed indoors and outdoors (under cover) in locations ranging from the Kimberleys to the South Coast. A detailed assessment of data will be made, but this paper discusses the moisture content variations in specimens of the five species which were located at all sites. Detailed data analysis will subsequently be carried out and reported in a journal article. The aim of this trial was to collect information on moisture contents of timbers used in different areas of W.A., which could assist timber suppliers.

MATERIALS AND METHODS

Exposure sites and timber species

The following geographic areas of Western Australia were selected;

North to South : Kununurra, Broome, Karratha, Geraldton, Perth (Como), Harvey, Busselton, Manjimup and Walpole

West to East : Narrogin, Kalgoorlie and Esperance.

These locations were selected because district or regional offices of the Department of Conservation and Land Management (CALM) were situated there and had staff and facilities to conduct this trial.

Species assessed at all sites were:
Jarrah (*Eucalyptus marginata* Donn ex Sm.)
Karri (*E. diversicolor* F. Muell)
Tasmanian blue gum (*E. globulus* Labill subsp. *globulus)* - W.A. grown
Radiata pine (*Pinus radiata* D. Don)
Douglas fir (*Pseudotsuga menziesii* Mirb.).

At Como and Harvey additional species were assessed, but these data are not presented.

At each site, moisture content was monitored in three replicates of each timber species by weighing specimens at the beginning of each month. A particular set of replicates at each site was cut from the one sample board. Specimens were randomly allocated to exposure sites.

Sample board preparation

Specimens from backsawn boards 750 x 100 x 30 mm cut from the outer heartwood of the log and free of sapwood were assessed for basic density, dried to 12 per cent moisture content then assessed for air-dry density. Boards were dressed to 20 mm then three replicates 200 x 80 x 20 mm were cut from each board. A hole was drilled in one end of each specimen and a cup hook inserted into the hole. Both ends were end sealed with two coats of enamel paint to prevent excessive rates of moisture exchange through the end grain.

Field placement

Specimens used outdoors were suspended by cup hooks in situations which were protected from the weather but offered unrestricted air-flow, e.g. under verandas or in open sheds. Indoor specimens were also suspended by cup hooks in air conditioned or heated offices. Records of ambient conditions in the office were taken. Specimens were weighed to an accuracy of 0.1 g on the first working day of each month for a period of two years, although some locations did not provide full data.

Meteorological data

Meteorological data for the duration of the study, including monthly rainfall, 12.00 pm temperature and relative humidity and evaporation figures (if possible) were obtained for each site from CALM District Offices or Bureau of Meteorology records. Indoor conditions of temperature and relative humidity, and the duration of air-conditioning or heating were obtained from District Offices. EMCs based on meteorological data were calculated using an equation given in Simpson (1971).

Determination of moisture content

A 30 x 30 x 100 mm piece was cut from the end of each sample and oven dried to determine moisture content. The mass of the residual piece was then taken and the subsequent changes in mass over the trial period were compared to the initial weight (measured at the time of assessing initial moisture content) at a known moisture content and used to give an indication of moisture content variation. At the completion of two years assessment, specimens were returned to the Wood Utilisation Research Centre (W.U.R.C.) in Harvey, where the whole specimen was oven dried. For the denser species up to two weeks drying was required to achieve a stable mass. The oven-dry mass and monthly weighting for each specimen allowed the exact determination of moisture content at each assessment. These moisture contents were compared to those determined during the trial, based on the moisture content of the 30 x 30 x 100 mm section.

RESULTS AND DISCUSSION

Results and discussion will centre on only the species assessed at all sites, that is jarrah, karri, radiata pine, Douglas fir and Tasmanian blue gum. Results for Broome and Kununurra are not given as only eight months data are available.

Effect of density

Basic and air-dry densities of specimens assessed at all sites are listed in Table 1.

TABLE 1. BASIC AND AIR-DRY DENSITIES OF SAMPLES ASSESSED AT ALL SITES

Species	Basic density			Air-dry density			Sample Size
	Mean	S.D.	Range	Mean	S.D.	Range	
Jarrah	647.2 (658)	22.2	602.1 - 682.3	840.5 (823)	34.7	774.7 - 901.6	24
Karri	732.5 (695)	18.9	676.3 - 756.0	967.0 (905)	26.1	908.6 - 1003.5	25
Douglas fir	-	-	-	531.7	41.8	465.4 -	24
Radiata	(372)			(449)		642.5	
pine	435.7	34.9	377.8 -	520.0	33.1	467.5 -	25
Tasmanian	(485)		523.8	(593)		599.7	
blue gum	-	-	484.0 -	813.0	24.4	768.6 -	24
	(561)	29.7	634.0	(790)		867.1	

Figures in brackets are the species average given by Kingston and Risdon (1961). Air-dried densities are before reconditioning.

Specimens for Douglas fir and Tasmanian blue gum were obtained from dry timber, therefore basic densities were not measured. Basic density figures for these two species are from Kingston and Risdon (1961).

Standard deviations and ranges indicated a large variation in basic and air-dry densities which is consistent with the results given by Kingston and Risdon (1961), and considered representative of these timber species.

EMC survey

Table 2 lists the mean monthly EMCs of specimens assessed at all sites throughout W.A. (outdoors and indoors) over a two year period, indicate the likely maximum and minimum EMCs that can occur. Results for Kununurra and Broome are not given as only eight months of data was available. Monthly fluctuations in the EMCs of specimens assessed at Manjimup (a high rainfall area) and Kalgoorlie (a semi desert area) and EMCs based on ambient conditions can be seen in Figure 1.

Outdoor EMC

The EMC curves of the different species in most cases closely follow the EMC curves based on ambient conditions, indicating clearly how sensitive timber is to changes in the ambient conditions of the surroundings. EMCs in the south-west locations showed the greatest seasonal fluctuation, for example Manjimup had summer EMCs from 10 to 13 per cent and winter EMCs from 16 to 19 per cent (Figure 1).

Kalgoorlie (a Goldfields town with annual rainfalls between 150 mm and 300 mm) had a mean EMC for all species of 5.9 per cent, which is 4.2 per cent lower than the next highest EMC (Busselton and Esperance) and 8.5 per cent lower than the EMC for Manjimup. Kalgoorlie had exceptional high rainfall in March, April, May and June 1992, with 3.5 times the average for those months, giving a higher EMC than the expected long term figure. Lamond and Hartley (1991) report that in the very dry western areas of New South Wales, such as Broken Hill, timber will dry down to approximately 7 per cent moisture content during summer.

Manjimup and Walpole's EMCs are similar and the highest recorded in this trial. High mean annual rainfall (between 1000 mm and 1040 mm) and high humidities (mean 9 am R.H. of 75 per cent) would result in high EMCs.

Indoor EMC

Indoor conditions are not as predictable as outside conditions because of varying forms of heating and circulation that are encounted (Orman 1955). However in many situations ambient conditions can be constant due to modern air-conditioning and central heating as occurs in large office buildings. Generally the EMCs of indoor specimens show less seasonal fluctuations than the outdoor specimens, as shown for Manjimup and Kalgoorlie.

The Kalgoorlie indoor samples had the lowest range in mean EMCs between species of 1.6 per cent, while Manjimup and Walpole the highest, with 3.5 per cent and 3.7 per cent respectively. Finighan (1966) showed that there is a distinct tendency for indoor values (non-centrally heated houses) to be 1 to 4 per cent lower than the outdoor values, depending on the microclimatic conditions.

Mean indoor EMCs varied from Kalgoorlie ; 5.6 per cent and Karratha ; 6.1 per cent to Narrogin ;10.9 per cent and Walpole ;11.8 per cent. Specimens at Kalgoorlie and Karratha were stored in air-conditioned environments, whereas Narrogin and Walpole had no air-conditioning. Perth had a constant indoor EMC of 10 .3 per cent. Lamond and Hartley (1991) reported that in air-conditioned buildings timber should be seasoned to about 10 per cent. Timber dried for the higher outdoor EMCs is not appropriate for use in indoor air-conditioned environments and the timber should be strip stacked within the air-conditioned environment prior to fixing.

Variation between species

Although the EMC of certain species for any specific set of psychometric conditions is often found to be approximately the same, the rates of moisture movement for these species often differ very markedly. This phenomenon of varying rates of absorption cannot be due solely to climatic differences, but other features such as the degree of heating, ventilation and sheltering and the density of the timber. Because of the greater response of some timbers than others, the maximum and minimum figures vary considerably for fluctuating conditions. The mean EMCs for jarrah, karri and radiata pine were higher than Douglas fir and Tasmanian blue gum in both outdoor or indoor situations. This survey indicates that species EMCs may vary by more than two per cent, both indoors and outdoors, for a given location and time. Hardwoods usually possess a lower mean EMC than softwoods, though exceptions do occur (Orman 1955). Hartwig (1959) found the EMC of eucalypts was significantly higher than that of the pines when the minimum values only were compared. However when the mean values were examined, no significant difference in EMC was found between the eucalypt and pine specimens.

Practical aspects of the results

EMC and seasonal changes in moisture which have so far been discussed and the results illustrated by curves would be of no practical importance but for the shrinkage and swelling which accompanies them. Seasonal variation must be expected to occur in the moisture content of timber in normal use as furniture and panelling, and that this will be accompanied by an approximately proportional change in dimension. The shrinkage or expansion of wood in common use can be minimised by choosing, as the moisture content at manufacture, the mean of the extreme values of the range of seasonal variation. Furniture should also be designed to allow some freedom for shrinkage and expansion of timber components.

In certain types of products, shrinkage may be a more serious matter than expansion, or alternatively the most appropriate moisture content for the timber at manufacture should tend towards the lower or higher extremity rather than to the mean value. In these cases it is necessary to leave the actual choice of moisture content to the manufacturer, to be decided according to the requirements of his product.

Bootle (1983) referred to an inverse relationship between the EMC and the density of a timber. That is the lower the density, the higher the EMC and the faster the rate of moisture exchange however, they have an appreciably lower movement (shrinkage or swelling) per one per cent change in moisture content. This advantage over the dense

timbers tends to be counterbalanced by their greater short-term susceptibility to large moisture content movement through greater sensitivity to humidity variations.

Perth, the south-west locations and the coastal towns of Geraldton and Esperance have higher outdoor EMCs than Karratha and Kalgoorlie. Difficulty may be experienced in supplying seasoned timber from Perth and the south-west to these areas of lower EMC. In such cases it is recommended that the seasoned timber should be allowed to come to the specified EMC for its in-service location. This could be done by strip stacking the timber under shelter for two to four weeks prior to fixing. This is particularly important with flooring and joinery timber. In the case of timber going from lower EMCs to higher EMCs e.g. from Perth to Manjimup, Walpole or Albany, allowances must be made for swelling.

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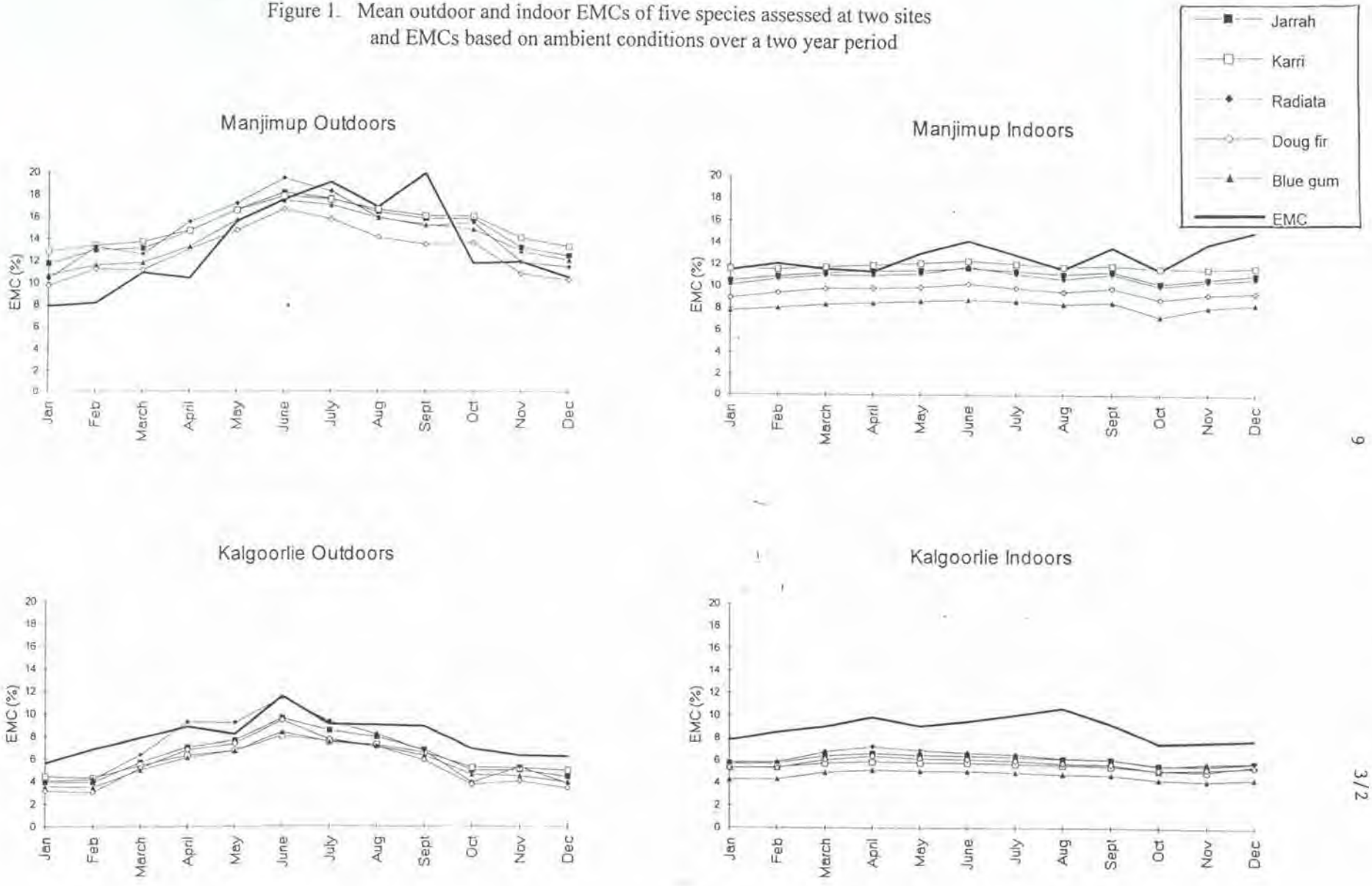
Table 2. EMCs of samples assessed at all sites throughout W.A. (outdoors and indoors) over a two year period

Site	Jarrah			Karri			Radiata pine			Douglas fir			Tasmanian blue gum			Combined species		
OUTDOORS	Mean	Range	SD	Mean	Range	SD	Mean	Range	SD	Mean	Range	SD	Mean	Range	SD	Mean	Range	SD
Karratha (22)	6.4	4.1-9.3	1.2	5.6	3.9-8.1	1.1	6.3	2.9-11.5	2.0	5.6	2.8-9.6	1.5	5.3	3.2-7.7	1.1	5.8	2.8-11.5	1.5
Geraldton (17)	11.8	9.6-13.2	0.8	12.4	11.3-13.4	0.6	12.3	8.6-14.2	1.3	11.4	8.9-12.9	1.0	10.6	8.8-12.5	0.7	11.7	8.6-14.2	1.1
Perth (24)	11.8	8.6-15.0	1.9	10.5	7.6-13.1	1.5	10.7	6.6-14.6	2.4	9.5	5.9-13.2	1.9	9.4	7.1-12.5	1.6	10.6	5.7-15	2.1
Harvey (27)	13.4	10.1-17.7	2.5	13.2	10.6-16.8	2.1	12.3	5.1-20.6	3.6	10.7	5.0-16.1	3.3	10.3	5.2-16.7	3.9	12	5.0-20.6	3.4
Busselton (26)	10.9	6.4-14.7	2.2	10.3	7-13.4	1.7	10.9	5.6-17.8	2.9	9.0	3.8-13.6	2.3	9.5	5.6-13.8	2.3	10.1	3.8-17.8	2.4
Manjimup (20)	14.9	10.2-18.3	2.1	15.2	12.5-17.9	1.7	14.7	7.7-19.8	2.8	12.9	8.8-16.9	2.2	14.0	9.2-17.8	2.4	14.4	7.7-19.8	2.4
Walpole (24)	15.4	13.1-17.8	1.2	15.2	11.9-17.6	1.2	15.0	12.0-18.2	1.7	12.4	10.3-14.6	1.2	13.1	10.8-15.2	1.1	14.2	10.3-18.2	1.8
Narrogin (23)	13.0	9.6-17.6	2.4	11.8	8.9-15.4	2.0	12.2	7.3-18.3	3.2	10.8	7.1-15.3	2.4	10.6	7.2-15.0	2.4	11.7	7.1-18.3	2.7
Esperance (24)	11.0	8.6-12.6	0.9	10.3	8.8-11.5	0.6	11.0	8.2-13.4	1.3	8.9	6.3-10.7	1.0	9.1	6.6-10.6	0.9	10.1	6.3-13.4	1.3
Kalgoorlie (26)	6.2	3.4-9.6	2.0	5.9	4.2-8.4	1.4	6.6	1.4-11.8	2.9	5.4	1.9-9.7	2.3	5.4	2.9-8.6	1.8	5.9	1.4-11.8	2.2
	11.5	3.3-18.3	3.6	11.0	3.9-17.9	3.5	11.2	1.4-20.6	3.8	9.6	1.7-16.9	3.2	9.7	2.7-17.8	3.3			
INDOORS																		
Karratha (22)	6.9	5.5-7.9	0.7	5.9	4.7-8.1	0.8	7.1	4.5-8.6	0.9	5.6	3.9-7.2	0.8	5.0	3.9-6.0	0.6	6.1	4.0-8.6	1.1
Geraldton (17)	10.5	9.4-11.2	0.4	10.2	9.3-11.5	0.5	10.1	8.1-11.2	0.7	8.4	6.7-9.4	0.6	8.2	7.3-8.7	0.3	9.5	6.7-11.5	1.1
Perth (25)	10.3	8.7-11.7	0.7	10.6	8.7-12.0	0.8	9.7	7.5-11.6	1.0	10.3	7.7-12.1	1.1	8.8	7.4-10.0	0.7	10.3	7.4-13.3	1.2
Harvey (27)	11.8	10.0-13.7	0.9	11.5	10.1-13.0	0.7	10.8	5.5-13.0	1.5	8.7	5.1-11.2	3.3	8.4	6.1-10.9	2.1	10.2	5.1-13.7	2.1
Busselton (26)	9.6	7.3-12.0	1.0	9.2	7.5-10.4	0.7	9.5	5.6-12.6	1.3	7.8	4.8-10.2	1	8.2	6-10.8	1.1	8.8	4.8-12.6	1.3
Manjimup (20)	11.2	10.1-11.9	0.4	11.9	11.2-12.4	0.3	10.9	9.9-12.0	0.5	9.7	8.6-10.6	0.5	8.4	6.6-9.0	0.4	10.4	6.6-12.4	1.3
Walpole (24)	13.9	11.4-18.0	1.5	12.3	10.0-14.9	1.1	11.4	8.3-16.1	1.8	10.2	7.7-14.1	1.5	11.1	9.1-14.1	1.2	11.8	7.7-17.6	1.9
Narrogin (23)	12.6	9.3-16.5	2.3	11.4	9.0-14.1	1.6	10.9	6.4-15.6	2.7	9.9	6.5-13.7	2.2	9.7	6.5-13.6	2.2	10.9	6.4-16.5	2.5
Esperance (24)	9.4	7.8-11.1	0.7	8.8	7.3-10.1	0.6	9.0	7.1-10.9	0.9	8.3	6.9-10.	0.7	7.2	5.7-8.5	0.6	8.6	5.7-11.1	1.0
Kalgoorlie (26)	6.0	5.1-7.4	0.5	5.5	4.8-6.7	0.5	6.2	5.0-7.9	0.7	5.7	4.8-7.0	0.6	4.6	3.8-5.8	0.5	5.6	3.8-7.9	0.8
	10.2	4.9-18.0	2.6	9.7	4.7-14.9	2.5	9.5	4.5-16.1	2.2	8.5	3.9-14.4	2.1	8.0	3.7-14.1	2.3			

Note: Number of months assessed are given in brackets

Data from Kununurra and Broome are limited and therefore not given.

Figure 1. Mean outdoor and indoor EMCs of five species assessed at two sites and EMCs based on ambient conditions over a two year period



TIMBER DRYING AND ACOUSTIC EMISSION

James Booker
University of Tasmania
PO BOX 252C, Sandy Bay, Tasmania 7005

ABSTRACT

Tasmanian eucalypt boards are particularly prone to surface checking during seasoning. The acoustic emission (AE) generated during drying in surface checked backsawn and quartersawn Tasmanian eucalypt boards was investigated. A detailed examination of the processes involved in surface checking is described in this paper. The onset of surface checking in backsawn and quartersawn boards dried at room temperature was successfully related to a particular level of AE activity.

INTRODUCTION

AE are the stress waves generated in a solid material under load when localised events such as plastic deformation processes or the growth of flaws redistribute the local stress field. AE are detected with a very sensitive accelerometer or transducer clamped to a specimen surface. During timber seasoning differential shrinkage between the rapidly dried surface of a board and the saturated internal regions causes surface tensile stresses and balancing internal compressive stresses. These stresses generate AE.

AE in timber has typically been attributed to the sudden extension of microfractures, Debaise et al. (1966), Adams (1969), Honeycutt et al. (1985). Rice and Skaar (1990) reported that differences in behaviour in AE detected in green and drying wafers under transverse bending supported the proposition that a major cause of AE in drying wood was shrinkage at the cellular level. Dinwoodie (1968) observed the sequential development of different types of dislocations in spruce specimens compressed parallel to the grain. The slip planes were regarded as a crinkling of the fibrils comprising the cell walls. Dinwoodie (1966) reported that slip planes had also been detected to a limited extent in timber subject to shear and tension parallel to the grain.

Based on Dinwoodie's studies, it was hypothesised that crystalline slips within fibre walls also occurred during tension across the grain and that such slips were the source of the AE recorded during seasoning. Stress release events also occur in the amorphous regions of the cell walls and within the middle lamella between cells but these are not expected to be sufficiently energetic to trigger the transducer. Siau (1984) reported that the cellulose content of normal wood of softwoods and hardwoods is remarkably constant at 42±2% by mass. Further, the cellulose is between 40 and 50% crystalline by mass. On this basis, it was predicted that the AE in drying eucalypt specimens would be independent of the direction of sawing. In other words, the AE was thought to be a fundamental property of the structure of the cell walls and independent of the bulk material properties.

The AE seasoning research reported in the literature has focused on the feasibility of developing an automatic kiln that controls the severity of the drying conditions based on the AE generated in sample boards, Becker (1982), Honeycutt et al. (1985), Noguchi et al. (1987). If a characteristic AE parameter, the AE checking threshold, were related to the onset of surface checking, the kiln conditions could be ameliorated when the AE approached this threshold during drying. In this manner, the drying process could be performed without the development of seasoning degrade.

Surface checks form on board surfaces to relieve the stress field when crystalline slips alone are not sufficient to reduce the stress field. No matter how small the incipient check, the stress concentrations at the tips drive them both along and into the board with further drying, resulting in cracks running the full length of boards. Clearly, if boards are to be seasoned without degrade, check initiation must be prevented. Therefore, it is critical that an AE parameter be related to check *initiation*.

A literature review revealed that no AE parameter had been successfully related to incipient check formation. Only Quarles (1992) reported the dimensions of the surface checks observed. It appears researchers have not considered a board to be checked until the checks are visible to the naked eye. Early trials revealed that checks were as small as 1mm long and were visible only with a 10-times magnifying glass, especially when the board surface was relatively rough and contained many upturned fibres. Noguchi et al. (1987) painted conducting material on drying *Zelkova serrata* disks to detect surface checking when the paint was broken by an underlying fracture. It is likely the paint would stretch slightly when a particularly small fracture formed underneath and thus would not represent check initiation. If the check formed some distance from the paint, significant AE would be recorded before the conducting material was broken. Quarles

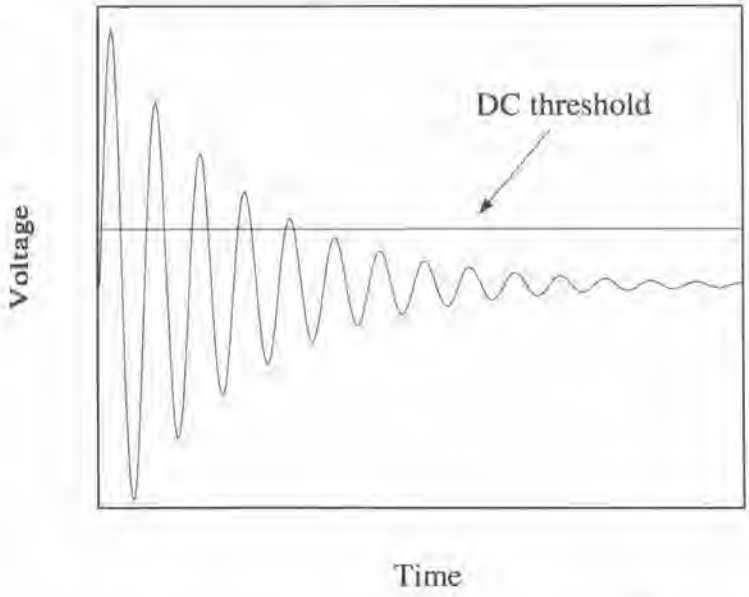
(1992) employed a video camera to detect check initiation, playing back the recorded video tape to relate the formation of incipient checking to a particular AE level. However, it is likely the resolution of the video camera alone without magnification would be insufficient to detect checks as small as 1mm long in the rough surface of a board.

On this basis, check initiation was detected manually by continuously scanning the board surface with a 10-times magnifying glass. Examination of surface checked boards at a sawmill revealed large checks propagating into the boards directly perpendicular to the wide surfaces. Therefore, the boards were viewed from directly above with the glass.

MATERIALS AND METHODS

AE Data Acquisition

AE was detected using Physical Acoustics R6I transducers clamped to rough sawn board surfaces. Petroleum jelly was used as a transmission couplant between the board surface and the transducer wear plate to limit signal attenuation. Sudden energetic changes in the local stress field near the transducer cause the undamped wear-plate to ring at its natural frequency, giving an output that was typically a decaying sinusoid. The transducer converts these surface oscillations into an electrical signal. The amplified output is compared with a preset DC threshold voltage and a digital counter is incremented each time the output exceeds the threshold. The total number of threshold crossings during a 15 second data period is accumulated and expressed as an AE rate. This data analysis technique is the common "ring down counts" method. The figure above represents the idealised transducer response to an AE



"event". The transducer output exceeds the threshold five times, corresponding to an AE rate of 5 counts.

Kline (1983) reported that ring-down counts were related more closely to the energy of the acoustic emission than any other parameter. On this basis, surface check initiation was expected to be related to AE rate rather than cumulative counts (the cumulative ring down counts over the period of the test). Noguchi et al. (1987) reported that cumulative counts were not significantly related to surface checking in *Z. serrata* disks. However, these tests typically lasted less than 24 hours whereas eucalypt seasoning generally takes at least a month. It was plausible that over a sufficient period of time, the cumulative affect of a large number of insignificant stress release events might cause material failure.

Crystalline slips are expected to be intermittent, energetic rearrangements of the local stress field. Examination of a typical AE response detected (Figure 2) in a drying eucalypt board reveals intermittent bursts of energy release, followed by periods of relatively low AE until the next burst. The bursts represent effective stress release occurring in fibres across the whole board width, whereas the periods of relatively low AE levels represent isolated bundles of fibres experiencing stress release. The AE is generated immediately drying commences, meaning AE is not due to the extension of surface checks but is generated by stress release events preceding surface checking. However, once a surface check forms, the strain energy released by propagation produces significantly more AE than that released through slips.

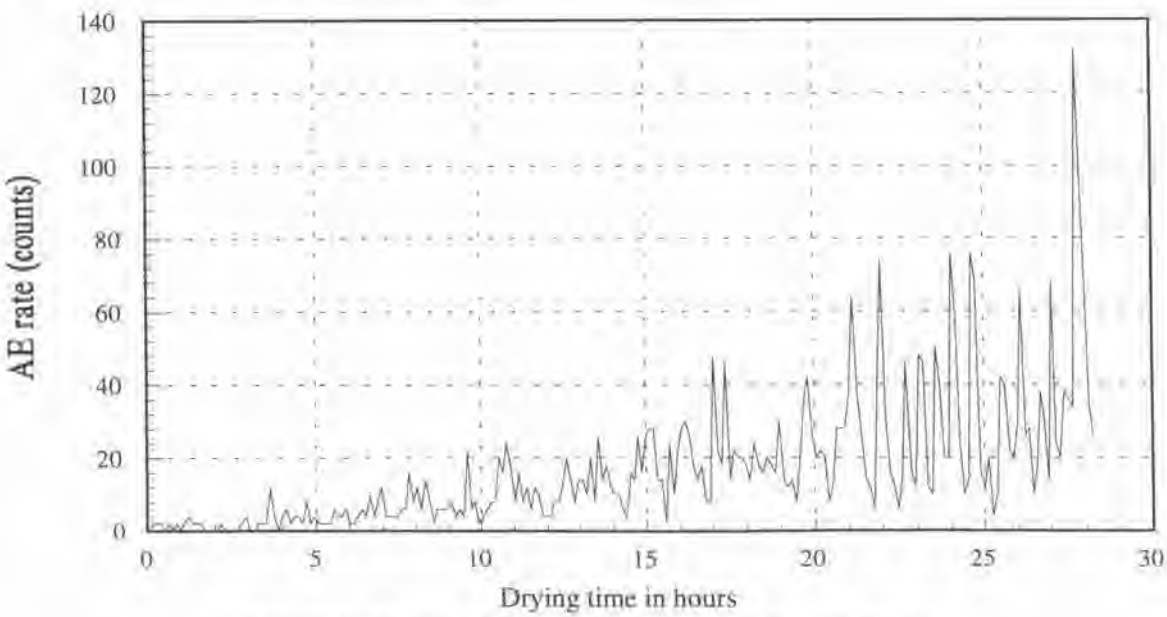


Figure 2. Typical AE response detected during drying

Determining the AE Checking Threshold

A batch of clear, backsawn mature *Eucalyptus regnans* boards was obtained from a sawmill and block-stacked and wrapped in plastic. The boards were processed into 250 x 120 x 30mm specimens. A nominal checking threshold was selected. The AE transducer was clamped to the centre of a green specimen dried at room temperature. The board surface immediately surrounding the transducer was periodically observed with the magnifying glass. With experience, incipient checks were relatively easy to detect in backsawn boards as the moisture beneath the surface was exposed by the fracture and the check appeared as a wet, dark line. If surface checks were observed prior to the AE attaining the preselected checking threshold, a new test was commenced. The preceding maximum AE level was assumed to correspond to check initiation. The transducer was clamped to a new green sample and the process repeated with the decreased checking threshold. Eventually, the AE attained a particular level without surface checks forming. This test provided a lower bound on the checking threshold, while the previous tests provided an ever-decreasing upper bound.

RESULTS AND DISCUSSION

Using this strategy, it was determined that surface checks were not observed in these backsawn eucalypt specimens until the AE rate exceeded 100 counts per 15 seconds. Backsawn boards were obtained from five more trees and further drying tests performed at room temperature revealed surface checks were only observed after the AE rate exceeded 100 counts per 15 seconds. Given the inherent variability of timber within species and even within the one tree, this repeatability was strong evidence that the AE was related to slips within the crystalline cellulose of fibre walls.

Trials to determine the checking threshold in quartersawn material were commenced. It was soon apparent that the threshold was significantly higher than in backsawn material, with AE rates as high as 300 counts per 15 seconds being recorded in boards free of surface checking. This lead to a detailed examination of the behaviour of surface checks.

Schaffner (1981) used a scanning electron microscope to examine drying checks in *E. delegatensis* specimens. Schaffner reported that "checks appeared to start at vessels and propagate in the radial direction, parallel to the rays but not necessarily along them". The orientation of the weak, thin-walled rays makes the radial-longitudinal plane the

radially before being arrested when it strikes wood beneath the surface capable of resisting the applied stress and the stress concentration at the check tip without further propagation. In the backsawn boards, propagation is aligned with the direction of initiation but in perfectly quartersawn boards, the two directions are perpendicular. In the quartersawn boards, the checks change direction when the tensile stress field grows sufficiently to overcome the tendency for checks to travel through the weaker radial plane. It was assumed that this would occur soon after initiation.

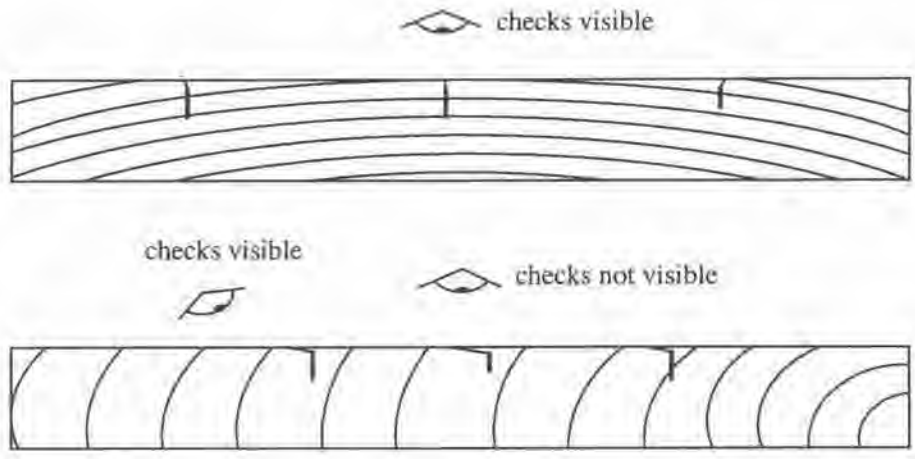


Figure 3. Surface checking in backsawn and quartersawn boards

However, it was realised that considerable drying may be required before the surface tensile surface stress was sufficient to drive the checks perpendicular to the surface. Incipient checks in quartersawn material would only be visible when the board was orientated so that one was looking directly radially or perpendicular to the growth rings. The previously "unchecked" quartersawn boards were re-examined in this manner and surface checks travelling almost parallel to the surface were detected. The checks were invisible when viewed from directly above. This is shown diagrammatically in figure 3, where incipient checks are drawn thin and propagating checks are drawn bold. Checks in backsawn boards propagate directly perpendicular to the surface and are readily visible, whereas the checks in the quartersawn board propagate radially and are not seen from above. Examination of boards at the sawmill revealed air-dried quartersawn boards with radial surface checks propagating significant distances into boards without propagating perpendicular to the surface. It appears the surface stresses during air drying are often insufficient to drive checks directly into boards whereas kiln dried boards typically contain checks travelling directly into the board.

Further tests on green quartersawn specimens cut from other trees revealed that surface checks formed in the quartersawn eucalypt boards at the 100 count AE rate. This proved that the AE rate was independent of the bulk material properties such as density, stiffness and ultimate stress.

The cumulative counts at failure however were dependent on the bulk material structure. The cumulative counts in the backsawn material was typically twice to four times the cumulative counts measured in quartersawn material at failure. Dinwoodie (1968) reported slip planes developed preferentially in that part of the tracheid in contact with a ray. The ray is contorted at this point and acts as a natural stress concentration site. In tangential boards, the weak, thin-walled medullary rays are subject to tensile stresses whereas in the quartersawn boards, the rays are parallel to the surface stress and thus are not expected to contribute significantly to the measured AE rate. The cumulative counts in backsawn material would be expected to be higher than in quartersawn material.

The AE checking threshold was repeated in backsawn and quartersawn material deliberately dried at room temperature to prevent collapse. In trials performed with backsawn boards at 30°C, collapse occurred in particularly wide earlywood bands near the surface. This collapse shrinkage added to the normal surface shrinkage and localised surface checks occurred directly above the collapsed region before the AE rate exceeded 60 counts per 15 seconds. The repeatable 100 count AE checking threshold is not characteristic of the surface energy required to initiate a crack but represents the combined stress release activity of the fibres surrounding the transducer. During the drying tests, the position of the first surface checks relative to the transducer had no bearing on the AE rate at failure. AE can not be used to prevent surface checking when localised regions of a board surface are subject to higher stresses than the rest of the board. This situation arises when a board contains natural stress concentrations such as knots, as surface checks will initiate at the knot before the stress acting on clear regions attains the ultimate stress.

ACKNOWLEDGEMENTS

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MATHEMATICAL MODELLING OF WOOD DRYING

John W. Sutherland
CSIRO Division of Forest Products
Private Bag 10, Rosebank MDC, Clayton, Vic. 3169

ABSTRACT

In this work computer program WOODRY, developed for the analysis of one-dimensional convective drying of a single board, was extended to cope with varying drying conditions of dry-bulb and wet-bulb temperature and air velocity. The modified program was applied to experimental runs of the drying of *Pinus radiata* timber in order to predict the influence on performance of changing conditions during the drying process. The results indicate that there appears to be potential for lowering energy costs by reducing dry-bulb temperature and air velocity at the expense, however, of some increase in drying time.

INTRODUCTION

During 1992, a new project was added to the Wood Science and Technology program of the CSIRO Division of Forest Products, namely computer-aided wood process engineering. The objectives of the project are to develop an improved understanding of wood during processing through mathematical modelling and computer simulation, and to apply this understanding to solid wood processing operations (particularly drying and preservation) to enable their more efficient and economic application in the timber industry.

As part of this work, the author has developed a one-dimensional mathematical model of the drying from green of a single board in a stream of heated air. The model includes the effects of convection, evaporation, conduction, diffusion and capillarity, and three moisture phases are recognised, namely free (liquid) water, bound (adsorbed) water and water vapour. The heat and mass transfer partial differential equations were solved using the Crank-Nicolson finite difference method and a digital computer program (named WOODRY) was written. The program computes gradients and averages in wood moisture content and temperature at any desired stage of the drying process.

Mathematical modelling of wood drying is vital in gaining an understanding of the physics of the process and in optimisation from thermodynamic and economic viewpoints. Computer simulation readily enables the influence of operating parameters and wood properties to be ascertained for both the design and prediction of performance of drying kilns.

Good agreement was obtained between predictions by program WOODRY and results of experiments on the convective high-temperature drying of Australian *Pinus radiata* timber carried out in the Division some years ago (Northway, 1989). The work was presented at the 3rd IUFRO International Conference on Wood Drying (Sutherland, Turner and Northway, 1992), as a result of which the Division has become actively involved in a world survey of wood drying models.

This paper describes an extension of our computer wood drying model to enable it to handle varying inputs of dry-bulb and wet-bulb temperatures and air velocity. This allows the influence on performance of changes in drying schedules to be assessed.

Northway (1990) has suggested that computer-based mathematical models of the wood drying process have the potential to greatly reduce the difficulty of choosing appropriate drying strategies and equipment, in order to improve performance and reduce degrade and cost.

MATHEMATICAL MODELS

Sutherland, Turner and Northway (1992) developed comprehensive and simplified models for the convective drying of Australian *Pinus radiata* timber. The work showed that two versions of the simplified model had acceptable computation time and sufficient accuracy for engineering purposes, when compared with experimental results obtained by Northway (1989). One of these (Model SM 1) has been further developed to incorporate changes in drying conditions, so that the effect on performance of varying dry-bulb and wet-bulb temperatures and air velocity during the drying process can be determined.

The modified computer program (WOODRY) can handle an initial ramping of conditions followed by a period of constant conditions, then a final ramp before a second uniform period.

RESULTS AND DISCUSSION

The results used in this study apply to the experimental drying runs 2, 3 and 4 as described by Sutherland, Turner and Northway (1992) and shown in Table 1.

TABLE 1. EXPERIMENTAL DRYING RUNS ON AUSTRALIAN *PINUS RADIATA* TIMBER (NORTHWAY, 1989)

Run	Air temp. (°C)		Air velocity (m/s)	Initial wood temp. (°C)	Initial wood m.c. (%)	Basic wood density (kg/m³)
	Dry-bulb	Wet-bulb				
2	125	70	3	20	119	485
3	122	70	8	22	112	484
4	152	67	8	20	113	493

Firstly, the effect of a linear ramp of dry-bulb temperature from 20 to 152°C and wet-bulb temperature from 20 to 67°C over periods of 0.25, 0.5 and 1 h for Run 4 were examined. The variation of predicted average wood m.c. with time is shown in Fig. 1, and after 7 h the values were 11.0, 11.9, 12.8 and 14.6% for ramping times of 0, 0.25, 0.5 and 1 h respectively. The corresponding centre m.c. values were 45.3, 47.5, 49.8 and 54.4% with a surface m.c. of 0.3% in each case. After 1 h of drying, the predicted average temperatures were 90.1, 87.1, 81.3 and 54.7°C for 0, 0.25, 0.5 and 1 h ramping, but after 2 h they became almost coincident (Fig. 2). The final temperature gradient (after 7 h) in each case was from 140°C at the surface to 100°C at the centre, showing that the latter was still above fibre saturation point.

A step change in conditions during the drying process was then investigated. Changing from Run 4 to Run 3 conditions (Table 1) after 4 h resulted in a predicted average m.c. of 18.5% being reached with a reduced temperature gradient (16 compared with 40°C), average temperature (106 compared with 115°C) and moisture content gradient (48 compared with 64%), but with a drying time of 9.5 h instead of 6 h for uniform Run 4 conditions. The time to reach 18.5% for Run 3 conditions was approximately 12 h. As a check on the effect of air velocity, Run 4 conditions were applied for 4 h and then changed to Run 2. It was found that results were similar to the case for Run 3 with the average m.c. after 9.5 h being slightly higher at 19.0%. Hence, reducing air

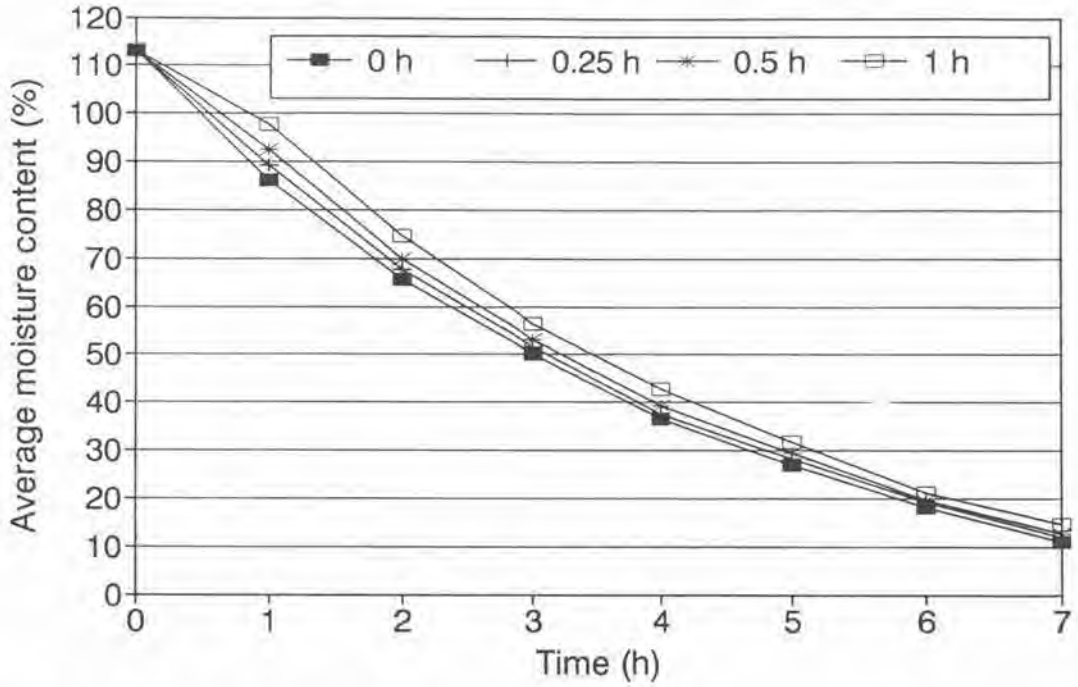

Fig. 1. The effect of initial ramping time on predicted average wood m.c. (Run 4).

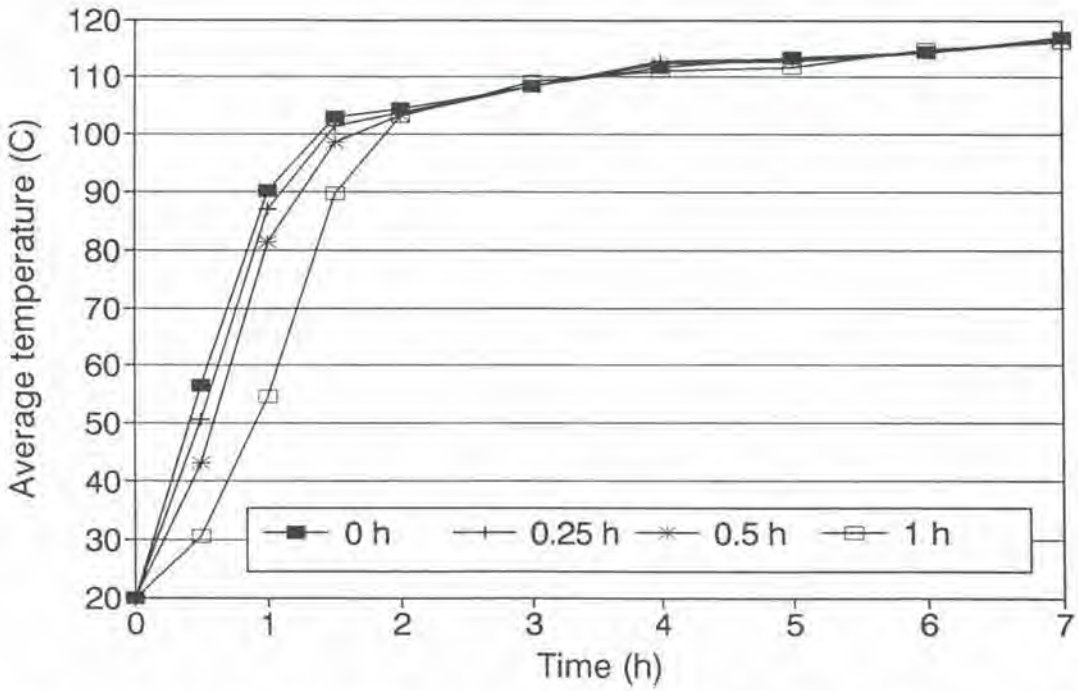

Fig. 2. The effect of initial ramping time on predicted average wood temperature (Run 4).

velocity from 8 to 3 m/s after 4 h does not significantly affect drying performance confirming that the drying rate at this stage depends largely on the moisture movement within the wood. By contrast, the time required to reach 18.5% average m.c. for Run 2 conditions (3 m/s from the start of drying) was 18 h.

If instead of a step change after 4 h from Run 4 to Run 3 conditions, a linear ramping in dry-bulb and wet-bulb temperatures over 4 h is employed, then a predicted average wood moisture content of 18.5% was reached in 6.5 h with a temperature gradient of 25°C, an average temperature of 110°C and a m.c. gradient of 59%. For a step change in air velocity from 8 to 3 m/s after 4 h (before the ramp), only a slight decrease in drying rate was obtained with an average m.c. of 18.5% being reached in 7 h. For the case of an initial ramping of dry-bulb and wet-bulb temperatures over 1 h and then 3 h at Run 4 conditions followed by a ramping to Run 3 conditions over 4 h, an average m.c. of 18.5% was reached in 7.5 h. The variation of predicted average wood m.c. and temperature with time for these three drying schedules is shown in Figs. 3 and 4 respectively.

CONCLUSIONS

Although the model predictions have been validated for constant drying conditions, those for varying conditions have not. However, the results described in this paper indicate the versatility of computer program WOODRY, and it is planned to use it to examine a range of control strategies for softwood drying in terms of performance and economy.

The mathematical model is presently being further refined, and it is a vital component of planned research and development work concerning the on-line computer control of timber drying kilns, which is of great interest to the timber industries of Australia and overseas countries.

ACKNOWLEDGEMENTS

The author is indebted to his colleague, Richard Northway, for many helpful discussions during the course of this work.

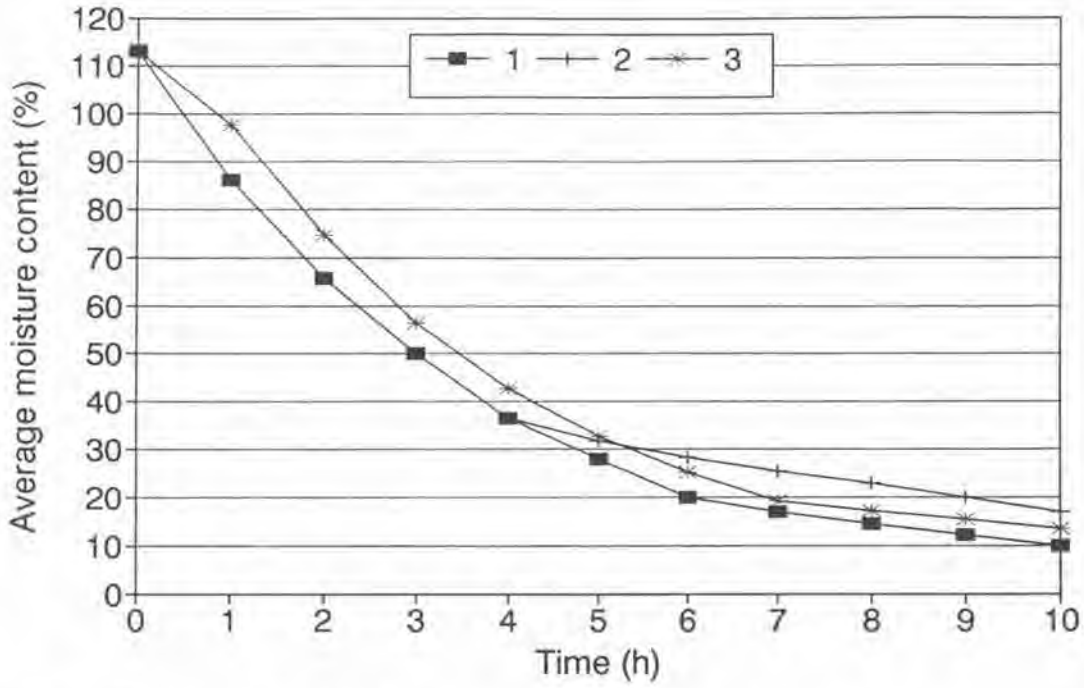

Fig. 3. The effect of drying schedule on predicted average wood m.c. (1: 4 h at Run 4, then ramped over 4 h to Run 3 and 2 h at Run 3; 2: 4 h at Run 4 followed by 6 h at Run 3; 3: Initial ramp of 1 h, followed by 3 h at Run 4, then ramped over 4 h to Run 3 and 2 h at Run 3).

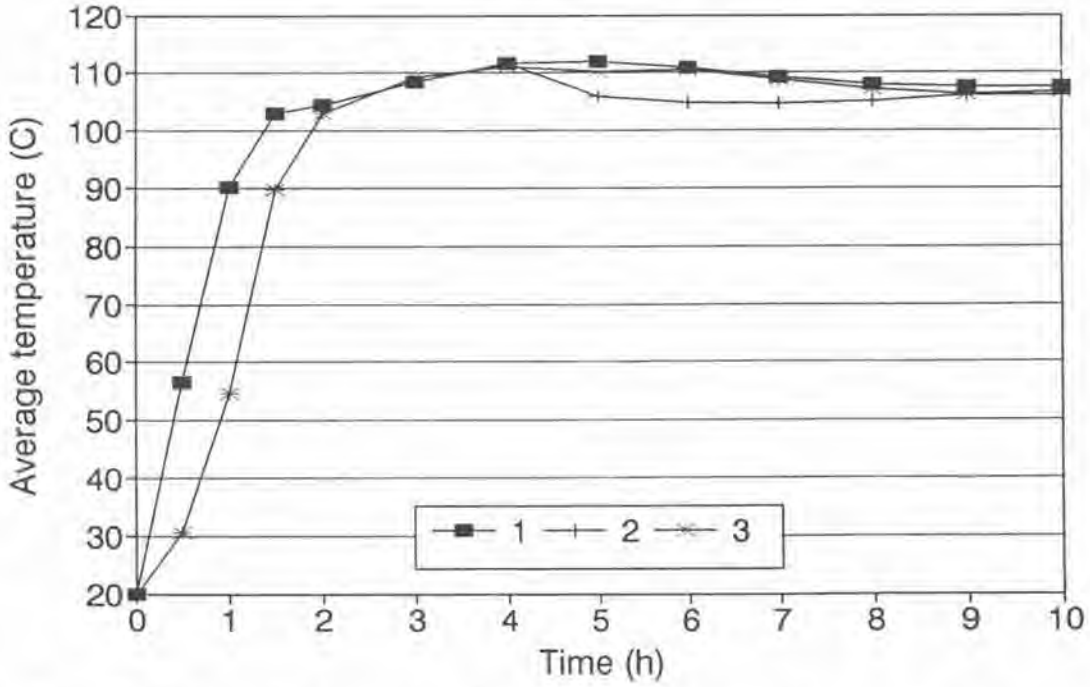

Fig. 4. The effect of drying schedule on predicted average wood temperature (1: 4 h at Run 4, then ramped over 4 h to Run 3 and 2 h at Run 3; 2: 4 h at Run 4 followed by 6 h at Run 3; 3: Initial ramp of 1 h, followed by 3 h at Run 4, then ramped over 4 h to Run 3 and 2 h at Run 3).

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THE EFFECT OF PREHEATING ON COLLAPSE AND INTERNAL CHECKING IN MOUNTAIN ASH

S.C. Chafe
CSIRO, Division of Forest Products,
Private Bag 10, Rosebank MDC, Clayton South, Vic. 3169.

ABSTRACT

Recent results of experiments exploring the effect of preheating green wood on shrinkage, collapse and internal checking are presented. It is suggested that given appropriate temperatures, times and type of treatment, a significant increase in collapse recovery and reduction in internal checking can be achieved.

INTRODUCTION

Heating has been shown to increase permeability and drying rate in wood and reduce the drying time (Campbell 1961; Ellwood and Ericson 1962; Simpson 1975; Gunzerodt *et al.* 1986; Haslett and Kininmonth 1986; Kanawaga *et al.* 1988). Such treatment, however, may reduce the strength of wood (Campbell 1961; Stubenvoll 1985) and increase shrinkage and collapse (Greenhill 1938; Kauman 1961; Haslett and Kininmonth 1986). Increased drying rate has been attributed to conformational changes in heartwood extractives (Kininmonth 1971; Alexiou *et al.* 1990) whereas reduced strength and increased shrinkage are thought to be caused by changes in chemical bonding of cell wall constituents or heat degradation of lignin and hemicelluloses (Kauman 1961; Kubinsky 1971). Haslett (1986) reported that pretreatment in hot water significantly reduced internal checking in red beech but not in hard beech.

In mountain ash, changes in shrinkage and collapse have been found to occur after preheating green material by steaming (Chafe 1990), by boiling water (Chafe 1993) and by varying water temperature and type of treatment (Chafe 1992; 1994). The present paper presents some of these results and illustrates how preheating may assist in increasing collapse recovery and the reduction of degrade.

(1) PRESTEAMING

Matched increment cores were taken from five trees of 48-year-old *Eucalyptus regnans* F. Muell (mountain ash) regrowth and divided into segments *ca.* 30 mm in length. One set of segments was presteamed at 100°C for 30 min and all samples were oven-dried, reconditioned in steam, and oven dried again. Collapse (C) was calculated as the shrinkage recovered after reconditioning, or $C = S_v - S_r$, where S_v = shrinkage before reconditioning and S_r = shrinkage after reconditioning.

Figure 1 shows the distribution of S_v, S_r and C with respect to distance from the stem periphery for control

and presteamed samples. Initial shrinkage (S_v) was almost invariably higher for presteamed samples, as was collapse, while shrinkage after reconditioning was little changed.

It was concluded from this study that while permeability may be increased by the effect of presteaming, such increase is more than compensated for, in terms of collapse reduction, by a reduction in cell wall strength due to heat degradation.

(2) BOILING IN WATER

Matched increment cores, *ca.* 75 mm in length, were taken from seven, 52-year-old trees of mountain ash regrowth and divided into *ca.* 25 mm segments: one outer (sapwood) segment and two inner (heartwood) segments. Segments were separated into nine groups such that one core from each tree was represented in each group. Of the nine groups, one was chosen as a control and the others were assigned boiling times of 0.5, 1, 2, 4, 8, 16, 32 and 64 min respectively. Treatment samples were boiled in water for their assigned times and all samples were oven-dried, reconditioned, and oven dried as in the above presteaming experiment.

Results were expressed as the difference (ΔX) between boiled samples (X) and controls (X_c), or $\Delta X = X - X_c$, and average values were plotted against the time of boiling (logarithmic). In the sapwood, shrinkage before reconditioning (S_v) was less than the control (Fig. 2a) as, generally, was shrinkage after reconditioning (S_r) (Fig. 2b). In the heartwood, however, as in the above presteaming experiment, S_v was higher after boiling and increased linearly with the logarithm of boiling time (Fig. 2a). However, S_r was lower between 2 and 32 minutes and, as in the sapwood, described a highly significant cubic relationship with boiling time (Fig. 2b). The consequence was that recoverable collapse in the heartwood increased markedly after boiling, peaking at around the 16 minute mark (Fig. 2c).

When collapse was expressed as a percentage (C_k) of the difference between shrinkage before reconditioning after each boiling time (S_b) and shrinkage after reconditioning of the control (S_{rc}), or $C_k = 100C/(S_b - S_{rc})$ (Kauman 1961), it can be seen that collapse recovery was increased more than 30% after pre-boiling for times of 8-16 minutes (Fig. 2d).

It was concluded from this study that while boiling green wood increases the amount of initial shrinkage in the heartwood, collapse recovery, and hence the final volume of the seasoned product, can be significantly improved. However, the time of pre-treatment is critical: too short or too long and the amount of recoverable collapse will be decreased (Fig. 2d).

(3) HEATING IN WATER

(a) Increment cores

It was found that when matched, green increment core segments of mountain ash, prepared and processed as in the previous experiment, were heated in water at temperatures of 40, 50, 60, 70, 80, 90 or 100°C for 12 min (considered a probable optimum time as determined from (2) above), shrinkage before reconditioning (S_v) in the heartwood was generally higher than controls (Fig. 3a); shrinkage after reconditioning (S_r) was less and decreased with increasing temperature (Fig. 3b); and collapse (C) was greater and increased linearly with temperature (Fig. 3c). Per cent collapse recovery (C_k) similarly increased with temperature (Fig. 3d) and, at 100°C, indicated a value (ca. 30%) similar to that obtained in (2) (Fig. 2d).

The experiment demonstrated that although reduction in initial shrinkage through preheating proved fairly intractable, the proposition that collapse recovery could be significantly improved was reaffirmed.

(b) Board sections

Matched, flat-sawn, green board-sections, 9 cm in length, from nine trees of mountain ash representing three ages (16, 23 and 31-years-old) were preheated in water at temperatures of 50, 60, 70, 80, 90 or 95°C by three different treatments: (a) gradual heating – placed in water at ambient temperature (20°C), heated to desired temperature and removed; (b) gradual heating-extended – heated as in (a) but, additionally, left in water at the assigned temperature for one half the time it had taken to reach that temperature, and removed; and (c) sudden heating – plunged into water preheated to the assigned temperature, left for the time it had taken to reach that temperature in (a), and removed. Samples were oven-dried, cross-cut at the centre and measured for shrinkage and internal and surface checking by means of image analysis.

Of the three treatments, gradual heating was most effective in reducing external shrinkage (S_v) and internal checking (S_{vi}) (Fig. 4a,b), sudden heating next effective (Fig. 4c), and gradual heating-extended least. Most effective temperatures were 50, 70 and 80°C. Best results were obtained with the youngest material (16-years-old) with reductions in internal checking and total shrinkage ($S_{vt}=S_v+S_{vi}+S_{vs}$) of ca. 4 and 7% respectively (Fig. 4a,b,d). Surface checking (S_{vs}) was generally higher than controls for all treatments.

It was concluded from this experiment that both external shrinkage and internal checking can be reduced through preheating, provided the appropriate times and temperatures can be ascertained. At this stage, gradual heating appears to be the most promising method.

CONCLUSIONS

It is demonstrated here that preheating green mountain ash wood can assist in increasing collapse recovery and reducing internal checking. The mechanisms involved are unknown at this stage although it is probable, in view of previous work, that changed permeability is contributory. Notwithstanding analyses, the average values illustrated here sometimes tend to mask between-tree variability, and it is this variability which must be surmounted if such treatment is to be universally applicable. Further experiments aimed at lessening such variability are underway.

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DESCRIPTION OF FIGURES

Figure 1. Average values for shrinkage before reconditioning (S_v), shrinkage after reconditioning (S_r) and collapse (C) plotted against distance from periphery. Control and presteamed samples.

Figure 2. Average change in (a) S_v, (b) S_r and (c) C after boiling plotted against logarithm of boiling time. Sapwood and heartwood samples. (d) Average change in percentage collapse recovery (C_k) after boiling for the heartwood.

Figure 3. Average change in (a) S_v, (b) S_r and (c) C after heating in water plotted against water temperature. Sapwood and heartwood samples. (d) Average change in C_k after heating in water for the heartwood.

Figure 4. Average change in shrinkage of board sections after heating in water plotted against water temperature. Heartwood. (a) Gradual heating, external shrinkage (S_v). (b) Sudden heating, S_v. (c) Gradual heating, internal checking (S_{vi}). (d) Sudden heating, S_{vi}.

Figure 5. Average change in shrinkage of board sections after heating in water plotted against water temperature. Heartwood. (a) Gradual heating, S_{vi}, age 16 yrs. (b) Sudden heating, S_{vi}, age 16 yrs. (c) Gradual heating, S_{vi}, age 31 yrs. (d) gradual heating, total shrinkage (S_{vt}), age 16 yrs.

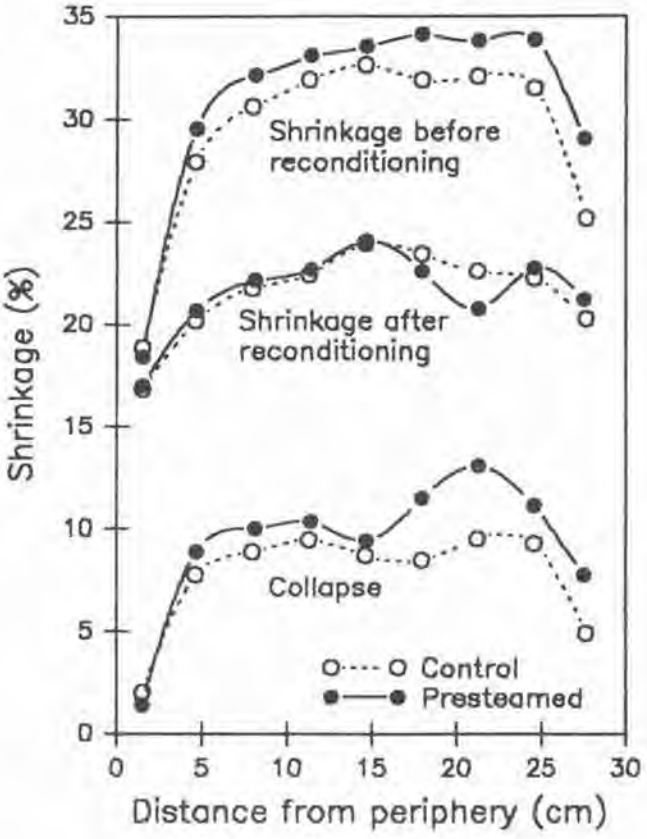

Figure 1

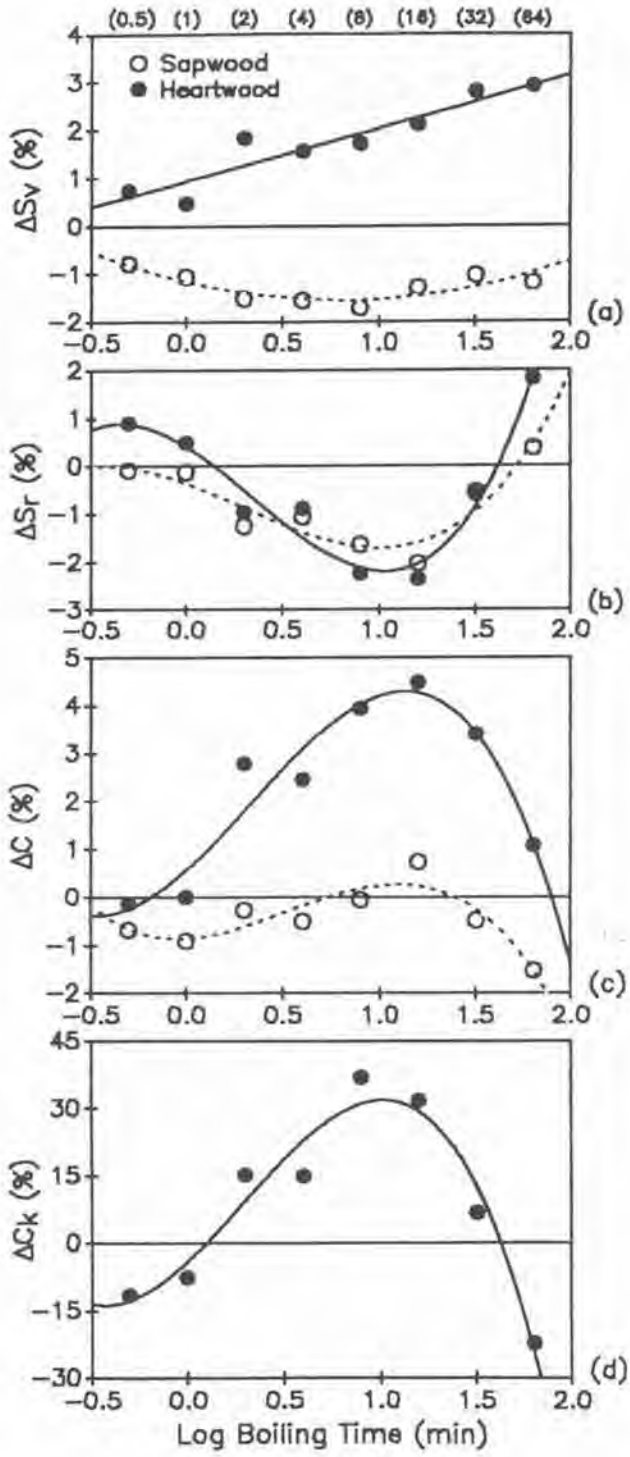

Figure 2

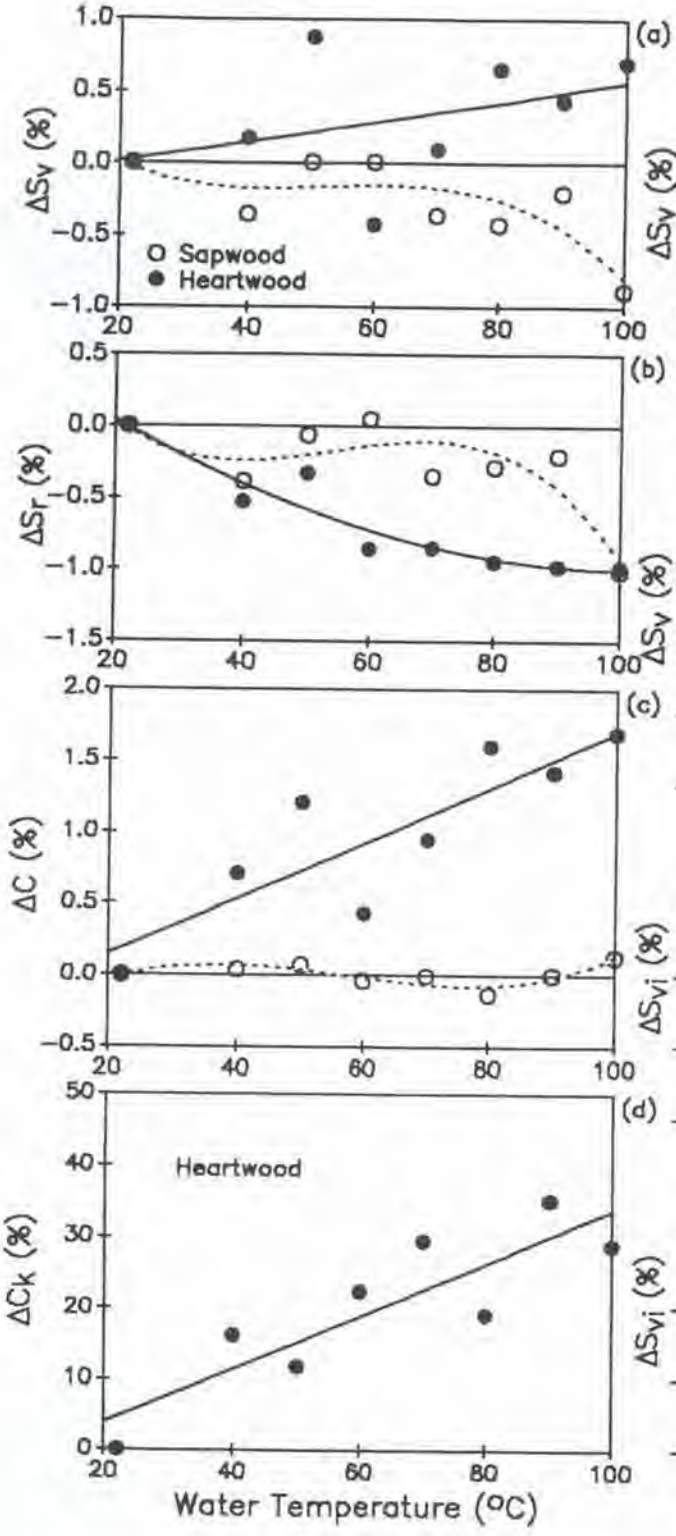

Figure 3

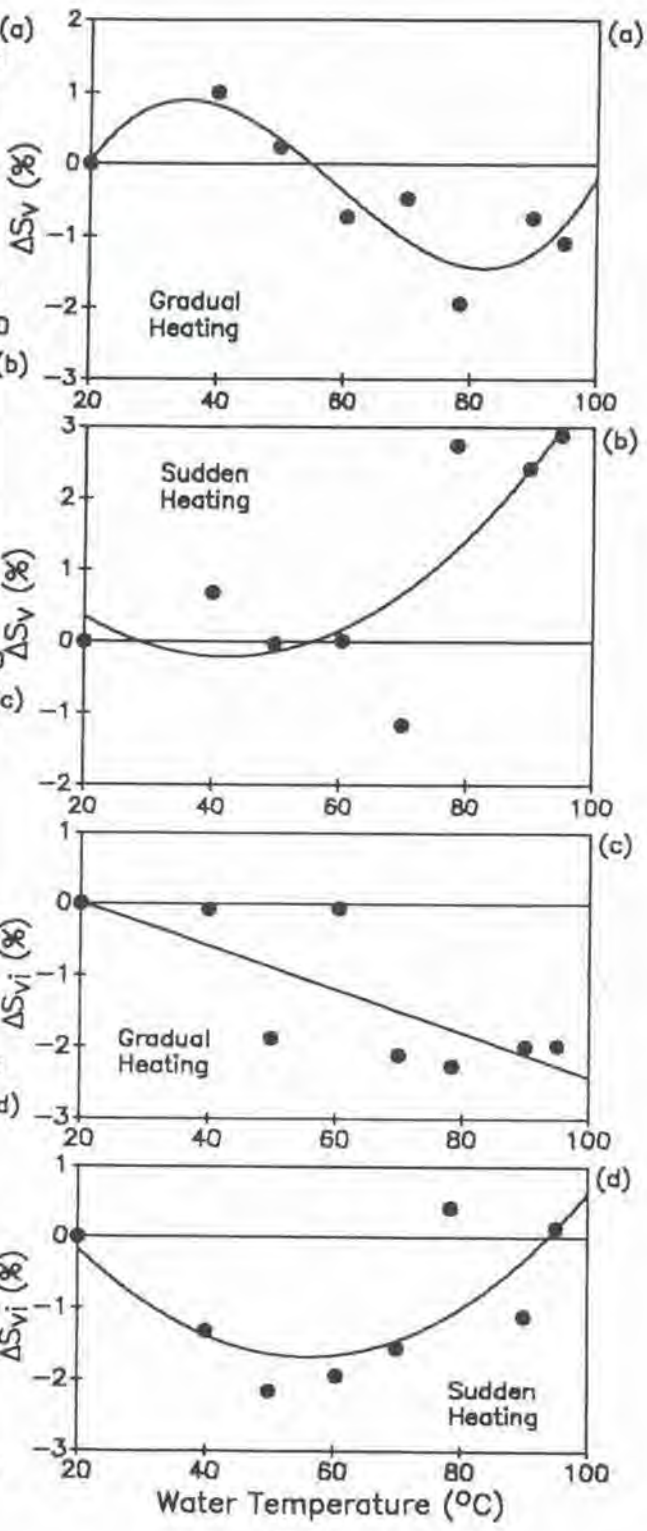

Figure 4

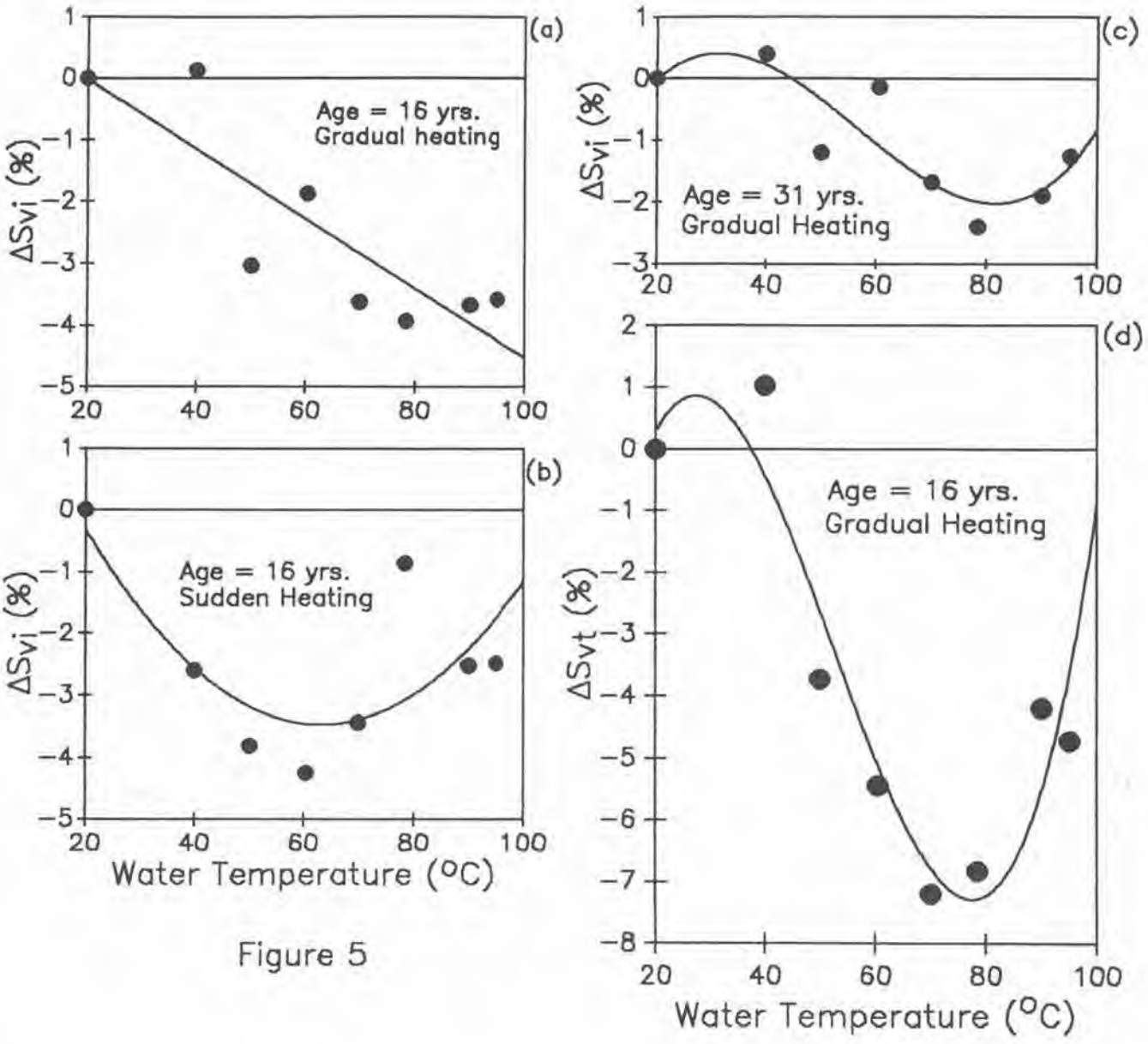
(a)
Age = 16 yrs.
Gradual heating
ΔSvi (%)
(b)
Age = 16 yrs.
Sudden Heating
ΔSvi (%)
Water Temperature (°C)
(c)
Age = 31 yrs.
Gradual Heating
ΔSvi (%)
(d)
Age = 16 yrs.
Gradual Heating
ΔSvt (%)
Water Temperature (°C)

Figure 5

DIMENSIONAL ANALYSIS AND THE CONVENTIONAL DRYING OF WOOD

Aleck J. Hunter
CSIRO Division of Forest Products
Private Bag 10, Rosebank MDC, Clayton, Victoria 3169

ABSTRACT

The conventional drying of timber (by the passage of warm air over it) is difficult to model accurately because of several factors. For example, moisture content is not a simple function of vapour pressure which motivates the movement of moisture. A very good starting place therefore is dimensional analysis.

THEORY

Heat transfer

To demonstrate how dimensional analysis is applied to phenomena such as conduction of heat, consider the one dimensional, transient heat flow equation:

$$H\frac{d^2T}{dx^2} = \rho c\ \frac{dT}{dt} \qquad (1)$$

H is the thermal conductivity, W/mk, T, the temperature, K, x the linear dimension, m, ρ the density of the wood, kg/m^3, c the specific heat of the wood, J/kg K, and t the time, s.

Consider the non-dimensional variables

$$y = \frac{x}{x_c} \text{ and } \tau = \frac{t}{t_c} \qquad (2)$$

where x_C and t_C may be called the characteristic length, m, and the characteristic time, s, respectively. With these substitutions (1) becomes

$$\frac{H}{x_c^2}\ \frac{d^2T}{dy^2} = \frac{\rho c}{t_c}\ \frac{dT}{d\tau} \qquad (3)$$

If we set

$$\frac{H}{x_c^2} = \frac{\rho c}{t_c} \qquad (4)$$

then (1) becomes

$$\frac{d^2T}{dy^2} = \frac{dT}{d\tau} \qquad (5)$$

Let the solution to this equation be

$$T = T(y,\tau) \qquad (6)$$

then the solution to (1) is

$$T = T\left(\frac{x}{x_c}, \frac{t}{t_c}\right) \qquad (7)$$

If x_C is set to correspond with the thickness of the timber, L then by (4) the characteristic time

$$t_c = \frac{\rho c L^2}{H} \qquad (8)$$

By (2) then the time taken for the conduction process to proceed to the state corresponding to τ in (6) will be

$$t = \frac{\rho c L^2}{H}.\tau \qquad (9)$$

For two different pieces of wood indicated by the subscripts 1 and 2 respectively we have from (9)

$$\frac{t_1}{t_2} = \frac{\frac{\rho_1 c_1 L^2_1}{H_1}}{\frac{\rho_2 c_2 L_2^{\,2}}{H_2}} \qquad (10)$$

It follows for example from (10) that a piece of wood 40% thicker than another piece will take twice as long ($1.4^2 \approx 2$) as long to heat, the other parameters being assumed equal.

The effect of differences in ρ,c, and H will be in proportion to their magnitude.

Mass transfer

Consider now mass transfer within the wood, i.e. the drying process. In a manner analogous to that described above we find for the drying time

$$t = \frac{\rho \Delta w L^2}{D \Delta p} . \tau \qquad (11)$$

where ρ is the dry density of the wood, kg/m^3, Δw the change in moisture content, D the diffusivity, kg/msPa, and Δp the difference in the pressure of water vapour, Pa;

$$\Delta p = p_{sw} - r\ p_{s\infty} \qquad (12)$$

where p_{sw} is the pressure of water vapour at saturation at the temperature of the wood, r the relative humidity of the drying air, and $p_{s\infty}$ the pressure of water vapour at saturation at the temperature of the drying air.

Heat and mass transfer

The ratio of the time taken to dry to the time taken to heat can now be obtained from (9) and (11) and we find

$$\frac{t_d}{t_h} = \frac{H \Delta w}{D \Delta p c} \qquad (13)$$

Typical values we might take for these parameters are: H = 0.2 W/mK (Kollman and Côté, 1984); $\Delta w = 1.0$; $D = 60 \times 10^{-12}$ kg/msPa (Hunter, 1994); $\Delta p = p_s (1-r) = 7400 \,.\, 0.5 = 3700$ (40°C); c = 2300 J/kg K (Kollman and Côté, 1984).

With the above parameter values (13) gives

$$\frac{t_d}{t_h} = 392 \qquad (14)$$

The clear indication is that the conduction process in wood is much faster than the mass diffusion process so that for most of the drying process the assumption of constant temperature is a reasonable approximation.

The transfer of heat and mass at the surface film may be expressed respectively by

$$Q = h \, \Delta T \qquad (15)$$

and

$$F = d \, \Delta p \qquad (16)$$

Q is the flux of heat, W/m²; h the heat transfer film coefficient, W/m²K; F the mass flux, kg/m²s; and d the mass transfer film coefficient, kg/m²s Pa.

Now since the heat transferred to the wood must be converted to the latent heat of water we have the relation

$$Q = - \ell F \qquad (17)$$

where ℓ is the latent heat of vaporisation of water, J/kg. Combining (15), (16) and (17) we find

$$\frac{\Delta p}{\Delta T} = -\frac{h}{\ell d} \qquad (18)$$

Also since mixing of air and water vapour in the surface film is adiadatic we have

$$\frac{dp}{dT} = - \frac{c_a P}{0.622 \ell} = \frac{\Delta p}{\Delta T} = - \frac{h}{\ell d} \qquad (19)$$

where c_a is the specific heat of air, J/kg K and P is the atmospheric pressure, Pa. From (19) we see that

$$\frac{h}{d} = \frac{c_a P}{0.622} \tag{20}$$

which is the equivalent of the Lewis relation.

Considering again conduction and diffusion within the wood we have

$$Q = H \frac{dT}{dx} \tag{21}$$

$$F = D \frac{dp}{dx} \tag{22}$$

(17) is again applicable and so with (21) and (22) we have

$$\frac{dp}{dT} = - \frac{H}{D\ell} \tag{23}$$

On the vapour pressure-temperature diagram (Fig. 1) these gradients show the air state through the film and into the wood as the drying proceeds.

A typical value for dp/dT outside the wood is

$$- \frac{c_a P}{0.622\ell} = - \frac{1000}{0.622} \cdot \frac{101325}{2450000} \tag{24}$$

$$= - 66 \text{ Pa/K.}$$

Starting from the state of the drying air in Fig. 1, a line is drawn with the above slope and represents the state of the air in the surface film.

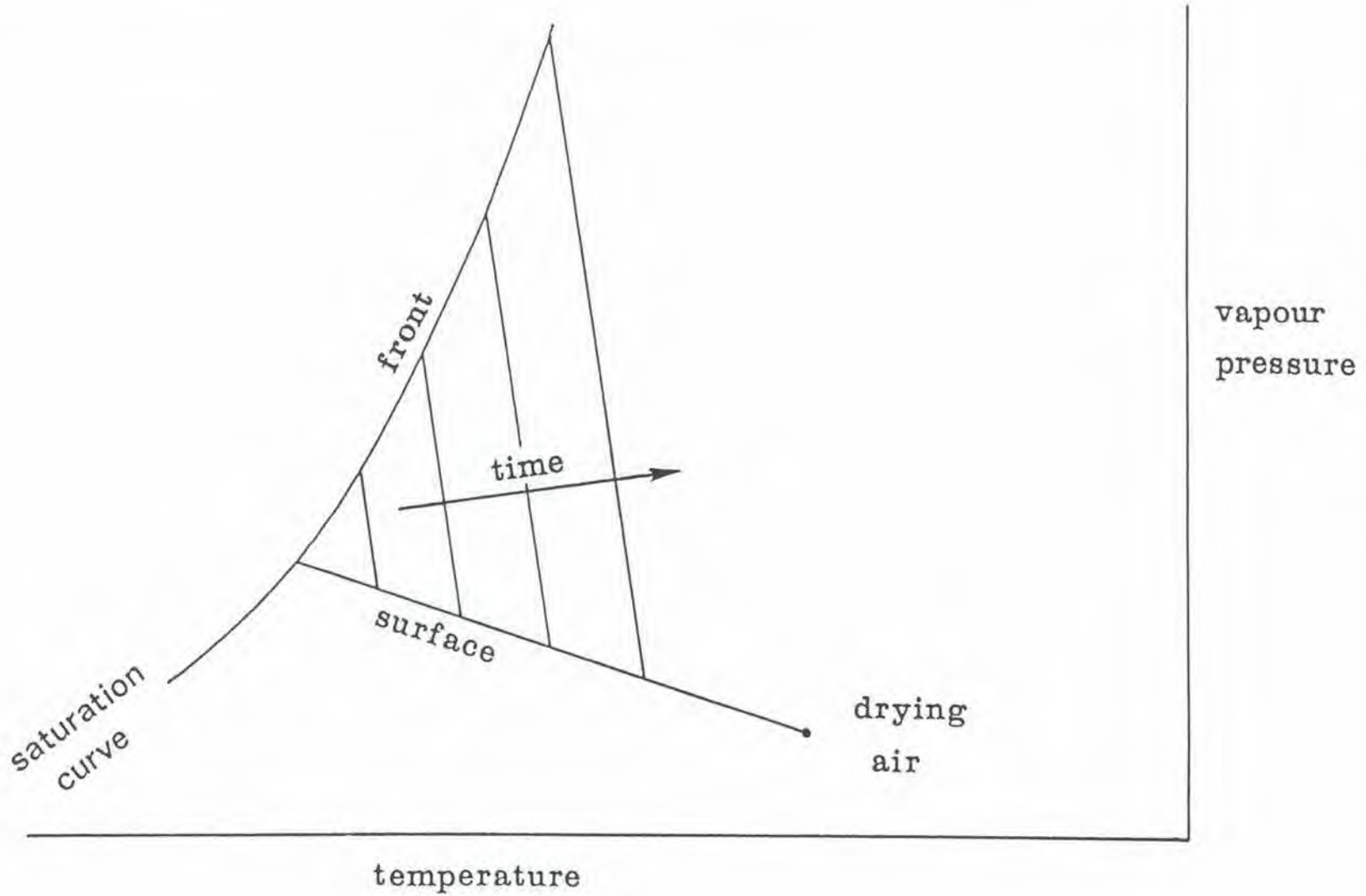

Fig. 1. Vapour pressure-temperature diagram showing air and wood equilibrium state loci as the drying front recedes from the wood surface.

Within the wood

$$-\frac{H}{D\ell} = -\frac{0.2}{60\times10^{-12}\ .\ 2450000} \qquad (25)$$

$$= -\ 1360\ \text{Pa/K}.$$

The locus of the instantaneous equilibrium state of the wood with regard to temperature and moisture content is then obtained at various times as lines of the above slope drawn from the above air state line through to the drying front at saturation.

The importance of the surface film resistance

The additional thickness of timber equivalent in resistance to the surface film is for heat transfer

$$x_h = \frac{H}{h}$$

and inserting typical values,

$$x_h = \frac{0.2}{10}$$

$$= 20\ \text{mm}.$$

For mass transfer using (20) to calculate d,

$$x_m = \frac{D}{d}$$

$$= \frac{60\times10^{-12}}{6\times10^{-8}}$$

$$x_m = 1\ \text{mm}$$

The dimensionless number which expresses the significance of the surface film is for heat transfer

$$\frac{H}{hL} = \frac{x_h}{L} \qquad (26)$$

and for mass transfer

$$\frac{D}{Ld} = \frac{x_m}{L} \qquad (27)$$

DISCUSSION

Dimensional analysis will often provide an insight as to the effect of the various parameters involved in a complex process. In this case for example the fact that the square of the length parameter comes into both the heating and the drying time means that the two times can be compared regardless of the size of the timber.

The expressions for the differential coefficient dp/dT for within the timber and in the surface film enable the thermodynamic states of the process to be presented on a vapour pressure - temperature diagram and provide a basis for further investigation of the drying process.

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COMPUTER AIDED WOOD IDENTIFICATION USING CSIROID

J. Ilic
CSIRO Division of Forest Products
Private Bag 10, Rosebank MDC, Clayton, Victoria, 3169

ABSTRACT

A wood identification program, CSIROID, is described. The program is interactive, completely self contained and is capable of running identification keys using two-state features. A new procedure to indicate the 'best subsequent feature' to use during identification is discussed. The procedure is also useful for checking differences and similarities between species. Potential for using graphics images to illustrate features and taxa are indicated. All communication and data access is performed via pop-up window displays.

INTRODUCTION

Wood identification procedures using personal computers have simplified the process of wood identification and surpassed manual procedures such as written descriptions, dichotomous keys and edge-clipped cards. The advantages of computerised wood identification have been discussed by Miller (1980), Wheeler et al (1987) and Ilic (1990) . The computer permits a large amount of anatomical information to be readily searched for specific details. In addition to providing a means of matching taxa without error, the computer can provide instruction to assist the user in making the correct choices for identification.

The Cardbox-Plus package, Ilic (1991), has been used in CSIRO for nine years, and although it is highly efficient for searching large data sets, it has a number of shortcomings which have been addressed with a new program, CSIROID. The aim of this paper is to describe its application and the advantages that this new program can offer for wood identification.

THE PROGRAM

Computer procedures and code were written in 'C' (van der Touw 1990) and implemented on an IBM type MS-Dos machine. File handling operations are handled by the main program and are transparent to the user.

Preparation of a new identification database (getting data into suitable form for CSIROID) is carried out using CARDBOX-PLUS. However, any database can easily be adapted to run with CSIROID provided data are presented in ASCII form. The program can handle 2000 anatomical features and 500,000 records However, only one unknown sample can be identified at a time.

USER INTERFACE

Pop-up windows provide a means of communication between the user and the information in the keys. There are five major sections for information retrieval: i)

selection of a database or key, ii) selection of features to describe an unknown, iii) search of a key by taxon name (genus, species, family or common name), iv) listing of taxa resulting from searching the key database (keying out taxa based on features) v) and listing features used in previous searches.

SELECTION OF A KEY

Currently 12 keys or databases are available, any one of which can be chosen by highlighting the appropriate key name displayed in the menu illustrated in Fig. 1 (only 8 keys shown). When a key is selected, the corresponding set of features, are displayed in the features window (Fig. 2). Before a search is performed, all taxa from the key are shown as selected. Ten species are displayed at the taxa window which can be scrolled over for all taxa contained in the selection.

SELECTION OF FEATURES

Observed features for a sample are chosen from the list displayed in the 'feature' window. Each feature is assigned a number to be used by the program as a concise reference. In most cases these numbers correspond to the original feature numbers from the edge-clipped cards. More detailed feature definitions can be viewed by using a help option (Alt F1). The 'feature' window shows approximately 17 features at a time including headings of feature groups. Features from the entire list can be scrolled as required.

Once a set of features has been chosen, the key can be searched for matching taxa (F6). After a search is performed, the selected feature numbers are transferred to the 'features at last search' window to serve as a reference for features used (Fig. 2). This feature list is also transferred to the 'history function'. The 'history' window is not visible until it is invoked (F7). Every time a new search is performed, 'features selected' window is updated and the previous list of features is added to the history window.

FEATURE STATES

Feature state used in CSIROID indicates the condition that a feature is permitted to have. Feature states used in coding are the same as those used by edge clipped cards - Features present are coded for each taxon. Features not assessed for the taxa in a key are coded as unknown and variable features are coded as present with a 'v' identifier. Feature states allowed for an unknown are only present or absent. 'Mismatches', 'required presence' and 'required absence' are not implemented by the program.

SEARCHING A KEY FOR MATCHING TAXA

A search always results in a new group of taxa that match set features. The taxon names from this group are displayed in the 'taxa' (species) window. The process of setting features and searching can be repeated as many times as required until a reduced list of taxa is produced; a short list of one to a few taxa is a desirable final result.

Only the features selected can affect the outcome of a search. The matching procedure produces a similar result to the mechanical process of sorting edge-clipped cards. The following criteria are used to produce a match: if features set as present correspond exactly to coded features; features selected as present or absent match features coded as unknown; features selected as present or absent match features set as

variable, and variability is indicated to the user. For example, 'v' in the 'species features' window (Fig. 6) indicates that feature 3 is variable.

FEATURE DEFINITIONS AND ILLUSTRATIONS

Feature definitions and explanations can be accessed from the 'features' window by using the 'feature help' option (Alt F1). Help is available for any specific feature which has been highlighted at the 'feature' window. A typical feature help window for feature 5 is illustrated in Fig. 3. This information has been specifically prepared to clarify the precise meanings and interpretation of features.

A system under development will enable graphics images of photomicrographs to be displayed on the screen after the help option is invoked. In addition, images of authentic species will be available to illustrate all taxa in the key. Appropriate images are being digitised from CSIRO photomicrographs and slides. As file size of graphics images can be between 64K bytes and 256K bytes, depending on their dimensions, storage and retrieval of data will present some challenging problems for development. It is envisaged that fully illustrated keys will probably require mass-media storage such as a CD-ROM.

THE 'BEST SUBSEQUENT FEATURE' OPTION

A search using features chosen on the basis of an initial examination rarely produces a list of taxa short enough for subsequent comparisons. To assist with the next step, an alternative search procedure - 'the best subsequent feature' has been implemented to indicate features with potential to reduce the number of taxa remaining. The procedure is carried out by counting the number of taxa for each coded feature remaining. The results (scores) are sorted and displayed in a new window illustrated in Fig. 4. This procedure can be carried out from any window except the 'History' window.

Any number of features can be set either as: selected, excluded, or to any desired combination of the two directly from this window in the same way as for the 'feature' window. The procedure can be applied as many times as required to achieve the desired result, i.e., a short list of taxa. Although the 'best subsequent feature' option can be invoked at any stage, it will be most useful near the end of the identification process.

HISTORY WINDOW

A list of feature numbers used in any search step, is displayed on a new line, and a series of lines indicates a sequence of searches performed. The number of taxa that result from searches is shown in a column headed 'score' (Fig. 5). Stepping back to a previous search step can be performed by highlighting the particular row containing the score and the corresponding features. Other operations such as resetting or beginning a new search are also indicated.

SELECTION OF TAXA BY NAME

As an alternative to matching taxa from a series of features, selection can be made by family, genus, species, or common name. The 'names selected' window can be activated and names set at any time. After a search is performed, matching taxa are displayed in the taxa window (Fig 7). The key (database) currently selected can be searched for any valid combination of names. Information related to name searches is not transferred to the 'history' option in the current version of CSIROID.

DISCUSSION

The length of time taken for the computer to match all the chosen features is not affected by the number of features chosen, only by the number of taxa in the key. This time is referred to as 'search time'. For example, a typical search time for a key with 5200 taxa takes approximately 15 seconds on a 25MHz, Intel 80386, CPU system. As all searching is memory based, speed of the hard disk only affects the time required to load files and has no effect on search time.

For the same number of taxa, the 'best subsequent feature' search time is considerably greater than for a standard search (F6). For example, a typical best-subsequent search time for 100 taxa takes approximately 6 seconds. This time increases with the number of features per taxon as well as the number of taxa. For that reason, it is preferable to use this option toward the end of the identification process.

Although the system has no prior knowledge of the taxon being sought, the scores resulting from the 'best subsequent feature' search act as a guide for the user to check if specific features occur in the sample being examined. Features with low scores indicate significant differences between taxa, while a high score indicates similarity.

Selecting any feature which is coded as unknown, would be of no benefit in reducing the species list. Similarly, selecting features coded as variable would be less useful than ones that are not. For example, (1) in the 'variable' column corresponding to feature 18 indicates that 1 of the possible 2 taxa (from score column) have feature 18 coded as variable.

CSIROID was designed to replace the use of edge-clipped cards and two-state features (characters), present or absent, with provision for variable and uncoded. Quantitative and multistate characters were not used since they can be represented as a series of categories and hence two state characters. In this case, all two state-features have equal weight in terms of the order in which they are applied in a search, but may not necessarily have the same discriminating power. For example, feature 97 from the IAWA list, 'ray width 1-3 cells', may have equal weight when compared to feature 96, 'rays exclusively uniseriate', but the discriminating power of feature 96 would be much greater. The approach in coding used in CSIROID is consistent with the new IAWA list of features (IAWA Committee 1989) and with data currently available from edge-clipped cards.

Easy exchange of information between programs is another important requirement for computerised wood identification. The best way to achieve this is with a standardised information exchange format. The most important requirement for an exchange system is that records, and the associated fields within each record, are uniquely specified. In this way most word processors (eg. Microsoft Word, Word-Perfect, etc.) can be used to adapt data.

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FIGURE CAPTIONS

Figure 1. First screen after CSIROID program is loaded. The active window (double border) includes 8 keys. The desired key is chosen by highlighting the name.

Figure 2. Screen display indicates: Key chosen, in this case, Macro-Subset (Aust. spp.) in the top left, the active window (double borders), 'features' showing the first 17 features, 'names selected' window (top right), 'features at last search' window and 'taxa' window (bottom right), 259 next to taxa indicates the number of taxa currently selected and the window shows the first 10 species. Arrow-heads indicate that windows can be scrolled.

Figure 3. Screen shows 'features help' window (Alt F1), retrieved from 'features' window with feature 5 highlighted; detailed information is presented for feature 5, 'Streaky'.

Figure 4. Screen showing 'best subsequent features' as the active window. Features are listed in the first column, with a corresponding 'score' in the next column; score indicates number of taxa that would remain if the corresponding feature were selected. 'Variable' column with numeral in brackets indicates number of taxa with the corresponding feature coded as variable. Similarly a numeral in the 'unknown' column (not shown) would indicate the number of taxa with the corresponding feature not coded.

Figure 5. Screen showing 'history' window and typical sequence of searches. Features (number), selected at each step are shown with the corresponding 'score'. 'Score' (shown in a different colour on a colour screen) indicates the number of taxa matching the features selected at that step. A flashing cursor (not shown) can be moved to any desired step and the feature and taxa settings prior to that step can be restored.

Figure 6. Typical 'species details' screen showing the third record, Acacia melanoxylon, of 24 currently selected (3/24). The current window (double line border), specifies features coded for the species displayed. The 'v' next to the feature number indicates that the feature is coded as variable. Any of these features can be highlighted and 'features help' displayed if required. Arrow head in double border indicates that window can be scrolled.

Figure 7. Typical screen showing 'names selected' window as active and two *Ackama* species are shown as selected following entry. Features used in a search prior to name search are shown in 'features at last search' window. (NB. name search sequences are not included in the 'history' option.)

FIGURES

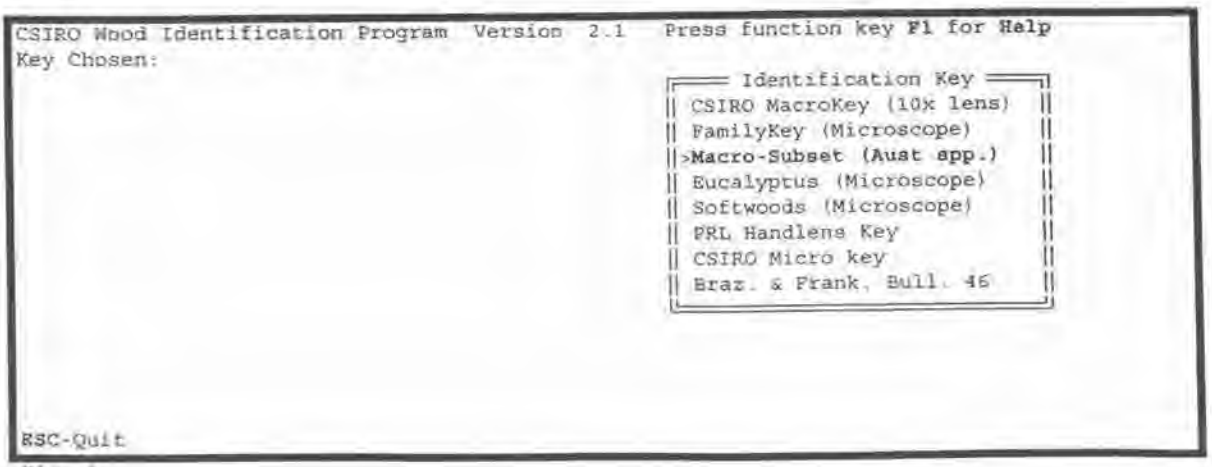

Fig. 1

```
PiCSIRO Wood Identification Program  Version  2.1   Press function key F1 for Help
Key Chosen: Macro-Subset (Aust spp.)
╔═══════════ Features ═══════════╗ ┌──── Names Selected ────┐
     COLOUR                      ‖ |Species:                |
  1. Whitish, pale brown, pale yellow, straw ‖ | Family:                 |
  2. Dark brown, definite brown  ‖ | Common:                 |
  3. Pink or red tints           ‖ └─────────────────────────┘
  4. Other: black, purple, bright yellow etc ‖ ┌ Features at Last Search ┐
  5. Streaky                     ‖ |                         |
     RAYS                        ‖ |                         |
  6. Of two distinct widths      ‖ |                         |
  7. As wide or wider than pores ‖ |                         |
  8. Narrower than pores         ‖ └─────────────────────────┘
  9. Markedly heterogeneous      ‖ ┌──── 259 Taxa ────┐
 10. High and conspicuous on radial surface ‖ | Acacia aulacocarpa |
 11. With radial canals          ‖ | Acacia cambagei   |
     PARENCHYMA (SOFT TISSUE)    ‖ | Acacia dealbata   |
 12. Absent                      ‖ | Acacia harpophylla |
 13. In regular bands wider than pores ‖ | Acacia melanoxylon |
 14. In regular bands narrower than pores ‖ | Acacia penninervis |
 15. In irregularly spaced bands ‖ | Acer spp.         |
 16. Surrounding pores           ‖ | Ackama australiensis |
 17. Wing-like or confluent      v| Ackama paniculata |
                                  | Acmena hemilampra  v|
                                  └──────────────────────┘
ESC-Quit  F2-Key  F3 Features  F4-Names  F5-Species  F6-Search  F7-History
```

Fig. 2

```
CSIRO Wood Identification Program  Version  2.1   Press function key F1 for Help
Key Chosen: Macro-Subset (Aust spp.)
┌──────────┐┌──────── Features Help ────────┐┌─ lected ──┐
     COLOUR |Streaky                       |
  1. Whitish|Feature 5.                    |
  2. Dark br|Observed on a cleanly cut TANGENTIAL SURFACE.
  3. Pink or|Heartwood with streaks refers to variations in
  4. Other: |colour of heartwood deposits (extractives),
  5. Streaky|not due to figure caused by anatomical features
     RAYS   |such as distinct growth rings or large pores.
  6. Of two |  Streaky is always used in combination with
  7. As wide|the general heartwood colour, for example, Gluta
  8. Narrowe|renghas L. (Malaysian blackwood) has a golden
  9. Markedl|brown heartwood colour striped with dark brown
 10. High an|streaks and Dracontomelon dao (Blanco)Merr. &
 11. With ra|Rolfe  (New Guinea walnut) has a pale yellowy-
     PARENCH|brown heartwood with prominent grey to almost
 12. Absent |black streaks.
 13. In regu| Other examples of streaky timbers include:
 14. In regu|Acacia melanoxylon R.Br. (blackwood) Longitudinal
 15. In irre|surface has a pale brown to reddish-brown heart-
 16. Surroun|wood with occasional dark brown streaks,
 17. Wing-li|Rhodosphera rhodanthema Engl. (tulip satinwood)
└──────────┘└──────────────────────────────┘
ESC-Return to program
```

Fig. 3

```
CSIRO Wood Identification Program  Version  2.1   Press function key F1 for Help
Key Chosen: Macro-Subset (Aust spp.)
┌──────── Features ────────┐ ┌──── Names Selected ────┐
     COLOUR                ‖ |Species:                |
  1. Whitish, pale brown, pale yellow, straw ‖ | Family:                 |
> 2. Dark brown, definite brown ‖ | Common:                 |
  3. Pink or red tints     ‖ └─────────────────────────┘
╔═══ Best Subsequent Features ═══╗
‖     Feature                    Score   Variable  Unknown ‖
‖ 10. High and conspicuous on radial surface   1     (1)     ‖
‖ 11. With radial canals        1               ‖
‖ 23. Vertical canals           1     (1)       ‖
‖ 24. Distinct oiliness, greasiness  1          ‖
‖ 30. Europe, Africa & Americas  1              ‖
‖ 34. Philippines              1               ‖
‖ 49. Tangential               1     (1)       ‖
‖  6. Of two distinct widths   2               ‖
‖ 18. Diffuse                  2     (1)       ‖
‖ 25. Splinter burns to charcoal  2  (1)       ‖
‖ 32. West Irian, Papua New Guinea & Neigh.  2  ‖
‖ 33. Burma, Indonesia etc.    2               ‖
‖ 35. Malay Peninsular         2               ‖
‖ 44. Ring porous or semi-ring porous  2  (1)  v‖
╚═══ Score = Number of species remaining ═══╝
ESC-Quit  F2-Key  F3 Features  F4-Names  F5-Species  F6-Search  F7-History
```

```
 CSIRO Wood Identification Program  Version  2.1   Press function key F1 for Help
Key Chosen: Macro-Subset (Aust spp.)

                                  History
Score Features selected at each step
  24   2   5
   2   2   5 32
   1   2   5 17 32
   1   2   5 17 32
 259 Features reset
  11   4   6   8
   1   4   6   8 23

                        Score = Number of species remaining
ESC-Features
```

Fig. 5

```
CSIRO Wood Identification Program  Version  2.1   Press function key F1 for Help
Key Chosen: Macro-Subset (Aust spp.)
                              Species Details 3/24
     Species: Acacia melanoxylon
      Family: LEGUMINOSAE
Common names: Blackwood
                                    Remarks
 A.D. Density: 560-770 Kg/cu.m
 Pores: 4-7/sq.mm.
 Burning splinter: partial ash which usually disintegrates.

                                 Species Features
  2.     Dark brown, definite brown
  3. V   Pink or red tints
  4. V   Other: black, purple, bright yellow etc
  5.     Streaky
  8.     Narrower than pores
 10. V   High and conspicuous on radial surface
 12.     Absent
 16.     Surrounding pores                                                    v
ESC-Species  F2-Hide Species Features window  F8-Print
```

Fig. 6

```
CSIRO Wood Identification Program  Version  2.1   Press function key F1 for Help
Key Chosen: Macro-Subset (Aust spp.)
                    Features                          Names Selected
     COLOUR                                    Species: Ackama
  1. Whitish, pale brown, pale yellow, straw    Family:
  2. Dark brown, definite brown                 Common:
  3. Pink or red tints
> 4. Other: black, purple, bright yellow etc   Features at Last Search
  5. Streaky                                      4   6   8
     RAYS
> 6. Of two distinct widths
  7. As wide or wider than pores
> 8. Narrower than pores                          2 Taxa Remaining
  9. Markedly heterogeneous                     Ackama australiensis
 10. High and conspicuous on radial surface     Ackama paniculata
 11. With radial canals
     PARENCHYMA (SOFT TISSUE)
 12. Absent
 13. In regular bands wider than pores
 14. In regular bands narrower than pores
 15. In irregularly spaced bands
 16. Surrounding pores
 17. Wing like or confluent                                                   v
ESC-Quit  F2-Key  F3 Features  F4-Names  F5-Species  F6-Search  F7-History
```

Fig. 7

THE EFFECT OF PREFREEZING ON COLLAPSE, INTERNAL CHECK DEVELOPMENT AND DRYING RATE IN *EUCALYPTUS REGNANS* F.MUELL.

Jugo. Ilic
CSIRO Division of Forest Products
Private Bag 10, Rosebank MDC, Clayton, Vic. 3169

ABSTRACT

Results from experiments on the effect of prefreezing on shrinkage related degrade is presented . Collapse reduction of 36% was achieved by prefreezing green wood, but internal check count and drying rate were not reduced.

INTRODUCTION

It is well known that ash-eucalypts are difficult to season compared with non-eucalypt hardwoods and softwoods. The wood dries slowly, usually with high moisture gradients resulting in a high degree of transverse shrinkage which gives rise to 'difficult' to dry or 'refractory' material. Although all wood must shrink when it dries, a part of the high level of shrinkage is due to wood 'collapse' which is particularly evident in low to medium density *Eucalyptus* species of the ash-group. As a general rule, and as a result of the high levels of shrinkage, lower density wood (<400kg/m^3) with cells of low rigidity, is often observed to have cracks known as 'internal-checks' (honeycomb-checking). In higher density specimens (>600kg/m^3), surface-checking may be more evident particularly in backsawn boards.

Considerable research effort over the last 5 decades has been directed toward a means of preventing or reducing excessive collapse and thereby minimising drying degrade in timber from ash eucalypts (Campbell 1978). 'Prefreezing', a less known pretreatment has been used successfully to reduce shrinkage and associated drying defects and in some cases increase the drying rate in a number of timber species mainly from the USA. Prefreezing is carried out by freezing the green wood before air drying or kiln drying. It differs markedly from freeze-drying (Choong et al 1973, Erickson et al 1968), in which the wood is kept frozen in a cylinder with a relatively high vacuum applied while moisture is being removed.

The subject of this communication is to assess the suitability of prefreezing as a treatment to reduce or eliminate collapse and internal checking, and to determine its effect on drying rate. The proposition being presented is that prefrozen material will collapse less, and correspondingly, this reduction should lessen the incidence of internal checking.

MATERIALS AND METHODS

Test material, 1939 regrowth *Eucalyptus regnans* F. Muell., was obtained from Drouin West, in East Gippsland, Vic. The material consisted of 31 backsawn boards 1500 mm long, each from a different butt log taken from approximately the mid-radius position in the tree. The boards were green dressed to 100x50mm, three end matched boards, 300 mm long, were then cut from each long board and labelled P1, C, and P2. A

thin section, 1mm along the grain, was also cut between P2 and C for the determination of collapse free shrinkage. Further, a 25mm end-section was cut next to P1.

The P1, C and P2 boards were subsequently endcoated with 'Silastic 1080' silicon RTV adhesive sealant and aluminium foil to enable simulation of full length boards.

A prefreezing temperature of -20°C was chosen since previous research has indicated that temperatures of less than -20°C did not produce additional improvement in degrade and that these conditions would be easily maintained by commercial systems.

The P1 and P2 boards were stickered with 19 mm stickers, wrapped in plastic and stored in a walk-in freezer at -20°C for 72 hours. Following freezing, the samples were warmed to ambient temperature in 4 hours, and together with the 'C' samples, they were dried in a chamber set to run at 32° C, dry bulb, 65% relative humidity (EMC approximately 12%) with an air speed of 0.5m/sec. Weighing to determine drying rate was carried out daily for the first week, then less frequently.

All comparative measurements of shrinkage were carried out in the oven dry condition on a light box using an image processor. Shrinkage calculated from the thin sections was used to provide a measure of collapse free shrinkage (normal shrinkage) which would obviate the need for reconditioning. At the end of drying, the P1, C and P2 boards were cross-cut and a 'medium-section', 2mm along the grain, cut from each board. Total shrinkage and the number of internal checks were measured from the medium sections. The level of collapse in boards was determined from the difference between the total shrinkage and that of the corresponding thin sections (oven dry.) The 25mm end-sections were used to assess the moisture content of boards.

Drying rates were calculated on the basis of the weight of water lost per unit time determined from the start of drying. Moisture contents were converted to evaporable moisture remaining (E) to normalise all the starting moisture contents to 1. The equation used was:

$E = (M-M_e)/(M_o-Me)$
where
M - current moisture content (at test)
M_e - equilibrium moisture content
M_o - initial moisture content

RESULTS

Drying rates

A small but significant difference in the average drying rate between prefrozen and control boards was observed as shown in Figures 1and 2. This difference was highly significant during certain stages of drying.

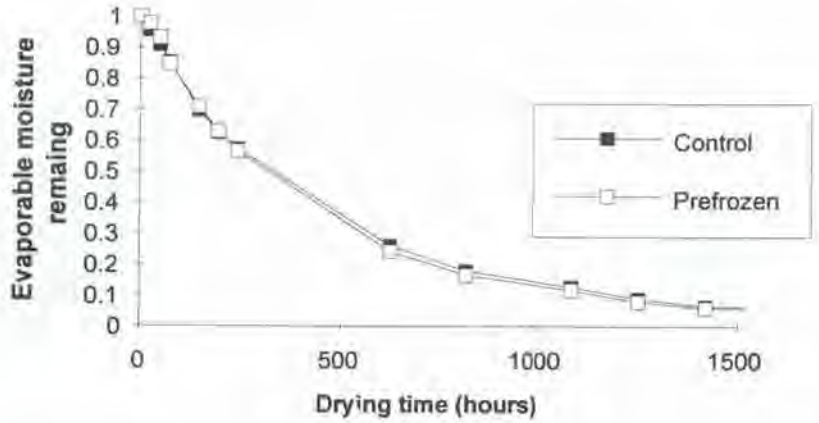

Figure 1. Average drying curves for prefrozen and control boards with drying time shown only to 1400 hours. (Moisture content normalised to evaporable moisture remaining.)

A simple indication of the difference in the drying rate between prefrozen and control boards is illustrated in Figure 2 by the difference in the average evaporable water remaining.

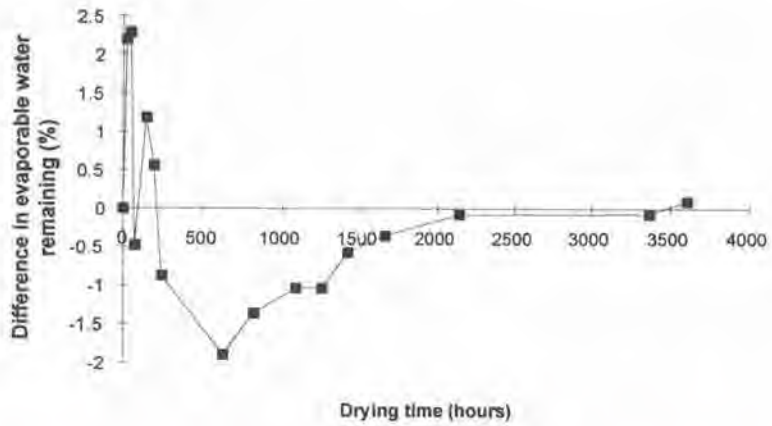

Figure 2. Difference in average evaporable water remaining between prefrozen and control boards. (Moisture content normalised to evaporable moisture remaining.)

Initially the control boards began to dry more quickly, but after 200 hours, and for the next 2000 hours (approximately 83 days) the amount of evaporable water remaining in the prefrozen boards was significantly lower than in the control boards which indicates that prefrozen boards dried more quickly during that period. After 2200 hours there was very little difference in the drying rate between frozen and control boards. At the end of the drying run, the samples had reached a moisture content of

approximately 15% and at that stage there was no significant difference between the moisture contents of the prefrozen and control specimens (Table 1).

Table 1. Moisture loss in prefrozen and control boards up to various stages of drying and the moisture content remaining at the conclusion of drying
of 31 boards. (Significance using paired t-test shown in brackets)

	Moisture loss (grams per day)			**Final MC (%)**
	Day 1	**Day 3**	**Day 26**	**Day 150**
Control (C)	36.0	40.1	23.3	14.9
Prefrozen (P2)	18.1	41.5	24.1	15.0
	Paired t-test; probability and significance			
P2-C	0.0005 (***)	0.95 (n.s.)	0.0003 (***)	0.87 (n.s.)

Note: * = $P < 0.05$
** = $P < 0.01$
*** = $P < 0.001$
n.s. = not significant

Shrinkage associated drying degrade

Overall the degrade was quite severe in many of the specimens dried under the conditions used in the experiment. Mean internal check counts, total shrinkage, collapse and normal shrinkage obtained for the test material are summarised in Table 2. Basic density and Initial Moisture Content (IMC) are also indicated. The density and IMC are typical for mature *E. regnans*. Of the 31 backsawn boards, only 2 were substantially free of internal checking and 25 of the boards had more than 10 internal checks per cross-section and typically all the checks were in the earlywood. During the first two weeks of drying, many of the boards developed wide surface checking which had closed firmly by the end of drying.

While the average check count was slightly higher in the control boards, the difference in check counts was not significant (Table 2). On the other hand, the total shrinkage was significantly less in the prefrozen boards; the prefrozen samples looked noticeably larger than controls. In this case the difference in the total shrinkage was due to the lower magnitude of collapse in the prefrozen samples.

Table 2. Mean values of properties measured to assess prefreezing effects on internal checking and shrinkage in 1939 regrowth *Eucalyptus regnans* (Basic density and IMC of test samples: (492 (447-564) kg/m^3 ;122(100-143)%)

	Prefrozen Mean & range	**Control** Mean & range	**T-test**, t-value & significance	**Result**
Check count	53 (0-166)	56 (0-194)	0.96 (n.s.)	No improvement
Collapse (%)	6.3 (0.1-18.0)	9.2 (2.5-22.0)	0.0000 (***)	Highly significant
Total shrinkage(%)	18.6 (11.7-30.8)	20.9 (14.8-35.0)	0.0000 (***)	Highly significant

Note: * = P <0.05
** = P < 0.01
*** = P < 0.001
n.s. = not significant

Other characteristics related to internal checking

Although the level of collapse was markedly reduced by prefreezing, the check count (internal checking) was not reduced accordingly, and a paired t-test failed to show a significant difference between the check count in prefrozen and control boards (Table 2). This unexpected result did not support the original hypothesis, that a reduction in collapse should produce a reduction in the number of internal checks . Furthermore, it was observed that internal checking in all samples was related to collapse (highly significant, positive), initial moisture content (highly significant, positive) and basic density (significant, negative), but green density was not related to check counts (Table 3).

Table 3. Relationships between internal check count and some physical characteristics of prefrozen and control boards. (Probability, significance level and regression coefficient using linear regression analysis)

	Green density	**Basic density**	**Initial moisture content**	**Collapse**	**Normal shrinkage**
Prefrozen	0.39 (n.s.)	- 0.03 (*) R^2=16%	0.0000 (***) R^2=66%	0.00000 (***) R^2=68%	0.98 (n.s.)
Control	0.42 (n.s.)	- 0.02 (*) R^2=17%	0.0001 (***) R^2=51%	0.00001 (***) R^2=51%	0.91 (n.s.)

Note: * = P <0.05
** = P < 0.01
*** = P < 0.001
n.s. = not significant

DISCUSSION

The small but significant improvement in drying rate during the early stages of drying obtained for the prefrozen specimens was not maintained to the end of drying. It is interesting to contrast that result with work reported in the literature for other hardwoods. Generally the reports are variable, with prefreezing causing an improvement in some cases, but not in others. For example, prefrozen black walnut dried faster than matched controls down to 46% moisture content (Cooper et al 1970), average drying rate increased in prefrozen taun and Asian oak (Park 1989) reported to be 5-8% respectively, however in taun, as in this experiment, the prefrozen samples dried more slowly initially than the controls. Haslett and Kinninmonth (1986) found no reduction in the drying rate of New Zealand red beech (*Nothofagus fusca*), while in Pacific madrone (*Arbutus menziesii*), Erickson et al (1966) found that prefrozen material dried 30% more slowly than the controls. Neylon (1979) reported a reduction in drying time of several days for prefrozen ash eucalypts. However, drying data were only recorded to approximately just below FSP and no additional comments were made about the length of time it took for the samples to reach equilibrium. Glossop (unpublished) obtained a reduction of approximately 5 days for twice prefrozen material. His results show that the initial drying rate of prefrozen jarrah and karri was greater during the first week of drying than that for controls, but by the seventh weel: the prefrozen material dried significantly more slowly. Overall, the early gains in drying time for jarrah and karri were maintained to produce an overall reduction in the drying time. Another point of difference between the drying method used in this experiment and much of the work reported from the literature is that the drying conditions were constant throughout the entire drying period.

An interesting aspect in this experiment was the initial slower drying of the prefrozen boards. This effect was highly significant and it can be seen very clearly in Figure 2. It would appear that initially it was more difficult for water vapour to escape from the surface of the prefrozen boards. One possible reason may be that water is more difficult to remove from capillaries of reduced diameter from the cell wall which was under considerable compression due the water to ice expansion during freezing.

To explain increased permeability, Hyashi & Terazawa (1974) reported profound changes in the structure of the pit membrane and cracks in some cell walls due to freezing in balsa wood. However, no such changes have been observed in eucalypts. In any case the fibre pits in eucalypts are heavily encrusted with highly branched vestures which are also surrounded with extractives. The small change in the drying rate of the prefrozen material attained in this experiment does not suggest a significant change in the permeability and so seems to be more consistent with the positional rearrangement of extractives.

The most surprising result obtained from this experiment was that check count (internal checking) in prefrozen boards was not reduced despite a significant reduction in collapse. It is difficult to explain why check count was not affected. It was originally conjectured that if the overall level of shrinkage can be reduced that tensile stresses developed during drying should be less and thus fewer checks should develop. However, this has not happened. In an attempt to investigate the reason for this apparent anomaly, levels of collapse, IMC, basic density and green density were regressed against check counts (Table 3). It can be seen that the level of collapse is significantly related to

internal checking and that it explains 68% of the variation in prefrozen and 51% in the control samples which should give more support for the original proposition. Initial moisture content was also highly related (positively) to check counts, but that may be expected as IMC and collapse are also highly positively related (Chafe 1985, Ilic & Chafe 1986). It can be suggested that a knowledge of IMC may be useful in a predictive sense, i.e., that it may prove to be useful in identifying specimens highly susceptible to degrade. Furthermore, it may also be suggested that, if indeed the relationship between IMC and check counts is so striking, that by reducing the green moisture content before freezing the wood a lower incidence of degrade may again be expected. This has been reported by Cooper & Barham (1975), and Erickson (1968). Unfortunately, in an approach that required green wood to be predried, degrade would begin to form immediately predyring begins prior to freezing.

It is not immediately obvious why check counts (internal checking) were not reduced in prefrozen samples other than to suggest that internal checks can develop in the presence of even low average levels of collapse. As checks occur over short distances due to high concentrations of stress, high levels of tensile stress may still develop locally and initiate a crack.

CONCLUSION

Considering that check counts and drying time were not reduced, it can be concluded from this experiment that prefreezing is unlikely to form a suitable procedure for the alleviation of internal checking despite significant reductions of collapse that can be achieved. However, as a result of the collapse reductions that were achieved, prefreezing may be of considerable benefit for reducing drying degrade of sliced or peeled veneer, and if the magnitude of collapse reduction can be attained or improved for veneer, it may well be worth optimising the prefreezing conditions to eliminate or markedly reduce collapse in this material and thus form the basis of an alternative to the reconditioning process.

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HYGROSCOPIC CHARACTERISTICS OF RADIATA PINE DRIED AT HIGH TEMPERATURE

Richard Northway

CSIRO Division of Forest Products
Private Bag 10, Rosebank MDC, Victoria 3169

ABSTRACT

Specimens of radiata pine which had been dried at temperatures ranging from 90°C to 210°C without final steaming were sawn to produce slices through the thickness. The slices were successively conditioned in moist and dry atmospheres and the moisture content of each slice determined. While slices from the surface of high temperature-dried specimens initially equilibrated at moisture contents below the expected equilibrium moisture content of the environment, the moisture content cycling tended to reduce this effect.

Two pairs of matched specimens were dried at 150°C and one of each pair steamed after drying. Assessment of the moisture content of slices from these specimens in moist and dry atmospheres indicates that the effect of high temperature drying on surface hygroscopicity is reduced or eliminated by the final steaming treatment.

INTRODUCTION

The acceptance of radiata pine as a building material has been in part due to the claim that high temperature drying produces boards which are stable in the normal service environments. It has been found that specimens of wood dried at higher temperatures reached lower equilibrium moisture content (EMC) compared to matched specimens dried at lower temperatures, when conditioned in the same environment (Fricke and Northway, 1977). It has been speculated that exposure to high temperature while at a low moisture content reduces potential sorption sites for water molecules in the wood cell wall, thus lowering the equilibrium moisture content of the affected wood, and slowing the absorption or desorption of moisture. Whether this is a permanent or reversible effect has been in question.

Reduced hygroscopicity is generally seen as a benefit, with the dried timber being more stable and responding more slowly and to a lesser extent in response to local changes in air humidity. However if the effect is confined to surface layers then some processing options are restricted. Re-sawing boards after drying through the thickness or width may expose surfaces with sorption characteristics significantly different to the other board surfaces. A similar, although less extreme, situation may result when more material is removed from some surfaces than others during machining.

This paper describes tests to explore the extent of any reductions in hygroscopicity through the thickness of specimens dried at conditions which covered the range of current and proposed industrial kiln drying practices.

MATERIALS AND METHODS

Boards of radiata pine, all backsawn sapwood and matched from one tree were selected from those dried in a set of experiments (Northway, 1989). Each of the 22 boards which had been approximately 100mm wide and 40mm thick when green were sawn to produce a set of tangential slices 20mm wide and 2mm thick. Blocks 20mm wide and 160-200mm long for cutting into the slices were sawn from the boards, with the centreline following the crown of the growth rings. Slices were then cut from the blocks using saws with a kerf of 2mm, starting with the original board faces against the saw fence. Slices were numbered from 1 to 5 cutting from the outer face and from 10 to 6 cutting from the face closer to the pith, with any remainder from the core of the board numbered 0 (Figure1). The sets of slices were cut to 120mm long, with the offcuts being used to determine moisture content (MC) by oven drying.

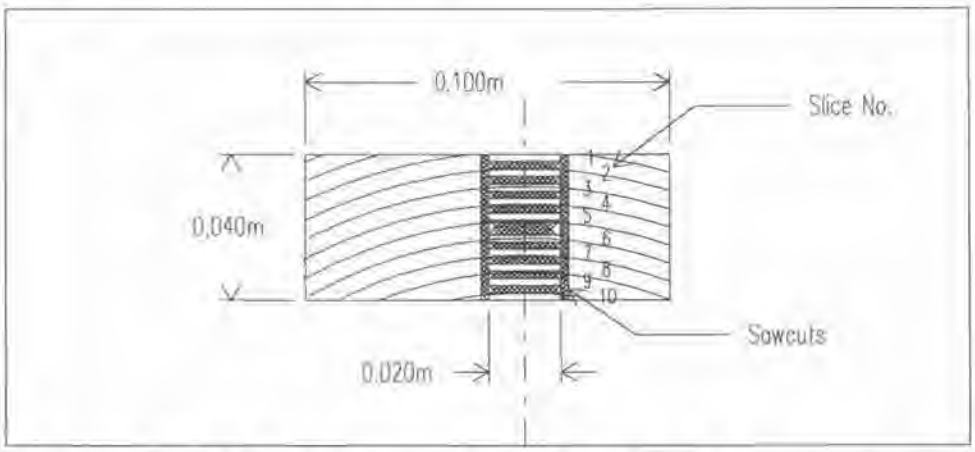

Figure 1. Method of cutting 2mm slices from drying specimens

Figure 2 shows the MC profiles immediately after drying for six of the specimens which had been dried at various conditions (Table 1). These specimens were stored for several years before being sawn to produce the slices.

Table 1. Drying conditions for six specimens

Specimen	Run.	DBT °C	WBT °C	Velocity m/s	Time Minutes	Initial MC%	Final MC%
A013	3	150	70	12	360	114	13
A024	6	90	70	3	5505	110	8
A053	9	120	70	3	1080	113	10
B011	16	120	70	5	960	115	9
B021	4	210	70	12	180	130	7
B024	8	150	70	5	420	122	10

The sets of slices were cycled between high and low humidity conditions as shown in Figure 3. Before each change of conditions and at frequent intervals the slices were weighed and measured, however only MCs calculated from the measurements of mass are discussed here. Figure 4 shows some of the MC profiles determined during humidity cycling.

To investigate the effect of steaming, material from the same specimen group as previously used and which had been kept frozen was thawed and two pairs of specimens prepared and dried at 150°C for 6 hours. One of each pair were steamed for two hours after drying. Partial moisture content profiles determined after cooling are shown in Figure 5 (These profiles represent the wood in the sawn slices numbered 1 to 4). Slices were sawn from these specimens as previously described and the slices were conditioned to 12% EMC and then treated according to Figure 6. MCs of the slices after initial conditioning and at 5% and 22% were determined (Figure 7).

RESULTS AND DISCUSSION

Radiata pine boards dried at high temperature without final steaming had significant MC gradients (Figures 2, 5). Comparison of the moisture content of specimens B152 and B151 (average 12%) and A091 & A095 (18%) show the effect of steaming in reducing these gradients.

The initial MC profiles of individual specimens dried at high temperatures and conditioned at 12% EMC had a 'bell' shape with the slices from near to the surface at lower MCs (Figure 4(a)(i)). This effect was considerably reduced after a number of conditioning cycles (Figure 4(a)(iii)). The reduction was less great but still obvious at low MC (Figure 4(b). At high MC the effect was apparently unaffected.

Figure 7(b) shows remarkably high MCs in that wood of Specimen A095 which had not been dried to within the hygroscopic range i.e. slices 4 to 6, perhaps indicating that temperatures of 100°C while wood is above fibre saturation do not reduce and may increase hygroscopicity. The B specimens, dried to 12%, reached a smaller range at a lower MC and B152 which was steamed shows reduced variation.

The 2mm thick sawn slices used in this work responded quickly to a changed environment (the change in MCs from those in Figure 7(d) to (e) in one day are increased only slightly to those in (f) with two days). This is indicative of the behaviour which can be expected of surface layers of boards in service.

While the material used in this study probably does not fully represent the radiata pine processed by the industry, the results indicate that boards dried to MCs below 15% in the centre and steamed after drying to eliminate the MC gradients can be expected to have similar hygroscopic characteristics through the thickness and therefore can be resawn with little concern.

ACKNOWLEDGEMENTS

The author wishes to thank Geoff Turville and Sharon Manley for their careful specimen preparation and taking of measurements.

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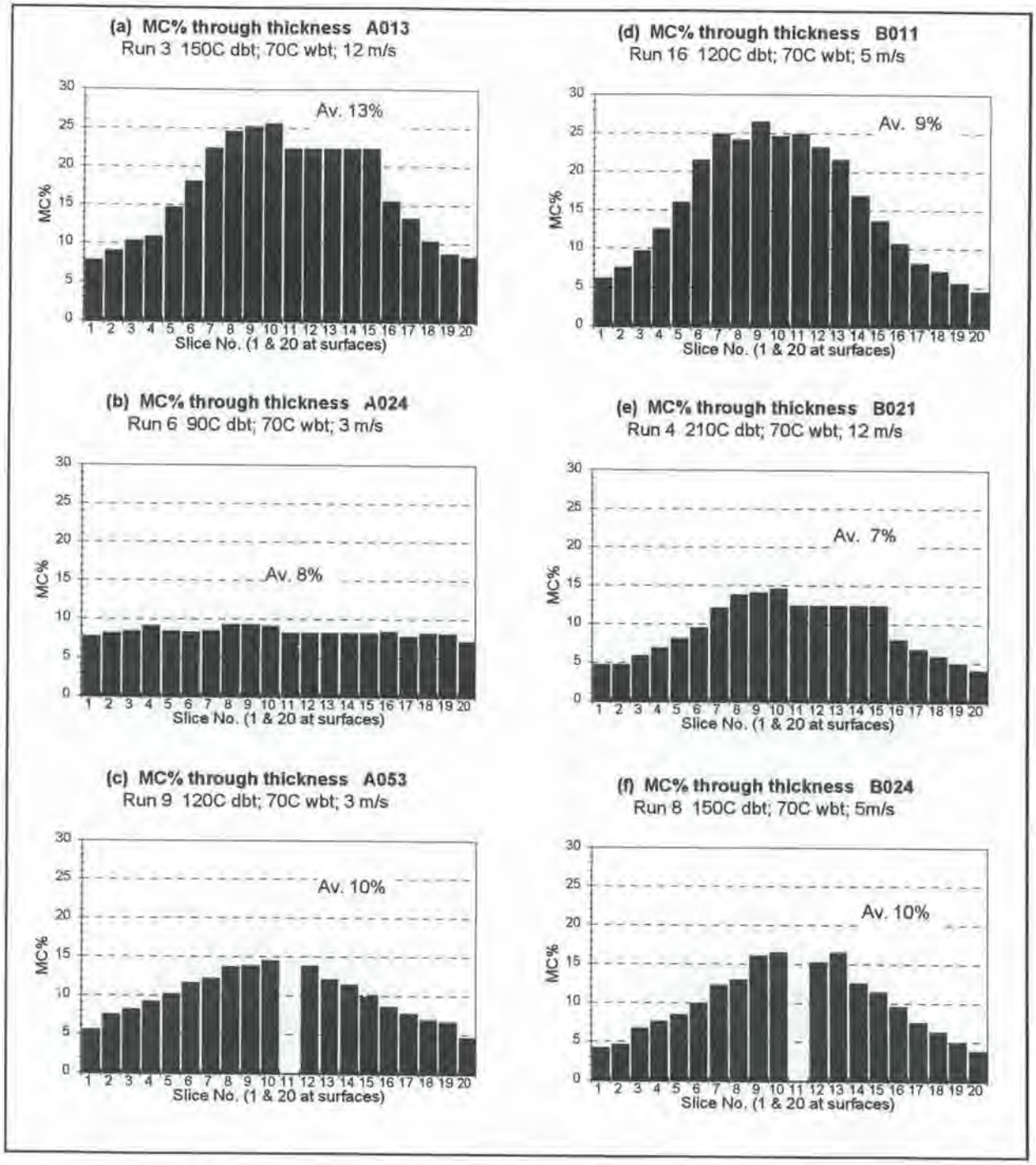

Figure 2 Moisture content profile through the thickness of specimens after drying

Radial cores sliced in 1mm increments from each surface and oven-dried

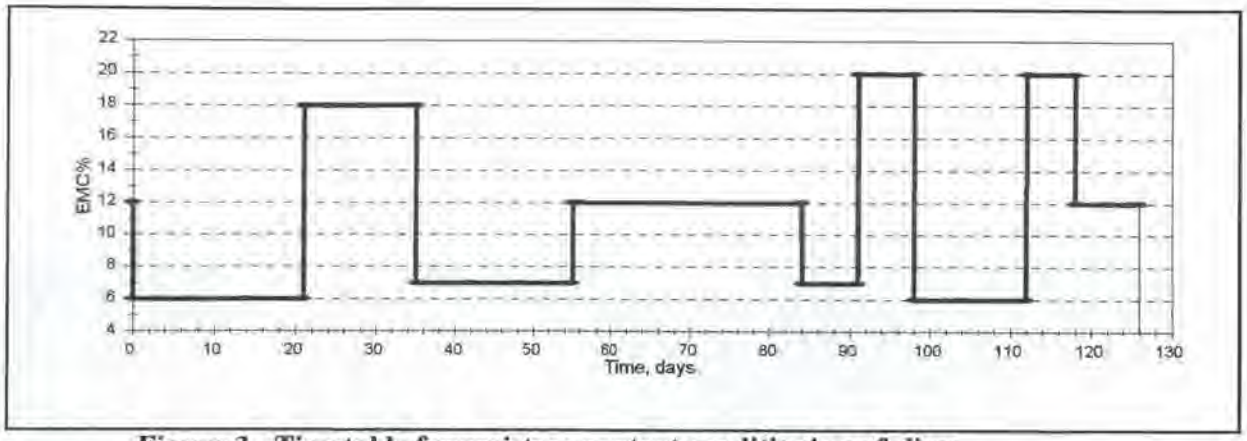

Figure 3. Timetable for moisture content conditioning of slices

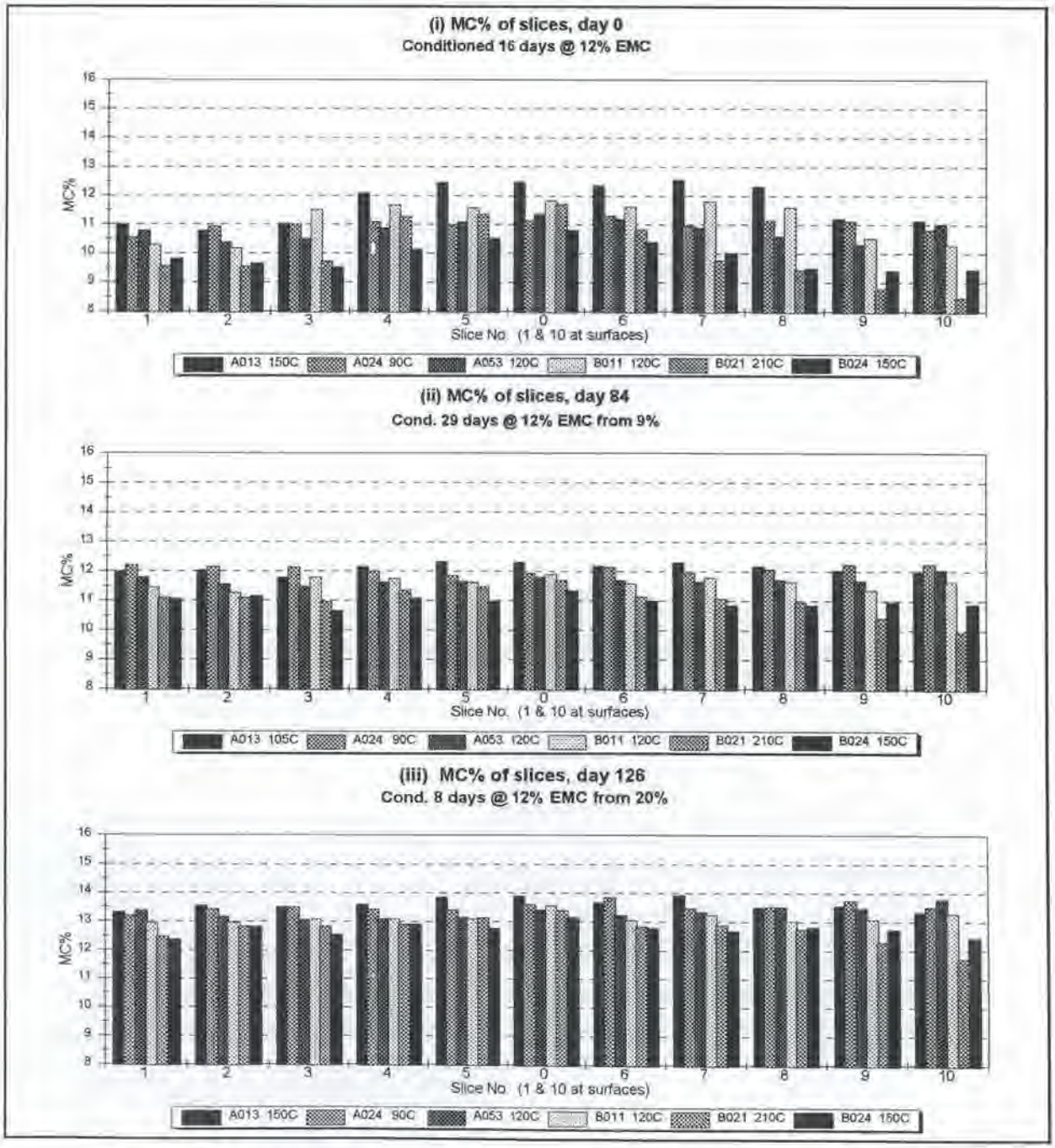

Figure 4(a). Moisture content of slices conditioned to 12% EMC at several stages

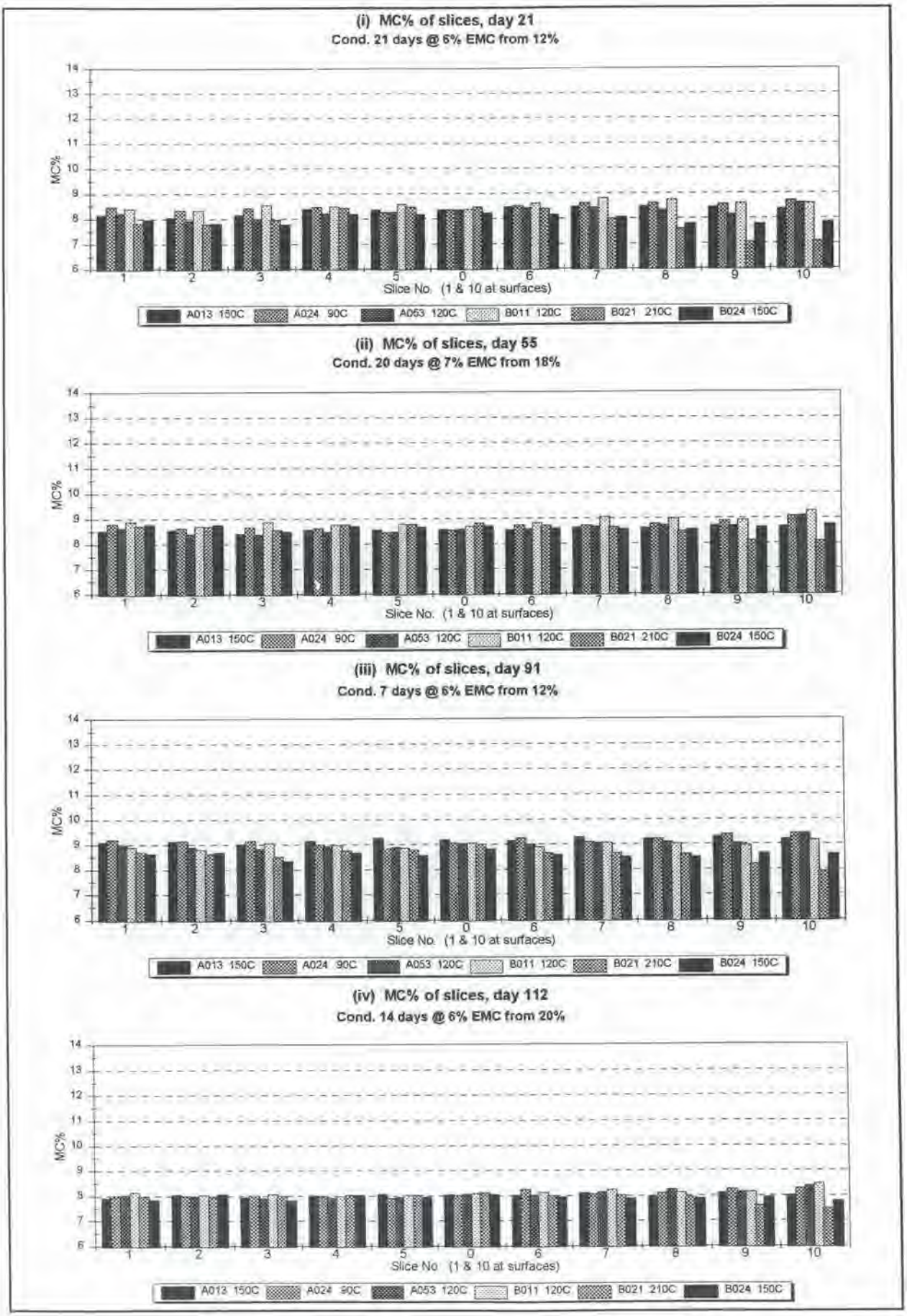

Figure 4(b). Moisture content of slices conditioned to low EMC at several stages

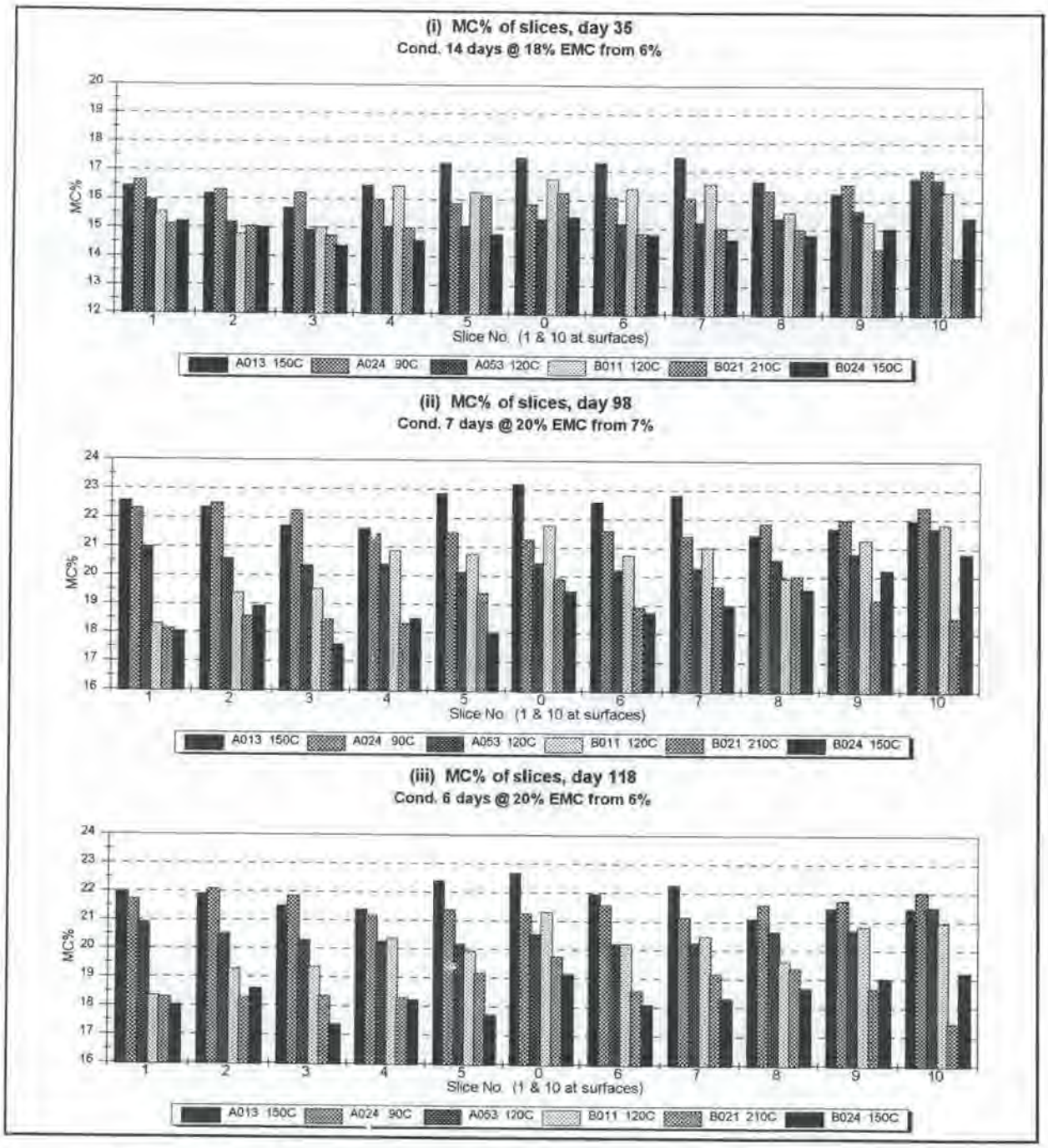

Figure 4(c). Moisture content of slices conditioned to high EMC at several stages

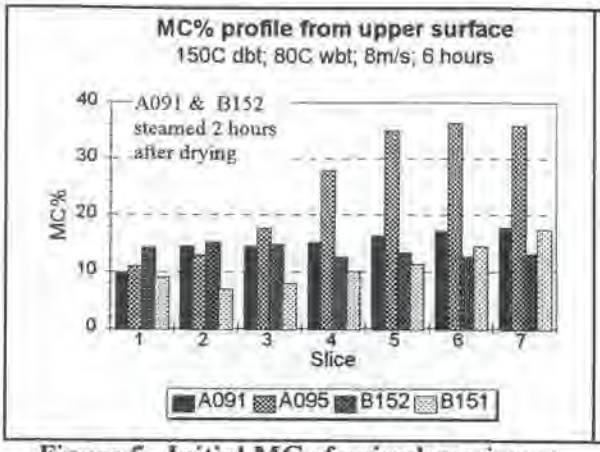

Figure 5. Initial MC of paired specimens

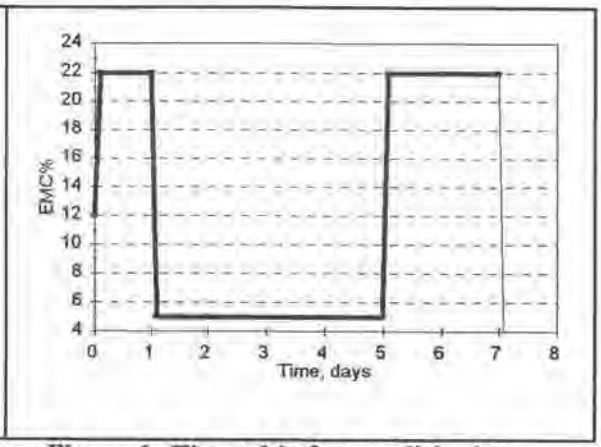

Figure 6. Timetable for conditioning

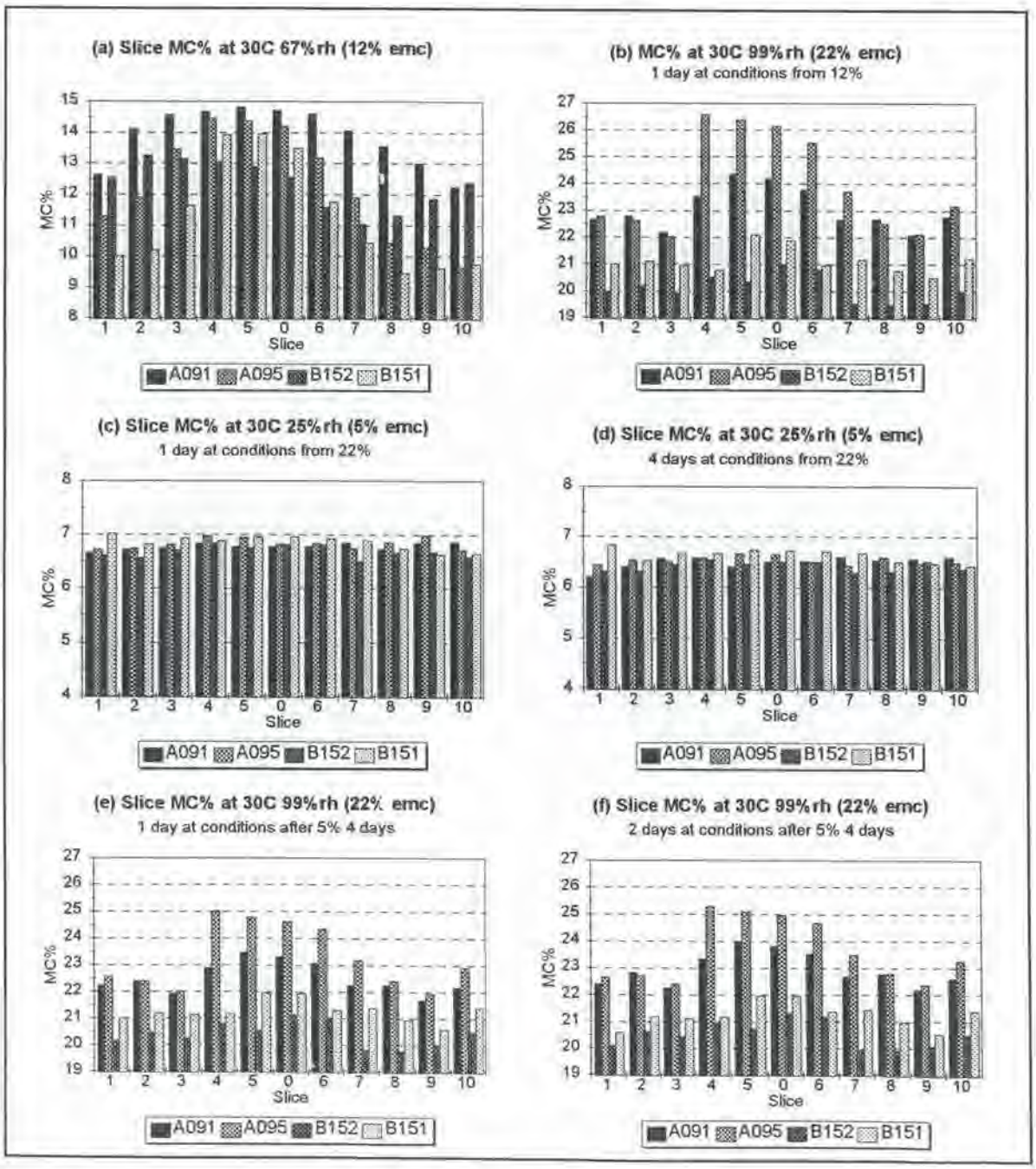

Figure 7. Moisture content of slices from paired specimens conditioned to 5% and 22%

DRYING AND DEGRADE DEVELOPMENT CHARACTERISTICS OF PLANTATION-GROWN *EUCALYPTUS REGNANS* F. Muell.

Richard Northway and Andrew Rozsa

CSIRO Division of Forest Products
Private Bag 10, Rosebank MDC, Victoria 3169

ABSTRACT

Specimens from three ages of plantation-grown *Eucalyptus regnans* were dried at several conditions and the rate of drying and development of surface checks monitored. Internal checks and collapse were assessed after drying. The early development of surface checks seems to be the result of collapse and its occurrence is dependent on the specimen surface characteristics, particularly the earlywood of growth rings in heartwood. Drying treatment had no apparent influence on the level of surface checking or collapse, the milder conditions only delaying the onset of surface checking.

INTRODUCTION

Drying rates and drying degrade development characteristics for plantation-grown *Eucalypts* are not well known but are critical for making decisions on plantings processing and products. Advantage was taken of the availability of carefully selected material (Waugh and Yang, 1993) to undertake drying tests so that this information could be collected. It is proposed to develop the methods and equipment used into a standardised procedure so that comparisons with and between other species and tree ages can readily be made as material for testing is available.

MATERIALS AND METHODS

Three backsawn boards, 100mm wide and 40mm thick of each age (Table 1.) were selected so that four end-matched specimens 500mm long could be cut generally free of inherent defect and heart and with similar growth ring pattern. Moisture content and basic density were determined using sections cut from between the specimens. Specimens were weighed, end-coated with silicon sealant and randomised into four batches. On the surface furthest from the pith of each specimen, areas 100mm square were marked for measurement of surface checks. In one batch, part of this surface of each specimen was planed and marked, and adjacent to the marked sawn and planed areas artificial surface checks were made. These comprised longitudinal knife cuts 20mm long and 2mm deep, terminated by short transverse cuts, and it was expected that monitoring when they opened would provide a means of identifying surface stresses prior to surface checks opening normally. Width and thickness were also measured at marked positions but the measurements are not discussed in this paper.

Table 1. Age and source of *Eucalyptus regnans* material

Code	Age, years	Source
7	16	South Gippsland, Victoria
8	23	South Gippsland, Victoria
9	31	South Gippsland, Victoria

The specimens in each batch were made into a small stack and dried in controlled environment chambers with low air flow (<0.5 m/s) at the conditions listed in Table 2. The mass of each specimen was recorded periodically and the average moisture content (MC) calculated. Figure 1 shows plots of MC with time for (a) all boards in each batch and (b,c,d) a typical board from each age.

The total length of surface checks within each 100mm square area was recorded at intervals until they closed (Figure 2), and the opening of the artificial checks monitored.

Batch (d) was moved from the 5% EMC conditions to 12% conditions after 35 days, batches (a) and (b) after 84 days.

When all specimens were equalised at 12% EMC, 100mm was cut from one end of each and the specimens re-coated and steamed for six hours to recover collapse. Collapsed and reconditioned sections were cut for scanning and image analysis to count internal checks and calculate collapse in cross-sectional area.

RESULTS AND DISCUSSION

The drying rates of all specimens were considerably slower with the higher humidity environments, although that of individual specimens varied quite widely. The slower drying rates did not however necessarily reduce surface checking or collapse, but only delayed the onset. It can be seen from Figure 2 that surface checks occurred later in the 20°C, 17% EMC conditions but the total checks recorded are not significantly lower for individual specimens (Table 2). Additionally, the most severe conditions, 5% EMC at 30°C, did not generate the highest level of checking, nor the most collapse in all specimens (Figure 3). Comparison of checking in sawn and planed areas was generally unproductive as the surfaces often differed in character.

The plots in Figure 3 as well as inspection of the specimens indicate that internal checks and surface checks are both associated with collapse, being generally confined to earlywood in heartwood. There was little or no surface checking in wood identified as sapwood or not clearly heartwood, even in specimens where there was considerable collapse. Further assessment using densitometry is expected to clarify this picture.

The behaviour of the artificial surface checks was inconsistent, apparently due to the variation in specimen surface characteristics, and closer matching of local surfaces would be necessary for the technique to be of any use.

CONCLUSIONS

A high level of surface checking resulting from collapse was found, and control of drying conditions offers little scope for controlling collapse degrade in plantation-grown *Eucalyptus regnans* up to 30 years old. Further assessment of material properties will be needed to explain why individual specimens behave differently. The low level of checking found in some specimens offers encouragement for wood properties assessments being incorporated into tree breeding programs. Development of methods for assessing wood properties in trees and logs may be justified.

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Geoff Turville and Sharon Manley for technical assistance and Jugo Ilic for advice on image analysis and specimen assessment.

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Waugh, G. and Yang, J.L. 1993. Potential for plantation-grown eucalypts as a resource for sawn products in South-Eastern Australia. Proc. 24th Forest Products Research Conference, Clayton, Victoria, Australia, Paper 3/13.

Table 2. Specimen and degrade details

Specimen	Green MC %	Basic Density kg/m³	Surface Checks cm	Internal Checks No.	Collapse %	Surface Type (#)	Dist. pith mm (*)
(a) Specimens dried at 20 °C, 83%RH (17% EMC); < 0.5 m/s air velocity							
713	165	382	0.0	51	8.2	I	65
721	129	408	0.0	4	2.3	I	75
7313	165	381	15.3	69	12.5	E	60
812	151	423	12.9	10	8.1	E	70
823	107	461	0.0	31	6.4	S	125
8313	113	425	31.7	33	5.4	E	65
9115	120	464	44.2	60	6.3	E	120
9314	100	513	2.0	6	1.4	E	145
9412	148	406	29.1	97	10.7	E	75
(b) Specimens dried at 30 °C, 85%RH (17% EMC); < 0.5 m/s air velocity							
712	163	388	0.0	57	12.5	I	80
723	138	424	0.0	1	0.0	I	85
7312	161	389	22.8	73	14.2	E	75
813	158	406	22.7	9	9.3	L	60
822	103	452	15.2	25	6.4	S	100
8312	114	424	0.0	43	4.7	L	75
9114	116	478	55.6	51	9.7	E	105
9312	101	511	0.0	19	3.8	S	170
9413	156	389	47.2	69	12.6	E	85
(c) Specimens dried at 30 °C, 67%RH (12% EMC); < 0.5 m/s air velocity							
711	164	391	0.0	66	9.7	I	75
724	140	433	0.0	6	0.8	E	85
7311	161	389	25.7	28	6.5	E	165
811	144	441	9.1	3	5.0	I	100
824	112	469	9.1	31	6.0	S	140
8314	115	424	23.8	31	4.9	E	75
9113	112	494	32.4	84	9.3	I	125
9313	101	507	0.0	21	1.6	S	125
9414	160	380	53.8	72	9.8	E	125
(d) Specimens dried at 30 °C, 25%RH (5% EMC); < 0.5 m/s air velocity							
714	168	372	0.0	29	6.7	I	80
722	136	416	0.0	1	0.0	I	90
7314	163	388	54.7	59	13.7	E	80
816	150	400	7.7	3	5.0	E	95
821	106	439	34.1	33	4.0	H	100
8311	115	418	0.0	10	1.0	L	95
9112	110	499	62.0	55	7.0	E	130
9315	98	525	29.6	0	1.9	H	140
9411	138	429	28.6	74	9.0	E	75

S = sapwood; H = heartwood; I = intermediate (or outer heartwood); E = earlywood; L = latewood

* Distance of the centre of the cross-section to the pith estimated from growth ring curvature.

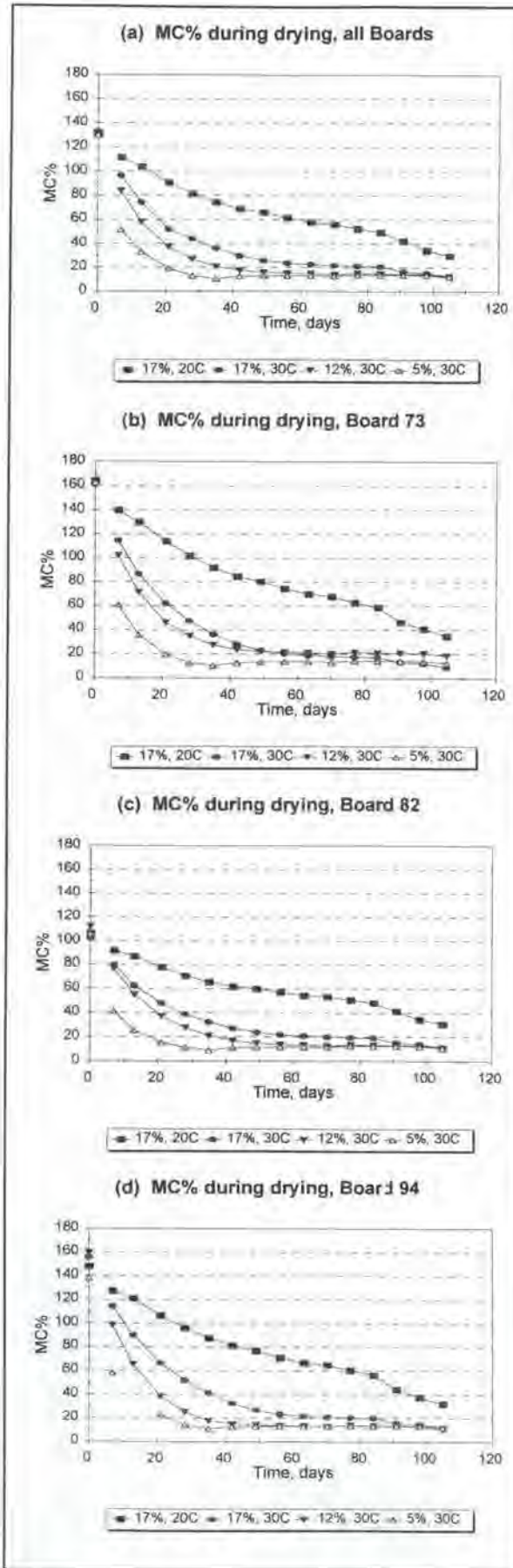

Fig. 1. Moisture content loss in drying

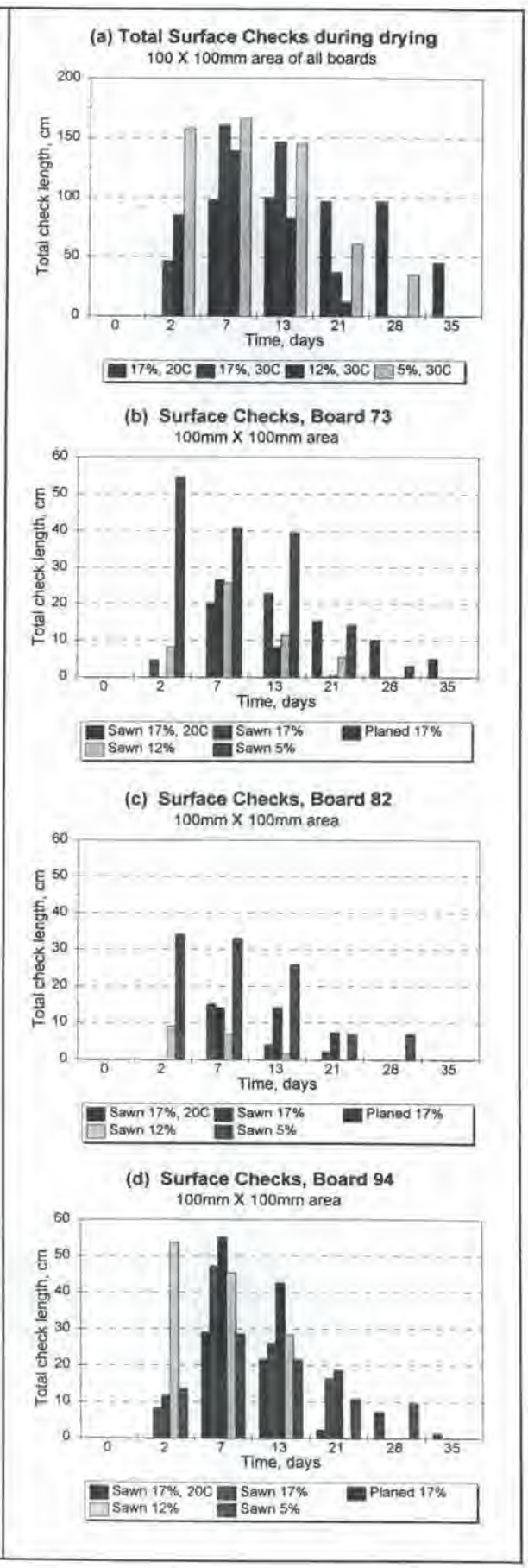

Fig. 2. Surface check development in drying

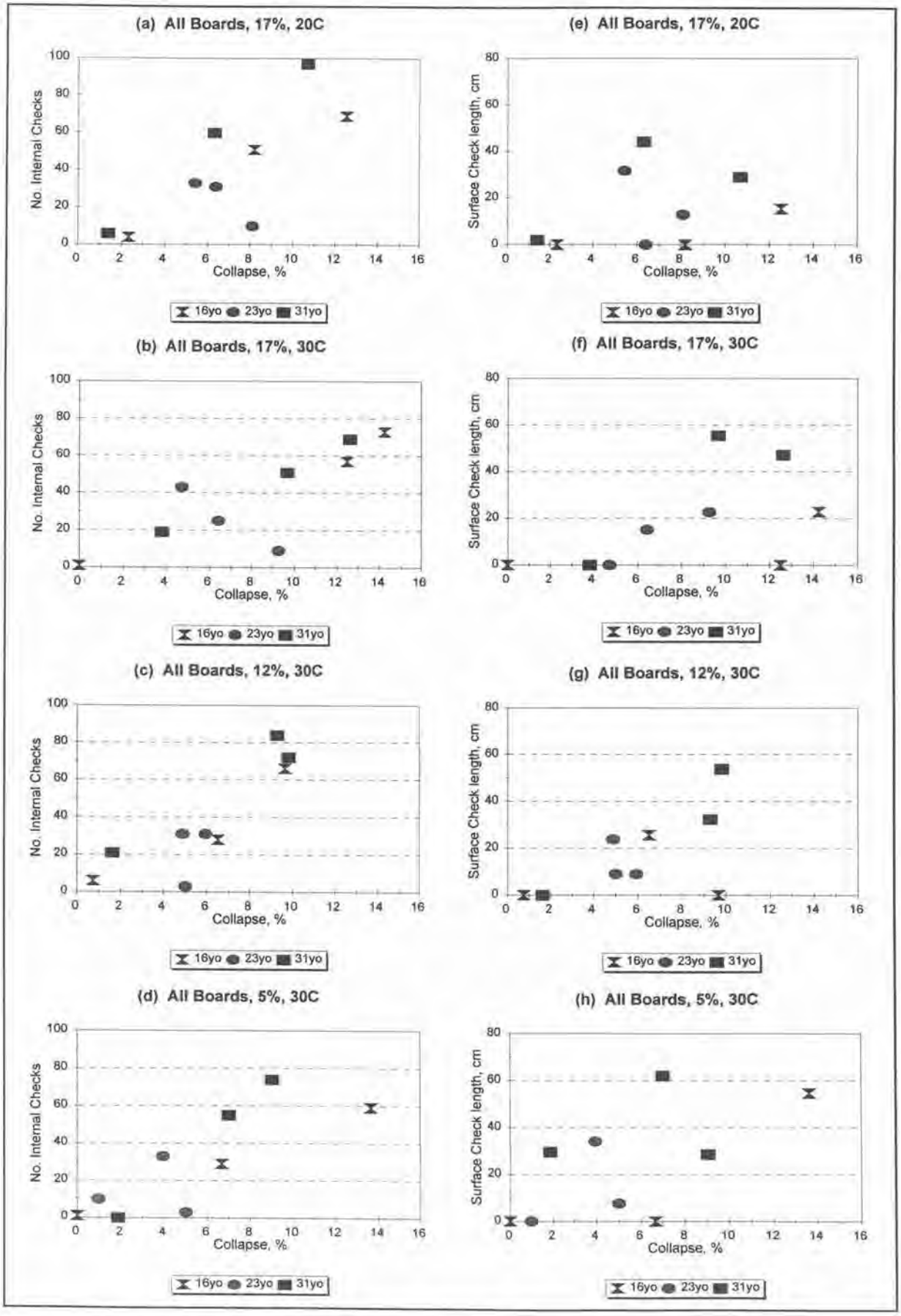

Fig. 3. Surface check and internal check severity against collapse for drying treatments

Potential for plantation-grown eucalypts as a resource for sawn products in South-Eastern Australia

G. Waugh and J.L.Yang.
CSIRO Division of Forest Products
Private Bag 10, Rosebank MDC, Clayton, Vic. 3169

Abstract

The primary objective of a series of studies was to investigate the potential of a range of eucalypt species, both endemic and introduced, which could have the potential to be grown in South-Eastern Australia under plantation conditions for high quality sawn products. Trials were carried out on *Eucalyptus regnans, E. globulus* and *E. nitens*, all of which are endemic to Tasmania and Southern Victoria, to examine the effect of tree age and growth attributes (branches, knots, kino occurrence) on the recovery and quality of sawn products. Preliminary qualitative sampling was also carried out to determine the potential of sub-tropical eucalypts suited to provide land care values in the Murray-Darling basin to determine their potential to provide wood products at a young age.

The *E. globulus* and *E. nitens* trees used were mainly from plantations in North-western Tasmania, and the *E. regnans* trees were mainly from plantations in Southern Gippsland, Victoria. The ages of the trees ranged from 14 to 33 years. The sawn products were subject to visual grading for both appearance and engineering products and to four-point static bending test. The major findings were:

(1) Knots were much larger due to the larger branch size of plantation-grown trees than from comparable sized trees from natural regrowth forests of the same species.

(2) There appeared to be little commercial opportunity for appearance products. No species of any age achieved more than approximately 5% of product out-turn as select product grade or better with knots the predominating down-grading factor. However, for *E. regnans*, drying checks, kino, and decay associated with dead knots, were almost as severe in down-grading appearance products.

(3) All age classes of *E. nitens* and *E. regnans* failed to meet satisfactory strength requirements for construction use. The principal reason for the poor strength properties was the predominance of knots and low density.

Preliminary studies are showing that there is an excellent opportunity in providing treated round and sawn products from a range of species, including *E. maculata, E. grandis* and *E. saligna* grown in the Murray-Darling basin primarily for land care values. Studies are showing:

(1) Long-length clear section sawn products can be obtained from trees of less than 20 years of age, due to the excellent self-pruning properties of the three species growing at normally accepted spacing for plantations.

(2) While densities appear to be lower than those of mature trees, they do not approach threshold levels which would have an adverse effect on engineering products.

(3) Drying degrade appearing as distortion, collapse or checking appeared at minimal levels during the processing of these species.

Introduction

There has been a firm belief for many years in industrial forestry that many of our endemic South-Eastern Australian fast-growing eucalypts should have a high potential for being 'domesticated', growing under plantation conditions to provide solid wood products. In the last 15 years, improved establishment techniques, weed control, increased environmental concerns, and a recognition of the finite existence of our natural eucalypt forest resource, have created an increased interest in eucalypt plantations, initially as a resource for the pulp and paper industry, but in more recent years, as a potential sawlog resource.

Following on from the Young Eucalypt Program (Kerruish and Rawlins 1991), which determined the potential of wood products from intensively-managed regrowth forests of age up to 60 years, CSIRO supported by interested collaborators have investigated the opportunity of obtaining solid wood products from younger and faster-growing plantations. These studies have focused on two distinct areas of opportunity; establishing species endemic to Tasmania and Southern Victoria and also investigating the potential of sub-tropical eucalypts to be grown in the Murray-Darling River basin to provide land care values and wood products.

Tasmanian and Southern Victorian plantation eucalypts

Species of particular interest are *E. regnans*, *E. nitens* and *E. globulus*, which demonstrate a capacity to grow naturally as an even-aged monoculture and have been therefore regarded as suited for domestication as plantation species. Limited areas of plantations of these species have been established over the last 45 years, primarily as a supply of fibre for local pulp and paper manufacture. Following a reduction in resource availability in these states in the late 1980's, increased interest has been shown in these plantations and in extending the plantation areas for sawlog production. The increased availability of softwood sawn products which has made inroads into traditional hardwood structural markets now means that the Victorian hardwood sawmilling industry must follow Tasmania's lead, looking more toward producing higher quality hardwood appearance sawn products in order to find a market niche, but utilising smaller logs from younger trees.

Materials and Methods

Two trials were carried out. The first consisting of thirty-six trees of three species, *E. globulus*, *E. nitens*, and *E. regnans* over three age classes from 15 to 35 years which were harvested from nine plantations (mainly APPM plantations in North-Western Tasmania) with four trees per plantation. The second trial sampled six *E. regnans* plantations in Southern Gippsland, Victoria, again four trees per plantation, between the ages of 25 and 45 years. In the Victorian trial, butt logs were quarter-sawn; in all other cases however, the logs were back-sawn, using a slab-sawing strategy. Half-taper sawing was carried out on a log carriage to break-down the logs to minimise sawing-related sloping grain.

Products were dried using sheltered air drying in the early stages of the drying schedule, followed by steam reconditioning and final kiln drying to 12% moisture content, and graded to both appearance (Waugh and Rozsa, 1991) and engineering product specifications. In the first Tasmanian-based trial, only products cut from inner and outer heartwood zone along the north-south orientation of the standing tree, from the bottom three logs of each tree, were further used to assess internal checking and bending strength. Sawn product out-turn and appearance grade recoveries were determined, and compared with results of other studies on plantation eucalypts

and natural regrowth. Strength data was analysed to determine the influence of tree growth characteristics and compared to previous known data.

Results and Discussion

Growth characteristics

In most plantations sampled, stocking levels were between 50 and 65 m^2/ha, with trees around 400 mm diameter by about age 30. Despite the highest stocking and the youngest age, *E. nitens* showed the fastest growth rate, otherwise growth rates appeared comparable, given the limits of comparing different sites with different climatic conditions.

E. nitens and *E. regnans* demonstrated very poor self-pruning characteristics showing dead branches at a lower level and much larger branches than *E. globulus*, however for all species the majority of knots seen in the sawn boards were live or tight. Plantation-grown *E. regnans* also showed much larger and a greater number of dead branches than natural regrowth with a high incidence of decay associated primarily with the dead branch stubs. No decay associated with dead branches was found in *E. nitens* and only rarely seen in *E. globulus*. *E. nitens* in particular retained juvenile foliage dead branches, the proliferation of small branch stubs resulted in a much reduced length of clear panels. These branches resulted in a knot defect in sawn products even after the branch had disappeared and only a branch stub is left. Kino impregnation into the branch stub appeared to provide a physical barrier to fungal attack. Tree growth appeared to keep the stub at cambium level, rather than occluding it, drawing the stub out as the tree grew, leaving a trace about 8-10 mm behind which was full of kino.

Wood density for all species was much lower than for mature wood, with suprisingly little difference between inner and outer heartwood for *E. regnans* and *E. nitens*. The average basic density from the inner and outer heartwood for each species of each age group from the Tasmanian study is presented in Table 1.

Table 1

Average basic density of boards from inner and outer heartwood (kg/m^3)

Age (years)	Species						Mean		
	E. globulus		*E. regnans*		*E. nitens*				
	inner	outer	inner	outer	inner	outer	inner	outer	overall
15-20	542.2	614.3	459.6	443.5	474.1	442.9	482.0	500.8	491.4
21-28	602.8	647.1	482.2	484.6	434.5	448.7	496.6	522.1	509.3
29-35	564.5	653.2	554.9	575.4	481.2	522.6	519.7	586.6	553.1
mean	560.4	633.1	479.5	509.9	489.3	504.7	499.4	536.5	518.0

No direct measure of growth stresses were made for this study, but the width and length of end splits on the log ends were recorded, and analysed. End-splits of greater than four millimetres will result in considerable losses in both appearance and engineering products. It was found that *E. globulus* had the worst end-splitting with more than 30% of logs having splits of four millimetres or greater, while log end splits were almost negligible in *E. nitens*. *E. globulus* also exhibited greatest distortion related to growth stress during sawing, but the distortion was readily controlled using the back-sawing strategies adopted.

Sawn product out-turn

Any comparison of sawn recovery between age classes and species is difficult as through necessity sawing was carried out in two different sawmills, with different equipment configurations, although the same operators and sawing strategies were used. The sawmill used for the *E. globulus* and two younger age groups of *E. nitens* employed a circular headsaw as against a band headsaw used for the *E. regnans*. The difference in saw kerf, particularly in a slab-sawing strategy could account for about 10% difference in product recovery alone. Larger diameter logs sawn for the older age class could also improve product recovery from between 10% to 20%, as demonstrated with *E. regnans*, which was all sawn at the one sawmill. A high proportion of severe end-splitting in the older age class of *E. globulus*, along with a greater amount of distortion during sawing than for other species, had an effect in reducing product recovery below that of the other species for the same age group.

The green engineering product out-turn even for the oldest plantation-grown trees from the Tasmanian study (Table 2a) was below that achieved from what were similar diameter trees from 40-year-old natural regrowth (Waugh and Rozsa 1991). However, the larger diameter logs from older plantations in the Victorian trial (Table 2b) provided better sawn recovery results for *E. regnans*, but lower recoveries were recorded for the butt logs which were quarter sawn and which had the greatest taper.

Table 2a

Green sawn product recoveries (per cent of log volume) for each sampling site in the Tasmanian trial

Age	*E. regnans*		*E. globulus*		*E. nitens*	
(years)	No. of logs	recovery (%)	No. of logs	recovery (%)	No. of logs	recovery (%)
14-19	14	34.9	8		13	28.0
21-26	12[1]	33.4	15	27.8	12	28.2
28-34	21	40.4	24	25.8	26	46.6

Table 2b

Green sawn product recoveries (per cent of log volume) for each sampling site and log height for *E. regnans* in the Southern Victorian trial

Site	Log height				Mean
no.	1	2	3	4	
1	37.5	44.1	50.0	48.0	44.9
2	40.9	43.5	51.0	50.5	46.5
3	44.2	51.7	57.9	56.4	52.5
4	41.6	51.0	55.3	49.9	49.5
5	45.8	47.1	51.9	47.4	48.1
6	43.5	45.0	51.9	51.9	48.1
mean	42.2	47.1	53.0	50.7	48.3

Drying assessment

In the Tasmanian trial, *E. regnans* showed the worst drying degrade, followed by *E. nitens* and *E. globulus*, in terms of the average number of internal checks, average length of the largest internal checks, and the percentage of boards with five or more internal checks, when compared to the

[1] Five trees in sample, all others contain four trees.

other two species of the same age group. Surface checks precluded about 40% of the final product from achieving select grade or better and was even worse for the two younger age groups of *E. regnans*. Indications are that for *E. globulus* and *E. nitens*, back-sawn products with a final thickness of 35 mm could be dried to meet appearance specifications from all but the youngest wood (age 15-16 years).

Strength properties

The means of modulus of elasticity (MOE) and modulus of rupture (MOR), and lower 95 percentile levels from the Tasmanian trial are summarised in Table 3. *E. globulus* showed the highest strength properties, followed by *E. regnans* and *E. nitens* between which there is a less discernible difference.

Table 3

MOE and MOR, and lower 95 percentile (in brackets)

Age group	MOE (gPaX1000)			MOR (mPa)		
	E. globulus	*E. nitens*	*E. regnans*	*E. globulus*	*E. nitens*	*E. regnans*
15-20	12.2 (10.7)	8.9 (8.6)	10.3 (10.0)	42.0 (33.0)	33.6 (28.5)	43.3 (38.7)
21-25	15.6 (14.7)	10.4 (9.9)	10.2 (9.7)	66.5 (59.1)	39.9 (34.4)	38.5 (33.8)
28-33	15.9 (14.9)	11.8 (11.1)	12.9 (12.1)	65.6 (56.4)	60.2 (54.4)	53.2 (45.8)

All species showed a consistent and statistically significant increase in strength with increasing age, with the strength properties of *E. globulus* generally higher than that of the other two species. The modulus of elasticity of *E. regnans* and *E. nitens* are consistent with published data (Kloot, 1957; McKimm et al, 1988). However, the modulus of rupture of *E. nitens* is up to 50% lower than that of regrowth and mature growth (McKimm et al, 1988). However, it has to be remembered that this study was carried out with a predominance of low-density juvenile wood and the sawn products often contained large knots. Once these factors were accounted for in the regression analysis, the results were consistent with other published data.

Products visually graded to appearance criteria

Both the Tasmanian and Victorian trials showed that from all the plantations sampled of the three species, less than five per cent of the total product out-turn would have met appearance grade specifications for select quality or better (including polishing and joinery grades). This range of product specifications are the target product quality requirements for the Tasmanian sawmilling industry, and will need to be the objective of the Victorian sawmilling industry. In more than 75% of the plantations sampled, the grade-limiting defect was knots (Figures 1 and 2). While knots are a major contributor to product downgrade in *E. regnans*, other defects such as kino occurrence (veins and pockets), decay and drying degrade were almost as severe. An analysis, assuming knots were absent, suggested that a reduced incidence of knots could lead to a significant improved product quality out-turn for *E. globulus* and *E. nitens*, coming close to the quality out-turn expectations for the old growth forests of Tasmania. However, the contribution of the other down-grading factors would lead to little or no improvement in product quality for *E. regnans*. Overall product grade out-turn of select quality or better of *E. regnans* was about one-third behind that of natural regrowth (Waugh and Rozsa 1991), and only one-tenth of the quality out-turn expected of the old-growth forests.

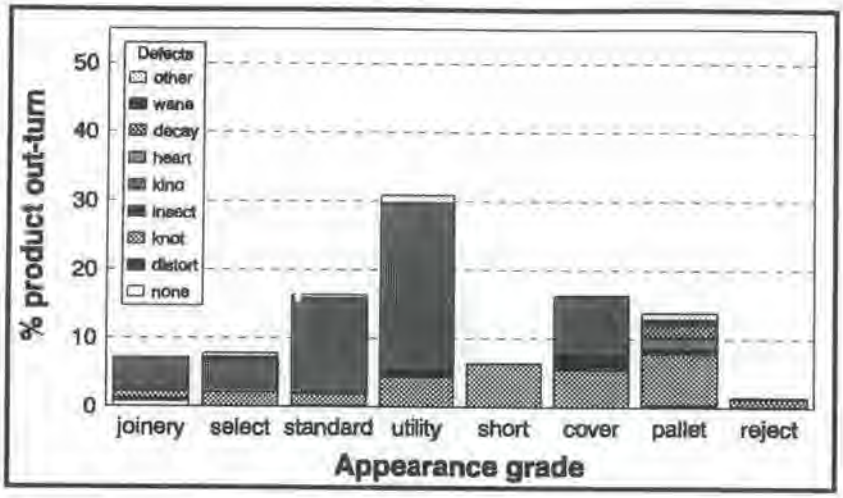

Figure 1
Product appearance grade out-turn and grade limiting defect contribution for 37-year-old plantation-grown *E. regnans* from Southern Victoria.

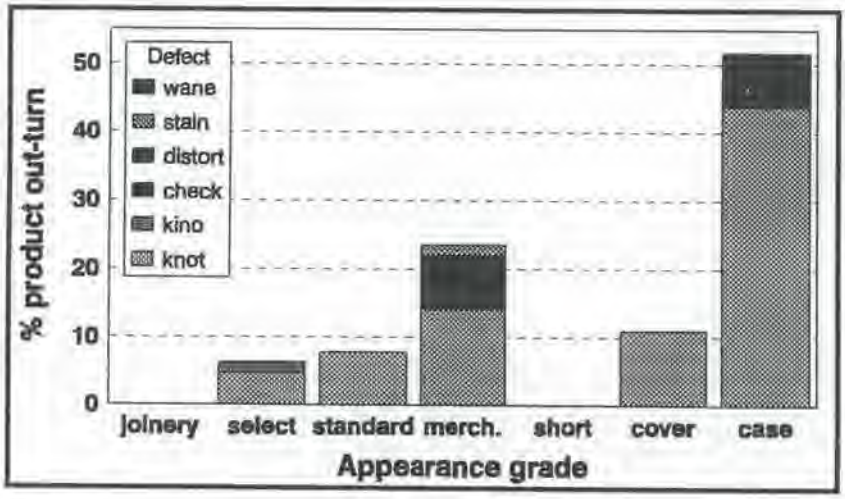

Figure 2
Product appearance grade out-turn and grade limiting defect contribution for 34-year-old plantation-grown *E. globulus* from Tasmania.

Trees grown for land care values in the Murray-Darling River basin

In the order of 500 000 ha of valuable irrigation land in the Central Murray Valley areas of Victoria and NSW alone has been identified as being under short to medium term threat in maintaining sustained agricultural production due to rising high water table levels. Ground water pumping is currently being practiced as one method of control, but an alternate proposal being seriously considered is to use trees as biological water pumps. Some sub-tropical and coastal eucalypts which have not evolved in a drought environment can be prodigious users of water, particularly during the summer growing season. Such species include *E. grandis, E. saligna* and *E. pilularis*, while other species such as *E. botryoides* and *E. maculata* may also be applicable. Limited establishment trials and wood-lots (of species other than *E. pilularis)* which have been grown over the years by interested farmers, have shown that given the adequate water supply, sunlight and ambient temperatures of this region, these species can be expected to show appreciable growth rates of between 20 to 35 m^3/ha/year. Other more drought resistant species such as *E. cladocalyx, E. sideroxylon* and *E. camaldulensis*, while showing much lesser growing rates have also shown to be able to grow quite well under these conditions. Plans are for trees to

be used as ground water pumps on existing aquifers and on check banks of irrigation bays, as plantations at the end of irrigation bays to intercept water which would otherwise recharge ground water levels and also to irrigate plantations with excess drainage water.

Research on tree water usage indicates that trees in the order of 40 000 ha would need to be established in strategic locations across this region, which conservatively could produce in the order of 800 000 m^3/year of wood. A preliminary exploratory project funded by the Rural Industries Research and Development Corporation (RIRDC) is being carried out to determine the potential of as many as possible of the above species to be used to provide solid wood products. Studies are being confined to the preservative pressure treatment of round timbers for posts and poles, sawing, the drying of sawn products, and the evaluation of sawn products for different end-uses. This work is being carried out on trees from 15 to 25 years of age (of similar age to trees used in the other two studies). While this work is still at an early stage, a number of significant observations have been made which are worthy of comment:

(1) All of these species appear to exhibit good self-pruning properties (*E. maculata* being exceptionally good), which make it possible to obtain high appearance grade long-length products from trees of less than 20 years grown at conventional plantation spacing. This was not possible to be achieved with the previous studies on indigenous southern species.

(2) While some problems were experienced with *E. camaldulensis*, all other species showed exceptionally good tree form, being able to be grown for longer-length poles and sawlogs. Tree form was not regarded as a problem for the southern species either.

(3) During the limited harvesting of trees for product evaluation, no major problems were encountered with end-splitting, however high growth stresses were evident as distortion during sawing, which was handled using back-sawing strategies.

(4) In the limited amount of drying of the young wood of these species which has been carried out to date, very little drying degrade in the form of distortion, surface or internal checking or collapse is evident in species other than *E. camaldulensis*. There appears to be no problem in drying back-sawn products from any of these species.

(5) None of the problems of decay associated with dead branch stubs, excessive kino production or reaction wood problems which at time were major degrade factors in the indigenous southern eucalypt species.

(6) The wood of the range of species under evaluation exhibit a wide range of characteristics. *E. sideroxylon* wood is characteristically dark red in colour and high-density, while wood from *E. grandis*, *E. saligna* and *E. botryoides* is all relatively low density (about 550 kg/m^3) and pale pink in colour and the other species even lighter straw coloured. *E. sideroxylon* and *E. maculata* both have fine textured wood, while the others are more coarse in texture, but still adequate for many appearance applications. Stability testing and the determination of shrinkage characteristics is still being carried out.

Further sawing studies are to be carried out on selected species to validate these early findings, along with strength testing, preservative treatment tests and heartwood durability tests, all of which will be needed to establish export markets for pole timbers and expand market opportunities for sawn products. Further work will also be needed to establish markets for residual wood. In the early days of project development, firewood will possibly be a major market for residual wood, but supply is anticipated to quickly exceed demand. Lower density species could be used for pulp and paper products or export wood chips, but research is needed to develop markets for higher-density residue wood. Potential may exist for liquid fuels, carbon products or for power cogeneration.

Conclusions

While good growth rates appeared to be possible from both indigenous southern species and trees grown in the Murray-Darling River basin for land care, there is clear evidence that the ability of trees to be able to self-prune branches is critical for the production of high-quality appearance products. In Southern Victoria and Tasmania, the poor product grade out-turn from *E. regnans, E nitens* and *E. globulus* sawn for both appearance and engineering grade products is mainly associated with branch and knot, or with secondary defects such as decay. The modulus of elasticity and modulus of rupture results for these species are considerably lower than the published data. However, based on regression coefficients, once both low density and large knots were taken into account, the results from this study were comparable with the published data.

Despite the fact that *E. regnans*, and to some extent, *E. globulus* and *E. nitens*, do occur naturally as an even-aged monoculture, some doubt must be expressed regarding the potential for domestication of these species, particularly *E. regnans* using conventional plantation technology. At this stage, based on the results of these and corroborating studies, the very low out-turn of higher-quality appearance sawn products would make it very difficult to seriously consider growing these species under existing plantation conditions as an alternate resource to either the old-growth or regrowth natural resource. There appears to be a need to examine the potential of growing these species under a range of different silvicultural options; planting at closer spacing or direct seeding, to provide higher stocking levels to promote better self-pruning (simulating natural forest conditions), or to go to the other extreme, of wide spacing and mechanical pruning.

In contrast, selected eucalypt species which have the capacity to be grown to provide land care values in the Murray-Darling River basin are showing a potential to provide high-quality appearance products while being grown using traditional plantation practices. Self-pruning properties which range from very good to excellent, good tree form and very little in the way of drying problems overcome most of the major barriers faced in utilising an even wider range of eucalypt species, even at a young age. Further work is being directed toward improving limited existing knowledge on utilisation potential and product characteristics of a limited range of the most promising species. In the future, opportunities should exist for the development of a viable wood processing industry in this region and to diversify farmers' production and income growing an alternate, longer term crop.

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HOOP PINE SEASONING PROBLEMS AND SOLUTIONS

Graeme Palmer
Timber Research, Qld Department of Primary Industries, Forest Service
PO Box 631, Indooroopilly, QLD 4068

ABSTRACT

This paper discusses research conducted by DPI-FS Timber Research and funded through the Timber Research and Development Advisory Council of Queensland.

Problems encountered by hoop pine sawmillers in seasoning hoop pine are summarised, and solutions discussed.

Results indicate that drying schedules previously adopted were inappropriate to operations that produce both appearance and structural grade products. Processing flexibility and kiln drying system design are important to successfully exploiting hoop pine.

The results of this industry funded research has lead to changes in processing that have in turn lead to significant increases in productivity.

BACKGROUND

While the results of research into seasoning hoop pine is the main focus of the paper, it also provides an example of a research program funded and directed by the hoop pine sawmilling industry in Queensland that resulted in tangible improvements in hoop pine processing. The research discussed here also gives an insight into the requirements of seasoning softwood for appearance grade products.

The projects undertaken were initiated by hoop pine sawmillers in response to difficulties in routinely drying hoop pine to a quality end product. It is recognised that hoop pine, which attracts a higher royalty than exotic pine in Queensland, has the potential to provide wood that can be processed to high value products. In particular, the plantation hoop pine resource features relatively large log sizes and has been silviculturally managed to provide clear wood. In addition, hoop pine which has regular whorled branching and long internodes,

lends itself to efficient production of fingerjointed boards and mouldings. A significant impedance to optimal processing of plantation hoop pine, was the variable drying behaviour of the wood. Of particular importance was the problem of slow drying in hoop pine "wetwood".

PROBLEMS

Before this research was undertaken, the drying schedules commonly employed by hoop pine sawmillers were similar to those applied to drying exotic pine for structural framing, which are summarised as follows:

i) A period of steaming prior to drying aimed at reducing distortion,

ii) A drying phase at high temperature (up to 140°C), and

iii) A reconditioning treatment to reduce drying stress and to reduce moisture content gradient within the timber.

The results of drying according to the above type of schedule were unacceptable for a number of reasons:

i) FINAL MOISTURE CONTENT DISTRIBUTION

The final distribution of moisture content for a kiln charge dried according to the above schedule was too wide. This was a reflection of uneven initial moisture content and variable drying rates in wetwood compared to normal wood.

Figures 1 and 2 show typical initial moisture content distributions for experimental kiln charges.

Uneven initial moisture content was due to partial air drying in some stacks prior to kiln drying and to differences in green-off-saw moisture content, between heartwood and sapwood.

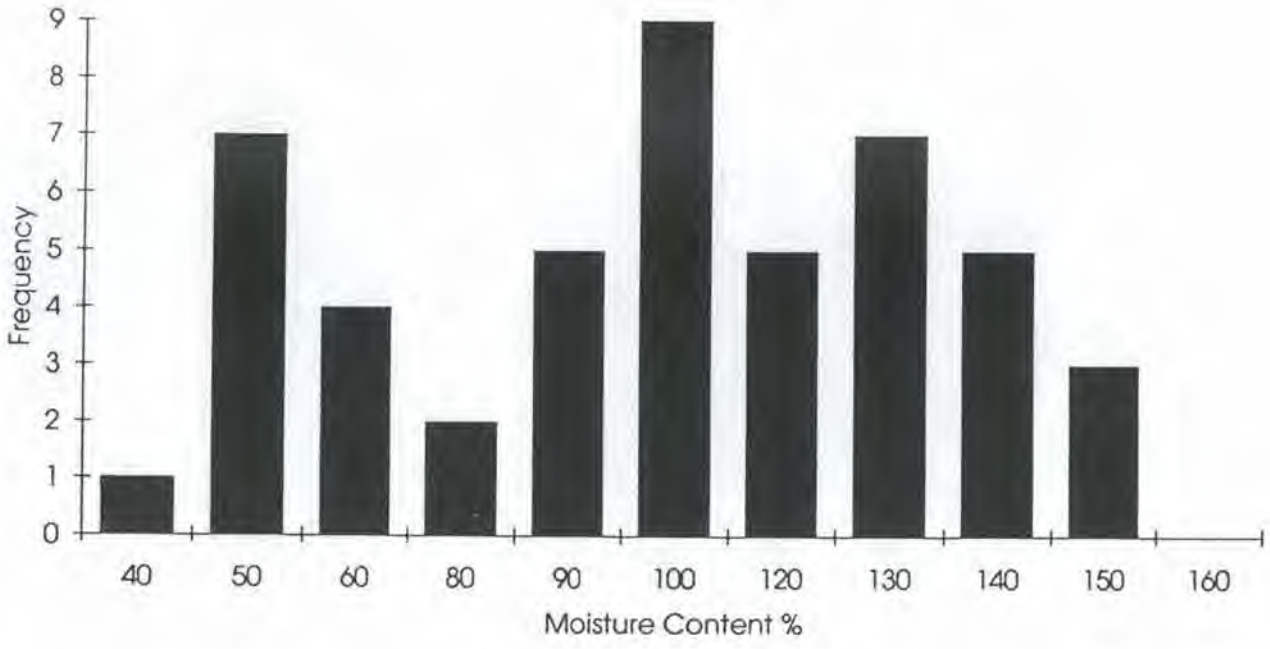

Fig. 1. Initial moisture content distribution of an experimental kiln charge comprised of material green off saw. (150 mm x 25 mm)

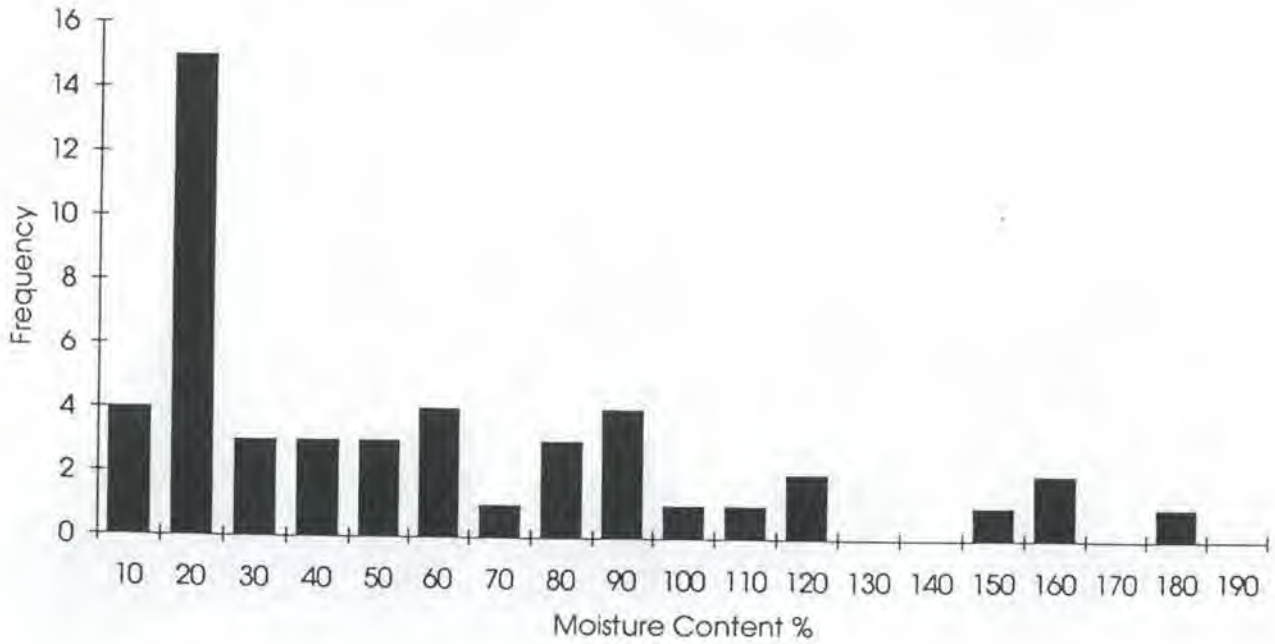

Fig. 2. Initial moisture content distribution of an experimental kiln charge comprising material 0 to 2 weeks since sawing. (150 mm x 25 mm)

Drying rates in wetwood compared to normal hoop pine are grossly different. Figure 3 shows the resultant moisture content distribution for an experimental kiln charge dried according to a schedule similar to that described above. Note that after 16 hours at 150°C, the wettest boards (boards including wetwood) were 20% to 30% higher in moisture content than the majority of material that was normal.

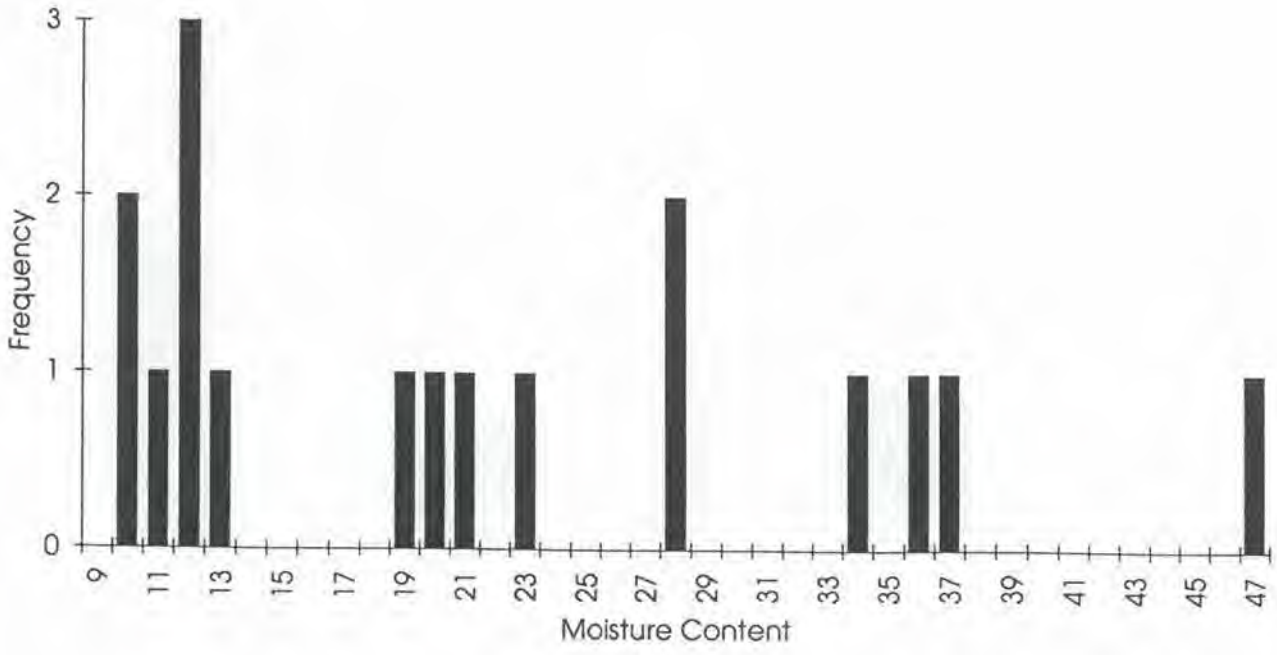

Fig. 3. Moisture content distribution after drying for an experimental kiln charge dried at 150°C for 16 hours and reconditioned for 4 hours. (200 mm x 50 mm)

ii) DISTORTION IN JUVENILE WOOD AND INTERNAL CHEMICALS

The schedule described above was developed to deal with distortion in plantation exotic pine which is marked by a high proportion of juvenile wood. Hoop pine, has a smaller proportion of juvenile wood, however this material requires a high temperature treatment during drying in order to minimise distortion. While this may not be a significant problem with drying hoop pine, as is discussed later it does limit the options for drying successfully.

In addition, at higher temperatures (approximately 140°C and higher) drying degrade due to internal checking becomes a significant problem in larger section hoop pine.

iii) DISCOLOURATION

When hoop pine is subject to high humidities at high temperature such as during presteaming and reconditioning, the accumulation and distillation of sugars in the sap at the surface of the board and in particular in the latewood bands, causes a dark discoloration as the sap sugars are heated. This phenomenon also causes the appearance of sticker shadows as the appearance of discoloration was restricted to surfaces directly exposed to heat and not under stickers.

iv) DRYING STRESS

Drying at high temperature invariably leads to the generation of drying stress within a board. This means boards that are to be milled should not be dried at high temperature.

SOLUTIONS

The discussion above summarises what had been the concerns expressed by hoop pine sawmillers in seasoning hoop pine. It also points to a number of key aspects that would be central to solving the problems. These aspects and solutions can be summarised as follows:

i) REDUCING INITIAL MOISTURE CONTENT VARIATION

A technique was required to reduce the initial wide distribution of moisture content in a charge. Under a typical high temperature drying regime as described in the previous section, the moisture content distribution before drying is narrowed only slightly during drying. This type of drying schedule is suited to an operation which processes large volumes of homogenous material in short periods, and therefore can generate whole kiln charges before any significant variation in initial moisture content can develop due to partial air drying. In a hoop pine sawmill where either volume turnover is small or where

some grading before drying is undertaken, it is difficult to generate sufficient volume to completely fill a kiln without partial drying occurring. This problem is exaggerated where kiln capacity is large.

The options for solving this problem are :

a) Accumulate kiln charges as quickly as possible by either not grading prior to drying and drying all grades of equal thickness together. This has the disadvantage of not allowing flexibility in drying schedules appropriate to different products. *i.e.* high temperature drying of structural sizes that include juvenile wood compared to conventional temperature drying of appearance grade products.

b) Store timber awaiting kiln drying such that drying before the material enters the kiln is minimised. This option is viable only where anti sapstain treatments are applied.

c) Install kiln drying systems that feature many small capacity kilns as apposed to few large capacity kilns. This offers flexibility in drying different grades to different schedules and at the same time reducing the time required to generate whole kiln charges. To persue this option drying system design must allow for both high temperature and conventional temperature drying.

d) Allow partial drying to occur, and therefore retain flexibility in product grading and schedule selection, and then treat variable moisture content with a equalisation treatment at the end of the drying cycle. *i.e.*, apply a temperature and humidity combination that corresponds to the equilibrium moisture content in wood that is the target of the drying process. For example, 90°C dry bulb temperature with a wet bulb depression of 5°C. This corresponds to an equilibrium moisture content of 11%. The use of equalisation treatments greatly increases kiln occupation time.

ii) CONTROLLING VARIABLE DRYING RATES

A technique was required to correct the development of wide moisture content distribution in a charge brought about by variable drying rates.

Hoop pine wetwood dries at a slower rate compared to normal wood. The slow drying behaviour of wetwood is suspected to be the result of bacterial activity in the standing tree.

Two options are available for dealing with this problem. Firstly, easily identifiable material that is known to dry slowly such as heartwood wetwood in hoop pine that is marked by a brown colour compared to clear hoop pine, can be separated prior to drying, and dried according to appropriate schedules. This technique optimises drying time in wood free of wetwood, however sawing patterns that are aimed at large section board recovery inevitably result in some non wetwood affected material being included in partially wetwood affected boards. While this improves the situation it does not solve the problem completely. This also provides another pre kiln drying grading, which exacerbates the difficulties discussed in the previous point (i).

A second option is to narrow the moisture content distribution at the end of the drying cycle by applying an equalisation treatment. This treatment offers a complete solution, however, the cost is long kiln occupation times.

iii) CONTROLLING DISTORTION IN JUVENILE WOOD

Juvenile material requires a high temperature treatment to minimise distortion. Timber cut from near the pith, is generally of a lower graded quality, and is normally directed to appropriate product classes, *e.g.* structural grade. If this material is graded and separated prior to kiln drying, then a schedule that features high temperature (>100°C) can be applied. If mixed grade charges are dried at high temperatures then the material that is of appearance grade quality will be subject to degrade (drying stress and discoloration) that would reduce its value.

iv) PREVENTING DISCOLOURATION

Maximum drying temperature is limited by the occurrence of discoloration, and high humidities at high temperature should be avoided. Discoloration is not considered to be a problem in drying structural grade timber. However, in appearance grade and preservative treated material, it is a significant defect. For appearance grade timber the darkened latewood bands prevent the use of clear finishes. For treated material, sticker shadows become increasingly evident after a period of weathering and this is unacceptable to the market.

A series of drying trials were undertaken to establish the conditions that led to discoloration. The results of this work showed that temperatures in excess of 120°C during the drying cycle would result in latewood discoloration. In addition it was shown that high humidity treatments at 100°C during or at the end of drying would also bring about discoloration. This showed that

reconditioning with steam was not appropriate for appearance grade material and suggested that equalisation was the appropriate treatment for reducing drying gradients because equalisation features a large enough wet bulb depression to prevent accumulation of sap sugars at the surface of the wood.

v) PREVENTING INTERNAL CHECKING

Maximum drying temperatures could not exceed approximately 140°C in order to avoid internal checking. In the context of other problems, this limitation in maximum temperature was secondary. For appearance grade material, the problem of surface and internal checking was solved when maximum kiln temperature was limited to avoid residual drying stress and discoloration. In addition, in both appearance and structural grade material, the need to equalise at the end of drying, and the associated long equalisation period, diminished the value of drying at temperatures in excess of 120°C.

vi) MINIMISING DRYING STRESS

If material being dried was intended for appearance grade end use, then the development of drying stresses should be avoided. This limits maximum drying temperature and minimum humidities. Drying trials showed that drying at conventional temperatures was required to minimise residual drying stress, and the best results were achieved when drying at 90°C with a 30°C wet bulb depression, followed by an equalisation at 90°C and a 5°C wet bulb depression.

Two research projects were designed to investigate the problems outlined above. The initial study focused on the behaviour and characteristics of hoop pine wetwood. A subsequent study was aimed specifically at developing appropriate drying schedules. It was during this second study that a series of drying trials in close cooperation with industry, lead to successful implementation of new processing techniques and drying schedules.

The schedules derived from this work are given in table 1.

TABLE 1. RECOMMENDED DRYING SCHEDULES FOR HOOP PINE

A. All mature wood, appearance important.

Thickness	Schedule		Drying Time (Hours)	
	Drying Phase	Equalisation	All Green-Off Saw	Varied initial Moisture Content (0-2 weeks old)
25	90°C DB 60°C WB	90°C DB 85°C WB	15 + 25 = 40	10 + 35 = 45
38	90°C DB 60°C WB	90°C DB 85°C WB	25 + 30 = 55	15 + 50 = 65
50	90°C DB 60°C WB	90°C DB 85°C WB	35 + 35 = 70	20 + 65 = 85

B. Mixed mature and juvenile wood, appearance important.

Thickness	Schedule		Drying Time (Hours)	
	Drying Phase	Equalisation	All Green-Off Saw	Varied initial Moisture Content (0-2 weeks old)
25	110°C DB 75°C WB	90°C DB 85°C WB	7 + 18 = 25	5 + 35 = 40
38	110°C DB 75°C WB	90°C DB 85°C WB	13 + 25 = 38	8 + 45 = 53
50	110°C DB 75°C WB	90°C DB 85°C WB	20 + 30 = 50	12 + 60 = 72

C. Mixed mature and juvenile wood, appearance not important.

Thickness	Schedule		Drying Time (Hours)	
	Drying Phase	Equalisation	All Green-Off Saw	Varied initial Moisture Content (0-2 weeks old)
25	130°C DB 75°C WB	90°C DB 85°C WB	5 + 18 = 23	3 + 30 = 33
38	130°C DB 75°C WB	90°C DB 85°C WB	10 + 25 = 35	5 + 45 = 50
50	130°C DB 75°C WB	90°C DB 85°C WB	15 + 30 = 45	10 + 60 = 70

The drying times given in table 1 are in the form "drying phase" + "equalisation phase" = "total drying time". During the development of these schedules, the change from drying to equalisation was made when the driest board in a sample of 5 boards indicated a moisture content of 9% (measurements were taken by electrical resistance based methods). The times given in table 1 are best estimates derived from the experimental results. Ideally, the change to equalisation phase should be determined by moisture content measurement in order to maximise the drying phase time and minimise equalisation time.

Note that the above table features recommendations as they relate to different processing options. In particular, schedules are provided for appearance grade and structural grade material, as well as schedules for mixed grade kiln charges. These options apply to operators who grade before kiln drying and those who don't. A group of schedules is also provided for charges comprised of green off saw material only, and for mixed charges of partially dried material. Note that it takes longer to equalise initially wide moisture content distribution in partially dried charges compared to charges of all green-off-saw material.

Under early high temperature drying regimes, results showed that in the worst cases, dried timber recovery was as low as 50% through the kiln drying process, with a small volume being over dry and a significant proportion remaining wet. Changes to drying schedules and processing techniques has brought about an increase in dry wood recovery from 50% to 90%, with negligible amounts over dried. Equalisation treatments are now routinely adopted where maximum drying temperatures are in the range 90°C to 120°C.

DISCUSSION

Although this work has focused on hoop pine seasoning, there are a number of issues worthy of discussion in relation to both structural and appearance grade products from all plantation grown softwood. Of particular importance is the issue of designing the appropriate kiln seasoning system for this type of operation. This research project has shown that the techniques for drying appearance grade material are fundamentally different to those that apply to structural grade products. To this end, seasoning systems should feature the flexibility to undertake both high and conventional temperature drying, and in the later case, with accurate control of both temperature and humidity. Equalisation requires accurate kiln control. The experimental kiln used in this research is controlled by an expert system. This system interrogates conditions within the kiln and determines setpoints based on an equivalent equilibrium moisture content given by the operator. In addition, the system can determine schedule change points and end points using resistance based moisture content measurements within the charge. The expert system can therefore handle both faults and schedule control, based on rules supplied by the programmer. The system does not replace a kiln operator completely, but does offer constant monitoring with decision making when the operator is absent.

The capacity of kiln drying systems should also be designed to meet the production volumes of each type of product to be recovered. The optimal condition at the beginning of drying is one of narrow moisture content distribution. This means charge volumes must be generated in as short a period as possible.

Finally, the experience of hoop pine sawmillers has exposed the need and importance of high quality moisture content measurement systems for dried material. Larger hoop pine sawmills invariably incorporate an in-line moisture content measurement devices that take readings along the whole length of every board entering the dry mill. These systems are essential to preventing inadequately dried boards leaving the mill, and for monitoring the performance of the whole seasoning system.

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FOREST INDUSTRIES RESEARCH AT THE SCHOOL OF FORESTRY, UNIVERSITY OF MELBOURNE

Peter Vinden
The University of Melbourne
Faculty of Agriculture and Forestry
Forestry Section
Creswick, Victoria 3363

ABSTRACT

A summary is given of Forest Industries Research at the School of Forestry, University of Melbourne, Creswick. The program, which was established in 1992, now supports 9 postgraduate research students in research projects aimed at value-added processing of Australian wood and wood products.

Future directions for research are discussed, in particular the need to integrate forest products and forest operations research and the need to evaluate future directions for timber engineering research and education.

INTRODUCTION

The Julia M. Hale Program in Forest Industries was established at the University of Melbourne in 1992. It's objectives were:

- to provide articulated education and training in forest industries (forest products and forest operations)
- undertake research
- collaborate with other organisations to enhance these activities

Training and education in Forest Industries in Australia has tended to be fragmented. Whilst certificate training in timber technology has been available, there has been no clearly articulated pathways to higher education, training and research. Collaboration between the University of Melbourne, Ballarat University College and the Victorian Timber Industry Training Centre has paved the way for providing an integrated program ranging from training for new entrants into the industry through to doctorate degrees. Collaboration with other institutions - for example the Division of Forest Products and Division of Forestry, CSIRO has ensured that research projects have been well resourced and relevant to the needs of industry.

All forest industry higher education and training degrees offered by the University of Melbourne have a strong research component. Innovation, research and technology adoption has to be part of the culture of the Australian forest industry to ensure its survival. Emphasis is also placed on new skills development - for example, total quality management, environmental care, occupational health and safety, electronics and process control, communication, technology management etc. These changes to the traditional timber technology or wood-science teaching, reflect changing skill requirements in the timber industry - a movement away from evaluating the technological attributes of different species towards market analysis of consumers requirements and industrial production of the required products.

In the 1970's and 80's, forestry and the forest industries experienced an identity crisis. Criticism from environmental lobbies has tended to cloud one of the key characteristics of production forestry ..... "that in the long-term, production forestry provides one of the few viable options for sustaining mans material well-being". This is not an arguement for justifying what has been a gross assault on the worlds' forests, but highlights the need for forest industries to embrace the principles of conservation and environmental care, so that a resource conscious and caring society will embrace a timber or forest based economy rather than squandering the earths finite resources.

You may question the relevance of these sentiments in a paper on research. In setting long-term research objectives for the Forest Industries, we have to be convinced that the pursuit is worthwhile and will benefit mankind. In designing the research outcomes we need to be convinced that they meet the four cardinal virtues.

Attributes of wood as a raw material

Plant fibre is a fraction of the cost of glass and carbon fibre. Uncertainty in future supplies and costs of oil provide obvious advantages for plant fibre. Low energy requirements for processing, low carbon emission, high intrinsic strength, surface chemistry making it reactive to glues, and reactivity of groups in lignin cellulose and hemicellulose as sites for chemical modification, provide a versatile raw material for industrial production.

Given these desirable attributes it is somewhat surprising that there has been such large-scale substitution with products which lack these desirable properties.

A number of attributes limit the full potential of wood as an engineering material. They include:

- Dimensional instability, including susceptibility to bow and twist
- Poor durability
- Fire-resistance
- Susceptibility to UV degradation, including yellowing

- Colour
- Surface hardness and scratch resistance
- Minor defects
- Wood property variability

Most of these undesirable attributes can be overcome through either species selection, or, by chemical modification of wood. Strength is not identified as a limiting factor on the basis that engineers should be competent to design or build using any material, providing they know its strength and behaviour in load-bearing situations. Minor defects and wood property variability pose significant problems.

High Performance Wood Products

Australia is well positioned for the development of high performance wood products. It has a hardwood resource of Eucalypts which rate among the best performing timbers in the world in terms of:

- aesthetic appeal, - colour, figure and lustre
- strength
- durability

The intrinsic strength properties of some eucalypt species approach that of steel. Research into the natural regeneration of many of these Eucalypt forests indicate that they can be managed on a sutained yield basis without reduction in vigour or variety. The last five years has seen a rapid adoption of value-added production. The focus has been on kiln-drying, derivation of stress grades and more recently the treatment of sapwood against lyctus and component production.

Research at the School of Forestry has focussed on both drywood and greenwood treatments using boron preservatives. The use of trimethylborate (TMB) as a drywood treatment (Romero et al, 1993) has identified the need for low wood moisture contents to achieve total sapwood penetration. Research is continuing to identify techniques to overcome this particular problem.

Australia also has an expanding resource of softwoods. Whilst radiata pine is regarded as a utilitarian species, it has two outstanding features - namely, very high permeability and secondly, excellent planing and machining characteristics. Chemical modification provides the means for adding value in terms of durability, surface hardening, colouring, dimensional stabilisation, finishing with scratch resistant surfaces and fireproofing.

Chemical modification can be used to improve the durability of wood by rendering it INERT to biological degradation. In the longer term, this approach will

almost certainly replace the use of inorganic wood preservatives in many end-use applications. This arises from environmental concerns, in particular the disposal of treated wood products at the end of their useful life (Vinden et al, 1991)

Ndegwa. (1993) has used an integrated approach to studying the concept of INERT woods. This involves investigations of the mechanisms of biological degradation using "soil-bed" techniques and investigation of the permeability and reactivity of wood components to chemical vapours and liquids, including vacuum pressure impregnation as well as passive diffusion.

Techniques for conditioning wood are also being investigated with a view to providing effective treatment of refractory heartwood (Cobham, 1993) Micro-transducers, implanted in the wood, are being used to measure changes in permeability resulting from the conditioning procedures. The technique is also being used to interpret responses in the wood to changes in treatment cycles.The treatment of refractory radiata pine heartwood poses a particular problem, particularly for engineers who require guaranteed performance.

The development of high performance panel products for structural application and exterior performance has been hampered by longitudinal swelling and shrinkage. Humidity changes can often result in sagging of the product and failure at the fastenings. Whilst changes in dimension due to absorption or desorption of water are well-understood, the changes due to stress relief built in during the manufacturing process are less well documented.Techniques for measuring stress relief involve the use of "rubber rulers" (Ho, 1993) These transducers record small dimensional changes very accurately and can be left in exposure trials for extended periods, Cimano (1993).

Chemical modification of panel products can be undertaken during 3-stages of the board manufacturing process:

- treatment of wood particles/fibres before manufacture
- treatment during pressing
- post-manufacture treatment

The choice of technique depends on the existing manufacturing process being employed and the proposed chemical to be employed. To-date, research has focussed on factory finished products. This has limited the choice of chemical and reaction mechanisms to non-polar chemicals/solvents (to avoid swelling) and "non-bulking" type treatments (for which swelling of the cell-wall is a pre-requisite). The panel product is also required to be porous and amenable to pressure impregnation. Various types of plastic have been formulated and applied by a modified Bethell treatment schedule and cured by low temperature kiln drying. Chemical penetration is limited to spaces in the board

matrix, ie. between particles and wood cell lumens. There is no bulking of the cell wall and therefore treatment effectiveness relies on closing moisture penetration pathways.

Whilst bulking of the cell wall is regarded as the ideal mechanism for achieving dimensional stabilisation, the technique is expensive in terms of chemical usage - (up to 25% weight gain to achieve swollen dimensions). The product also requires machining after fabrication leading to loss of chemical.

Board permeability is influenced by particle geometry and the density profile of the board. Typical density profiles indicate substantially higher densities on the surface and therefore limited penetration pathways. The problem is exacerbated if the board is characterised by smaller particles on the surface. Such products have been found difficult to treat even when the chemicals are applied in the vapour phase (Romero, 1993). If treatments of panels are to be contemplated after fabrication, consideration should be given to engineering particle size and distribution of the density profile of the product to optimise performance of the treated product.

A high proportion of the Australian reconstituted wood panels industry is based on utilising softwood sawmilling wastes and softwood plantation thinnings. During the drying process, there is a 5% material loss, representing a mixture of wood fines and the range of terpenoids that have been "steam-distilled". These form the "blue haze" associated with wood particle board plants. In the near future, legislation associated with the Clean Air Act is expected to limit emission of the oleoresin effluents from the stacks. Wet-Dry electrostatic precipitators are now available which can recover about 2% w/w oleoresin condensate. These contain mono-sesqui and di-terpens. The biochemistry and the mobilisation of terpenoids in the woody species is poorly understood, but it is clear that the presence of these substances plays an important role in the defence and resistance of the plants and environmental interaction of forest trees and their predators and parasites. Hermescec (1993) is identifying and quantifying particulate matter and the volatile oleoresin obtained during drying, characterising the oleoresin components. He intends to evaluate utilisation of oleoresin constituents for value-added products and oleoresin recovery processes. The research forms part of a collaborative project with the Division of Forest Products, CSIRO.

Secondary forest products, for example eucalyptus oil production from E. Polybractea (Blue Mallee) and E. Viridis (Green Mallee) was an extensive industry in Australia but has been unable to compete with cheaper imports. The forests have been harvested on a 2 year rotation for approximately 100 years. The most common method of Eucalyptus oil extraction is by steam distillation. Studies have shown that there is a 30-35% loss of terpenes in steam distillation of fresh leaves of Eucalyptus leucoxylon, E. globulus and E. plenissima compared to solvent extraction. Mude (1993) is investigating the use of solvent as an alternative extraction method. Solvents with lower

heat of vaporisation and lower boiling points than water and which will preferentially dissolve the oils from the leaves will be investigated. The project will utilise Capillary Gas Chromatography, Gas Chromatography, Mass Spectrometer and Critical Fluid Extractor techniques and is a collaborative project with the School of Biological and Chemical Sciences, Ballarat University College.

The research topics selected by masters and doctorate students have to a greater extent been determined by individual students interests and the funding agencies concerned and don't necessarily reflect the opportunities available at the Creswick campus. For example the facilities available for solid wood processing, eg., sawmill, drying and planing equipment are ideal for research projects into drying, machining, log yields, wood quality etc. but have yet to be utilised. This reflects industrial funding streams which have tended to flow from the panel products and wood treatment industries. The selected topics may not necessarily reflect national needs for the same reason. Research projects have been undertaken in the quality management areas, for example, wood drying, wood treatment and sawmilling by graduate diploma students. Hopefully some of these students will go on to on to higher degrees and will expand solid wood research. It is essential that solid wood processing is not neglected. A prosperous pulp and paper and panel products industry depends on an efficient solid wood processing industry.

Wood Quality Research

The Co-operative Research Centre for hardwood fibre is concerned with fundamental aspects of cambium physiology and relating fibre quality attributes - for example, filbre length and cell wall thickness with final paper characteristics. The project has a focus on Eucalypts and is a collaborative project with the Forest Products Division, CSIRO, Monash University and major pulp and paper companies.

Yield is a very important aspect of pulpwood quality. Selection for it requires screening of large numbers of trees which is prohibitively expensive by conventional means. An alternative being investigated by Schimleck and Mitchell (1993) is to measure yield indirectly by using a simple rapid test which can be correlated to pulp yield. Properties of bands in the vibrational spectra of wood meals contain much information about the chemistry of the samples and may provide a suitable test.

It is proposed initially to seek correlation between bands in near and mid-infrared spectra of plantation eucalypts and their pulpwood quality. The within tree variation will be examined to give a simple protocol for sampling standing trees.

A parallel project has a focus on radiata pine (clone 55). A morphological and chemical study of various progenies of clone 55 is being used to identify those parameters which lead to lower energy requirements (up to 20%) for pulping this

particular clone (Ngakuengama, 1993). Preliminary results indicate that the clone is characterised by having rounded cells with intercellular spaces - reminiscent of the characteristics of compression wood.

Research is desperately needed in the wood quality area. Softwood sawlog production will more than double during the 1990's. However, relatively little information is available regarding the quality of this material. Wood quality aspects have been researched in detail for radiata pine in New Zealand. These models are now used for economic evaluation of forest management options which are now becoming a pre-requisite for future investment in forestry.

The models are also being used to generate new research projects in innovative processing and mill design. The starting point for such models should be a projection of market requirements by end-use sectors and wood quality specifications. Other requirements include a national log grading system so that research into sawmill productivity can be undertaken to determine the impact of log grading on sawmill productivity, the influence of sawmill type, log geometry, saw kerf, log positioning, saw pattern etc. Simple techniques for segregating logs by quality are needed in the standing tree so that potential value of existing forests can be measured. Hopefully, the Forest Technology Program (an initiative involving the CSIRO Division of Forestry, Canberra, the University of Melbourne and the Forest Logging Council) will integrate these end-user requirements with forest operations management. Facilities for Geographic Information Systems (GIS) have been expanded at Creswick and are being used for researching aspects of forest hydrology, and the environmental impact of forest operations.

Product Development

Wood provides one of the most flexible raw materials available for product development and yet recent history (the last 15 years) has seen a steady loss in market share for most timber products. This has occurred despite some major inherent deficiencies in some of the substitute materials. This highlights a lack of innovation and investment in product development in the timber industry. Three areas require urgent investment: timber engineering; furniture; packaging.

It can be argued that immediate requirements in timber engineering relate to educational rather than research needs. Timber engineering receives scant attention at university, either in engineering or architectural schools. As a result practicing engineers find design in timber difficult to cope with primarily because of a mind-set that:

- it is difficult to design in timber;
- timber is variable;

- timber is non-durable;
- timber is susceptible to fire;
- there is poor service and poor technical back-up from industry

There is justification for this prejudice! When timber engineering is taught at engineering school, emphasis is placed on highlighting the variable nature of timber.

Several trends could radically alter the demand for timber as an engineering material:

i) The introduction of performance specifications

This is a world-wide trend whereby material specifications relate to structural performance and various social objectives eg. fire performance, rather than the specifications of specific materials eg. steel or concrete. This paves the way for timber to be used in multi-storey (3 - 4 levels) construction. However this requires organisations with a vested interest in the structural use of timber to seize the opportunity. The change to performance specification is a fundamental change which affects the approval system for building design and material use and also legal responsibility for building performance.

ii) Design and fabrication of timber structures

In the UK, design and specification of timber structures was traditionally left to architects. An increasing trend has seen the establishment of specialised joinery companies who provide the total service of design, manufacture and fabrication of timber structures as a contractor. This avoids the problems of inadequate drawings or specifications of structural elements and the communication gaps that proliferate between architect/specifier/manufacturer/contractor. The hurdle of identifying responsibility for poor workmanship is also overcome. Hopefully this trend will extend into Australia.

The design process for engineered structures is an activity that should be independent of the materials used. Unfortunately the specification of timber is fraught with potential difficulties and requires specialised knowledge and a good deal of patience and determination on the part of the engineer. One of the sacred cows or passions of timber engineers is "good detailing" that is acknowledging the perception that wood is dimensionally instable, susceptible to decay, chemical attack and UV light degradation.

Technology is now available which can eliminate most of the deficiencies and provide material properties more akin to steel. Whilst it is tempting to say that we should train more timber engineers, the problem is that we may end up perpetuating an approach in timber design that possibly should be made redundant! The methods we

use for visual grading of timber do not recognise re-manufacturing requirements. The techniques are outmoded and still rely on manual operation. New methods of forming, structural fingerjoints, automated defecting techniques for "on-line" machine stress grading and drying, treatment and coating techniques can provide engineered materials with uniform properties, and known performance characteristics.

Despite the softwood resource being characterised by a large juvenile core, there is currently no optimisation of the log to ensure that alternative commodities or products manufactured from the log make use of the inherently most suitable material in the log.

Direct component sawmilling (Van Wyk, 1988) is a concept whereby the sawmiller produces timber the customer uses in the most direct way. The process starts with identifying what the customer actually uses and wants and not what he is currently being sold. Customer needs are related back to the available log supplies and the best logs are selected to meet these needs. The logs are then sawn directly into the most appropriate cross-sections, defected and cross-cut to meet customer specifications.

Direct component sawmilling eliminates the intermediate timber grading stages. The ultimate mill will be capable of automated defecting, drying, machining, preservative treatment and fabrication as part of the production line. Important concepts are embraced by Direct Component Sawmilling. These include "just-in-time" processing, "flexible manufacture" and resource optimisation.

CONCLUSIONS

The Forest Industries research program at the University of Melbourne is now well-defined. In the absence of funding to meet all of the research requirements identified, some form of prioritisation has to be made. Research is directed into specific projects which collectively develop a common theme rather into research areas.

A major trend in training and education is the adoption of competency based learning, delivery, assessment and performance. The methodology does not encourage thinking or innovation and totally ignores the metaphysical learning processes. I believe this trend will heighten the need for postgraduate education and in particular the experience of undertaking research which should extend the student into evaluating cardinal virtues and applying innovation rather than the standards imposed by competency.

Establishment of the Forest Industries Program at Creswick has relied on very generous support from many other organisations, in particular, CSIRO. Hopefully this support will provide a generation of timber technologists who share the same enthusiasm for wood and wood products as the current generation of researchers.

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THE IMPORTANCE OF THE S3 CELL WALL LAYER IN COLLAPSE PREVENTION AND WOOD HARDNESS

Rolf Booker, NZ Forest Research Institute

ABSTRACT

It is generally accepted that collapse is governed by wood permeability, lumen saturation, cell diameter and cell wall thickness. In this article a collapse equation is defined that relates the effects of cell wall diameter and cell wall thickness. It is demonstrated that the S3 cell wall layer also has a very strong influence on collapse. A model has been developed to demonstrate this. Increasing the thickness of the S3 layer from zero to 0.1 µm, while keeping the total double wall thickness constant at 8.2 µm, increases the cell wall stiffness by 64%, assuming the elastic modulus of the S3 layer in the tangential direction is ten times that of the S2 layer. If this ratio is increased to 23, the stiffness is increased by 160%.

Consequently, the model predicts that the cell wall's stiffness and its resistance to collapse depends strongly on the thickness of the S3 layer and the amount of microfibrillar reinforcing, as well as the exact orientation of these microfibrils. These factors also govern the hardness of wood.

Tree breeders can ensure that wood from future tree crops will be both harder and more resistant to collapse by developing trees in which a small amount of biomass is diverted from the S2 to the S3 layer.

KEY WORDS: Collapse, cell wall structure, microfibrils, buckling, cell compression, water tension, tree breeding, hardness

2

INTRODUCTION

Collapse of cells during drying results in large financial losses for many hardwoods. While collapse in hardwood boards can usually be recovered by steam conditioning, frequently this irregular shrinkage results in internal checking. Once checks form they can never be repaired. While collapse occurs mainly in hardwoods, it has also been recently reported in the sapwood of radiata pine after high temperature drying (Miller and Simpson, 1992).

The factors that govern collapse are not yet fully understood. According to current theory collapse occurs in cells (particularly fibres) when water tension develops in fully water-filled lumens (Chafe et al., 1992).

In this article the resistance of the cell walls to collapse will be discussed, as well as the major contribution made by the S3 layer of the secondary walls to collapse resistance. It should be stressed at the outset that the following theory is an approximation which ignores a number of secondary effects. It is useful, however, in identifying and approximately quantifying a number of important parameters. These limitations are further discussed after development of the theory.

THEORY

Compression forces in the cell wall due to water stress

Consider a group of water filled tracheids/fibers in which the water is under tension (Figure 1). It is a property of liquids and gases that any hydrostatic forces acting in them always act perpendicular to the walls (Noakes, 1953). The tension acting on every element of wall is constant at T Newton/m^2, perpendicular to that wall element. Figure 2 shows the direction of the forces acting on cell "α" of figure 1. In Figure 2 the cross sections are assumed to be rectangular and the shape of the cells is idealised. Consider the forces acting on the lumen walls with corners A, B, C and D, widths a and b and single wall thicknesses c and d (Figures 2 and 3). If we consider an element of length f along the grain direction, the forces perpendicular to the walls AB and BC in Figure 3 are afT and bfT respectively.

The force acting perpendicular to AB is transmitted to the walls BC and AD placing them in compression, and the force acting perpendicular to BC is similarly carried by the walls AB and CD. Assuming all adjacent cells to be filled by water under the same tension, the compressive force in wall AB is bfT/2. The compressive stress in AB is this force divided by the cross-sectional area, ie. 0.5 bfT/cf = bT/2c pascals (Pa) . Similarly the compressive stress in wall BC is aT/2d Pa.

In other words the compressive stress in a wall is proportional to the ratio of the width of the cell in the direction at right angles divided by the wall thickness. Hence the thinner the cell walls and the larger the lumen cross section, the greater the compression of the cell walls.

Because adjacent cells are also water filled (assumed to be at the same tension T), the forces acting perpendicular to BC and EF are equal and opposite (Figure 2). These forces will hence not cause deflection of the BCFE double cell wall. However, these equal and opposite tension forces will tend to delaminate the cell walls. Normally the cell walls will be strong enough to resist these tension forces. In summary, a volume of adjacent water-filled cells tends to be compressed by the water stress, but is unlikely to collapse.

In the living tree this compression of the cell structure by the water stress removes water from the sapwood during drought conditions and at times of high transpiration in a completely reversible manner.

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* A pascal (Pa) is a pressure of 1 newton/m^2 (N/m^2), and 1 newton is 1/10th of a kg force

Buckling in cell walls caused by unbalanced water stress

Consider two adjacent cells, one of which is water filled at tension T, while the other is filled with water vapour at zero pressure (the saturated vapour pressure of +3 kPa is negligible compared to tensions in excess of 2 MPa). This is shown in figure 4. The surfaces in the vapour filled cell no longer experience the force T Pa perpendicular to the walls, so that the double wall BCEF now carries only half the previous compression force.

However, the force on surface BC is no longer balanced by an equal and opposite force from the other side. Hence the situation in figure 5 is created. This is equivalent to a plate compressed along its width and also subjected to uniform transverse loading, a condition that is known to be prone to buckling. The compressive force is afT/2, while the total transverse force is bfT.

It is difficult to define the boundary conditions for this problem, as the wall does not act as a simply supported plate. Instead, the ends are integrally connected to the side walls, which therefore obstruct bending. This results in cells not collapsing singly, but in groups.

This will be addressed in a later part of this analysis, but first it will be assumed that cells can collapse individually without interference from their neighbours.

The bending of an isotropic plate supported at the ends

The deflection at the centre of an isotropic plate or beam supported without restraint along two sides (Figure 6) is given by the following equation (Steel..., 1972):

$$\delta = \frac{k}{384}\,\frac{WL^3}{EI} \qquad (1)$$

where

L	=	length of the beam
f	=	width of the beam
t	=	thickness of the beam
W	=	total load
E	=	Young's modulus
I	=	geometric moment of inertia
k	=	5

If the plate is rigidly fixed at the ends, as occurs for instance when a thin steel beam is welded on both sides to a much more rigid frame, the deflection at the centre is given by the same equation, but with k = 1. The deflection in this case is exactly one fifth of that which occurs for a plate freely supported at the ends. In the case of cell wall segment EFBC in figure 4, the wall segment is neither freely supported nor rigidly fixed, but somewhere in-between. The deflection is hence given by equation 1, where k is a constant between 1 and 5.

The geometric moment of inertia of the plate shown in figure 6 is:

$$I = \frac{ft^3}{12}, \quad \textit{so that}$$

$$EI = \frac{Eft^3}{12} \qquad (2)$$

Substituting equation 2 into 1 yields:

$$\delta = \frac{k}{32}\,\frac{WL^3}{Eft^3} \qquad (3)$$

Now the cell wall EFCB in figures 4 and 5 acts as a plate of length b and thickness 2d, and is subjected to a sideways force W equal to bfT. Substituting these values into equation (3) yields:

$$\delta = \frac{k\, b^4 T}{256\, E d^3} \tag{4}$$

Failure by collapse will occur in this wall once a given critical deformation δ_F is exceeded. The critical water stress (T_F) at which this failure occurs is given by:

$$T_F = \frac{256 E d^3 \delta_F}{k b^4} \tag{5}$$

During drying, the water stress in cells that do not collapse reaches a maximum T_C at which cavitation occurs and a vapour bubble forms spontaneously (Booker, 1989). This results in a mixture of water and vapour in the cell lumen at the saturated vapour pressure of water, ie. a positive pressure of about 2.3 kPa at 20°C. The water stress at which cavitation occurs depends upon the adhesion strength between the water in the cell lumen and the cell wall or the cohesion strength in the water column itself (Booker, 1989). It is independent of the cell dimensions.

Collapse will not occur as long as the water stress at which cavitation occurs is smaller than the water stress at which collapse occurs, ie. when:

$$T_C < T_F \quad \text{(Condition for no collapse)} \tag{6}$$

Similarly, collapse will occur when:

$$T_C > T_F \quad \text{(Condition for collapse)} \tag{7}$$

ie. when:

$$T_F = \frac{256 E d^3 \delta_F}{k b^4}$$

In other words, collapse occurs when:

$$\left(\frac{b^4}{d^3}\right) > \frac{256 E \delta_F}{k T_C} \tag{8}$$

If the cell wall thickness d is large, the collapse factor ((b^4 / d^3)) is small, so that cells with thick walls are unlikely to collapse. This is the main reason why latewood cells seldom collapse. In contrast, when the lumen diameter b is large, the collapse factor is very large, and there is a high probability that collapse will occur.

The collapse factor is extremely sensitive to small changes in lumen diameter and wall thickness. For instance, if due to rapid growth the lumen diameter increased by 3% while the wall thickness decreased by 2%, both of which would be undetectable by normal microscope examination, the collapse factor would increase by 20%.

The effect of cell wall micro structure on collapse

In the previous analysis the cell wall was implicitly considered to have the same properties throughout its thickness. In reality this is not the case, as a single coniferous cell wall consists of a middle lamella (0.1-1 μm), primary wall (0.1-0.3 μm), S1 layer (0.1-0.2 μm), S2 layer (1-5 μm) and S3 layer (0.1 μm), where the quantity in brackets is the thickness in μm

(Salmen 1985). Hardwood fibres have similar structure, although the relative thicknesses are different.

Figure 7 shows the micro structure of the cell wall. The S2 layer is much thicker than the others and is heavily reinforced with cellulose microfibrils in the axial direction. The microfibril angle in radiata pine usually ranges from 10 to 30 degrees in mature wood. The microfibrils are aligned to carry loads in the axial direction. They impart little stiffening in the transverse direction, however. In contrast, the S3 layer is very thin, but is heavily reinforced by microfibrils in the transverse direction, which is exactly the right position to strengthen the cell against deformation by water tension forces (figures 4 and 5).

Microfibrils consist of interconnected cellulose single crystals about 3.5 nm in diameter (Fengel and Wegener, 1984). For most materials such as metals (Hirth and Lothe, 1968), carbon, and glass (Griffith 1924 a, b) the strength of fibres or whiskers is several orders of magnitude greater than that of the bulk material. It is highly probable that in a microfibril the strength of the cellulose will similarly be several orders of magnitude greater than in bulk cellulose, as for a thin fiber the probability of a pre-existing flaw is minute. According to Sakurada et al. (1962) and Salmen (1985) the MOE of cellulose crystals along the chain direction is 137 GPa, compared with 6 GPa for isolated hemicelluloses and 4 GPa for isolated lignins at room temperature. This gives an elastic modulus ratio between cellulose and matrix material of about 30. Differences in elastic modulus are normally reflected in similar differences in strength.

Young's modulus of wood is about 24 times greater in the axial direction than in the tangential direction for the 28 pairs of values given by Kollmann and Côté (1968). This difference is caused primarily by the microfibril orientation of S2 along the axis. Hence it is reasonable to assume that the S3 layer's modulus is roughly 20 times larger than that of the S2 layer in the transverse direction.

According to Salmen (1985) the double cell wall consists of a 0.1 µm layer of S3, followed by about 8 µm of S2, S1, P, ML, P, S1 and S2 layers, and an outer layer of 0.1 µm of S3. As far as the bending of such a wall is concerned, the wall interior can be treated as if it were isotropic with the elastic properties of the S2 layer, as the primary walls and middle lamella are very close to the neutral plane for bending. In contrast, the structural differences between the S3 and S2 layers are very important.

The effect of the S3 layer on the stiffness of the cell can be modelled by a plate reinforced on both sides with a thin layer of higher elastic modulus material, using a computer program by Bier (1991). The total thickness was assumed to be 82 mm, consisting of 80 mm of core material covered by 1 mm thickness of a material with a much higher elastic modulus on each side. This models a double cell wall 8 µm thick with 0.1 µm of S3 layer on each side. The results of this modelling are shown in Table 1.

If Young's modulus of the surface material is 10 times greater than that of the core, the stiffness is increased by 60 %. When the Young's modulus ratio is 23, the stiffness is increased by 160%.

The stiffness and the strength of a plate are strongly related, although the relationship is quite complicated. For simplicity it will be assumed that cell wall failure occurs once a given deformation is reached. Under this assumption strength is directly proportional to wall stiffness.

The second part of Table 1 shows the effect of reducing the thickness of the outer layer. Halving the thickness of the outer layers to 0.5 mm reduces the stiffening from 60% to 30%.

The benefit of placing the reinforcement at the outer surfaces can be seen from the following example, in which the 1 mm covering layers are shifted 10 mm towards the centre, creating a sandwich structure consisting of 10 mm of core material, 1 mm of higher

modulus material, 60 mm of core, 1 mm of high modulus and 10 mm of core material. The stiffness of this structure was calculated to be the same as that for a sheet of 0.5 mm of high modulus material at the two surfaces.

The model clearly shows that the stiffness and hence the strength and the resistance to collapse depend very strongly on the total thickness of the cell walls and the Young's modulus and thickness of the outer (S3) cell wall layers. The elastic modulus of the S3 layer depends on the number of cellulose microfibrils in the S3 layer and their exact orientation.

LIMITATIONS OF THE MODELS

The above models are only a first approximation. In the cell model the cells are considered to be of identical size and rectangular cross-section, with one of the four surfaces acting as a plate halfway between fixed and freely supported. In the three layer model it is an implicit assumption that the only force that deflects the plate is a force that acts perpendicular to the wall (in this case the water tension). The compressive force in the cell walls has not been taken into account.

Collapse of a single cell can not occur without affecting all its neighbours. As soon as a cell wall starts to collapse it starts to pull the side walls towards the kink that is forming in the cell wall (figure 8a). These side walls then transmit tension forces to adjacent cells and the result is that the collapsing cell is supported by its neighbours and does not collapse. In other words, collapse is an event that does not happen to a single cell, but to a large collection of cells at the same time.

Collapse does not only occur by a cell curving in upon itself as shown in figure 8a, forming a comma shaped cross-section. Usually the cells are flattened as shown in figure 8b. This would require further modification of the model.

To extend the model to cover these aspects fully would require:

1. Substitution of a better cell shape factor, as the cells are neither square nor circular in cross-section, but more like a polygon (figure 1). In addition to cell population has quite a large variance with respect to dimensions.
2. Incorporation into the model of the compressive stresses that encourage buckling in the walls.
3. The surface that buckles (BCEF in figure 2) is not a freely supported plate, and the coefficient k in equation 1 will need to be evaluated.
4. Collapse is a cooperative process with stress redistribution among adjacent cells prior to failure.
5. Collapse occurs at a plane of weakness, such as the area of contact between a row of ray parenchyma cells and a volume of fibres. Once the mutual support system of the fibres fails an avalanche effect occurs. The system is no longer static, but becomes dynamic. Shock waves will travel through the medium, and the rate at which water can drain from collapsing fibres will also become important.

Incorporating all these factors into an engineering model similar to those used in aeroplane design would be an excellent topic for a doctoral thesis, but lies outside the scope of this article. Its main aim is to demonstrate that the S3 layer is very important in making the cell walls resistant to collapse. To reduce the argument to its most simplistic level, no complicated mathematical analysis is required to visualise that the S3 layer has microfibril windings (figure 7) similar in orientation to the spirally wound steel wire in a vacuum cleaner hose. Just as this steel wire strengthens the vacuum cleaner hose immensely against collapse, the S3 layer similarly reinforces the cell wall against collapse.

WOOD HARDNESS

The hardness of a timber species is the ability of the wood to resist the formation of dents. In other words, it is the ability to resist the penetration of a sharp or blunt pin or wedge-shaped tool in the radial or tangential direction. Penetration occurs by compression of the cell wall material into the cell lumens (Figure 9). There is little or no compaction of the cell wall material itself (Figure 9). Hence as hardness is essentially a measure of the forces required to cause cell collapse in dry wood, the hardness of wood is governed by the lumen diameter, wall thickness, and thickness of the S3 layer.

IMPLICATIONS FOR TREE BREEDING

Plantation-grown trees have wider earlywood rings than slow-grown trees, while having a similar latewood ring thickness. This reduces the average wood density. While most of the extra earlywood growth comes from an increased number of cells laid down during the year, it is possible that the cell diameters are also slightly larger, or the cell walls thinner. As shown, even a barely detectable difference in cell diameter by as little as 5% would have a major effect on collapse susceptibility. The effect of growth rate on cell dimensions and cell wall structure has been assumed to be negligible, but has never been evaluated experimentally. Even if the faster growth rate of plantation grown trees has no effect on cell diameter and thickness, the increased fraction of earlywood tends to accentuate the effect of collapse. Tree breeders can ensure that the wood from the next crop of trees will be both harder and more collapse resistant by diverting a small amount of wood biomass from the S2 layer to the S3 layer.

CONCLUSION

It has been demonstrated by the use of two models that the S3 layer in the cell wall is of great importance in preventing cell collapse. It plays an equally important role in wood hardness.

For example, by breeding trees that increase the S3 wall thickness by as little as 0.1 μm to a total thickness of 0.2 μm in a total double wall thickness of 8.2 μm, the collapse resistance and the hardness of the wood could be practically doubled.

ACKNOWLEDGEMENTS

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Table 1: Stiffness ratio of a plate reinforced on both surfaces with a layer of higher elastic modulus

Thickness in mm		E Ratio	Stiffness Ratio	Remarks
Core	Surface			
80	2 x 1	1	1.0	Core Material only
80	2 x 1	10	1.6	Ration increases sharply
80	2 x 1	23	2.6	as the surface Young's
80	2 x 1	100	8.1	modulus increases
81	2 x 0.5	1	1.0	Core material only
81	2 x 0.5	10	1.3	
81	2 x 0.5	23	1.8	
81	2 x 0.5	100	4.6	

Notes: Calculations were carried out using a spreadsheet by H. Bier (1991)

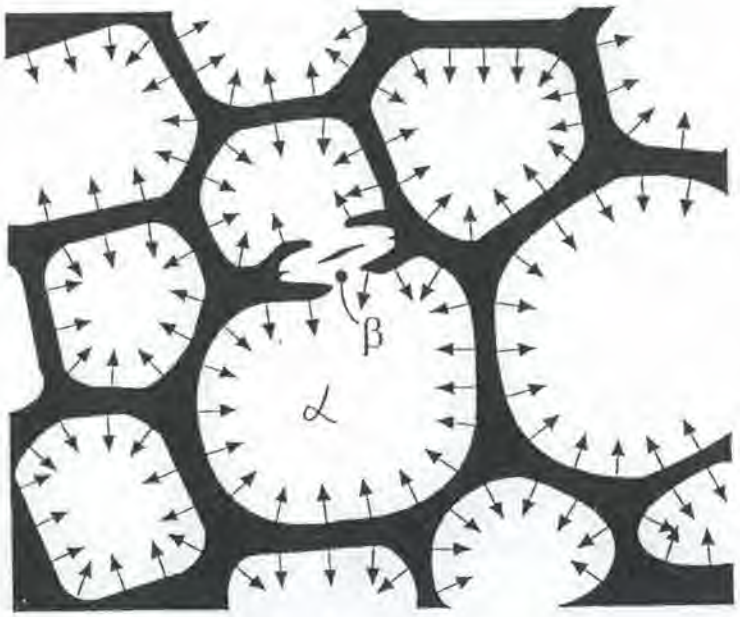

Figure 1.
Direction of the water tension forces acting on the earlywood cell walls of conifer sapwood. As the luminae are connected by bordered pits (β), the tension is the same in adjacent cells.

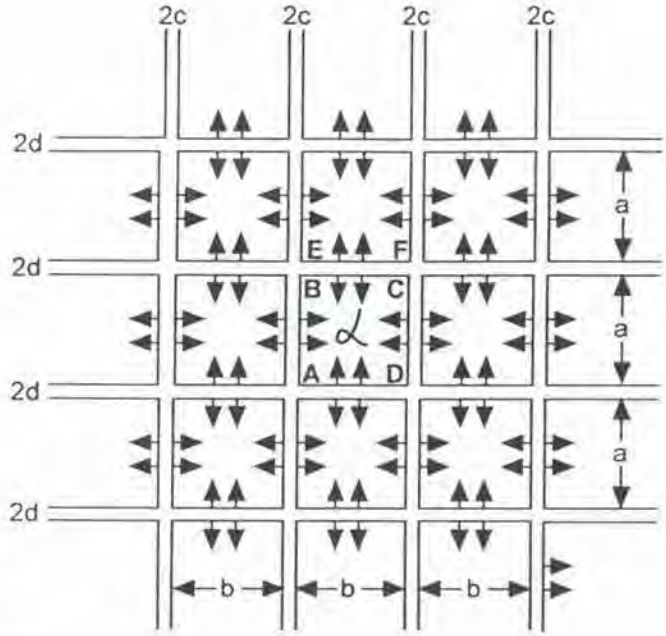

Figure 2.
Transverse section of idealised cell structure with water tension acting on the walls. The direction of the forces is arrowed.

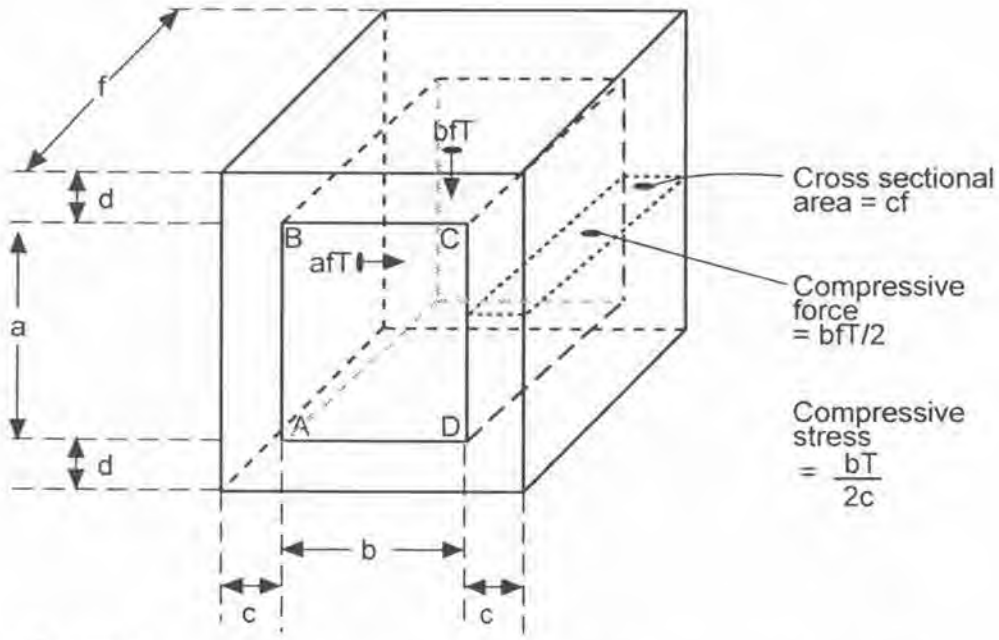

Figure 3.
Forces on and within the walls of a cell element of length f due to a water tension of T Newton/m^2

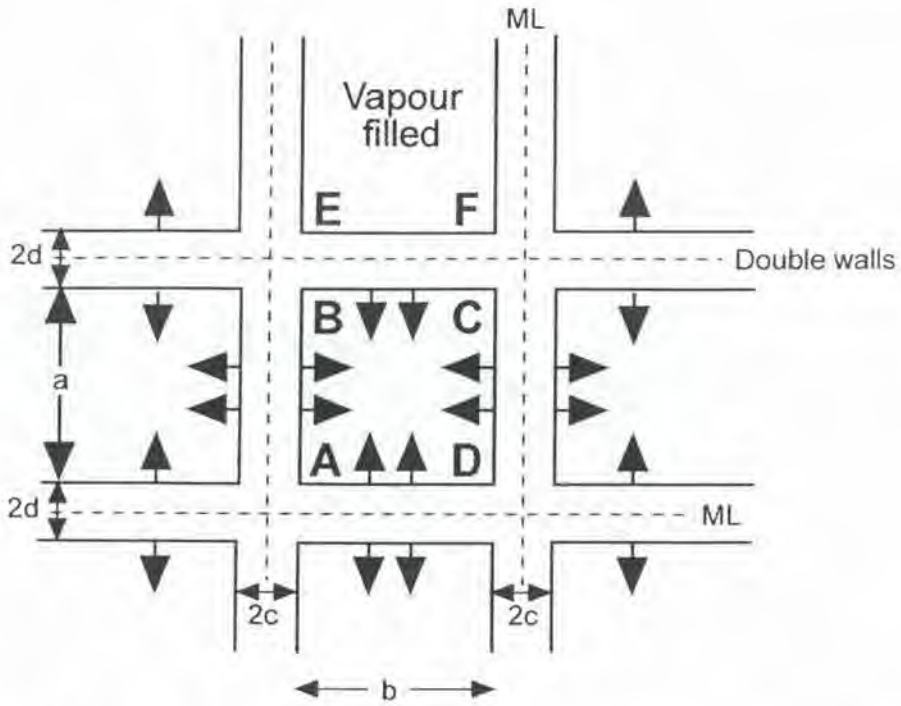

Figure 4.
Forces on the cell walls when one cell is vapour filled and the adjacent cells are water filled. The forces on wall E F C B are unbalanced. ML = middle lamella.

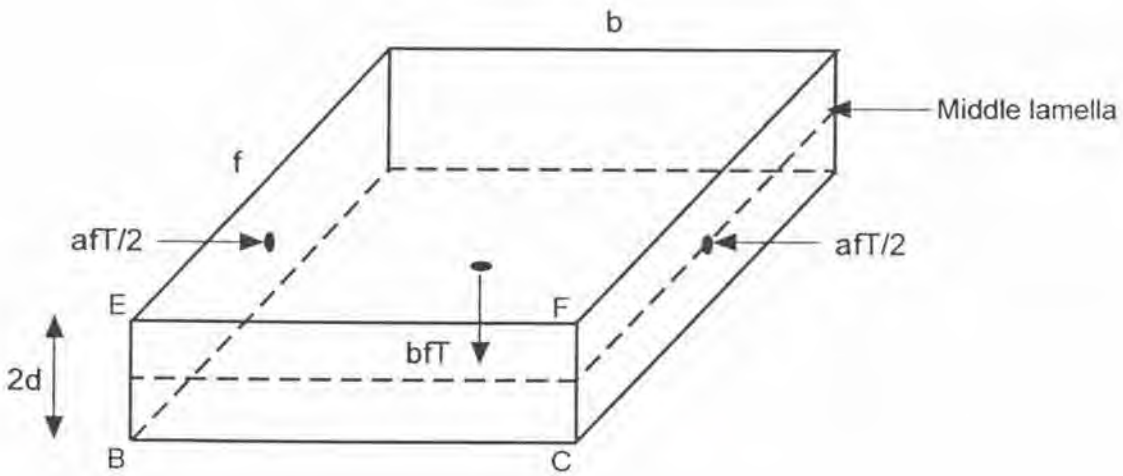

Figure 5.
Forces acting on a wall segment of length 'f' under an unbalanced water tension.

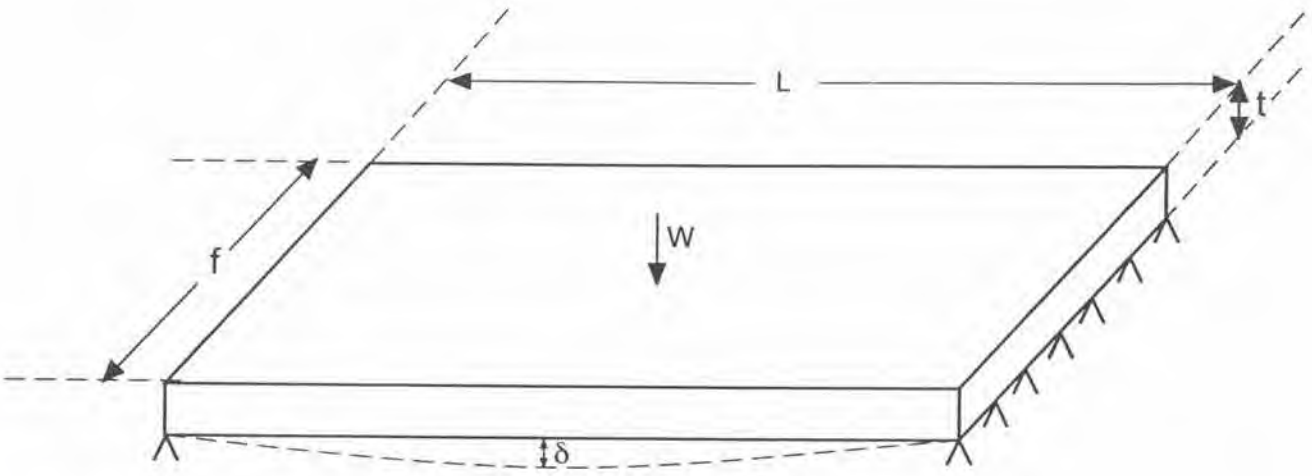

Figure 6.
Deflection of a beam or plate continuously and freely supported along two edges.

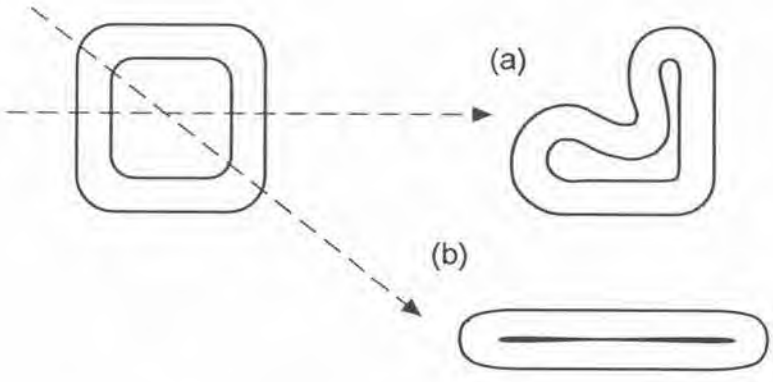

Figure 8.
Two alternative forms of cell collapse:
(a) Failure to kinking
(b) Compression of the cell with the cell walls deforming in opposite directions

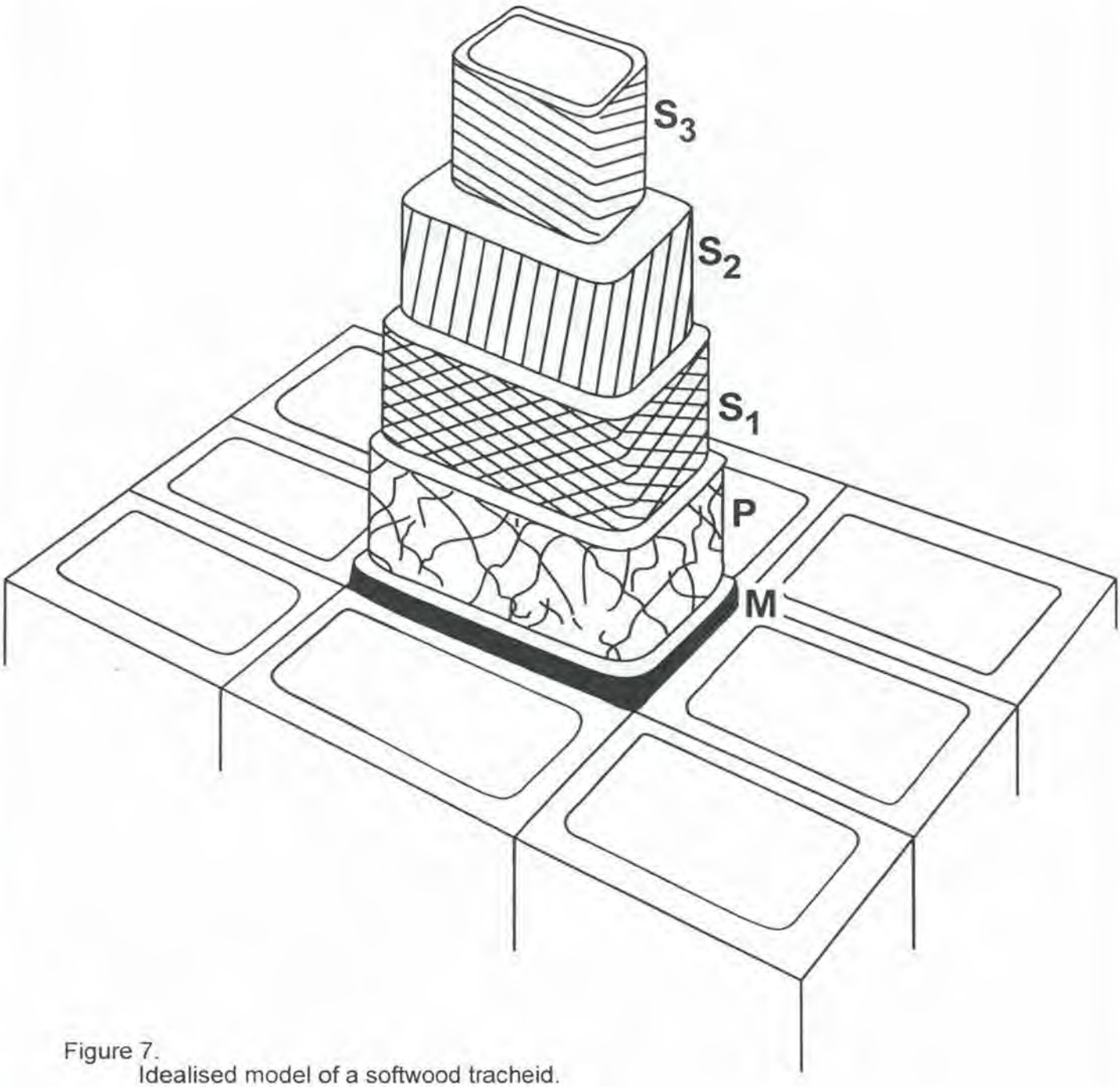

Figure 7.
Idealised model of a softwood tracheid.

MECHANICAL PROPERTIES OF TASMANIAN OAK RELEVANT TO SEASONING

Trevor Innes
University of Tasmania/Australian Furniture Research and Development Institute Ltd.
PO Box 2042, Launceston 7250.

ABSTRACT

Sawn timber which is to be used in decorative applications must be seasoned virtually free of defects. To assist in preparation of effective seasoning schedules, a predictive mathematical model of the drying process is required. This experiment was designed to provide information on the Young's Modulus, and stress and strain at proportional limit and at failure of Tasmanian Oak, for use in such a model. The experiment consisted of tension tests across the grain. The data gathered is compared with structural models for Tasmanian Oak currently in use in the timber seasoning simulation computer program KILNSCHED, by A.R. Oliver (1991).

INTRODUCTION

"Tasmanian Oak" is the marketing name for timber consisting mainly of *Eucalyptus regnans* F. Muell., *E. delegatensis* R.T. Bak., and *E. obliqua* L'Herit. It inherently includes minor amounts of other species, and hybrids. Thus, any study to provide useful data on such a variable material must be based on a relatively large sample space. To achieve this end, the timber used in this investigation was taken from many boards, and 128 individual specimens were tested.

Most Tasmanian Oak sold for furniture and decorative uses consists of quarter sawn boards. Backsawn material, although often considered to be more visually attractive than quartersawn, is rarely cut because of the difficulty experienced in drying it free of degrade. Its tendency to surface check more readily than quarter sawn material is due to the shrinkage in the tangential direction being approximately twice that in the radial direction, and the strength being about half. Thus the stresses developed in a board due to differential shrinkages induced by drying will be more likely to cause surface failure if the board is backsawn.

The experiments performed were aimed at producing data for backsawn Tasmanian Oak. This data was to consist of the Young's Modulus, and stress and strain at proportional limit and at failure, as functions of moisture content, basic density, and temperature. Tensile tests were thus performed in the tangential direction. Samples were tested at moisture contents from 10% to 80%, over a range of basic density from 540 kg/m^3 to 820 kg/m^3, and at four temperatures: 21.0, 33.5, 43.5 and 55.5°C. The samples were strained continuously at a rate of approximately 200 microstrain/minute.

Such tests have been carried out before by Schaffner (1981) on Tasmanian Oak, but only a small number of tests were carried out, with no allowance for density variation, and all at room temperature. Alexiou et al (1991) performed similar experiments on Blackbutt (*Eucalyptus pilularis* Sm.) at room temperature. Greenhill (1936) completed tests on American Beech (*Fagus grandifolia*) at temperatures up to 82°C in controlled humidity environments. Ellwood (1954) also investigated the properties of American Beech from 27°C to 71°C, for moisture contents from green to 6%. Ellwood's data forms the basis of the structural models currently used in KILNSCHED.

MATERIALS AND METHODS

Sample Preparation

Boards were selected from a stock of 100×25mm rough sawn green boards which had been gathered from a sawmill over a period of months and stored. Selected boards were as close to purely backsawn as possible. To prepare the specimens, approximately 8mm of material was removed from each of the board's wide surfaces in a thicknesser, so that the actual test specimens were cut from the central core of the board, to get the maximum moisture content with minimum MC gradient. The test specimens were then cut from the board using a router on a CNC machine. Approximately six specimens were obtained from each board. See Fig.1 for the sample shape. Immediately after cutting, samples were wrapped in plastic to minimise moisture loss. Samples were individually sealed with petroleum jelly for testing.

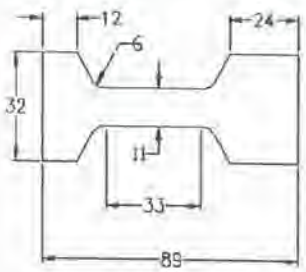

Fig. 1. Sample shape

Apparatus

The straining apparatus worked by means of a leadscrew and nut arrangement. The nut was toothed-belt driven from a stepper motor with a variable speed control, via a double reduction worm drive gearbox. Extension rate was variable from approximately 0mm/min to 0.04mm/min.

The fixed end of the sample was attached to an Ormond load cell connected to a Doric indicator unit. This combination was calibrated on a Shimadzu testing machine prior to use. Load readings were taken manually every 30 seconds.

Strain was measured by means of demountable strain gauges fitted to the two flat faces of the sample. These gauges were built by Schaffner (1981) for this type of test. The gauges were held together with orthodontic elastic bands, with the sample sandwiched in between. Each demountable strain gauge consisted of two knife edges, one attached to each end of a thin spring steel plate. The plate had electrical resistance strain gauges attached to its upper and lower surfaces. See Fig. 2. Thus, as the gauge length was increased, the steel plate was subjected to a bending moment at each end, so that one strain gauge measured tension, the other compression. Thus, the four strain gauges from the two demountable sets were wired into a full Wheatstone bridge. Excitation and measurement were performed by a Bruel and Kjaer AC strain gauge bridge. Readings were taken manually, coinciding with the load measurements. The demountable strain gauges were calibrated on a 4mm thick aluminium sample of known elastic modulus. Calibrations were carried out at each of the test temperatures.

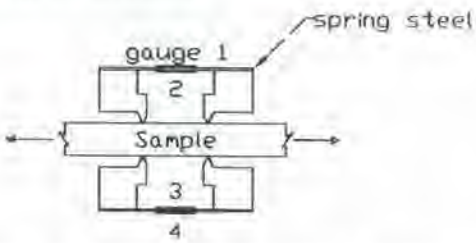

Fig. 2. Demountable strain gauge pair

The whole straining apparatus, excluding the readout units and stepper motor controller, was housed in an insulated plywood box. The box was equipped with three thermostatically controlled, shielded heating elements of total power 260 Watts, and a circulating fan. Maximum temperature possible for testing was governed by the temperature rating of the stepper motor.

Method

Before testing, a portion was removed from the end of each sample and used for MC and basic density determination. The green mass and volume of the portion were obtained by weighing on a Projecta balance, and by the water displacement method, respectively. The portion was then oven dried at 103°C, cooled in a desiccator, and reweighed.

The testing sample itself was sealed in petroleum jelly, placed in the apparatus and conditioned to the required temperature, before straining to failure. Data was read manually, collated in a spreadsheet, and processed using the SAS-Stat statistical package on a mainframe.

RESULTS AND DISCUSSION

The data was separated into that above fibre saturation point, for MC>25%, and that below FSP, for MC<18%. In this way, problems of curve fitting near the knee at FSP were avoided. Useful fits were found for Young's modulus and ultimate stress in terms of MC, BD and temperature, both above and below FSP.

For MC above FSP:

$\ln(E) = 4.206+0.003265(BD)-0.03029(T)$. $R^2=72\%$

$s_u = -4.103+0.01158(BD)-0.02866(T)$. $R^2=58\%$

For MC below FSP:

$\ln(E) = 5.115-0.03525(MC)+0.002758(BD)-0.009610(T)$. $R^2=78\%$

$s_u = 5.727-0.2395(MC)+0.004864(BD)-0.05583(T)$. $R^2=71\%$.

where: MC=moisture content (%), BD=basic density (kg/m^3), T=temperature (°C), E=Youngs Modulus (MPa), and s_u=ultimate stress.

No useful fits could be found for data on strain. This is thought to be due to problems with calibration of the strain gauges. Definition of a proportional limit was difficult for many of the stress-strain curves plotted, as they did not conform to the ideal of a distinct linear region followed by a non-linear region. Hence, no data for proportional limit stress or strain are presented.

As expected, the change in properties with moisture content above FSP is negligible, in accordance with the Tiemann free water/bound water concept.

A graphical comparison between some of these results and the structural model currently used in KILNSCHED is presented in Fig.3 and Fig.4, as the main purpose of this experiment was to test the data currently in use. For this purpose, the basic density used in the fits reported here was the average found, 673 kg/m^3. The basic density used in KILNSCHED for Tasmanian Oak is 680 kg/m^3.

This comparison shows a maximum difference between the two sets of data of approximately 20%. It is suggested that the structural model in KILNSCHED is

changed to match the information found in this experiment, and the output of the program compared with the current output.

The largest difference between the results of this experiment and the data in KILNSCHED occurs below FSP. Thus it is expected that changing the structural model would not have much effect above approximately 25% MC.

The largest source of uncertainty in this experiment is thought to have been the calibrations. These were performed by attaching the demountable strain gauges to a 4mm thick aluminium sample with elastic bands and epoxy. The epoxy was necessary to prevent slippage of the knife edges on the aluminium surface, but it is thought to have restricted rotation at the knife edge, thus subjecting the spring steel plate (to which the strain gauges were mounted) to tension as well as to bending. The aluminium was much stiffer than the timber to be tested so that the gauge factor had to be extrapolated to larger strains. A geometrical calibration was carried out for comparison to the practical calibrations and gave a result within 35%. The practical calibrations were used in preference to the calculated value, as the geometrical calculation was thought to be an oversimplification of the real situation, as, for instance, there was no allowance for temperature variation.

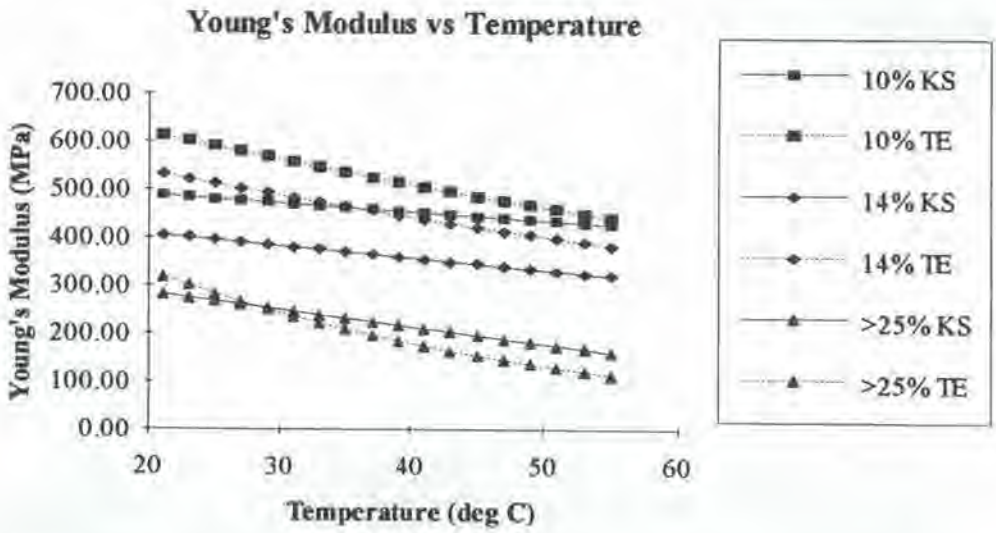

Fig. 3. Comparison of Young's Modulus as currently used in KILNSCHED (KS) and as measured in this experiment (TE). Legend numbers refer to moisture content.

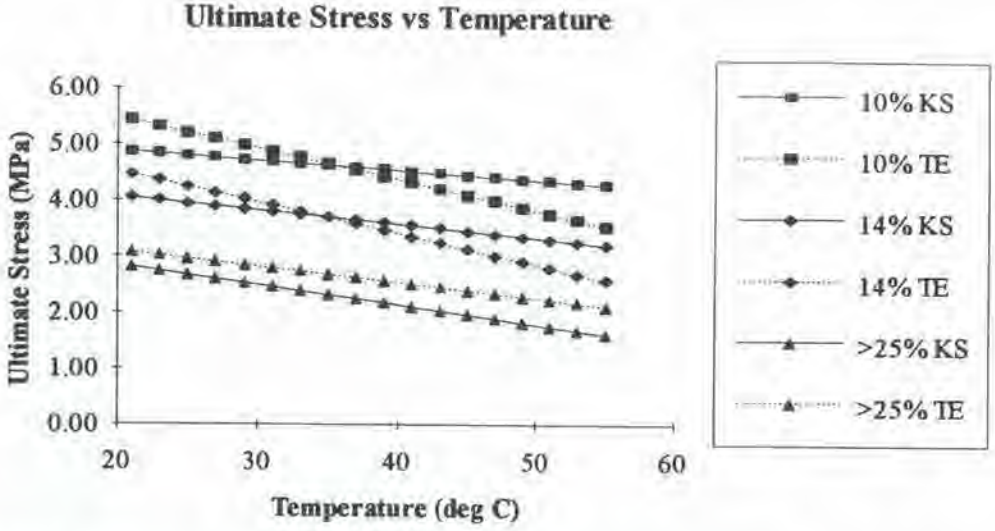

Fig. 4. Comparison of ultimate stress as currently used in KILNSCHED (KS) and as measured in this experiment (TE). Legend numbers refer to moisture content.

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CARBONISATION OF PLANTATION EUCALYPTS:- YIELDS OF PYROLYTIC PRODUCTS FROM CHIPPED SAWMILL EDGINGS

Paul Y.H. Fung, Soo H. Ng, Velauthapillai Muruganathan and Adrian de Vos
CSIRO Division of Forest Products
Private Bag 10, Rosebank MDC, Clayton, Victoria 3169

ABSTRACT

The establishment of salt tolerant tree plantations is one method currently used to combat salinity in areas affected by long-term irrigation. A return on this activity can be achieved through harvesting the trees in rotation for various wood products. Where the logs are converted to sawn products, it is important to be able to utilise the wood residues produced to improve the returns as this represents over half the log volume. The edgings from the sawing of six Eucalypt plantation species were chipped, dried and carbonised. The species studied were: *Eucalyptus camaldulensis* (river red gum), *E. maculata* (spotted gum), *E. cladocalyx* (sugar gum), *E. botryoides* (southern mahogany), *E. sideroxylon* (red iron bark) and *E. saligna* (Sydney blue gum) logged from trees grown on irrigated land in the Shepparton area of Victoria. Determination of the yields of the various pyrolytic products found that the yield of charcoal, tars and pyroligneous acid was species dependent but that of non-condensable gases was not. The charcoal yield was highest from red gum which confirmed that this was the most desired species for commercial charcoal making in the Murray River region. There were indications that the yield of pyroligneous acid was at the expense of the yield of charcoal and hence high charcoal yields produce low acid yields and vice-versa. There appeared to be no obvious relationship between tar yield and the yield of the other products. It was also found that the yield of charcoal was significantly less from the sapwood of red gum than from the heartwood. Since edgings contain a high proportion of sapwood, this could have a major influence on the yields of pyrolytic products.

INTRODUCTION

In a program to overcome salinity problems from long-term irrigation, experimental plots of Eucalypts were established in the Shepparton (Vic) region. It has been well established that soil salinity is a result of a rising water table caused by the removal of trees which act as water pumps in the transpiration of ground water through their leaves. Since the roots of trees often extend deep down into the subsoil, trees are very effective in controlling salinity by keeping dissolved salts well below the surface soil layers. Many tree species are adapted to soils with a high water table which may be part-saline, such as river red gum. This species can send roots to depths equivalent to its height. The extensive clearing of land over two centuries for farming, resulting in the loss of some 36% of national forests and woodlands (Wells, Wood, Laut 1984), has exacerbated the problem to the extent that increasingly, large tacts of land have become unusable for farming purposes. In an effort to reverse the problem, the re-establishment of tree plantations, particularly in and around saline affected land has been proposed. To improve the economics of reforestation, the productive conversion of the trees has been studied. Conversion into sawn timber recovers less than half the volume of the sawlog. The residues in the form of sawdust, slabs and edgings would need to be disposed of by

incineration or landfill dumping if not utilised. Carbonisation of the residues however, can offer more efficient utilisation of the wood resource. In addition, small diameter trees and thinnings can be carbonised because the ideal range of size to use in traditional carbonising kilns is 25-200 mm. This allows the prospect of either improving the quality of the trees for wood conversion through thinning or to set aside areas of plantation with harvesting over a short rotation cycle of five to eight years for charcoal production and allowing regrowth through coppicing. This latter practice has become well established in Brazil which relies heavily on fast growing Eucalypts with a rotation cycle of seven years. They harvest annually over 14 million tonnes of Eucalypt wood, most of which is used to produce metallurgical carbon for their steel industry (Guimaraes 1985) with a demand of some 10 million tonnes of wood carbon per year. The Murray River area has supported a traditional wood charcoal industry based on river red gum. Transportable charcoal kilns are often used producing lump charcoal. The volatile pyrolytic by-product in the form of smoke is not recovered and is a source of air pollution. To utilise the volatiles for energy, a fluidised bed carbonisation system was developed by the CSIRO for chipped wood and sawdust which burns the volatiles within the system and is able to recover the heat produced. The heat can be used to provide process heating for the kiln drying of timber (Fung, Ng, de Vos, Muruganathan, Harris 1992).

In the past, the volatiles were an important source of chemicals and specialised products refined from the condensed tars and pyroligneous acid. The non-condensable gases contain combustible gases which helped fuel the wood distillation process. However, when many of the chemicals were synthesised from fossil resources, the wood distillation industry declined. Since oil is now an expensive raw material, and there is potential for new chemicals and products which can be made from the various pyrolytic products, this study investigates the yield of these products in the form of charcoal, tar, pyroligneous acid and gas from the chipped edgings of six *Eucalyptus* species grown on irrigated land in the Shepparton area. The ages of the trees were 18 - 20 year old in the diameter range at breast height: 450 - 510 mm. Details of the source of logs are given in Table 1. The chemistry and chemical constituents of the volatile byproducts will be discussed in the second paper.

TABLE 1. SOURCE OF LOGS

SPECIES	*E. camaldulensis*	*E. maculata*	*E. cladocalyx*	*E. botryoides*	*E. sideroxylon*	*E. saligna*
Common Name	River Red Gum	Spotted Gum	Sugar Gum	Southern Mahogany	Red Iron Bark	Sydney Blue Gum
Location	Shepparton-Girgarre	Shepparton-Stanhope	Shepparton -Girgarre	Shepparton-Tatura	Shepparton-Katunga	Shepparton -Katunga/ Tatura
Site	Irrigated Land	Adjoining Irrigation Channel	Irrigated Land	Adjoining Irrigation Channel	Irrigated Land	Irrigated Land
Age	18-20 y.o.	18-20 y.o.	18-20 y.o.	20 y.o.	20 y.o.	18-20 y.o.
Diameter at Breast Height (mm)	380-460	460	380	610	380 1 of 2 major limbs forked 1.2 m above ground	380

EXPERIMENTAL METHOD

Preparation of Wood Chips

Edgings were obtained from the sawing of individual debarked logs. The material was chipped and the chips from each species were tumbled for 15 minutes to mix the chips well and split into a number of representative samples. One sample from each species was oven-dried to determine the as-received moisture content. This moisture content range was found to be 16 - 32% (oven-dried basis). Oven-drying at 105°C for 24 hours was sufficient to achieve complete dehydration. The remaining samples were allowed to air-dry in trays to a moisture content of 13 - 19% and then oven-dried to 0% moisture content.

Size Analysis

One air dried sample of each species was removed for size analysis where they were further split into two representative samples. Each sample was firstly sized through a set of screens with round holes followed by sizing through a set with slotted apertures. Both sets of screens were shaken in a "Chip-n-Saw Can-Car shaker". This effectively determined the projected size distribution in the first determination and thickness distribution of the chips in the second.

Density Measurement

The true densities of the wood chips were determined on oven-dried samples by weighing and measuring volume by mercury displacement. Twenty wood chip samples were determined for each species.

Carbonisation

A carbonisation retort was constructed which comprised of a horizontal cylinder, externally heated in a refractory lined furnace, fired indirectly with a natural gas burner. A charge of 10.4 litres of oven-dried woodchips was used forming a maximum bed depth of approximately 100 mm. A thermocouple projecting below the surface of the chip bed, 15 mm from the base of the retort measured the carbonising temperature. The chips were heated at a programmed rate according to the furnace temperature. From ambient to 180°C the heating rate was 5°C/min, from 180°C to 420°C this was decreased to 1.67°C/min and from 420°C to 655°C the rate was further decreased to 0.83°C/min. The heat was switched off after 7.7 hours at which time the bed temperature reached 650-680°C. The volatile products of pyrolysis were ducted out of the retort and cooled in condensers. The condensates produced were collected in volumetric measuring cylinders and weighed at the end of the run. The non-condensable gases were flared off. At the end of the run when the temperature programmer automatically switched off the gas burner,the retort was rapidly cooled by blowing air through the furnace. After approximately 25 minutes, the retort temperature was reduced to less than 80°C at which time, it was removed from the furnace, dismantled and the charcoal was weighed. The condensate was allowed to settle for half an hour to separate the heavier tar from the pyroligneous acid fraction. The tar was carefully pipetted out into another measuring cylinder and weighed. The weights and volumes of both condensates were recorded.

RESULTS

The physical properties of the species tested with regards to their mean diameter, mean thickness and oven-dried true density range are shown in Table 2.

TABLE 2. Size and true density of wood chips

Mean diameter (mm)	14.2
Mean thickness (mm)	3.6
Density (g/cm³)	0.70 - 0.90

The yields of charcoal and condensates were calculated from the ratio of the weight of product versus the weight of dry wood input. The yield of wood converted to non-condensable gas was determined by difference as this was not measured. Charcoal yields shown in Table 3 were generally averaged from three replications. The reproducibility of charcoal yields was very good with standard errors in the range 0.1 - 0.3%. The pyroligneous acid and tar yields in Table 3 were those of single runs.

TABLE 3. Yields of Pyrolytic Products from various Plantation Species

SPECIES	*E. camaldulensis*	*E. maculata*	*E. cladocalyx*	*E. botryoides*	*E. sideroxylon*	*E. saligna*
Av charcoal Yield (%)	34.8	29.2	29.7	32.5	31.1	30.6
Standard Error	0.3	0.1	0.1	0.2	0.1	0.1
Tar Yield (%)	10.4	11.6	9.6	12.5	12.1	13.0
Pyroligneous Acid Yield (%)	30.3	34.2	37.1	30.4	33.0	31.7
Wood Gas Yield (%)	23.9	24.8	24.0	24.4	24.2	24.7

DISCUSSION OF THE RESULTS

Charcoal Yields

There was a variation in yield of charcoal between the various Eucalypt species studied. *E. camaldulensis* gave the highest yield of 34.8%. This result is consistent with the traditional preference for river red gum species in making charcoal in the Murray River region. *E. botryoides* gave the next highest charcoal yield of 32.5% followed by *E. sideroxylon* (31.1%), *E. saligna* (30.6%), *E. cladocalyx* (29.7%) and the lowest was *E. maculata* of 29.2%.

The edging component of the log will naturally contain a large proportion of sapwood. Species such as red gum and red iron bark have strong colour differences between the sapwood which has a light colouration and heartwood which is dark red caused by the laying down of extractives in the cell walls as all the living cells in the sapwood dies to form heartwood. The extractives preserve the wood from decay and insects. Because of the distinct colour difference, it was therefore possible to separate the pure sapwood from the heartwood chips. This was undertaken for the two species and the results are shown in Table 4. There were a number of chips that were difficult to separate since these were a mixture. Also chip fines were also difficult to separate. Both types were therefore categorised separately. However, in determining the sapwood/heartwood ratio, only the data from the pure sapwood and heartwood was used. It is assumed that this ratio is the same in the mixed chips and fines components.

TABLE 4. Ratio of Sapwood to Heartwood for *E. camaldulensis and E. sideroxylon.*

SPECIES	*E. camaldulensis*		Average	*E. sideroxylon*		Average
	SAMPLE 1	SAMPLE 2	Composition (%)	SAMPLE 1	SAMPLE 2	Composition (%)
Sapwood	38.6	41.4	40.1	67.3	65.3	66.2
Heartwood	38.6	38.5	38.5	25.9	27.4	26.7
Mixed	20.5	18.2	19.3	5.7	4.9	5.2
Fines	2.3	1.9	2.1	1.1	2.5	1.8
Sapwood/ Heartwood			51/49			71/29

It can be seen from Table 4 that *E. camaldulensis* contains a more even distribution of sapwood to heartwood, namely, 51/49 whereas for *E. sideroxylon*, the distribution is predominantly that of sapwood with a ratio of 71% sapwood verses 29% heartwood.

To determine the difference in yield of charcoal between sapwood and heartwood, these components were separated from *E. camaldulensis* chips which were then carbonised separately to determine charcoal yields. The results in Table 5 show that the heartwood component yielded 37.0% charcoal which was higher than that from sapwood, namely: 32.4%. The charcoal yield from the chipped edgings was 34.8%. If the charcoal yield of the edgings were calculated from the product of the yield of the individual components and the proportion of each component (51% and 49% respectively), this gives a calculated yield of 34.7% which is in close agreement with the experimental results.

TABLE 5. Charcoal Yields of *E. camaldulensis* Sapwood, Heartwood and Edgings.

CHIP ORIGIN	Sapwood	Heartwood	Edgings
COMPOSITION	100%	100%	51% Sap; 49% Heart
CHARCOAL YIELD (%)	32.4	37.0	34.8%

It therefore appears that *E. sideroxylon* with a charcoal yield of 31.1% inherently contains less fixed carbon than even the pure sapwood of *E. camaldulensis* not withstanding that the iron bark edgings contain predominantly more sapwood than heartwood. On the basis of the red gum results, if the *E. sideroxylon* edgings had more heartwood, one would expect a higher yield of charcoal but not as high as that of red gum. Species differences therefore must play a more important role in determining fixed carbon content.

Tar Yields

Tar yield was the highest with *E. saligna* (13.0%) followed by *E. botryoides* (12.5%), *E. sideroxylon* (12.1%), *E. maculata* (11.6%), *E. camaldulensis* (10.4%) and

the lowest recovery was from *E. cladocalyx* (9.6%). The tars contain complex aromatic compounds.

Pyroligneous Acid Yields

This fraction consists of an aqueous solution of aliphatic acids, alcohols, ketones, methanol and acetone together with some dissolved tars. The water produced is derived from the chemical decomposition of the wood substance and not from the wood moisture since practically all of this was removed by oven-drying.

E. cladocalyx, which gave the lowest tar yield, resulted in the highest acid fraction (37.1%). This was followed by *E. maculata* (34.2%), *E. sideroxylon* (33.0%), *E. saligna* (31.7%), *E. botryoides* (30.4%) and lastly, *E. camaldulensis* (30.3%). The last two species were almost the same in acid yield. The lowest yield of pyroligneous acid came from the species that produced the highest yield of charcoal. In general, the order of yield of pyroligneous acid approximately followed the reverse order of yield of charcoal. This indicates that charcoal may be formed at the expense of the pyroligneous acid fraction and vice-versa.

Gas Yields

Gas yields were determined by difference between the original weight of dry wood and that of condensates plus charcoal. Surprisingly, the yields of non-condensable gases for all the species studied were very similar, in the range: 23.9 - 24.8%. The difference was only 0.9% over the range.

The main gases formed in pyrolysis are oxides of carbon, hydrogen, alkanes and alkenes.

CONCLUSION

The study gave a good indication of the yields of the various pyrolytic products one could expect from the six Eucalypts tested in the carbonising system used. This could help in the selection of a suitable plantation species to optimise the recovery of one or more of the products.

The charcoal, tar and pyroligneous acid yields were generally species dependent. However, the non-condensable gas yield was independent of the species. The yield of charcoal was found to be higher for heartwood than sapwood. It appeared that pyroligneous acid was formed at the expense of charcoal yield.

The study found that *E. camaldulensis* gave the highest yield of charcoal of the six species tested.

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TEMPERATURE EFFECTS ON THE PRODUCTION OF PYROLIGNEOUS LIQUORS FROM EUCALYPT WOODCHIPS

Paul.Y.H. Fung, Soo H. Ng, Velauthapillai Muruganathan and Adrian de Vos
CSIRO Division of Forest Products
Private Bag 10, Rosebank MDC, Clayton, Victoria 3169

ABSTRACT

In recent years, there has been some renewed interest in the use of condensates from wood pyrolysis. These can be recovered in the manufacture of charcoal as a byproduct tar and an aqueous liquid known as pyroligneous acid. The latter was a major source of acetic acid and methanol during the 1920's but has since been replaced by ethylene and synthesis gas from fossil fuel resources. The pyrolytic condensates however, are a rich source of phenolic compounds which are more difficult to synthesise directly. The formation of pyrolytic chemical compounds from the various wood components is reviewed. The pyrolysis of six plantation eucalypt species, namely: *E. camaldulensis*, *E. maculata*, *E. cladocalyx*, *E. botryoides*, *E. sideroxylon* and *E. saligna* grown on irrigated land in the Shepparton region (Vic) was studied. Edgings obtained from converting selected logs into timber, from 18-20 year old trees, were chipped and destructively distilled in a retort described in a previous paper. The volatile condensates were collected as a function of carbonising temperature to a maximum of around 650-680°C. It was found that the pyrolysis of all the species studied behaved in a similar way with the bulk of the condensate production occurring in the temperature range: 230-440°C. Studies on the sapwood and heartwood of *E. camaldulensis* showed that sapwood produced more tar and pyroligneous acid but less charcoal than heartwood. In addition, the condensate recovery curve was offset over a lower temperature range for sapwood compared to that of heartwood. It is postulated that this may be due to the different extractives in the two components. For example, heartwood contains more polyphenols which have greater thermal stability and pyrolyse with high aromatic carbon yields whereas simple sugars and starches are more predominant in sapwood. These tend to decompose at lower temperatures.

INTRODUCTION

When wood is carbonised, volatile by-products are formed consisting of a condensable liquid fraction and a non-condensable gas. The condensable liquid settles out into an immiscible heavy tar fraction and a lighter, aqueous pyroligneous acid fraction. These were an important source of chemicals during the turn of the century where acetic acid was a main product from pyroligneous acid and aniline dyes were synthesised from wood tars in Germany. In Australia, a wood carbonisation industry was established in Western Australia in 1948 to produce charcoal reductant for a blast furnace manufacturing spheroidal graphite iron and pyroligneous acid for a refinery producing glacial acetic acid, methanol and acetone (Harris, A.C. 1985). The settled tar was used as a fuel in the place of expensive oil in the steel works while the soluble tar was used as a moisturiser and plasticiser for making bricks and in cement mixing. As chemical prices fell due to competition from synthesis based on petrochemical ethylene and synthesis gas from fossil

fuel resources, the cost of transporting pyroligneous chemicals from WA to distant east coast markets became uneconomical. Chemical production ceased as a result. However, after half a decade of neglect, there is currently renewed interest in wood pyrolysis condensates for a number of niche applications. For example, Malaysia is researching the production of calcium acetate from the pyrolysis of rubber wood for use as a latex coagulant (Harris, E.M. and Hoi, W.K. 1992). In Japan, the pyroligneous acid is recovered from carbonisation kilns for use as "wood vinegar" in agriculture (Kishimoto and Satonaka 1992). Annual consumption in Japan has reached 4000 tonnes per year. At the height of the oil crisis, Brazil investigated the recovery of wood tars for use as a replacement for fuel oil, commencing production in 1982. Most of it is now used in the steel industry which also produces the charcoal. Fuel oil consumption by this industry represented 17% of the national consumption figures (Florestal Acesita 1983). Carazza *et al* 1992, investigated the synthesis of pharmaceutical and fine chemicals from Eucalypt pyrolytic tars, producing methylated syringyl derivatives.

Pyrolysis Process

Wood is made up of various chemical components, namely: cellulose, hemicellulose, lignin and extractives. Dadswell and Stewart 1962, published the chemical components of a number of Eucalypts. Some of these, which were tested in this present study, are shown in Table 1.

TABLE 1. Chemical Composition of some Eucalypt Species

SPECIES	Pentosans in wood (%)	Cross & Bevan Cellulose (%)	Klason Lignin (%)	Alkali Soluble Extractives (%)
E. camaldulensis	13	40	21	34
E. maculata	-	-	19	-
E. sideroxylon	16	40	19	38
E. saligna	12	59	26	16

When wood is heated in the absence of oxygen, volatile substances such as some extractives will be distilled off. The non-volatile components will undergo thermal decomposition. It is generally accepted that hemicellulose has the least thermal stability followed by cellulose and lignin.

The pyrolysis of cellulose, which consists of chains of glucose molecules, has been studied in detail by many researchers. Tang and Bacon 1964, postulated a mechanism of decomposition in different, temperature dependent stages. Dehydration of the cellulose unit occurred at 150 - 240°C. Thermal cleavage of the glycosidic linkage and scission of other C-O and some C-C bonds through a free radical reaction occurred at 240-400°C producing large amounts of tar, water, CO and CO_2. Above 400°C, there was aromatisation of the carbonaceous residues forming graphitic layers with the loss of hydrogen. It was also found by earlier workers that *levo*-glucosan (1,6-anhydroglucosan)

was first formed as an intermediate in dehydration reactions at 200-300°C. This compound further decomposed to acetic acid, acetone, phenols and water.

Hemicellulose is of lower molecular weight than cellulose and generally consists of chains, often branched, of non-glucose molecules. Most of the hemicellulose in the Eucalypts is attributed to pentosans or xylans. These tend to pyrolyse with high yields of acetic and homologous acids. Furfural and furan type compounds are also formed as final or intermediate products. The intermediates of hemicellulose also undergo condensation reactions, during pyrolysis, to produce charcoal.

Lignin is composed of a random, three-dimensional network of phenyl propane substructures. The most important groups in eucalypt wood comprise of syringyl and guaiacyl units. Lignin is said to be the main source of pyrolytic methanol, tars, charcoal and methane. Phenols and phenolic ethers are mainly derived from lignin most of which consists of homologs and derivatives of syringol, guaiacol and pyrogallol 1,3- dimethyl ether.

Literature on wood pyrolysis generally overlooks wood extractives. Most eucalypt woods contain considerable amounts of hot-water soluble extractives, as shown in Table 1, which are composed largely of low molecular weight polyphenols - tannins, sugars and starches. Many extractives occur in extraneous kino and gum veins of trees which are rich in tannins. Dilute alkali (0.1M sodium hydroxide) is used to remove remaining extractives such as polymerised polyphenols. This however, also dissolves small amounts of lignin and polysaccharides as shown in Table 1 where Dadswell and Stewart's data show the sums of the components total over 100%. Hillis and Carle 1959, determined the tannins: ellagic and gallic acids in *Eucalyptus delegatensis*. Baklien 1960, determined the ellagic acid content of *E. camaldulensis* woodchips and found this to be in the range 0.41-0.9% of the dry wood mass. It is likely that in pyrolysis, gallic acid is converted to pyrogallol. The proportion of extractives, and their chemical composition, is largely a function of species and tree component (i.e. sapwood, heartwood or bark).

In wood, the various components are both regionally dispersed and intimately mixed and it may be difficult to predict the pyrolytic behaviour of wood with respect to its individual components due to the influence of the micro- and macrostructure of the wood sample on the primary and secondary reactions. The inorganic ash constituents could also exert some catalytic effects on the pyrolysis reactions. The chemical compounds formed from pyrolysis are indeed many and varied. Some of these are shown in Table 2.

TABLE 2. Some Volatile Products from Wood Pyrolysis

GROUP	COMPOUND	GROUP	COMPOUND	GROUP	COMPOUND
Gases	hydrogen	Aldehydes	formaldehyde	Furans	furfural
	carbon monoxide		acetaldehyde		furfural alcohol
	carbon dioxide		proprionaldehyde		
	methane		butyl aldehyde	Phenols	phenol
	ethane		iso-butyl aldehyde		*p*-cresol
	ethylene		acryl aldehyde		*o*-cresol
			n-valeraldehyde		*m*-cresol
Alcohols	methanol		iso-valeraldehyde		pyrogallol
	ethanol		cis-2-furaldehyde		ethyl phenol
	propanol		trans-2-furaldehyde		guaiacol
	iso-propanol				4,ethyl guaiacol
		Ketones	acetone		pyrocatechol
Acids	formic		methyl ethyl ketone		syringol
	acetic		methyl propyl ketone		eugenol
	proprionic		methyl iso-propyl ketone		trans-iso-eugenol
	butyric				cis-iso-eugenol
	valeric				guaiacol cresol

EXPERIMENTAL METHOD

The pyrolysis of six plantation eucalypt species grown on irrigated land in the Shepparton area: *E. camaldulensis*, *E. maculata*, *E. cladocalyx*, *E. botryiodes* and *E. saligna* was undertaken using equipment and procedures as described in the first paper. The wood was in the form of edgings obtained from the conversion of logs from trees 18-20 year old with diameters at breast height: 380-610 mm. The edgings were chipped and oven-dried before carbonisation. A water-cooled condenser was used to recover the volatile condensate which was collected in measuring cylinders. The temperature of the carbonising woodchips in the retort was recorded over time and the corresponding volume of condensate collected was noted over the temperature range from ambient to over 650°C. The non-condensable gases were flared off. At the end of the run, the retort was cooled and the condensates were allowed to settle where the tar separated from the pyroligneous acid fraction. The heavier tar was pipetted out, the volume measured and weighed in another measuring cylinder. The weight and volume of the remaining pyroligneous acid were also recorded. The weight of charcoal produced was determined.

With *E. camaldulensis*, the sapwood chips were separated from the heartwood chips which was possible due to the distinct colour difference between the two. The heartwood was ochre red in colouration whereas the sapwood was pale pink. Separate pyrolysis runs were conducted on the sapwood and the heartwood chips.

RESULTS

The yields of condensate were expressed as a percentage ratio of the product to the original weight of oven-dried wood. The condensate comprised of tar and pyroligneous acid. The yields of non-condensable gases were determined by difference. For the six Eucalypt species, the yields of all pyrolytic products are shown in Table 3, including charcoal for the individual runs.

TABLE 3. Yields of Pyrolytic Products

SPECIES	*E. camaldulensis*	*E. maculata*	*E. cladocalyx*	*E. botryoides*	*E. sideroxylon*	*E. saligna*
Condensate (%)	40.7	45.8	46.7	42.9	45.1	44.7
Tar (%)	10.4	11.6	9.6	12.5	12.1	13.0
Pyroligneous acid (%)	30.3	34.2	37.1	30.4	33.0	31.7
Wood gas (%)	23.9	24.8	24.0	24.4	24.2	24.7
Charcoal (%)	35.4	29.4	29.4	32.7	30.8	30.7

At the end of the run, the total volume of condensate collected was recorded and the condensate recovery at various intermediate temperatures were normalised to a percentage recovery so that the data for all the pyrolytic runs with condensate recovery can be plotted on the one graph. The condensate recovery for the six species tested versus pyrolysis temperature is shown in Figure 1.

FIGURE 1. Pyrolysis of Eucalypt Plantation Species

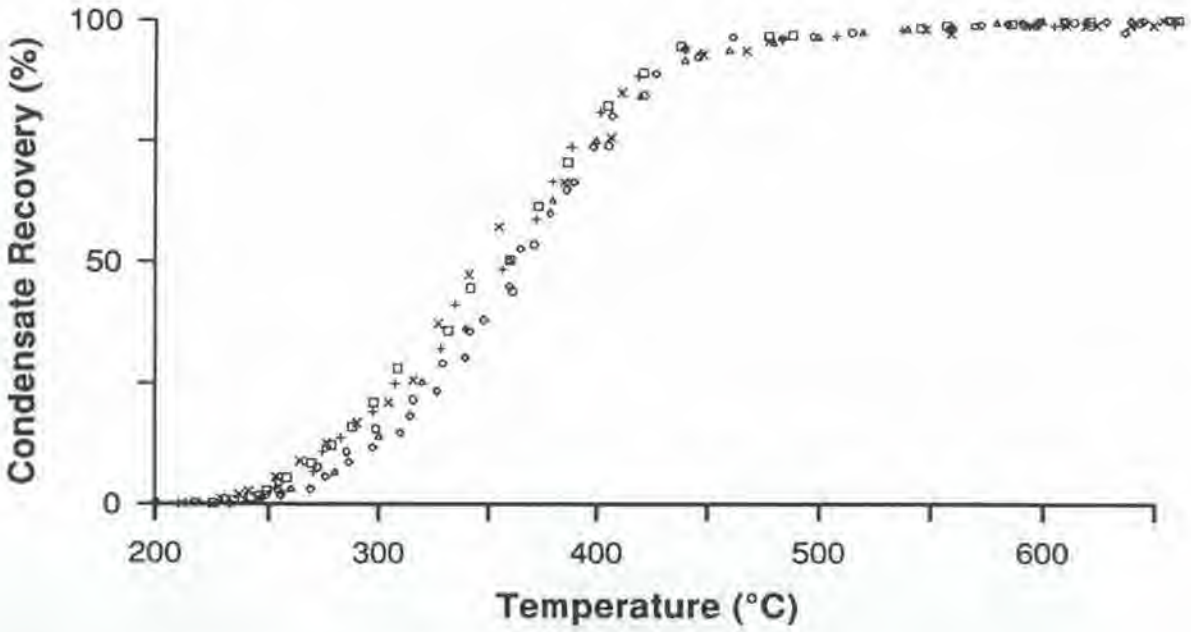


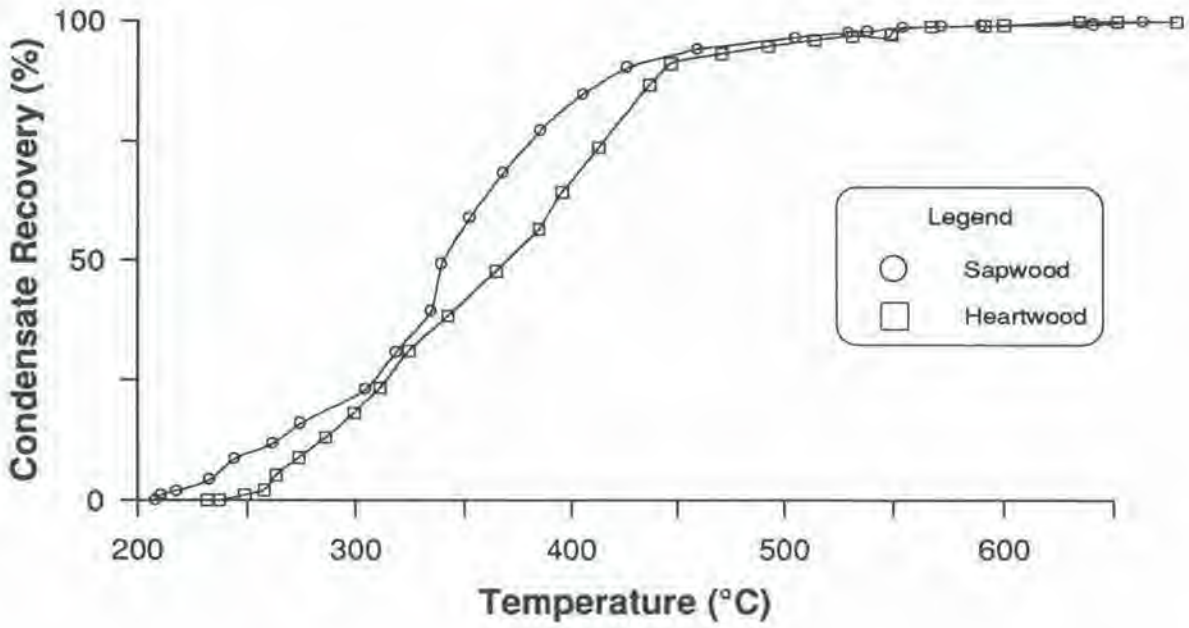
Table 4 shows the pyrolysis yields of the runs with separated sapwood and heartwood chips compared to the pyrolysis run on the original mixed chips from the edgings of *E. camaldulensis*.

TABLE 4. Yields of Pyrolytic Products from Sapwood, Heartwood and Edgings of *E. camaldulensis*

CHIP ORIGIN	Sapwood	Heartwood	Edgings
Wood Chip Composition	100%	100%	51% Sap; 49% Heart
Condensate (%)	41.9	37.9	40.7
Tar (%)	11.0	9.4	10.4
Pyroligneous acid (%)	30.9	28.5	30.3
Wood gas (%)	25.7	25.1	23.9
Charcoal (%)	32.4	37.0	35.4

The graph of condensate recovery versus temperature for the *E. camaldulensis* sapwood run is compared against that for the heartwood run in Figure 2.

FIGURE 2. Pyrolysis of *E. camaldulensis* Sapwood & Heartwood



DISCUSSION OF THE RESULTS

In the pyrolysis of six Eucalypt species, condensate began emerging at carbonising temperatures above 200°C as shown in Figure 1. This would correspond to the temperature at which dehydration of the cellulose and hemicellulose occurs forming water as the main product. This condensate is tinged with a yellow colouration but gradually darkens as temperatures reach 240-270°C from reactions which could correspond to breaking of glycosidic, C-O and C-C bonds. At 310-350°C, the condensate darkens

considerably with collection of tars. The maximum rate of production of condensate was within the temperature range 330-370°C. There is a shoulder in the curve around 440°C where condensate production slows considerably. Presumably, at these temperatures, aromatisation commences with the formation of graphite-type structures. This was observed by Fung and Brown 1986, in X-ray diffraction studies on charcoal prepared from *E. marginata* at 500°C. The graphitic diffraction pattern became more pronounced at a temperature of 1160°C. Experimental data on the pyrolysis of maple wood by Othmer and Schurig 1941, showed that hydrogen concentrations in the non-condensable gases rise to significant concentrations above 480°C and seem to dominate the gas composition above 750°C. This could possibly arise from aromatisation rearrangements of the molecular structures.

There appears to be a difference in the yield of volatile condensates between the sapwood and heartwood of *E. camaldulensis*. The heartwood produces less overall condensate, less tar and less pyroligneous acid than sapwood. It appears that the lower yields of these volatile components resulted in a higher yield of charcoal for heartwood. Non-condensable gas yields from the two tree components were similar. The effect of temperature on the pyrolysis production of volatile condensates also shows differences between the sapwood and heartwood of *E. camaldulensis*. It appears that the thermal decomposition of sapwood into condensates occurs at lower temperatures than that of heartwood indicating a higher concentration of less thermally stable chemical compounds in sapwood than in the heartwood. Heartwood contains more polyphenol extractives whereas in sapwood, there is more sugar and starches.

CONCLUSIONS

The effect of temperature on the production of pyrolytic condensates followed the same trend for the six eucalypt species tested. The temperature range where condensate production was dominant was 230-440°C. The sapwood of *E. camaldulensis* produced slightly more condensates in the form of pyroligneous acid and tar than the heartwood apparently at the expense of charcoal formation. The condensate from sapwood was produced at lower temperatures than for heartwood.

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MOLECULAR WEIGHT OF A PHENOLIC RESIN DETERMINED BY NMR

M.J. Reilly and Y. Yazaki

CSIRO Division of Forest Products
Private Bag 10, Rosebank MDC, Clayton, Victoria 3169, Australia

ABSTRACT

For the molecular weight determination of a novolac type phenol-formaldehyde (PF) resin, proton nuclear magnetic resonance (^{1}H NMR) spectrometry was used.

Based on the areas obtained by integration of the peaks in the ^{1}H NMR spectrum, functional groups of the PF resin were quantified and the number average molecular weight ($\overline{M}n$) of the PF resin was calculated to be 540.3.

The validity of the technique and the equations used in the calculations was confirmed with their application to two model PF compounds.

INTRODUCTION

An increasing demand for wood, environmental concerns, and a decreasing availability of large diameter logs of high quality will see a continuing emphasis on the most effective use of forest resources. Plywood panels, laminated veneer lumbers (LVL), and finger jointed studs are reconstituted wood products which offer a viable and more efficient alternative under these circumstances. In these products, phenol-formaldehyde (PF) adhesives play an important role.

The Wood Adhesives Group at the CSIRO Division of Forest Products have been collaborating with a wood adhesive manufacturer, Huntsman Chemical Company, Australia Limited in the design and development of PF resins that are fast curing and moisture tolerant in the gluing of high density wood species for the manufacture of plywood and LVL.

In order to design and develop PF resins, it was necessary to analyse them by nuclear magnetic resonance (NMR) spectroscopy and gel permeation chromatography

(GPC) and to characterise them in chemical terms, such as methylol/methylene ratio, degree of polymerisation, molecular weight distribution and so on. Molecular weight distribution (MWD) is one of the more important molecular characteristics of PF resins, as the molecular weight of resins may control the flow characteristics of the PF resins in the glueline during the hot pressing stage of plywood/LVL manufacture. However, there is no simple method available to measure MWD (Weller and Gollob, 1980). A previous ^{1}H NMR study of the molecular weight of a resole type PF resin revealed the calculated number average molecular weight to be in close agreement with those determined by GPC and by vapour pressure osmometry (VPO). This indicates that NMR, in addition to its primary role in molecular structure analysis, is also useful in the determination of molecular weight. In order to further examine the applicability of this technique to the molecular weight determination of PF resins, a novolac type PF resin was selected and its number average molecular weight determined.

Nuclear magnetic resonance (NMR) - An outline

Nuclear magnetic resonance is an observable phenomenon because certain nuclei (e.g. ^{1}H) behave like magnets when placed in a magnetic field. In a strong magnetic field, the proton for example, which has two permitted orientations, will tend to align itself parallel to the magnetic field and a certain precise amount of energy (i.e. radiation of a precise frequency) is required to turn this nuclear magnet against the magnetic field into its other permitted and less stable orientation. It is the absorption of radio frequency (rf) radiation by nuclear magnets in a magnetic field that is the phenomenon of NMR.

NMR is a technique accessible only to nuclei possessing a non-zero spin quantum number (i.e. $I \neq 0$). The spin quantum number, I, is a quantum mechanical term related to atomic and mass numbers. For example, those nuclei possessing both even atomic and mass numbers (e.g. $^{12}C^{6}$) have $I = 0$ and therefore show no NMR effect. Those nuclei having an even mass number and an odd atomic number (e.g. $^{2}H^{1}$, $I = 1$) or an odd mass number and an even atomic number (e.g. $^{13}C^{6}$, $I = ½$) will show an NMR effect. The proton, ^{1}H, is a special case in having both atomic and mass numbers odd ($^{1}H^{1}$, $I = ½$) and the most easily studied of all the magnetic nuclei.

Magnetically susceptible nuclei in slightly different electronic environments within a molecule require slightly different radio frequencies to cause a transition between allowed orientations. The NMR spectrum is presented as a measure of the frequency and the magnitude (amount) of nuclei resonating at each frequency.

Correlations between rf absorption and the electronic environment have been established over many years, thus readily permitting structural assignment of each resonance signal. For example, in the ^1H NMR of a novolac PF resin, protons in the methylene bridge group, $-CH_2-$, will be observed at a higher frequency than the aromatic protons due to circulation of the electron cloud in the aromatic system and a higher electron density at the $-CH_2-$ bonds. That is the methylene protons are more highly shielded than the aromatic protons from the magnetic field and require a higher rf to cause a transition. Thus ^1H NMR allows us to determine the types of various functional groups present in a molecule and to quantify them by integration of the signal area.

MATERIALS AND METHODS

Model compounds and a PF resin

The two model compounds used in this study 2,2'- and 2,4'-dihydroxydiphenylmethane (DHDPM) were obtained from Tokyo Kasei Kogyo Co. Ltd. The PF resin was an acid catalysed novolac resin which was commercially manufactured.

^1H NMR

All spectra were recorded in deuteromethanol on a Bruker AM-100 Fourier transform spectrometer equipped with an Aspect 3000 computer and operating at 100 MHz ^1H frequency. ^1H NMR spectra were collected on dilute solutions (10-30 mg/mL) employing a 30° pulse width and 4K data points to collect 64 scans. A solvent suppression technique was utilised to remove the signal due to absorbed water in the deuteromethanol solvent. All chemical shift data are reported downfield from internal tetramethylsilane. The number average molecular weight of each sample was calculated from the proton integration data using Woodbrey's equations. For the calculations, the average values obtained from four integrations were employed (Table 1) with the areas over the aromatic protons normalized to 12.00 and 8.00 for the resin and model compounds, respectively.

RESULTS AND DISCUSSION

The ^1H NMR spectra of the model compounds 2,2'-DHDPM and 2,4'-DHDPM and the novolac PF resin together with their molecular structures are shown in Fig 1. Signal assignments were based on established chemical shift tables and on Woodbrey's

assignments (Table 1). All the necessary data required to calculate the $\overline{M}n$ of the resin was obtained from the integration of the signal areas in the ^1H NMR spectra (Table 1).

Based on the integration of each signal area in the ^1H NMR spectrum the following information is obtained:

i) Relative numbers of aromatic ring protons, Ar$\underline{H}$, (A_2);

ii) Relative numbers of methylene protons in diphenylmethane type groups, Ar C$\underline{H}_2$ Ar, (A_3).

The relative number of phenolic hydroxy protons, Ar O$\underline{H}$ (A_1) cannot be measured experimentally, because of chemical exchange with other hydroxyl protons. However, the value of A_1 is readily calculated from other experimental integrals:

$$A_1 = \frac{1}{5}(A_2 + A_3). \qquad \textbf{Eqn 1}$$

According to Woodbrey *et al*, the number average molecular weight ($\overline{M}n$) can be calculated by the following equation;

$$\overline{M}n = \overline{n}\,[89 + R_A + 14R_{MB}] \qquad \textbf{Eqn 2}$$

where R_A and R_{MB} are the average numbers of aromatic ring protons and methylene bridge groups per aromatic ring, respectively. These parameters are calculated from the above integrals:

i) $$R_A = \frac{A_2}{A_1} \qquad \textbf{Eqn 3}$$

ii) $$R_{MB} = \frac{A_3}{2A_1} \qquad \textbf{Eqn 4}$$

Since methylene groups contain two protons, the average number of methylene bridge groups per aromatic ring can be obtained by dividing A_3 by $2A_1$.

The average number of aromatic rings per molecule, $\overline{n}$, may be calculated from:

$$\overline{n} = (1 - R_{MB})^{-1} \qquad \text{Eqn 5}$$

Since the figure of 89 is the molecular weight of the phenol ring without its 5 ring protons, and the figure of 14 is the molecular weight of one methylene bridge unit ($-CH_2-$) the $\overline{M}n$ of the PF resin can be simply calculated by multiplying the molecular weight per aromatic ring (in brackets) by the average number of aromatic rings per molecule, $\overline{n}$, as shown in Equation 2.

Since the NMR signals of the novolac PF resin (Fig. 1C) are noticeably broader than those of the model compounds (Figs. 1A and 1B), it should be noted that the accuracy of the molecular weight calculation is dependent upon the subjective selection of the integration limits. However, since the calculated $\overline{M}n$ values of the model compounds (205.6 and 197.7 for 2,2'- and 2,4'-DHDPM respectively) are very close to the theoretical value (200.24) and the equations for $\overline{M}n$ calculation are less complex for a novolac than for a resol PF resin, the $\overline{M}n$ value (540) would be a representative value for this novolac PF resin.

CONCLUSION

Following previous work on a resole type PF resin, the applicability of ^1H NMR to the molecular weight determination of a novolac type PF resin has been demonstrated in this study. In order to confirm the result obtained from this study, further work using GPC and VPO is being undertaken.

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Table 1. ^{1}H NMR chemical shift and integral data for a novolac type PF resin and model PF compounds

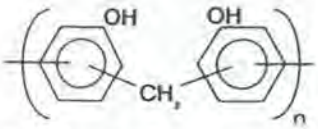
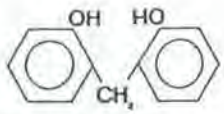
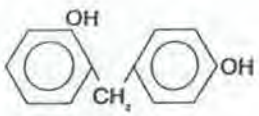
Structure	Assignment	Chemical Shift (ppm)	Integration	Parameter
	-C<u>H</u>$_2$-	3.5 - 4.15	5.74	A_3
	Ar<u>H</u>	6.5 - 7.3 ppm	12.00	A_2
Novolac resin	Ar<u>O</u>H	-	3.55 (calc.)	A_1
	-C<u>H</u>$_2$-	3.87	2.014	A_3
	Ar<u>H</u>	6.6 - 7.1	8.00	A_2
2,2'-DHDPM	Ar<u>O</u>H	-	2.06 (calc.)	A_1
	-C<u>H</u>$_2$-	3.87	1.99	A_3
	Ar<u>H</u>	6.6 - 7.1	8.00	A_2
2.4'-DHDPM	Ar<u>O</u>H	-	2.11 (calc.)	A_1

Table 2. Number average molecular weights for novolac type PF resin and model PF compounds

Parameter	Equation	Novolac	2,2'-DHDPM	2,4'-DHDPM
R_A	$\frac{A_2}{A_1}$	3.38	3.97	4.02
R_{MB}	$\frac{A_3}{2A_1}$	0.808	0.512	0.493
$\bar{n}$	$(1-R_{MB})^{-1}$	5.211	2.05	1.98
$\overline{Mn}$	$\bar{n}[89 + R_A + 14\ (R_{MB})]$	540.3	205.6	197.7

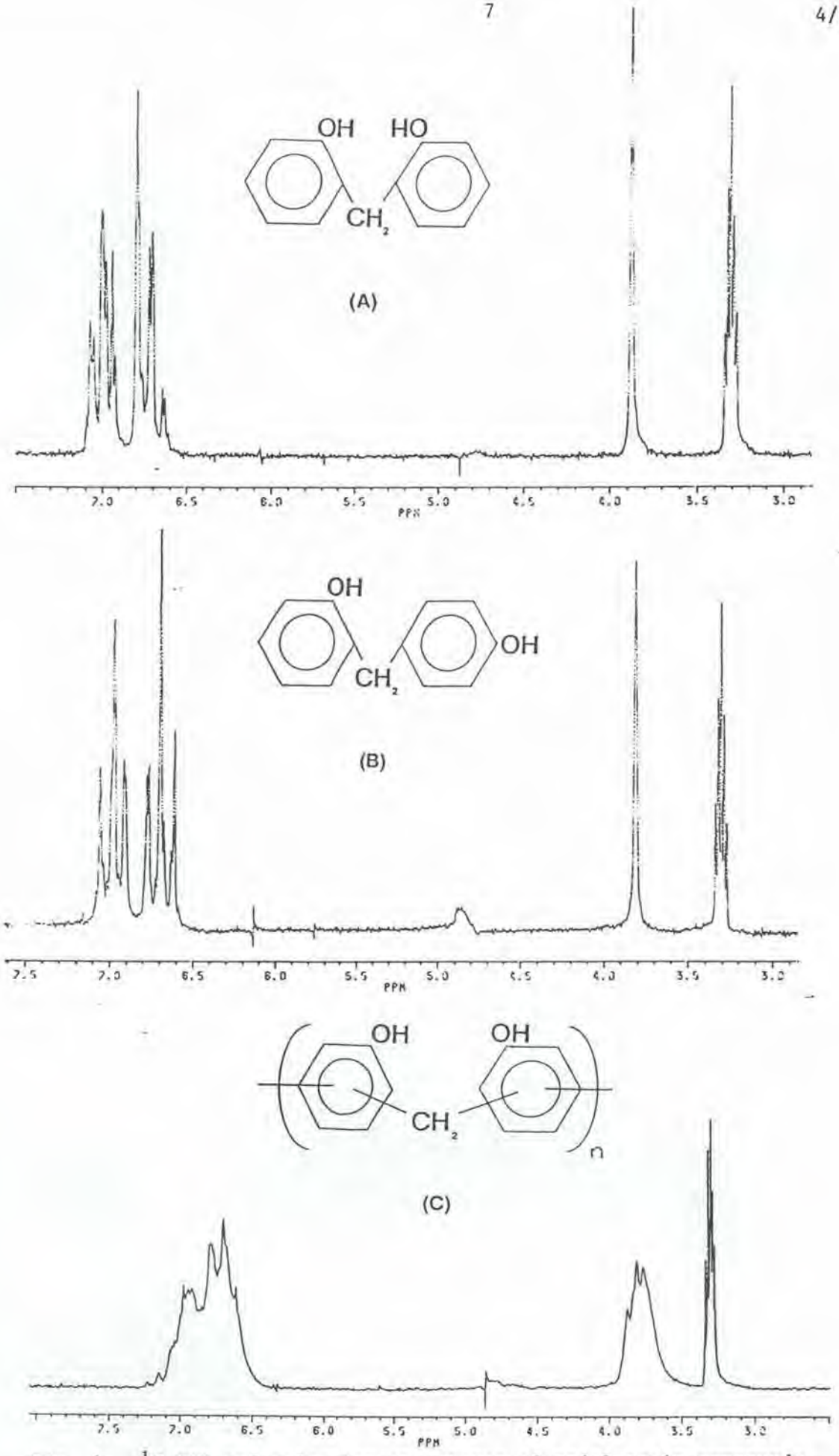


Fig. 1. ^{1}H-NMR and molecular structures of model resin compounds (A) 2,2'-DHDPM (B) 2,4'-DHDPM and (C) a general novolac resin.

MOLECULAR WEIGHT DISTRIBUTION OF PHENOLIC RESINS DETERMINED BY DIFFERENT GPC TECHNIQUES

S.D. Terrill and Y. Yazaki
CSIRO Division of Forest Products
Private Bag 10, Rosebank MDC, Clayton, Victoria 3169, Australia

ABSTRACT

Phenol formaldehyde (PF) resins were analyzed by gel permeation chromatography (GPC) using styrene-divinylbenzene copolymer columns with tetrahydrofuran (THF) solvent. Prior to analysis, the PF resins were either conventionally acetylated or treated with an ion-exchange resin to become soluble in THF.

The number average ($\overline{M}n$) and weight average ($\overline{M}w$) molecular weights of the ion-exchange treated resins were very low compared to those of the acetylated resins which were generally accepted as being representative of molecular weights of PF resins. The values obtained are discussed in conjunction with results obtained from a previous study using vapour pressure osmometry and nucler magnetic resonance spectroscopy.

Since highly polymerized sodium-free PF resin components are insoluble in THF, the GPC method combined with the ion exchange treatment is useful only for low molecular weight PF resins. For highly polymerized PF resins alternative methods need to be developed.

INTRODUCTION

Phenol-formaldehyde (PF) resins are widely regarded as producing the most durable bonding for reconstituted wood products suitable for use in all structural applications [1]. Plywood and LVL bonded with PF adhesives are examples of such structural bonded products. For these products, producing satisfactory bonds depends on how well the PF resin is distributed and cured within the glue joint. The assessment of bond failures has shown that the majority of these failures have been due to over-penetration of the resin into the wood, or dryout of the resin on the wood surface [2,3].

Studies on the viscosity of PF resins determined at high temperatures, show an initial rapid reduction in viscosity and then with temperature and time viscosity rises

dramatically, at an exponential rate. This study would indicate that in a glueline during hot pressing, the resin would experience increased flow behaviour between the wood surfaces and within the wood then as crosslinking reactions occur the resin flow would decrease until at gelation and cure it finally stops.

These properties of resin viscosity and curing are the end results of condensation and polymerization reactions of PF resins. In particular, the levels of viscosity and, subsequent flow characteristics can be quite dependent on the molecular weight distribution (MWD) of the resin. Therefore, the MWD of PF resins is one of the most important parameters for designing wood adhesives that are capable of high quality bonding.

The MWD can be determined by the technique of gel permeation chromatography (GPC) which separates PF resin components according to their molecular sizes. However, current GPC methods of measuring MWD of PF resins are complicated and time consuming [4].

The common GPC system for PF resins consists of a combination of Styragel separation columns and tetrahydrofuran (THF) solvent mobile phase [5]. Phenolic resins (resoles) are highly alkaline and are not soluble in THF and therefore need to be acetylated. Furthermore it is also known that PF resins treated with an ion-exchange resin became soluble in THF and could be analysed by GPC with THF [6].

This paper shows that there is a large difference between MWD of acetylated and ion exchange treated PF samples.

GPC - An Outline

The function of a gel permeation chromatograph is to efficiently separate a resin into its molecular size components by passing the dissolved sample through a column packed with a porous gel. As the mobile phase flows through the packed column the small molecules penetrate more deeply into the pores of the packing (solid phase) than the large molecules. Consequently, the larger molecules emerge from the column first followed by the smaller molecules.

By this process, size fractions can be distinctly separated within a reasonable time interval before passing through a detector and recorded as a collection of peaks on a chromatogram. The retention time and concentration data is then read into a computer

program and molecular weights are calculated using a calibration equation derived from GPC of known molecular weight standards. From this a MWD curve is plotted and the number average ($\overline{M}n$) and weight average ($\overline{M}w$) molecular weights and the dispersity (D = $\overline{M}w/\overline{M}n$) can be calculated. Thus, the MWD of PF resins can be expressed with these parameters.

MATERIALS AND METHODS

Phenol-Formaldehyde Resins

The PF resins analysed in this study were NaOH catalyzed resoles, which were commercially manufactured for plywood. Since resoles are not soluble in THF, they were firstly freeze-dried and then either acetylated with pyridine/acetic anhydride or treated with Amberlite IR-120 (H-form). The acetylated and ion-exchange treated (sodium-free) resins were obtained in powder form after freeze-drying. The details of the acetylation and ion-exchange treatment has been described previously [7].

GPC Analysis

GPC of acetylated, and ion-exchange treated resins was carried out using a Waters instrument comprising Waters Wisp 710B autosampler, Waters 590 programmable HPLC pump and Waters 481 UV detector fitted with a series of Shodex columns (300 mm x 8 mm ID) packed with styrene-divinylbenzene copolymers. The column series consisted of Shodex KF800p (guard column), KF 803, KF 802.5 and KF 802 with exclusion limits 7×10^4, 2×10^4 and 5×10^3 Dalton respectively for polystyrene. THF degassed by continuous helium sparging, was used as the mobile phase. A sample (5 mg) of freeze-dried acetylated or sodium-free PF resin was dissolved in THF (5 ml) and Toluene (1 µL) was added as an internal standard. An aliquot (50 µL) of the sample solution was injected, eluted with THF at a flow rate of 1 ml/min and UV absorption was detected at 280 nm. Polystyrene standards of nominal molecular weights, 100000, 9000, 2000 and 580 were used for calibration. Data acquisition was made using a Spectra Physics 4100 integrator and GPC analysis using PC with GPC software (© CSIRO).

RESULTS AND DISCUSSION

The MWD curves of the acetylated and ion-exchange treated PF resins are shown in Figs. 1 to 4 and the average molecular weights ($\overline{M}n$ and $\overline{M}w$) of these PF resins are given in Table 1. The $\overline{M}n$ and $\overline{M}w$ of the acetylated PF resins are very similar to those of PF resins determined by other workers [4,8] which have been regarded as representative of molecular weights of PF resins. On the other hand, the $\overline{M}n$ and $\overline{M}w$ of the ion-exchange treated PF resins were much lower than those estimated from the acetylated resins.

Wellons and Gollob [4] observed very similar phenomena and pointed out that more work is needed to determine how acetylation modifies MWD and if acetylated polymer chromatographs are free of any association effects. Furthermore, Reidl [9] pointed out that results reported so far may not be representative of true molecular weight.

The previous study [7] showed that the number average molecular weight ($\overline{M}n$) of an ion-exchange treated PF resin agreed well with those determined by vapour pressure osmometry and ^1H NMR, then concluded that the $\overline{M}n$ of the ion-exchange treated PF resin may be close to true molecular weight. The number average ($\overline{M}n$) and the weight average ($\overline{M}w$) molecular weights were much lower than those estimated from the acetylated resin (Table 1) and were similar to VPO measured values [7].

However it was found that highly polymerized PF components become insoluble in THF after ion-exchange treatment. Consequently, the GPC technique combined with ion exchange treatment can be effectively applied to low molecular weight PF resins. Alternative methods need to be developed for higher molecular weight PF resins.

CONCLUSIONS

The molecular weights of ion-exchange treated sodium-free PF resins were determined by GPC and the $\overline{M}n$ and $\overline{M}w$ values of the resins were found to be much less than those estimated from their acetates. These results are very similar to those previously determined using vapour pressure osmometry and ^1H-NMR which may be close to true molecular weights of PF resins.

However, this GPC method combined with the ion-exchange treatment is very effective only for lower molecular weight PF resins. Alternative GPC methods need to be developed for high molecular weight resins.

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Table 1
Molecular Weights of PF Resins

PF Resin	$\overline{M}n$	$\overline{M}w$	D
Acetate A	3886	43385	11.16
Ion-exchange treated A	430	562	1.31
Acetate B	3416	34033	9.96
Ion-exchange treated B	318	367	1.16

FIGURE CAPTIONS

Figure 1. Molecular Weight Distribution of acetylated PF resin A.

Figure 2. Molecular Weight Distribution of ion-exchange treated PF resin A.

Figure 3. Molecular Weight Distribution of acetylated PF resin B.

Figure 4. Molecular Weight Distribution of ion-exchange treated PF resin B.

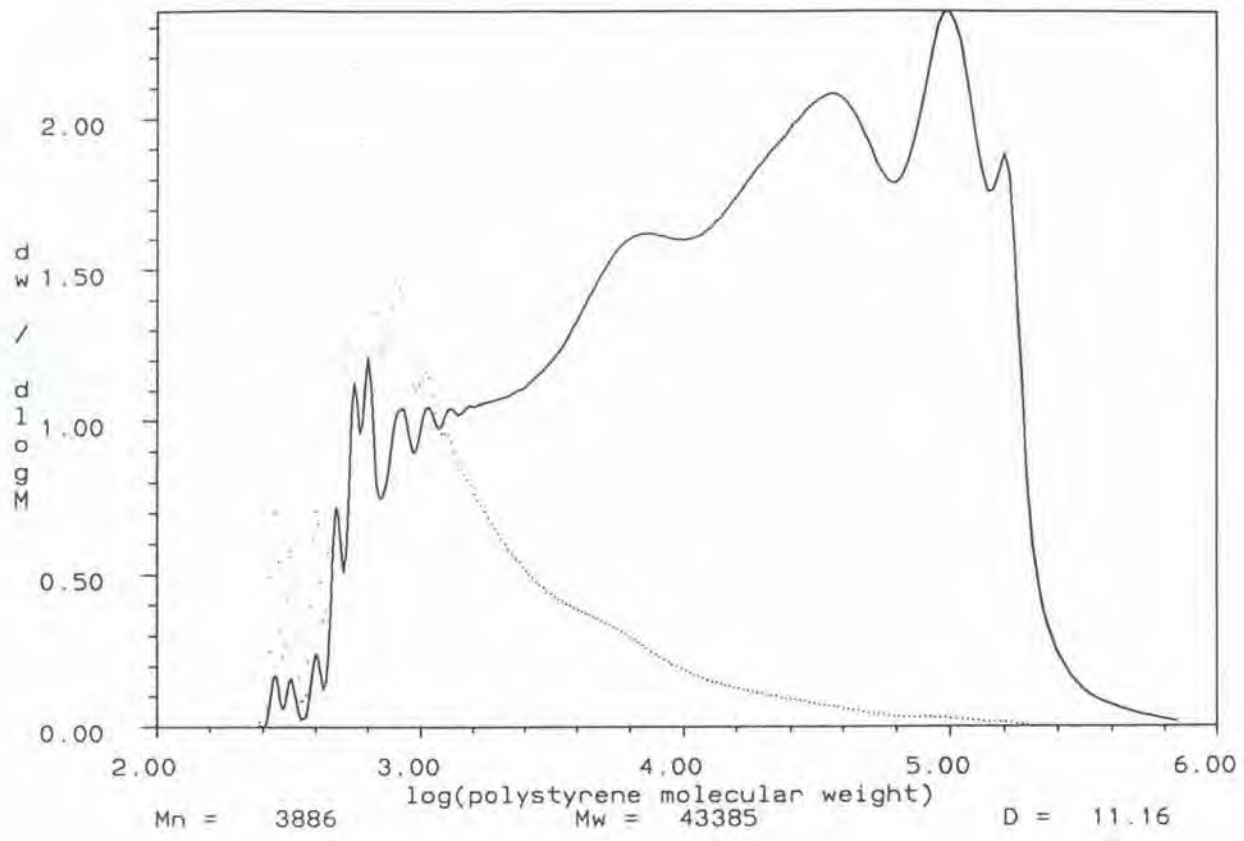

Figure 1. Molecular Weight Distribution of acetylated PF resin A

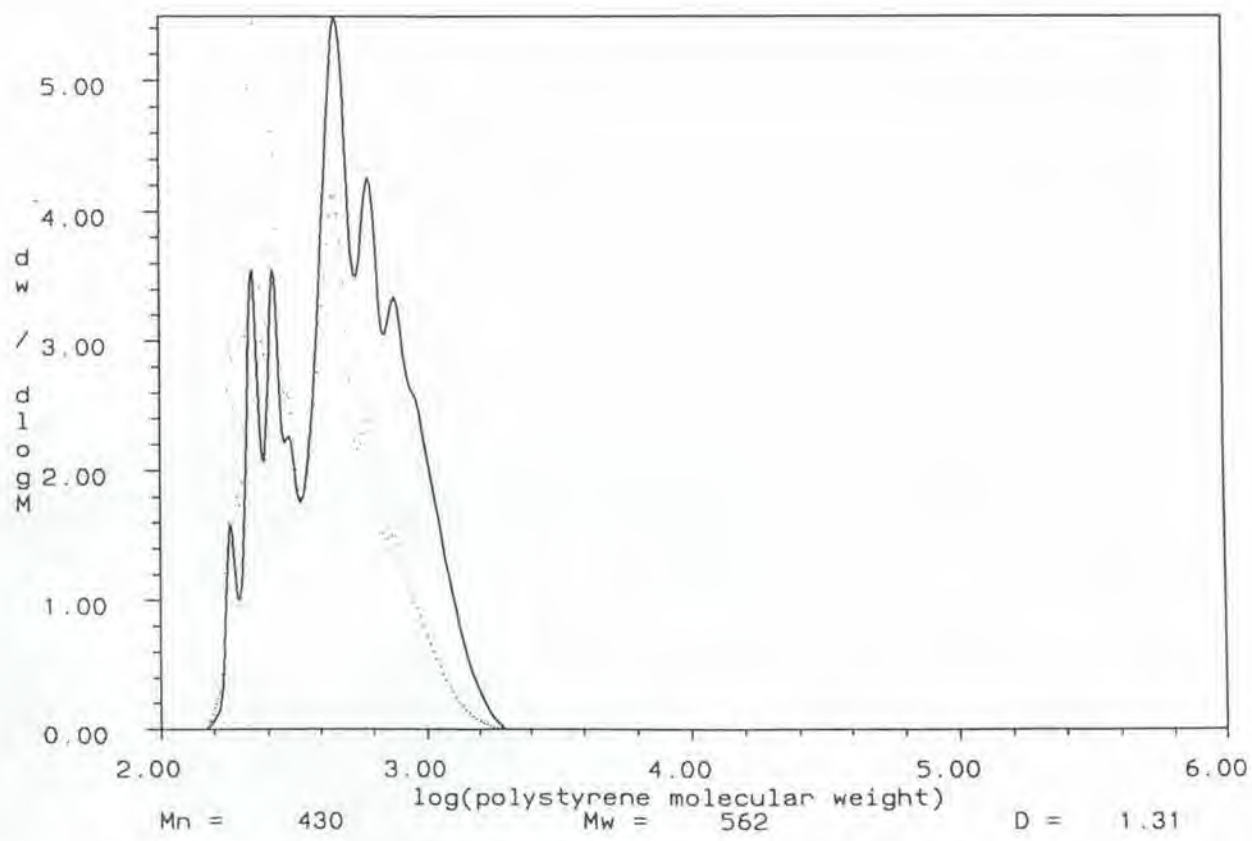

Figure 2. Molecular Weight Distribution of ion-exchange treated PF resin A

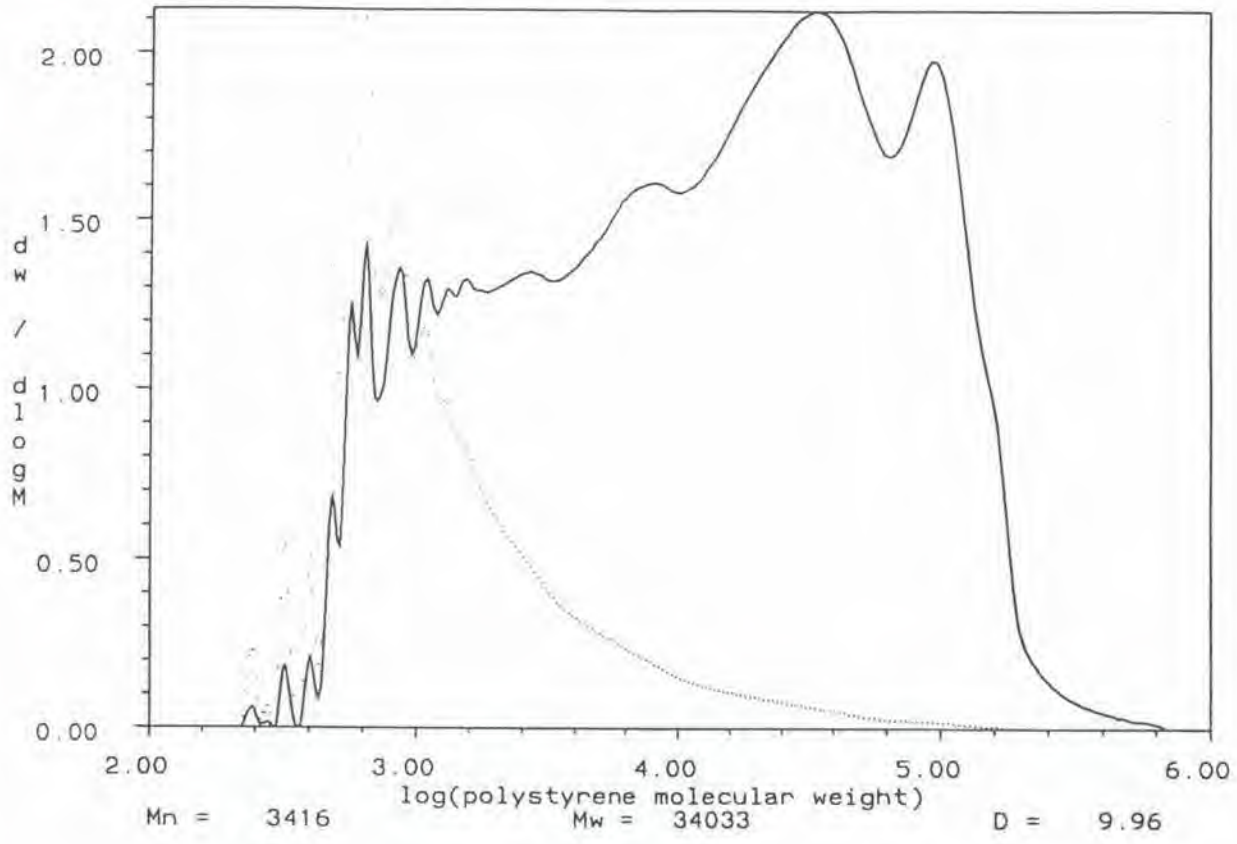

Figure 3. Molecular Weight Distribution of acetylated PF resin B

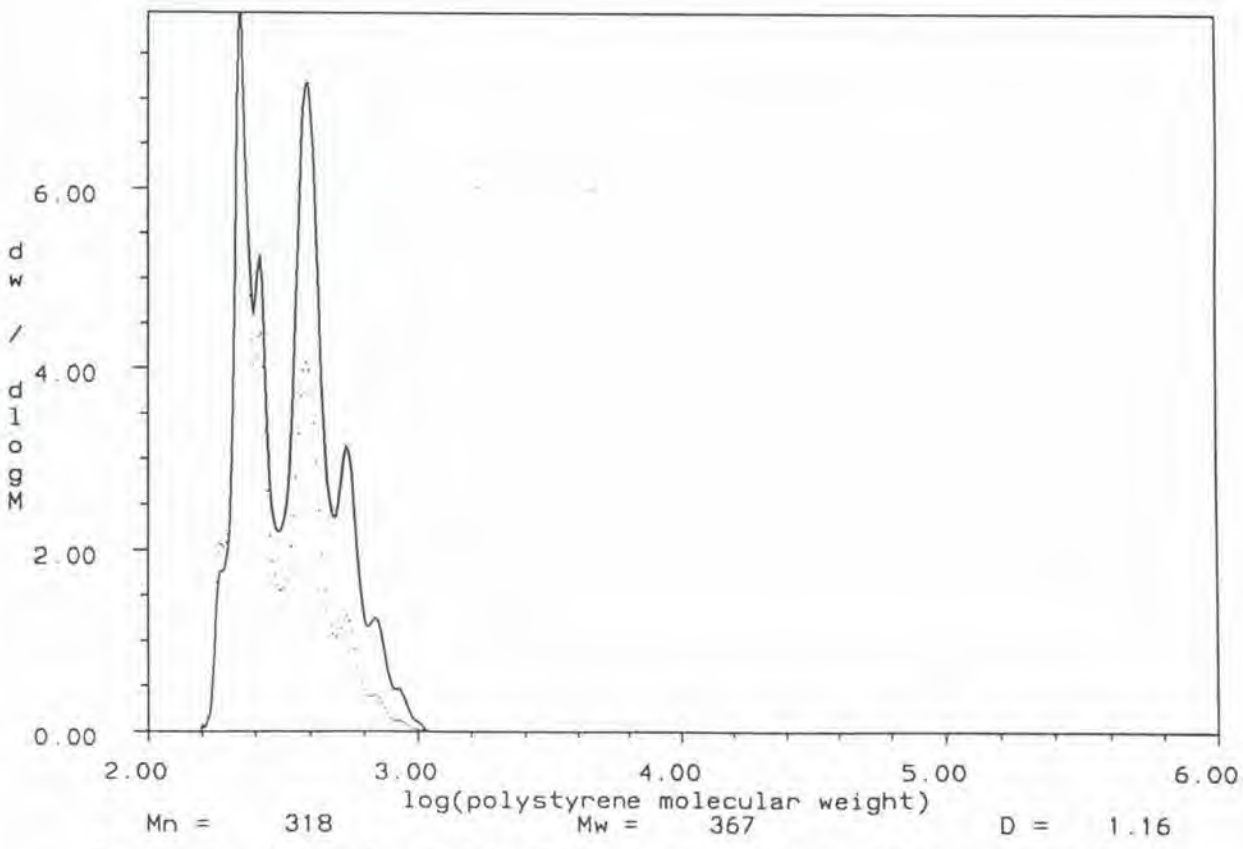

Figure 4. Molecular Weight Distribution of ion-exchange treated PF resin B.

CAN WE MAKE UNIVERSAL TYPE WOOD ADHESIVES?

Y. Yazaki

CSIRO Division of Forest Products
Private Bag 10, Rosebank MDC, Clayton, Victoria 3169, Australia

ABSTRACT

No universal wood adhesives exist at present. Characteristics of typical wood adhesives being used in the Australian reconstituted wood industry have been briefly described. Since PF adhesives are regarded as those which can provide the most durable and high quality wood bonding, PF adhesives should be considered as a basis for universal type wood adhesives.

Recent developments in PF wood adhesives and adhesion technology at CSIRO have been briefly reviewed and a possibility in developing universal type adhesives through the "molecular designing" concept has been outlined, where the molecular characterization of PF resins by NMR and GPC and the establishment of a computer-assisted data base play an important role.

INTRODUCTION

With growing concern about global ecological changes and environmental problems, future emphasis will be on more effective use of forest resources. In this situation, wood adhesives will play an important role and more cost effective and environmentally acceptable wood adhesives as well as new gluing technology will be required.

Since the Wood Adhesives Group was formed at CSIRO, Division of Forest Products in 1988, the Group has been deeply involved in developing more efficient wood adhesive systems in collaboration with a commercial adhesives manufacturing company as well as the Plywood Association of Australia. Projects are related to the development of wood adhesives for gluing of high density and "difficult to glue" wood species such as blackbutt (*Eucalyptus pilularis*), the gluing at higher wood moisture content and the development of fast-curing PF adhesives for plywood and LVL. The efficient development of these adhesives has been accomplished due to a special "molecular designing" concept which has been described previously (1). This concept was initially generated after the overseas study tours to USA and Canada in 1990 (2) and the validity of this concept was confirmed when we visited to Japan (3) and USA in 1991 (4).

There are neither universal type wood adhesives which can glue any wood species covering from softwoods to hardwoods nor any wood adhesives for gluing over a wide range of wood moisture content, e.g. 0-25% even in one single wood species. This means that the performance of wood adhesives is still insufficient for negating the effect of gluing variables derived from wood properties such as wood density, moisture content, extractives and anatomical features on gluebond quality. However, CSIRO believes that

the extension of the "molecular designing" concept will lead to the development of universal type wood adhesives in the near future.

A BASIS OF UNIVERSAL TYPE WOOD ADHESIVES

Australia produces more than one million m^3 of reconstituted wood products (Table 1) using more than 50,000 tonnes of a range of wood adhesives such as phenol- (PF), resorcinol- (RF), tannin- (TF), melamine- (MF) and urea-formaldehyde (UF) (Table 2).

The durability of wood adhesives have been studied for a long time and the most comprehensive study has been carried out at the Princes Risborough Laboratories, England (5,6). According to the Australian Plywood Bond Type Classification (7), those gluelines bonded with synthetic phenolic PF, RF and PRF and natural TF adhesives are classified as Type A which can pass a 72-hour boil test and are most suitable for external and structural applications. On the other hand, MF, MUF and UF adhesives are far less durable than phenolic adhesives and in particular the application of UF adhesives is restricted to interior, fully protected and non-structural purposes.

The details of classification and glueline durability of wood adhesives have been summarized previously (1). This grading of wood adhesives depending on their chemical types has been generally accepted in other reconstituted wood products (6).

Advantages of using UF adhesives are low cost and the abilities to cure quickly at lower temperatures and to tolerate relatively wider gluing conditions. However, since the durability of the glueline bonded with these UF adhesives is very low, UF wood adhesives in Australia are being used in the manufacture of particleboard and MDF for furniture or interior and non-structural applications. Although MF and MUF wood adhesives have not much advantage in their costs compared with PF adhesives, the curing speed and the tolerance against gluing variables are better than PF wood adhesives. The durability of the glueline bonded with MF and MUF is classified as Type B which meets a 6-hour boil test, instead of 72-hour for PF adhesives, and is used as structural wood panels where exposure to weather will be 2 years maximum, instead of 50 years and more for PF adhesives.

Recently, isocyanate and epoxy type adhesives have been becoming popular for wood adhesives in overseas such as USA, Canada and Japan. However, these adhesives lack the experimental data particularly on the long term durability tests and are inferior to PF adhesives in water resistance.

Since formaldehyde has a pungent odour and causes health problems such as eye irritation and respiratory discomfort, the release of formaldehyde from reconstituted wood products has been becoming a very important problem. It has been mentioned that reconstituted wood products bonded with UF adhesives release significant amounts of formaldehyde whilst the release of free formaldehyde from those products bonded with PF adhesives is almost negligible (8).

Consequently, when universal type wood adhesives are sought, phenolic based wood adhesives should be considered. However, problems of the PF adhesives relating to slow-curing and relatively restricted tolerance against gluing variables should be solved.

RECENT DEVELOPMENTS IN PF WOOD ADHESIVES AT CSIRO

Gluing of high density "difficult to glue" wood species

In 1982, the declaration of large national parks locked up most timber resources from the rain forests in Australia. Differing from the rain forest wood species, blackbutt (*Eucalyptus pilularis*) is available as a substitute wood resource but known as a high density "difficult to glue" wood species (9). Hot water extractives from blackbutt wood affected gelation time of a PF resin resulting in inferior bonding quality of the plywood (10). A further study revealed that wood density and extractives content of blackbutt wood varied from log to log (11). However, since hot water extractives were identified as ellagitannins (10), a new PF adhesive system to negate the effect of extractives in blackbutt gluing has been developed (12) and further improved.

Gluing at higher wood moisture content

Using PF adhesives the veneer moisture content is usually less than 5% in the manufacture of radiata pine plywood. If the gluing at 12% veneer moisture content is successful, nearly 40% savings in drying cost can be obtainable (13). Furthermore, since pine species have been difficult to dry uniformly, the gluing at higher veneer moisture content provides a great benefit to tolerate wet and dry patches in pine veneers. During the development of high density wood gluing technology, a new interpretation of the adhesive curing mechanisms in the glueline was introduced. According to this interpretation, the PF adhesive formulation for the high density blackbutt gluing should be applicable for gluing of radiata pine veneer at 12% moisture content. Based on this, a simple and novel adhesion system has been developed and is capable of manufacturing radiata pine plywood at least 12% average veneer moisture content.

Fast-curing PF adhesives

Since significant reduction in hot pressing time for plywood and LVL can result in significant savings for manufacturers, the development of PF adhesive systems for fast-curing is of the highest priority. Reduction in press time may be achieved by the use of more advanced resins, higher platen temperature, resin with higher formaldehyde to phenol ratios, use of catalysts or combinations of all those.

CSIRO has developed this fast-curing PF resin system which significantly reduces hot pressing time. For example, the laboratory experiments using the CSIRO fast-curing PF system revealed that LVL consisting of 21-ply 3 mm radiata pine veneers, 63 mm thickness were successfully produced by hot pressing at 185°C for less than 40 minutes, instead of up to 47 minutes in conventional PF systems.

The first plywood factory trial was carried out using the CSIRO PF system in 1991 and demonstrated that the system was able to cure in 8 minutes or less, instead of up to 11 minutes with conventional PF systems. This CSIRO PF adhesive system has been commercialized.

MOLECULAR CHARACTERIZATION OF PF RESINS

During the development of these PF systems as mentioned above, it has been noticed that specific PF resins and adhesive formulations were required for these different applications. However, using conventional parameters such as gelation time, viscosity, total solids and etc., these PF resins were sometimes indistinguishable. CSIRO has been working on the establishment of more detailed characterization methods called "molecular characterization" particularly using NMR and GPC. The outlines of these methods have been described previously (1, 14, 15).

However, it should be mentioned that although molecular characterization using NMR and GPC is believed to have been established, it is not true. There is neither an established GPC method available for determining the molecular weight distribution of PF resins nor detailed information particularly on quantified molecular species of PF resins from an established NMR method.

Consequently, it is essential to improve these existing NMR and GPC methods in order to obtain more detailed information on PF resins. CSIRO has been working on these NMR and GPC methods and some of the results and problems are presented in this conference (16, 17).

The information obtained from NMR and GPC allows us to describe PF resins in terms of the quantified molecular structural characteristics and molecular weight distribution. We believe that strong correlations exist between their molecular characteristics and specific gluing functions such as abilities to glue high density wood species, fast-curing and wider moisture content tolerance.

A DATA BASE ON WOOD ADHESIVES AND GLUING

Contrary to the fact that only low density, easy to glue and relatively uniform quality wood species such as Douglas-fir, hemlock, spruce, poplar and southern pine have been used in the North American reconstituted wood industry, in Australia there are many varieties of wood species from softwoods to hardwoods, whose densities may range to near double those of species available in North America and which may contain very large quantities of differing types of extractives. These variable factors have potentially enormous effects on gluebond quality. Therefore, our wood adhesives research at CSIRO has not been able to be carried out without having a great understanding of woods. Consequently, enormous amounts of data and experience on wood substrates relating to wood adhesion and on gluing conditions have been accumulated since CSIRO, Division of Forest Products became actively involved in wood adhesion in the 1950s.

Furthermore, the Australian situation in the reconstituted wood industry is in a unique position, in that overseas technology is not always applicable for manufacturing our reconstituted wood products. This is mainly due to different wood species, and different climatic and mill situations. CSIRO and Australian industry have been developing several systems specifically applicable for the Australian conditions. In other words, an accumulation of empirical methods has also become the basis for current industrial practice in Australia.

Based on these empirical methods, the possibility exists for the establishment of a computer-assisted data base. This data base consists of the information on wood species and characteristics, conventional resin characteristics, gluing parameters and molecular characteristics of resins. The details of this data base are presented as a poster paper in this Conference (18).

The information on wood species and characteristics includes density, moisture content, extractives type and content and characteristic anatomical features of wood substrates to be glued. Conventional resin characteristics include total solids content, viscosity, gelation time, alkalinity, free formaldehyde content and so on. Gluing parameters are based on such gluing conditions as glue formulation, glue spread, conditions of pressing time and temperature, open and closed assembly times and also include bonding quality of the products. Furthermore, this data base includes information on chemical characteristics of resins obtained from both NMR and GPC analyses, which can characterize the resins in such molecular terms as chemical structure, species, methylol content, degree of polymerization, F:P ratio and the molecular weight distribution of the resin.

Since our Wood Adhesive Group was formed at the Division, 22 successful gluing examples have been accumulated. These 22 successful examples cover gluing of high density wood species, fast-curing gluing and gluing at higher wood moisture contents of both plywood and LVL and finger-jointing. Based on these examples, the establishment of a data base containing more than 70 parameters relating to successful wood gluing has been in progress. This computer-assisted data base will play an important role in the development of universal type wood adhesives in the near future.

APPROACH TO UNIVERSAL TYPE PF WOOD ADHESIVES

In the actual mill situation, wood species and gluing conditions are rather limited. When wood species and a range of gluing conditions are known, it is much easier to prepare suitable PF resins for obtaining high bond quality, compared with preparing universal resins which can glue under any conditions. CSIRO and the PAA laboratories have established that "glue-flow" in the glueline at the time of hot pressing is one of the most important parameters to be monitored for optimizing gluebond quality.

The majority of bond failures have been due to either over-penetration or dryout of wood adhesives. The cause of this type of failure is related to "glue-flow". In the case of over-penetration bonds, the "glue-flow" is excessive, whereas the reverse is the case for a dryout. The "glue-flow" is directly proportional to glueline moisture content at the time

of hot pressing. The glueline moisture content can be controlled to a certain degree by adjusting gluing conditions such as veneer moisture content, glue formulation, glue spread, open and closed assembly times and so on.

Due to the establishment of PF resin characterization by NMR and GPC, PF resins are now being characterized in such molecular terms as the molecular weight distribution, methylol content, degree of polymerization and F:P ratio. Furthermore, the "glue-flow" may be correlated to the resin characteristics which are defined in the molecular terms of resins.

The molecular data obtained are fed into the data base mentioned previously so that manipulation of the data base can allow us to model new adhesives by molecular designing. This approach can lead to the synthesis of PF resins with certain specific functions. These specific gluing functions may be designed for fast-curing, high moisture content tolerance, high density wood, high extractives content, variable wood porosity and so on.

Through the accumulation and expansion of the data base coupled with PF resin synthesis of desired characteristics, we will be able to make more universal type wood adhesives.

Based on the "molecular designing" concept, the first generation universal type PF resins have been successfully synthesized and the elucidation of the chemical mechanisms for synthesis of these universal type PF resins has been in progress. Some gluing properties of these universal type PF wood adhesives are presented in this conference (19).

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Table 1. Australian wood-based panels production (x1000 m^3)

	1980	1985	1990
Wood-based panels	847	899	1023
Plywood, LVL	87	89	125
Particleboard	622	675	743
Fibreboard	110	106	126
Others	28	29	29

(FAO 1990)

Table 2. Wood adhesives market in Australia (1990)

	Consumption (ton)	A$/Dry ton	Market (A$M)
PF	3,500	1650	5.8
UF	35,000	600	21.0
MF/MUF	10,000	1400	14.0
RF	300	11000	3.3
TANNIN	7,000	1100	7.7
Total	**55,800**		**51.8**

DEVELOPMENT AND PROPERTIES OF UNIVERSAL TYPE PHENOLIC RESINS

P.J. Collins
CSIRO Division of Forest Products
Clayton, Victoria 3168, Australia

ABSTRACT

A new generation of universal type phenolformaldehyde resins have been synthesised in both laboratory and commercial quantities.

Trials indicate that these resins are expected to compete very favourably with existing phenolics and other formaldehyde based resins of lower durbility classes.

Extensive use has been made of Nuclear Magnetic Spectroscopy (NMR), Gel Permeation Chromatography (GPC), Differential Scanning Calorimetry (DSC) and traditional parameters in the development of universal type phenolics. These resins offer enhanced properties for use in a very wide range of reconstituted wood products.

INTRODUCTION

The use of reconstituted wood products such as laminated veneer lumber (LVL), laminated timber, plywood, medium density fibreboard (MDF), particleboard and their combinations offers the means to more efficiently utilize forest resources. However, the viability of all these reconstituted wood products is dependent on the use of suitable adhesives. For this reason the Wood Adhesives Group at CSIRO, Division of Forest Products in collaboration with an adhesives manufacturing company has been developing adhesives that are capable of successfully bonding a wide range of reconstituted wood products over a very wide range of gluing conditions. Presently all these adhesives are based on phenols and formaldehyde (phenolics), because they are the only fully structural adhesives capable of performing under all climatic conditions (1).

This paper reviews the development and properties of universal type phenolic adhesives developed at CSIRO. However, because of commercial restraints detailed information on resin synthesis technology cannot be given in this paper.

Phenolic resins

Conventional phenolic resins for use in the manufacture of most reconstituted wood products are known as resoles and are usually prepared by reacting a phenol with formaldehyde in the presence of an alkaline catalyst such as sodium hydroxide or potassium hydroxide. The molar ratio of formaldehyde to phenol (F/P ratio) used is typically from about 1.6 to 2.4. This reaction especially during its initial stages is highly exothermic requiring precise control over the reaction temperature. This initial condensation reaction, the substitution of up to three formaldehyde molecules at either the 2, 4 or 6 position on the phenolic ring is influenced particularly by formaldehyde ratio but also catalyst type and concentration. Various methods are used to control this exothermic reaction. For example, some or all of the formaldehyde and/or the alkali catalyst may be added to the phenol at the beginning of the reaction, with the remainder being introduced portionwise or at a controlled rate. The viscosity of the reaction mixture rises as the reaction proceeds, due to the formation of phenolformaldehyde polymers due to reaction between methylol groups and unsubstituted positions of phenol with the formation of methylene bridges between phenolic nuclei. This mechanism is responsible for an ever increasing resin molecular weight and consequential increase in resin viscosity as the reaction progresses. Viscosity is carefully monitored and is usually used to determine when further addition of formaldehyde or catalyst, or both should be made.

The reaction is continued after the addition of all reactants until the desired final end point viscosity is achieved to yield resins termed resoles. These resoles are hardened by the application of heat and pressure forming very highly crosslinked thermoset materials. In this form they have negligible creep, are completely insoluble in most solvents, no longer flow or melt under the further application of heat but very importantly are incapable of being hydrolysed by water as is the case with other commonly used formaldehyde resins such as those based on urea (UF), melamine (MF) or their combinations (MUFS).

A typical resin suitable for plywood or LVL gluing may consist of a water soluble solution of 40-42% solids content, viscosity 200-400 mPa.s, alkalic content 4-8% and a typical formaldehyde to phenol mole ratio of 1.7-2.4:1. The time to double viscosity when stored at 25° varies between a few days to 6 to 8 weeks. A resin that has doubled viscosity is considered to be no longer useable. Stability is influenced by initial formaldehyde mole ratio final free formaldehyde content and also by the use of stabilizers such for example as polyamines (2) and alkali content.

Development of universal type phenolic resins

Traditional phenolic resins have either been quite limited in their allowable gluing conditions, suffered from storage instability, required complicated and sometimes dangerous mixing procedures in the reconstituted users factory or were quite intolerant of varying wood moisture contents especially at moisture contents greater than about 8%.

Furthermore, it should be noted that resin technology that is appropriate for other countries such as the USA is not necessarily applicable for use in Australia. This is because of vast transport distances often under extreme temperatures to reconstituted wood factories scattered relatively thinly throughout Australia, lower rates of usage and consequently the need for longer storage stability, differing species and a range of wood densities ranging from medium to high.

Detailed studies of many experimental and commercial resins of the traditional type using such techniques as NMR, GPC, DSC, coupled with storage stability, gelation time, alkalinity, viscosity, solids content and their gluing behaviours have provided an insight into how such parameters as variation in the substitution pattern of the phenolic nuclei, molecular weight distribution, formaldehyde to phenol molar ratio etc. could be used to expand the range of conditions over which phenolic resins could be made to perform satisfactorily. For example these universal type resin are aimed at covering such variables as wood moisture content variations and its upper limits, extent of filler and water addition yet still providing acceptable bonding, storage stability, cure speed, ease of manufacture and use and still maintaining cost competitiveness. This extensive use of both traditional but especially chemical characterization of resins can perhaps be best described as Molecular Designing of Phenolic Resins (3).

Properties of Universal Type Phenolic Resins and Examples of their uses

These universal type phenolic resins whether they contain low alkali levels required for such reconstituted wood products as MDF and particleboard or greater alkali levels allowable for plywood and LVL can be characterized as having relatively long term storage stability and yet still be fast curing. Of course these resins can also be accelerated "in house" by the addition of paraformaldehyde/urea, lactones, esters, organic carbonates (4), resorcinol etc. methods which have and are being used to improve the cure speed of traditional phenolics. These resins are also extremely wood moisture tolerant and are also able to tolerate very wide assembly time conditions without either washout (excessive penetration of resin into the wood substrate) or dry out (lack of adequate resin flow in the wood/glue interface). One very noteable feature of these

resins is their ability to be very simply formulated with fillers and added water at "normal" extensions for such demanding uses as LVL and yet be very much more greatly extended by minor adjustment of filler composition and the addition of large amounts of water without the loss of glue mix viscosity or without hot NaOH digestion of wheat flour yet still be relatively fast curing, and wood moisture content tolerant for plywood production. Whilst flour digestion with NaOH may pose no special problems if carried out in a chemical manufacturing plant it is a relatively hazardous operation requiring protective clothing and great care, not well suited to be performed in a reconstituted wood factory. The following example is typical of the type of resin properties, formulations and bonding parameters referred to above.

Resin properties 504/6
Viscosity 300-350 mPa.s @ 25°
Total solids content 41-42%
Free Formaldehyde less than 0.1%
Gelation time @ 100° 20-25 mins
Time to double viscosity @ 25° 30-40 days

Example 1. LVL glue mix (Medium shear mixing)

Resin 100 parts
Nutshell flour 10 parts
Wheat flour 5 parts
Water 15-20 parts
Glue mix stability 940-1190 mPa.s over 2 hours @ 25°

LVL construction:
21 ply x 3.2 mm sapwood *Pinus radiata* veneers conditioned to 5% VMC
Glue spread: 260-270 gm/m^2 single glueline
Open assembly time 6-8 mins
Cold pressed at 0.07 mPa for 8 mins
Total assembly time less than 40 minutes

Hot press conditions:
Temperature 184-186°C
Pressure (Starting) 1.2 mPa - 0.1 MPa (final)
Time under pressure - less than 40 minutes
Centre glueline temperature at press opening: less than 100°

Bond quality assessment:

Samples taken immediately after press opening and up to one hour and subjected to a cold water Vacuum Pressure Soak test (VPS) followed by chiselling in the wet state show an average bond quality exceeding 70%.

Example 2: Highly extended plywood glue mix (High shear mixing)

Resin 100 parts
Wheat flour 9 parts
Nut shell flour 7 parts
Water 36 parts - No NaOH "predigestion"
Gluemix viscosity 930-1160 mPa.s over 2 ½ hours @ 25°

Plywood construction:

7 ply x 2.4 mm Pinus radiata veneers conditioned to 5% VMC
Gluespread 360-400 g/m^2 double glueline
Open assembly time 5-15 mins
Cold pressed 0.7-1.0 MPa 5-10 mins
Total assembly time 30-180 minutes

Hot press conditions:

Temperature 140°C
Pressure 1.0 MPa
Time under pressure - 8 minutes or less
Bond quality assessment (5) greater than 8.0 average.

These two examples highlight the ability of these universal type resins to perform quite disparate gluing tasks the major difference being the different levels of added water.

Other preliminary tests have also shown the ability of these resins to tolerate average VMC conditions of 3% or less and up to 12%.

Future Directions

Work is presently in progress particularly regarding the more complete understanding of the detailed structure of these resins. Whilst variations in synthesis procedures are being related to actual gluing properties perhaps more importantly individual molecular species are now being identified as they are being formed and reformed by the use of NMR

techniques. New GPC methods presently under development will also lead to a more thorough understanding of "real" molecular weights, their distribution and how they can be related to resin performance. We at CSIRO Division of Forest Products believe that PFs have enormous potential for further utilization in other reconstituted wood products such as MDF and particleboard, providing that resin manufacturing costs can be kept down and that cure speeds can be improved, PFs are the logical replacement in many cases for MUF and perhaps UF. The chemistry of PFs solves the problem of formaldehyde emissions that occur from MUF and UF bonded products without the need to resort to slower curing low formaldehyde role ratio MUFs and UFs, without the need for formaldehyde scavengers which still have an unknown effect on long term durability of these resins. Overall the future for PFs appears to be quite unlimited in their scope.

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EUCALYPT LVL POTENTIAL USING PHENOLIC RESINS

David R. Syme
Research Officer
Forest Products Section
State Forests of N.S.W.
PO Box 100. Beecroft N.S.W. 2119.

ABSTRACT

The Forest Products Section of the State Forests of N.S.W. has been undertaking peeling and adhesive studies on various species of Australian hardwoods with the goal of identifying alternate species for plywood production rather than the previously used Rain forest species. The author chose three of those species to carry out pilot laminated veneer lumber (LVL) tests using phenolic resins. The results suggested that not only could some of these species be bonded successfully but engineering properties of LVL, such as the Modulus of Elasticity and the Modulus of Rupture, were much higher than those specified in the Australian Standard for sawn, seasoned timber of these species.

BACKGROUND

The history of laminated veneer lumber (LVL) development and its superior structural reliability over sawn timber, have been the subject of discussion at previous Forest Products Research Conferences by Lyngcoln(1986), O'Halloran(1986) and Hutchings & Leicester(1990).

The Australian LVL market was developed by International Panel and Lumber Australia Pty Ltd (IPL). IPL laminates Radiata Pine veneers, from the Mount Gambier region in South Australia, using phenolic adhesive. The author, during his previous employment at Ralph Symonds Australia Ltd, was involved in laminating 15m lengths of Slash Pine LVL using phenolic adhesive. He was also successful in laminating Blackbutt veneers into 2.7m by 1.2m LVL sheets using a tannin adhesive from South Africa.

When the author joined the State Forests of N.S.W., an Australian hardwood peeling and adhesive study was already in place within the Forest Products Section. The objective of the study was to identify alternate species for plywood production rather than the previously used Rain forest species. A number of different adhesive formulations have been trialled in the Section's Research Plymill to achieve A-type, B-type and C-type bonds. The author became involved in this study through initially trialling pilot LVL tests on three species, with the view to extending the work if successful.

SPECIES

The three species, together with their strength group and mean density in the seasoned condition, as given in AS 1720 Part 2(1990), are listed in **Table 1**.

TABLE 1

SPECIES	COMMON NAME	STRENGTH GROUP	DENSITY (kg/m^3)
Eucalyptus obliqua	Messmate Stringybark	SD3	750
Eucalyptus tereticornis	Forest Red Gum	SD4	1000
Eucalyptus grandis	Flooded Gum	SD4	750

Trial Species

PROCEDURE

PEELING

The logs were chain sawn into billets about 1250mm long. The billets were inserted with thermocouples and fully immersed in water inside an insulated aluminium tank. Preheating temperatures between 30^0C and 70^0C were used to optimise veneer quality. Peeling of 2.6mm thick veneer was carried out on the rotary veneer Uroko lathe housed at the Research Plymill. The Matsunaga programmed clipper cut the veener into sheets 670mm wide, which was a little over half the test panel size. Quality C veneers, in accordance with AS 2269(1979), were placed in air drying racks. They were reduced to about 8% moisture content using a chamber drier. A second selection process was then carried out on the seasoned veneer to cull any poor quality sheets.

MANUFACTURE

Adhesive Formulations

Each adhesive was mixed in a large container using a metallic stirrer attached to a high speed drill. The adhesive formulations are listed in **Table 2**.

TABLE 2

Formula	Messmate Stringybark	Forest Red Gum	Flooded Gum
HWP 4000	100.0%	100.0%	100.0%
HWP Hardener	10.0%	10.0%	6.3%
Wheat Flour	6.6%	7.0%	
Nutshell Flour			9.5%
Water	4.2%	3.0%	5.3%
TOTAL	120.8%	120.0%	121.1%

Adhesive Formulations

The viscosity readings, using the modified Ford A Cup, for Messmate Stringybark, Forest Red Gum and Flooded Gum were 25, 22 and 25 seconds respectively.

Glue Spreader

Test glue spread veneers were clipped to a width of 200mm and then passed through the 1000mm Goldie glue spreader. The glue spread rates refer to double glueline rates. These rates for Messmate Stringybark, Forest Red Gum and Flooded Gum were 404, 310 and 325g/m^2 respectively. The top and bottom veneers were passed through the glue spreader in pairs so that only one face of the veneer had adhesive applied to it.

Layup

Two 16 ply LVL specimen panels 1200mm * 1200m were assembled for each of the species. The longitudinal joints were staggered through assembling a 1200mm * 600mm veneer in the middle and then 1200mm * 300mm veneers on either side. This method was carried out for every second layer. A thermocouple was inserted between the centre veneers in each specimen to ensure that the whole panel reached curing temperature in the hot press. Each of the specimens were numbered on the top veneer immediately after layup.

Prepress

Each specimen was left for a specific open assembly time, which was determined as the time required for the adhesive to develop sufficient tack. They were then placed in the 2400mm * 1200mm 5-Daylight Siempelkamp hot press, which had already been converted into a cold prepress. The open assembly time(O.A.T.) and the prepressing conditions for each specimen are listed in **Table 3**.

Hot Press

The closed assembly times(C.A.T.) was varied to monitor adhesive effectiveness over extended time. The specimens were placed in the 1200mm * 1200mm Transfer hot press. The values for these operations are listed in **Table 3**. The hot press was programmed to gradually release the pressure in stages at the end of the heating cycle. Upon removal, the specimens were strip stacked to cool.

TABLE 3

SPECIES	Messmate Stringybark		Forest Red Gum		Flooded Gum	
SPECIMEN NO.	60	61	50	51	10	11
Room Temp.	35°C	35°C	27°C	27°C	27°C	27°C
O.A.T.	10min.	14min.	14min.	10min.	15min.	15min.
Prepress	15min. 175psi	15min. 175psi	15min. 175psi	15min. 175psi	15min. 175psi	15min. 175psi
C.A.T.	15min.	30min.	42min.	72min.	12min.	28min.
Hot Press	35min. 175psi 140°C	34min. 175psi 140°C	45min. 175psi 140°C	45min. 175psi 140°C	35min. 175psi 140°C	35min. 175psi 140°C

TESTING

Bond Tests

Each specimen was sawn into 75mm wide strips along its full length to provide twelve test pieces. The ends were then docked square, which gave final nominal dimensions of 75mm * 40mm * 1150mm. The fourth test piece from each specimen was cut into four bond tests specimens so that replicate testing could be carried out. The specimens had nominal dimensions of 75mm * 40mm * 150mm. Two of these bond test specimens were chisel tested dry, while the other two boiled under pressure before chiselling to test for A-type bond. Both test methods were carried out in accordance with AS 2098 Part 2(1977). All evaluation of bond quality was done in a dry condition under a 2*lens with integral lighting.

Engineering Tests

The Modulus of Elasticity(MOE) of the remaining 22 test pieces, for each of the three species, was determined by three point bending on the flat over a span of 1050mm. This gave a span to depth ratio of 14:1 for the Modulus of Rupture(MOR) tests. The tests were carried out on the Shimadzu universal testing machine.

The Modulus Of Rupture(MOR) is generally determined by four point bending on the edge of the third points to destruction. However, the ratio of the distance from the reaction to the first load point as compared to the depth would in this case be less than 5:1. In such instances, a high percentage of the test pieces could be expected to fail in shear(ASTM 1984). Most of the MOR tests were therefore carried out by three point bending on the edge, while a small number were tested on the flat. The Shimadzu was also used for the MOR tests.

RESULTS

BOND TESTS

A full account of the individual glueline results for each of the twenty-four bond test specimens, as well as the retested Forest Red Gum specimen, are listed in **Appendix 1-3**.

The majority of tests revealed good dry and A-type bond quality. The average bond quality results for Messmate Stringybark, Forest Red Gum and Flooded Gum ranged from 6.7 to 8.1, 6.6 to 8.0 and 8.4 to 9.5 respectively.

The main exception to this was for a couple of the Forest Red Gum gluelines. These failures were found to be isolated and generally in the replicate pieces. A third wet bond piece was tested and all of the gluelines passed.

ENGINEERING TESTS

All of the specimens displayed a very low coefficient of variation. This is in good agreement with Lyngcoln(1986). The test results, as well as those values derived from the working stress code equations in AS/NZS 4063(1992), are listed in **Tables 4**.

TABLE 4

Messmate Stringybark				Forest Red Gum				Flooded Gum			
SPEC.	MOE	MOR (MPa)		SPEC.	MOE	MOR (MPa)		SPEC.	MOE	MOR (MPa)	
NO.	(GPA)	Edge	Flat	NO.	(GPA)	Edge	Flat	NO.	(GPA)	Edge	Flat
60 - 1	21.87	120.21		50 - 1	22.05	150.78		10 - 1	19.30	105.90	
60 - 2	22.87	125.42		50 - 2	21.24	137.25		10 - 2	18.98	111.78	
60 - 3	22.04	112.08		50 - 3	22.96	138.66		10 - 3	18.34	97.01	
60 - 5	21.26	123.76		50 - 5	22.80	140.20		10 - 5	19.02	115.94	
60 - 6	21.44	128.70		50 - 6	23.21	145.56		10 - 6	18.66	112.33	
60 - 7	22.18	124.77		50 - 7	22.46	129.59		10 - 7	19.14		111.87
60 - 8	22.62	128.81		50 - 8	23.51		161.59	10 - 8	19.17	116.04	
60 - 9	21.37	131.33		50 - 9	23.25		154.92	10 - 9	18.75	113.07	
60 - 10	21.66	125.79		50 - 10	21.93		142.43	10 - 10	18.99		116.22
60 - 11	20.84	118.11		50 - 11	22.74	135.22		10 - 11	18.58	101.44	
60 - 12	20.20	123.11		50 - 12	23.20	135.94		10 - 12	19.08		111.28
61 - 1	20.38	120.08		51 - 1	19.07	133.67		11 - 1	18.07	102.17	
61 - 2	19.74	118.14		51 - 2	19.63	141.45		11 - 2	17.29	100.47	
61 - 3	19.78	112.22		51 - 3	18.34	125.87		11 - 3	16.68		108.39
61 - 5	18.80	113.17		51 - 5	22.04	145.50		11 - 5	17.43	100.08	
61 - 6	19.07	122.80		51 - 6	22.02		134.38	11 - 6	17.58		111.86
61 - 7	19.29	121.87		51 - 7	21.79	142.18		11 - 7	17.36	99.83	
61 - 8	22.11	123.39		51 - 8	23.65	148.67		11 - 8	18.84	104.16	
61 - 9	20.72		84.76	51 - 9	24.09		164.39	11 - 9	17.91	107.20	
61 - 10	19.87		133.02	51 - 10	23.07		144.79	11 - 10	17.98	100.99	
61 - 11	20.41		141.77	51 - 11	21.87	139.50		11 - 11	17.43		108.33
61 - 12	20.46	128.93		51 - 12	21.76	139.98		11 - 12	17.63	100.54	
Mean	21.17	122.25	119.85	Mean	21.91	139.38	150.42	Mean	18.47	105.56	111.33
S.D.	1.14	5.65	30.70	S.D.	1.43	6.58	11.77	S.D.	0.76	6.32	2.90
V	5.38%	4.62%	25.62%	V	6.53%	4.72%	7.82%	V	4.11%	5.99%	2.60%
P0.05	18.96	112.14		P0.05	19.10	126.99		P0.05	17.29	97.86	
Ek	21.01			Ek	21.68			Ek	18.36		
Rbasic		46.51		Rbasic		52.52		Rbasic		39.99	

Where : S.D. is the Standard Deviation
V is the Coefficient of Variation
P0.05 is the 5th Percentile
Ek is the Characteristic Modulus of Elasticity
Rbasic is the Basic Permissible Stress

Engineering Test Results

CONCLUSIONS

1. It is possible to use phenolic resin in manufacturing certain species of Australian hardwood LVL.

2. Engineering properties, such as MOE and MOR, are far superior in hardwood LVL than in their respective sawn counterparts.

FUTURE DIRECTION

As the results in this pilot study were promising, there are plans to undertake further work on other hardwood species. While the species chosen will depend upon projected resource availability, some of the species which the author expects to test, as well as their estimated timber properties from AS 1720 Part 2(1990), are listed in **Table 5**. The Strength Group value in brackets indicates that the value is only a provisional classification. Bootle(1983) was used as a source for any species not listed in the AS 1720 Part 2.

TABLE 5

SPECIES	COMMON NAME	STRENGTH GROUP	DENSITY (kg/m^3)
Eucalyptus cameronii	Diehard Stringybark	SD5	770
Eucalyptus fastigata	Brownbarrel	SD4	750
Eucalyptus laevopina	Silvertop Stringybark	(SD2)	850
Eucalyptus microcorys	Tallowwood	SD2	1000

Proposed Future Test Species

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APPENDIX 1

	Messmate				Stringybark			
SPECIMEN NO.	60-A	60-B	60-C	60-D	61-A	61-B	61-C	61-D
BOND TEST	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry
Glueline 1	9.0	8.0	7.0	8.5	5.5	9.5	8.0	9.5
Glueline 2	7.5	9.5	8.0	7.0	6.5	7.7	8.5	6.0
Glueline 3	7.0	8.5	9.0	9.5	7.0	5.0	6.0	9.5
Glueline 4	7.0	3.0	8.5	7.5	7.5	7.5	5.0	5.0
Glueline 5	8.5	7.5	9.0	9.0	8.0	7.5	8.0	8.0
Glueline 6	9.5	8.0	9.0	9.5	7.5	5.0	8.5	9.0
Glueline 7	9.0	8.5	7.5	9.0	8.5	8.5	9.0	7.5
Glueline 8	9.5	5.5	7.5	9.0	9.5	4.5	7.5	5.0
Glueline 9	9.0	9.0	8.0	8.5	8.0	5.0	8.0	9.0
Glueline 10	8.0	6.0	7.5	8.0	9.0	5.5	9.0	6.5
Glueline 11	7.0	8.5	8.0	7.5	9.0	8.0	8.5	9.5
Glueline 12	6.5	9.5	7.5	6.5	9.0	5.0	9.5	8.5
Glueline 13	9.0	9.0	8.5	8.5	4.5	8.0	8.0	8.0
Glueline 14	8.5	9.0	8.5	5.5	9.0	9.0	9.0	8.0
Glueline 15	6.5	9.0	8.0	9.0	9.5	5.5	8.5	8.5
AVERAGE	8.1	7.9	8.1	8.1	7.8	6.7	8.0	7.8

Messmate Stringybark Bond Quality Results

APPENDIX 2

	Forest				Red				Gum
SPECIMEN NO.	50-A	50-B	50-C	50-D	51-A	51-B	51-C	51-D	51-E
BOND TEST	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
Glueline 1	8.5	9.0	9.0	9.0	7.5	9.5	9.0	7.5	7.5
Glueline 2	8.0	8.0	8.0	9.0	8.0	4.5	6.5	3.0	9.0
Glueline 3	8.5	7.5	7.5	8.5	7.0	5.0	5.0	6.0	8.0
Glueline 4	9.0	6.0	7.0	3.0	7.0	8.5	2.0	8.5	5.0
Glueline 5	8.0	5.0	5.5	4.5	8.0	8.0	9.5	8.5	5.0
Glueline 6	8.5	9.5	9.0	9.5	9.0	7.5	9.0	8.0	8.0
Glueline 7	5.5	9.5	7.0	9.5	9.0	8.0	9.0	8.5	8.5
Glueline 8	7.0	6.0	7.0	7.0	8.0	7.5	8.0	9.0	5.0
Glueline 9	7.0	9.0	3.0	5.0	7.0	6.0	5.0	6.5	5.5
Glueline 10	8.0	6.5	5.0	9.0	7.5	8.5	7.5	7.5	6.0
Glueline 11	9.0	9.0	8.0	9.5	7.5	7.0	6.0	5.0	6.5
Glueline 12	8.0	5.5	5.5	9.5	8.0	8.0	7.0	2.5	6.0
Glueline 13	8.0	6.5	5.5	9.0	5.0	9.0	7.5	7.5	9.0
Glueline 14	9.0	9.0	5.0	9.5	9.0	8.0	9.0	9.0	8.0
Glueline 15	8.0	9.0	8.0	8.5	7.5	7.5	7.5	8.0	9.0
AVERAGE	8.0	7.6	6.6	8.0	7.6	7.5	7.1	7.0	7.0

Forest Red Gum Bond Quality Results

APPENDIX 3

	Flooded				Gum			
SPECIMEN NO.	10-A	10-B	10-C	10-D	11-A	11-B	11-C	11-D
BOND TEST	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry
Glueline 1	9.5	9.5	7.5	9.5	9.5	9.0	5.0	9.5
Glueline 2	7.5	9.5	7.5	9.5	9.5	9.5	4.5	9.5
Glueline 3	9.5	9.5	8.5	9.5	8.5	9.5	8.5	9.5
Glueline 4	9.5	9.5	9.5	9.5	9.5	7.5	4.0	9.5
Glueline 5	9.5	9.5	9.0	9.5	7.5	8.5	9.5	9.5
Glueline 6	9.5	9.5	9.5	9.5	9.5	9.0	9.0	9.5
Glueline 7	9.5	9.5	8.5	9.5	8.5	8.5	9.5	9.5
Glueline 8	9.0	9.0	8.5	9.5	7.0	9.0	9.0	9.5
Glueline 9	9.0	9.5	8.5	9.5	4.5	9.5	9.5	9.5
Glueline 10	6.0	9.5	5.5	9.5	9.0	9.5	8.0	9.5
Glueline 11	9.5	9.5	9.0	9.5	9.0	9.0	8.5	9.5
Glueline 12	9.0	9.5	9.0	9.5	8.0	9.5	9.0	9.5
Glueline 13	9.0	9.5	9.5	9.5	9.5	9.5	8.0	9.5
Glueline 14	9.5	9.5	9.0	9.5	8.0	9.5	7.0	9.5
Glueline 15	9.0	9.5	9.5	9.5	9.0	9.5	9.5	9.5
AVERAGE	8.9	9.4	8.5	9.5	8.4	9.1	7.9	9.5

Flooded Gum Bond Quality Results

EUCALYPT PEELING AND GLUING STUDIES; AN ONGOING SURVEY BY THE FORESTRY COMMISSION OF NSW

John Wade (retired) PO Box 1495, Armidale 2350

Previously Plymill Manager, Research Division;

West Pennant Hills

ABSTRACT

Six years of work in the Commission plymill has produced a mass of practical data on peeling and gluing those NSW eucalypts present in any commercial volume. The large range of properties of the eucalypt timbers has necessitated specific production techniques for quality plywood manufacture from many of these species. Higher glue viscosities and higher rates of spread are general requirements. Most of the plywoods are very strong with high surface hardness. The potential for LVL manufacture is indicated. Tables of some typical properties, processing demands and results are given. The work to date need to be extended for some of the species but the results warrant attention from the plywood industry. The eucalypts in general have problems associated with high density including moisture content, and low void space for steam escape. Extractives are a major additional problem in some species.

1. INTRODUCTION

Those eucalypts of NSW available in useable volumes exhibit a wide range of densities, porosites, textures and extractives. The goals of the Commission have included replacement of rainforest timbers, the more valuable usage of forest resource and finally the evaluation of less appreciated species for possible future plantation developments specifically for plywood production. This paper summarises six years of work by a small team of four in the commission plymill at West Pennant Hills. Its aim is to draw the attention of foresters and wood processors to the potential of the eucalypt plywood and eucalypt LVL in particular.

Due to the number of variables present and the limited manhours available, statistical techniques were not attempted. Repetition of runs with fresh material gave similar results within the limits of mill requirements. The work was practical in its approach. The scale of the equipment gave results directly applicable to plant usage. It was necessary to cover as many species as possible so research on each species was limited by time and cost constraints.

2. EQUIPMENT

The equipment included an automatically controlled log heating tank with thermocouple recording of billet core temperatures. The production sized "Uroko" lathe possessed high precision combined with instrumented electronic speed controls. Clipped sheets were air dried in racks to fibre saturation point and then brought down to 4 to 6% moisture content in an electronically controlled screen drier heated electrically. Gluing was carried out on a "Goldi" production spreader followed by an instrumented prepress and finally a "Transfer" research hot press with a 1.2 x 1.2 metre single daylight. This was an excellent press with electronic controls. An automatic pressure reduction at the end of each cycle was found to be essential. A temperature of 140^{o}C was used in all cases (except for "C" bond) together with a specific pressure of 12.25 kgs cm^{-2} (175 psi per sq. inch).

3. SUMMARY OF PEELING METHODS

A series of water bath temperatures were used to yield optimum temperature ranges. Various lathe settings were used. Recoveries were considered against specific tree, position in tree, temperature, and lathe settings. A few major species were evaluated from more than one region, eg. spotted gum. Veneer thickness green an dry was recorded and veneer quality green and dry was noted.

4. SUMMARY OF METHOD FOR GLUING

A glue manufacturer provided adhesives and technical backing. The bonds were chisel tested with a pneumatic chisel in terms of the Australian standard. The aim was to nominate successful formulations for each species and several basic resins were tested with successive formulations, viscosities and rates of spread. The tolerance of each species to a range of closed assembly times particularly on hot days was noted. The bonding quality of veneer of various ages was also checked.

In general, bond ratings of 8 or higher were sought to give a margin for safe operation in working plymills. Wetting agents were tested when surface problems occurred. Phenolics used in normal softwood plywood production were evaluated where possible to indicate species useable interchangeably with softwoods in a mill. LVL was made from promising species and trial engineering tests were made on this LVL. Overlay tests were also carried out in some cases.

5. RESULTS FOR PEELING TESTS; WITH COMMENTS

Table 1 Optimum Heating Ranges for Billets*

SPECIES	OPTIMUM RANGE (°C)	COMMENTS
E. agglomerata	60	Smooth; good quality
E. cameronii	60	Wavy below 60°C, split free
E. campanulata	60-70	Smooth. Billets shell out**
E. camaldulensis	70	Smooth. Defects in logs common.
E. deanei	60	Good when free of insect attack.
E. delegatensis	45-60	Smooth. Good quality.
E. fastigata	60	Smooth; tight.
E. grandis	Ambient	Smooth (Urunga) ***
E. grandis	40	Smooth (Kendall)
E. maculata	40-70	Smooth; good quality
E. nitens	60	Popping; terrible splitting.
E. nobilis	50	End splitting major.
E. obliqua	50	Smooth
E. piperita	50-80	Smooth; good quality
E. saligna	60	Smooth; tight
E. tereticornis	60-70	Smooth

* Note 1: The temperature range giving the highest recovery may well vary from that giving the smoothest veneer. The above figures are a compromise.

** Note 2: "Shelling out" means shearing along growth rings in a generally circular pattern.

*** Note 3: The E. grandis from Urunga was from a 20 year old plantation, while that from Kendall was from older natural forest.

Table 2: Lathe Settings:

Species	Thickness (mm)	Horizontal Gap (mm)	Vertical Gap (mm)	Wedge angle (°)	Cutting angle (°)
E. cameronii	2.6	2.56	0.50	20°	21.0
E. campanulata	2.6	2.55	0.50	20°	21.5
E. grandis	2.6	2.43	0.65	20°	20.5 (Kendall)
E. grandis	2.6	2.41	0.75	20°	21.0 (Urunga)
E. maculata	2.6	2.41	0.75	20°	20.5 (Bateman's Bay)
E. nitens	2.6	2.48	1.55	20°	20.5
E. nobilis	2.6	2.50	0.70	20°	22.0
E. obliqua	2.6	2.45	0.65	20°	20.5
E. sieberi	2.6	2.36	0.75	20°	20.5
E. tereticornis	2.6	2.48-2.53	0.5-0.75	20°	21.0

Note the respectively small amounts of compression represented by the above horizontal gaps which are probably a maximum compression. Use of greater compressions yields veneer so stiff that it will not pass successfully through the spreader.

Table 3: Effect of Position in Tree

SPECIES	BUTT BILLETS POOR	TOP BILLETS POOR
E. obliqua	Poor results	-
E. saligna	Excessive defect	-

On the limited work carried out to date, some species were subject to a major incidence of defects in one zone. Butt zones were of course more prone to both mechanical and fire damage (excluding crown fires) in the standing forest.

COMMENT ON A WIDE RANGE OF LOGS FOR ONE SPECIES

Spotted gum was drawn from a range of forests from Bateman's Bay to Casino. Several sources all gave excellent peeling and excellent gluing, so that genetic variation did not seem to have major effect on these two properties for this given species. It is hoped that evaluation can proceed on logs from fresh forests for other promising species.

Table 4: Typical Veneer Recoveries

SPECIES	GREEN RECOVERY (1% of Billet Vol).	Dry Recovery (% of Billet volume).
E. agglomerata	38-67	-
E. cameronii	47	-
E. campanulata	31	-
E. camaldulensis	20 (Millewa)	-
E. camaldulensis	33 (Deniliquin)	-
E. deanei	25-63	-
E. delegatensis	40-60	-
E. fastigata	32-55	-
E. grandis	35 (Urunga)	-
E. grandis	45 (Kendall)*	-
E. maculata	50	-
E. nitens	29	-
E. nobilis	45	-
E. obliqua	40	-
E. piperita	31	-
E. saligna	33-59	-
E. sieberi	11	-
E. tereticornis	-	41

* Note: The E. grandis from Kendall had a higher recovery since the logs were of larger diameter than the younger (twenty year old) trees from Urunga plantation.

Table 5: Species not suitable for Peeling on the Results to Date.

SPECIES	COMMENTS
E. sieberi	Heart breakdown typical in source area
E. nitens	Extensive popping; diametric expansion on lathe
E. nobilis	Terrible end splitting.

6. RESULTS FOR GLUING TESTS WITH COMMENTS
I "A" BOND

Table 6: Special Hardwood Liquid Phenolic (HWP 4000) ***

SPECIES	Moisture Content %	Viscosity Ford A Cup (secs)	Spread (gms m^{-2})	Closed assembly range (minutes)	"A" Bond Average Results (Scale:0-10)
E. cameronii	7	-	-	-	Poor results
E. campanulata	8	-	-	-	Poor results
E. camaldulensis	-	30	429	18-105	Pass "A" bond well
E. deanei	-	28	452	-	6
E. delegatensis	8	28	411	77 @ 18°C	Pass
E. fastigata	9	35	460	44	MC% too high
E. grandis*	8	25	325	29 @ 27°C	8 as LVL
E. maculata	-	27-35	425-480	136	Pass
E. obliqua	7	25	300-400	15-30 @ 35°C	8 as LVL
E. pilularis **	6-8	33	384	22	Just pass
E. piperita	7	29-35	483-496	90 @ 23°C	Passwell
E. saligna	6	24-30	380-450	115 @ 18°C	-
E. sieberi	>9	-	-	-	Pass
E. tereticornis	7	25	404	80 @ 35°C	6-8 as plywood
E. tereticornis	7	22	310	70 @ 27°C	Min 5 as LVL

* Note 1: For LVL are internal veneers are coated on both sides.
** Note 2: Veneer only 2 months old and not too tight.
*** Note 3: HWP 4000 is based on resin SP7300

Over a four year period, more than fifty blackbutt glue runs were carried out. The best results only gave a 50% probability of an average rating of 5 and a minimum of 3 when fresh veneer was glued with the high solids HWP400 at a moisture content of 6%, a viscosity of 33 to 35 seconds and a spread of 450 gms/sq.metre.

Table 7: Standard Softwood Liquid Phenolics (SP900 or M373)

SPECIES	Moisture Content %	Viscosity Ford A Cup (secs)	Spread (gms m^{-2})	Closed assembly range	"A" Bond Average Results (Scale:0-10)
E. cameronii	-	-	-	-	Poor. Kedo
E. campanulata	-	-	-	-	Poor. Kedo
E. delegatensis	5	25-31	410-450	160 @ 20°C	Pass well
E. grandis*	8	23	430	55 @ 23°C	7.5
E. maculata	6	28-35	440	50 @ 19°C	Pass
E. maculata	4-6	34	480	153 @ 21°C	Pass
E. nobilis	5-9	33-36	425	60 @ 25°C	6 to 7
E. obliqua	8	26	423	60 @ 19°C	6 to 7

COMMENTS ON "A" BOND REQUIREMENTS

The problem of obtaining satisfactory "A" bonds with eucalypts is due to a number of factors. Experience in the commission plymill suggests

(a) There needs to be as much fully cured phenol formaldehyde matrix as possible in the gluebond to withstand the tremendous shear forces caused by the large uptake of hot water into the veneer in the plywood under test. The addition of even a small amount of water in excess of the critical percentage can lead to a failure. Excess wheat flour or nutshell flour can have a similar effect. The distributed nutshell flour particles probably confer some degree of elasticity upon the cured bond but if in excess they reduce the bond's ability to resist shear. A high solids phenolic resin gave far better results with difficult species.

(b) Most of the eucalypts have tangential shrinkages far in excess of softwoods so that the shear problem is increased by this factor.

(c) Extractives can be present as a considerable percentage of the weight of the basic wood material eg. E. pilularis which contains probably in excess of twenty extractives. These extractives can react with the resin components.

(d) There may be surface wetting problems from certain aqueous glue systems in contact with some eucalypt veneers.

II "B" BOND

Table 8. Melamine Urea Formaldehyde (CR560 + Melamine or WM 3294).

SPECIES	Moisture Content %	Viscosity Ford A Cup (secs)	Spread (gms m^{-2})	Closed assembly range (minutes)	"B" Bond Average Results (Scale:0-10)
E. agglomerata	-	25-30	430-480	190 @ 15°C	7
E. cameronii	7	30	435	>30 @ 25°C	8
E. campanulata	8	30	435	54 @ 25°C	8
E. camaldulensis	8	27	445	87 @ 20°C	8
E. deanei	6-8	25-30	430	180 @ 15°C	5-6
E. delegatensis	6-8	25	434	(Long)	Good
E. fastigata	-	25-27	382-484	7 to 223	8
E. grandis	8	32	430	40 to 57	8
E. maculata	7	27	445	170 @ 20°C	8
E. nobilis	9	29	448	-	6 (Tack poor)
E. obliqua	7	29-36	445-480	66 @ 29°C	8-9
E. pilularis	6	25	380	75 @ 20°C	7 (Spread low)
E. piperita	9	27	445	110 @ 23°C	8-9
E. saligna	6	21	470	110 @ 23°C	5-9 (Viscos low)
E. sieberi	9	27	445	27 @ 20°C	8-9
E. tereticornis	7-8	29	445	47 @ 29°C	7-85

III. "C" BOND

Table 9. Urea Formaldehyde Resins (CR560 (CR 625) or CR 3276)

SPECIES	Moisture Content %	Viscosity Ford A Cup (secs)	Spread (gms m^{-2})	Closed assembly range (hours)	"C" Bond Average Results
E. agglomerata	<6	27	382	210 @ 17°C	8.5
E. cameronii	7	29	450	80 @ 23°C	9
E. campanulata	8	29	450	-	8.5
E. deanei	<6	27	382	200 @ 17°C	5 (spread low)
E. fastigata	6-9	27	382	200 @ 17°C	7-9
E. grandis	8	25	440	70 @ 21°C	9
E. nobilis	9	28	420	-	8
E. saligna	<6	36	416	180	Good; excellent
E. tereticornis	8	25	440	67 @ 21°C	9

Note: The priority in urea formaldehyde type adhesive tests was given to "B" bonding. Results in the Commission plymill have confirmed that where "B" bonding was very successful, it was reasonable to assume that "C" bonding would also be successful. the assumption was extended to "D" bonding also.

7. FINAL: DISCUSSION OF RESULTS TO DATE

In general, the eucalypts make very strong plywood with hard surfaces. Some veneers are very dense and impervious, while others are of moderate density and are far more permeable. Some veneers are beautifully smooth such as E. agglomerata, while others are coarse textured.

Some species of eucalypts could produce cover veneer of an architectural grade for clear finishing due to lovely colours and/or patterns. However, such plywood would need to be marketed with included defects of a minimum nature promoted as part of the natural character of the wood.

The strength and stiffness of eucalypt plywood produces a desirable formwork, but there is a current need for special overlay films to apply directly to certain selected species of eucalypt timbers. Overlay manufacturers may be able to develop a composite product when the market will tolerate a higher cost for the overlay as the wood content of a sheet becomes more costly. Such an overlay might contain an inner resin coat to flow onto the veneer well, a thicker, denser and stiffer middle layer containing matt fibres and an outer flowing layer to produce a hard glossy surface.

Composite plywoods made from eucalypt longbands and softwood crossbands (radiata pine, hoop pine or slash pine) often give far better bonding than single eucalypt plywood, eg. blackbutt and radiata pine. The softwood veneer is a good glue carrier and it is also compressed readily to absorb small variations in the eucalypt long bands. The less dense softwoods also have more voids to accept steam towards the end of the curing cycle, and additionally they are far more permeable.

A major use for selected species of eucalypt is to provide veneer for high strength LVL. While manufacturing technology is more difficult, the high strengths enable shallower beams to be used. The feature of randomisation of minor defects in the layup of LVL means that one of the main barriers to the economical use of eucalypt veneer in plywood is overcome.

Limited beam testing at the engineering facility of the Commission upon LVL from several spp. including E. obliqua, E. tereticornis and E. grandis has given excellent results. Eucalypts subject to poor demand such as E. piperita would also make excellent LVL. This randomisation means also that E. grandis could be used in quantity.

The major problem in Australia at present is to obtain suitable eucalypt species in sufficient volume to warrant LVL plants. However, the converse applies in some overseas countries such as South America where there are enormous volumes of E. grandis with a world market seeking stable, reliable seasoned timber beams.

The moisture content of eucalypt veneers for use with liquid phenolics should be about 6%. This 6%water represents abut twice as much water per cubic metre as that in radiata pine at 6%. When it is remembered that there is much less air space in eucalypt timber to absorb steam, it is easy to realise why denser eucalypt plywood is so readily subject to "blows" above 140^{o}C in the hot press. Reducing moisture to these low values means that a eucalypt plymill needs about double the drying capacity of a softwood mill.

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UTILISATION OF PINEBARK VIA STEAM TREATMENT

Terry D. Lomax, Keith L. Mackie and Dale R. Smith
New Zealand Forest Research Institute
Private Bag 3020, Rotorua, New Zealand

ABSTRACT

Steam treatment of the young bark from *Pinus radiata* at a temperature of 210°C and for times ranging from 3 to 20 minutes has been investigated. Around 15% of the original bark is rendered water soluble as a result of the treatment and this material is almost exclusively carbohydrate. The steam treatment also reduces the levels of extractable materials (mainly tannins) that can be removed from the bark and, most importantly, reduces by approximately 80% the water soluble coloured polyphenolics that leach from untreated bark. The water insoluble treated bark matrix has been investigated as a medium for protein absorption, metal ion absorption (Cu, Cr, As), and as a horticultural growth mix. Preliminary results are presented which indicate that the levels of protein absorption (approximately 1% w/w) and metal ion absorption (approximately 0.1% w/w) are too low for commercial application but that further research is warranted into the benefits of steam treatment for the manufacture of a low toxicity plant growth substrate.

INTRODUCTION

The annual production of *Pinus radiata* bark (pinebark) in New Zealand is currently around 1.76 million m^3 and, in line with harvest projections (Edgar, Lee, Quinn, 1992), is expected to increase to 2.46 million m^3 by the year 2005. Not all this pinebark reaches the processing centres as approximately 50% is "lost" in the felling, harvesting and transportation phases (Prince 1993) but this leaves some 0.9 million m^3 that must be utilised annually.

The traditional demands for *Pinus radiata* bark in New Zealand as a fuel or horticultural medium are insufficient to use all this material and as a result substantial quantities are currently dumped into landfill (van Wyk 1989). The leaching of polyphenolics from pinebark in landfills has focussed attention on this practice, however, and the costs associated with bark disposal in this manner are increasing rapidly. Bark producers are being forced to explore new utilisation options for bark or face environmental pressure that is mounting under the recently enacted Resource Management Act.

The New Zealand Forest Research Institute initiated a multidisciplinary research programme in 1992 in response to industry problems in regard to bark utilisation and this paper presents results arising from one part of this programme - the utilisation of pinebark following steam treatment.

Steam treatment of hardwoods (Lora, Wayman 1978) and softwoods (Clark, Mackie 1987) has been extensively researched and based on this technology NZ FRI examined the effect of steam treatment on pinebark. The original premis behind this research was to enhance the extractability of tannins but it is noteworthy that in fact the premis was proved completely false and indeed the reduced extractability of tannins was observed. The chemistry associated with steaming of pinebark and preliminary results on the use of the treated bark matrix as a protein absorbent, metal ion absorbent and horticultural medium are presented in this paper.

MATERIALS AND METHODS

Bark substrate

The bark used for this work was from *Pinus radiata* thinnings aged between 12-14 years. The bark was obtained from a commercial debarking operation and hogged so that the largest pieces were approximately 30 mm. The bark, commonly called young bark or slimy bark, contained around 15% of cambial wood that was removed from the trees during debarking. The bark was used unscreened and had a dry content of 60%.

Steam treatment

The bark was treated in a 2 litre steam explosion unit at NZ FRI that has been described previously (Clark, Mackie 1987). Water washing of the steam treated bark was performed by twice stirring the exploded bark matrix with distilled water at 5% dry solids for 30 minutes and filtering on a 70 micron expanded polypropylene filter.

Analysis of water solubles from steam treated bark.

The yield of the water soluble fraction was quantified by freeze drying a sample of the wash liquor. Carbohydrates were determined as alditol acetates (Moore, Johnson 1967) on a sample of the wash liquor both before and after post hydrolysis with 3% H_2SO_4 in order to determine the degree of polymerisation of the carbohydrates.

Estimation of leachable colour from steam treated bark.

Unwashed steam treated bark samples (50 g oven dry equivalent) were soaked overnight at 20°C in 400 ml water. The water was filtered off, adjusted to pH 7.0 using 1% NaOH and absorbance measured at 465 nm.

Analysis of extractives in steam treated bark.

Air dried steam treated bark samples were coarsely ground in a Wiley mill to pass a 20 mesh sieve. A sample of untreated bark was also prepared in the same manner. The samples were sequentially extracted in a soxhlet apparatus with hexane, toluene, ethyl acetate, acetone, methanol and water. Each extraction was deemed to be complete when no further colour could be observed in the returning solvent. Solvents were removed under reduced pressure (except for water which was removed by freeze drying) and the weight of extractives removed from the bark samples in each solvent determined.

Protein absorption trials.

Using pinebark, treated at 210°C and subsequently water washed, a central composite design experiment was completed using bovine serum albumin (BSA) as a soluble test protein. Protein concentration of 100 mg.l^{-1} and 700 mg.l^{-1}, bark dosages of 0.1, 0.3, 0.5, 1.0, 1.58, 2.0 and 2.5 g (dry weight) per 100 m*l* of protein solution, and solution pH values of 4.0 and 6.5 were used. The moist steam treated bark was added to the BSA solutions and gently shaken at 27°C for 20 minutes. Aliquots of the protein solution were removed and analysed for protein concentration using Bradfords reagent.

Copper-Chrome-Arsenic (CCA) absorption trials.

To a diluted commercial CCA wood preservation solution (137 mg.l^{-1} Cu, 238 mg.l^{-1} Cr, 192 mg.l^{-1} As) samples of steam treated and water washed bark were added (10 g oven dry equivalent per 100 ml of CCA solution). Aliquots were removed from the mixture at various time intervals and analysed by atomic absorption spectroscopy.

Horticultural trials.

Only preliminary growth trials have been completed by NZ FRI nursery staff. Growth media, prepared from or containing steam treated and water washed bark (210°C, 3 minutes), were compared with well established and proven media (containing NZ Hauraki peat, sand and pumice) used for the on-growing of tomato, lettuce and chrysanthemum transplants. Plant growth was qualitatively assessed based on survival, plant form and appearance, and size at termination of experiment.

RESULTS AND DISCUSSION:

Effect of steam treatment on pinebark chemistry.

Steam treatment primarily results in a chemical modification to wood and bark substrates (Clark, Mackie 1987) but physical modifications are also observed depending upon the steam treatment equipment used. Only the chemical modifications are addressed in this paper.

TABLE 1: EFFECT OF STEAM TREATMENT CONDITIONS ON YIELD AND COMPOSITION OF WATER SOLUBLE AND WATER INSOLUBLE FRACTIONS FROM PINEBARK. (All figures % oven dry equivalent pinebark feedstock).

	Treatment Time (minutes) (Temperature 210°C).			
	3	6	12	20
Yield of total product	94.5	93.6	92.2	90.1
Yield of water insoluble matrix	81.1	82.3	80.8	81.5
Yield of water soluble material	13.4	11.3	11.4	8.6
"Lost" material[1].	5.5	6.4	7.8	9.9
Carbohydrates in water solubles[2]				
Arabinose	1.05(1.66)	0.68(1.12)	0.55 (0.8)	0.36 (0.22)
Xylose	0.64(1.89)	0.55(1.52)	0.49(1.22)	0.36(0.31)
Mannose	0.24(2.46)	0.36(2.72)	0.44(2.56)	0.47(2.19)
Galactose	0.56(2.28)	0.55(2.20)	0.58(1.97)	0.47(1.42)
Glucose	0.47(2.69)	0.47(3.13)	0.53(3.12)	0.58(2.72)
Total	2.96(10.98)	2.61(10.69)	2.59(9.67)	2.24(6.86)
Total neutral carbohydrate in water solubles as % of all material in water solubles	82	95	85	79

[1] Difference between total product yield and dry weight of original bark. [2]Bracketed values refer to levels of monosaccharides determined following post-hydrolysis of water solubles with 3% H_2SO_4.

Table 1 summarises the yield and chemical composition data for a series of treatments of the *Pinus radiata* young bark (pinebark) at 210°C for 3, 6, 12, and 20 minutes. Over these treatment conditions between 5-10% of the original pinebark is converted to volatile products, some of which arise from the degradation of

carbohydrates. The yield of water insoluble bark remains remarkably constant at around 81% and, as will be demonstrated in this paper, results from the loss of carbohydrate being offset by the condensation of polyphenolics (tannins). The water soluble fraction is, rather surprisingly, largely comprised of carbohydrates with 79-95% of all solids in this fraction being accounted for as neutral carbohydrates. The water soluble carbohydrate is predominantly in polymeric form.

The effect of steam treatment conditions on the extractability of components from the unwashed bark matrix is shown in Table 2. The sequential extraction protocol used follows closely that performed by Markham and Porter (Markham, Porter 1973). Higher treatment temperatures decrease the quantity of extractives in the more polar solvents and, overall, the total level of extractives drops from 36.6% to 18.7%. The marked reduction in the acetone and methanol solvents, where the tannin components are expected to appear, leads us to conclude that the steam treatment has caused the tannins in the bark to condense.

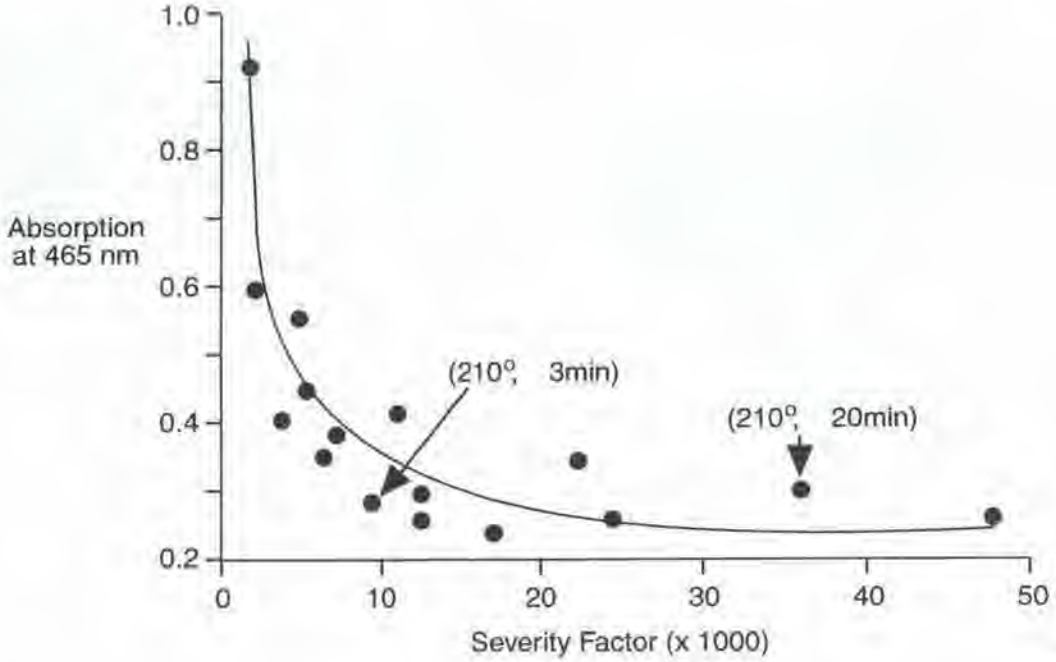
TABLE 2: EFFECT OF STEAM TREATMENT CONDITIONS ON THE SEQUENTIAL EXTRACTABILITY OF PINEBARK USING A VARIETY OF SOLVENTS.

Treatment conditions	Hexane	Toluene	Ethyl acetate	Acetone	Methanol	Water	Total
	(wt % of O.D. bark sample, average duplicate experiments)						
Untreated	2.72	0.99	2.90	14.01	9.75	6.26	36.6
150°C/3 min	2.83	1.01	2.85	6.96	11.47	6.66	31.8
170°C/3 min	3.30	0.93	3.95	7.90	12.00	6.58	34.7
210°C/3 min	3.26	0.98	4.40	5.66	9.12	3.41	26.8
245°C/3 min	3.44	1.23	2.92	4.18	5.06	1.90	18.7
Untreated[1]	1.7	1.6	4.0	13.3	5.0		

[1] Taken from Markham and Porter 1973.

Further evidence for the condensation of water leachable polyphenolics being condensed is shown in Figure 1. In order to facilitate the presentation of results a term embracing the combined influences of temperature and time, "severity factor," has been used. (Overend, Chornet 1987). The substantial reduction in leachable colour as a result of steam treatment is a key finding. The phytotoxicity and colour of bark leachates are the issues of greatest environmental significance. It should be noted that at higher pH (pH 8-10) the colour is released from the matrix due to the solubility of tannins at this pH.

Fig 1: EFFECT OF STEAM TREATMENT CONDITIONS ON THE WATER LEACHABILITY OF COLOURED MATERIALS FROM PINEBARK.



Protein absorption.

The interaction of soluble tannins with proteins is a well known phenomenon. (Hagermann, Klucher 1981). Far less research has been undertaken on polymer based immobilised tannins and their reactions with protein. The greatly reduced water leachability of coloured polyphenolics from steam treated bark and the possibility of composting a protein saturated bark matrix lead us to investigate the options for using the water insoluble matrix as an absorption medium for protein. Figure 2 shows a typical outcome from the protein absorption trials. Absorption is significantly better at lower pH but the quantity of protein absorbed per unit of dry bark equivalent is very low (between 0.3% to 1.0% w/w). Additional work using high strength meat industry processing wastestreams (viz, stickwater) confirmed the ability for the steamed bark to absorb protein but only up to a level of 2% w/w. At this level of absorption it is unlikely that steam treated bark will find application as a matrix for reducing the waste treatment costs associated with high protein discharges.

Metal ion absorption.

The possible use of a bark based matrix as an absorbent for the control of CCA spillages would be an attractive option for the wood processing sector. For this reason the water washed steam treated bark was investigated in this specific application. Figure 3 shows the results obtained. Copper and chromium are absorbed onto the bark matrix and, in these preliminary trials, 56-75% of the elements were removed from solution after a period of 15 minutes. In contrast, arsenic is only poorly absorbed (22% removal).

Fig 2: RELATIONSHIP BETWEEN QUANTITY OF SOLUBLE PROTEIN ABSORBED, PH, PROTEIN SOLUTION STRENGTH AND DOSE RATE OF STEAM TREATED BARK.

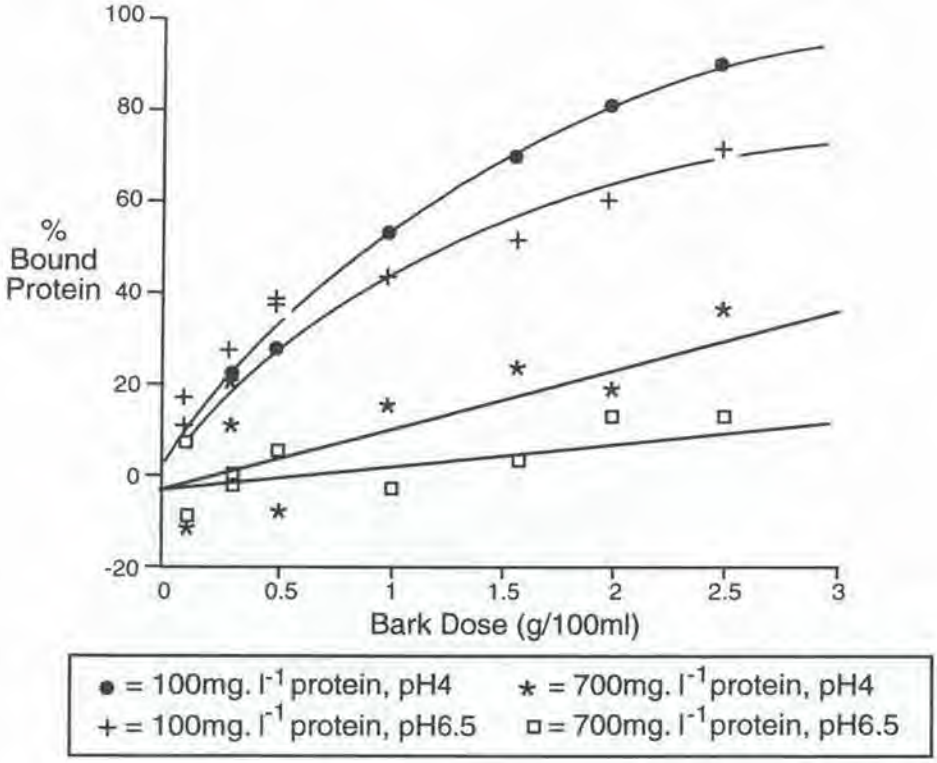
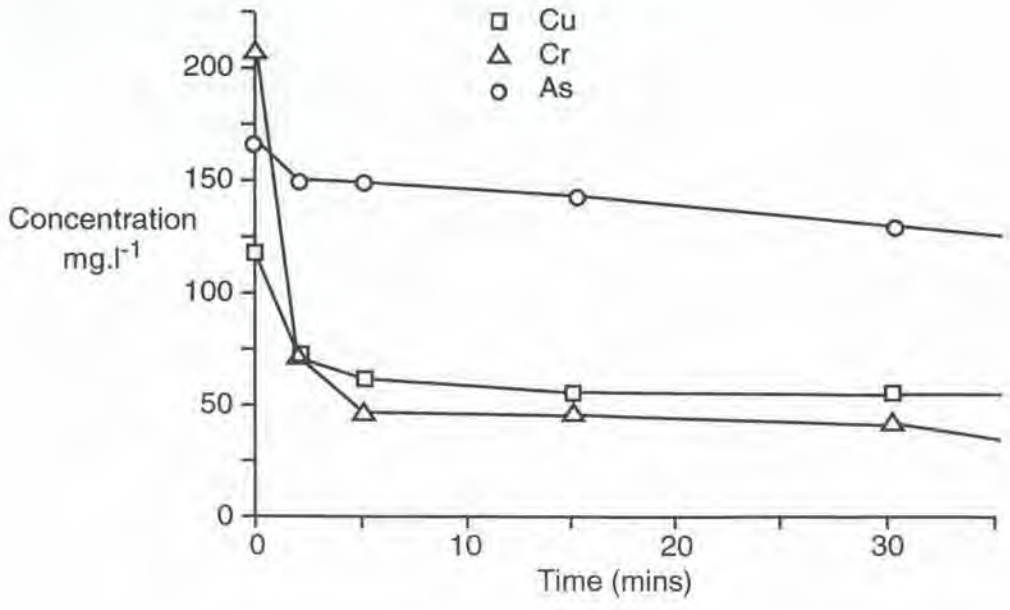


Fig. 3. ABSORPTION OF COPPER, CHROMIUM AND ARSENIC (CCA) ONTO WATER WASHED STEAM TREATED BARK.



Further work (not reported here) has subsequently shown that the capacity for the treated bark to absorb copper and chromium is very low - only approx. 0.1% w/w of each. At these absorption levels it is unlikely that the low cost of such a matrix will offset the high cost but high capacity of more traditional ion exchange media.

Horticultural medium.

Bark has been extensively used as a substrate for composting (Hoitink, Kuter 1983) but problems encountered are (i) a high requirement for nitrogen, (ii) the exudation of coloured leachates from the bark pile, (iii) variability in product toxicity and (iv) poor rewettability of the bark. The qualitative trials undertaken at NZ FRI to date have shown that steam treated bark (water washed), when supplemented with a traditional nitrogen source such as Osmocote™, performs as well as the extensively trialled and proven, fully formulated growth media used in our nursery. The steam treated bark (supplemented with fertiliser) exhibited low phytotoxicity, excellent drainage characteristics and, importantly, good rewettability and water retention. Unlike 100% New Zealand peat or composted bark all of the tested species were able to grow directly in the steam treated bark without inert fillers such as pumice, sand or perlite. The condensation of tannins, removal of carbohydrate and partial hydrolysis of waxes during steam treatment all contribute to the observed plant growth medium properties. More extensive quantitative trials on the use of bark in this way are currently underway at NZ FRI.

ACKNOWLEDGMENTS:

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Influences of climate on wood formation in radiata pine.

Geoff Downes, Rob Evans and Patricia Brennan
CSIRO Division of Forest Products
Private Bag 10, Rosebank MDC, Victoria, 3169.

Summary

The development of new wood analysis equipment within the CSIRO Division of Forest Products makes it possible to examine variation in wood quality in considerably greater detail. Scans of increment cores showing variability in wood properties such as density, radial and tangential cell diameter and wall thickness are now attainable in a few hours. Wood characteristics within a tree, genotype or forest can be analysed non-destructively and used for the purposes of breeding, silvicultural management or decision making in regard to end use. The nature of the data output lends itself to physiological studies of internal and external influences on wood formation.

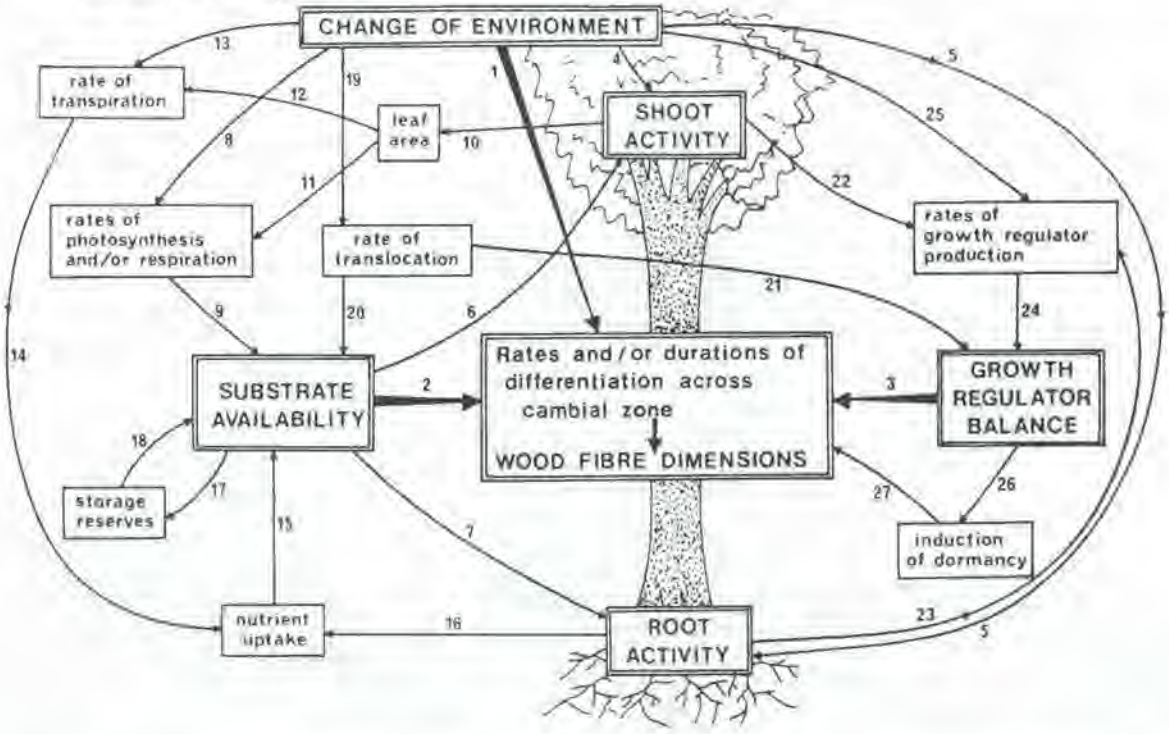
This paper examines the influences of rainfall, temperature and drought on patterns of wood formation within a single tree. Patterns of increasing and decreasing density within annual rings was found to be associated with patterns of increasing and decreasing drought index. Radial diameter was found to be more sensitive than density to drought index variation. Tha application of the analysis system will be a valuable research tool in tree physiology studies.

Introduction.

Wood formation can be influenced by forest growers at the genetic level through tree breeding, or at the silvicultural level through a variety of management options, beginning with site selection, and preparation. The end product used by the forest products industry is the result of a complex series of interactions between genotype, management regimes and environment. The major objective of the commercial forest grower is usually to produce the maximum merchantable volume of wood in the minimum time. Until recently the range of improved genetic stock has been limited, but increased availability is leading to increases in growth rate and reductions in rotation time. The establishment of plantations on more fertile sites, along with more intensive fertiliser regimes, has also led to large increases in growth rates.

Wood is produced by a thin layer of meristematic tissue enveloping the entire surface of the tree. This tissue produces wood cells to the inside and phloem or bark cells to the outside. Many factors control or influence cambial growth, and many reviews and books have been written on the topic (Zimmerman 1964, Fritts 1976, Phillipson et al. 1971, Barnett 1981). Figure 1 shows a diagram produced by Denne and Dodd (1981) which illustrates the many environmental factors that influence the cambium and cause variations in wood properties, however a detailed predictive model is still a long way from being available. Essentially commercial forest practice aims to optimise the match between the cambial processes and the site and management regime, to produce the best type and volume of wood product.

Figure 1 The diagram reproduced from Denne and Dodd (1981) illustrates the complex nature of the influences on cambial activity.



A current research option is to investigate the genetic / environmental interactions of known genetic stock to produce the best return in dollars, volume or a particular grade of timber. Until recently the cost of extensive wood quality measurements has been prohibitive, and most measurments have been of insufficient resolution to relate enviromental changes to changes in the characteristics of wood. The Silviscan system, developed at the CSIRO Division of Forest Products, allows continuous pith to bark measurements to be made of wood density, along with radial and tangential cell diameter (Evans et al. 1993). From these variables other parameters such as, wall thickness and fibre coarseness can be calculated. As most environmental monitoring data is in the form of a time series, it has often been difficult to compare these data with those describing wood characteristics. The data output from this new technology is essentially in a time series format which will allow environmental changes to be examined more thoroughly for their impact on wood formation. In addition the resolution of the data, and the speed with which it can be acquired makes it amenable to more extensive studies of wood variation in softwood plantations. This paper will attempt to demonstrate the type of wood characteristic data now available by examining some of the impact of three environmental variables on wood formation in a single *Pinus radiata*.

Methods.

In July 1992 64 *P.radiata* trees were sampled from Tallaganda, near Canberra. These 19 year old trees were of known genetic origin and were established in 1973 as a CSIRO Division of Forestry progeny trial. One of these trees was examined extensively to determine within tree variation (Evans et al. 1993). This paper will deal with a portion of the data generated in that study.

Continuous pith to bark scans were obtained from 15 heights, and from the four cardinal directions. The data obtained from breast height and from c. 15 metres was examined here. Summary data were extracted from the four cores at each height detailing the minimum, maximum and mean values of density, radial and tangential cell diameter, wall thickness, fibre coarseness and fibre perimeter, along with the positions of the maximum and minimum values and the standard deviations of the mean values. Average growth ring width and area were also calculated from these data.

Weather data for the Tallaganda region had been monitored by the New South Wales Forestry Commission over the course of the trial. Rainfall and temperature were measured daily and from these data the Keetch-Byram drought index was calculated. Measurements were not made directly on site. Average annual values for rainfall,

maximum daily temperature and drought index were determined. In addition the average seasonal values for spring (September, October, November), Summer (December, January, February), Autumn (March, April, May) and Winter (June, July August) were determined. Weather data and wood data were compared using simple correlation analyses.

Results and Discussion.

An advantage of the rapid analysis system is the nature of the data output. Rather than having wood characteristics determined as a few discrete data points, the data is in the form of a continuous scan from pith to bark. In essence it is in the same form as the climatic data. This will ultimately allow us to use different and more powerful statistical techniques for modelling wood formation as a function of external influences acting on the cambium. The data output also allows us to interpret changes in wood density by allowing us to determine cell dimensional changes and thus break density down into its cell diameter and wall thickness components.

Visual associations between climate and wood production

The seasonal pattern of summer drought can be seen over the years 1973 to 1991 in figure 2. In particular the extensive drought period of 1982/83 can be seen as can the winter drought of 1987/88 (arrows). Figure 2 also illustrates the pattern of variation in the density and radial cell diameter traces at breast height. In these traces the annual cycle of earlywood / latewood formation can be seen, along with less uniform patterns of change within each annual ring. In particular the sensitivity of the radial diameter trace to external influences can be seen.

A region of these traces over the period from August 86 to August 88 is shown at breast height (Figure 3a) and at 15 metres (Figure 3b). It should be noted that althought the annual pattern of density variation is chronological, within each year the scale is non-linear in time. Similarities between the density and drought index traces are apparent. A drought index above 30 or 40 appears to be needed before effects on wood density are observed, while the radial diameter trace is more sensitive.

Figure 2. Diagram showing drought index, density, radial and tangential diameter and wall thickness traces over the entire period of tree growth at breast height.

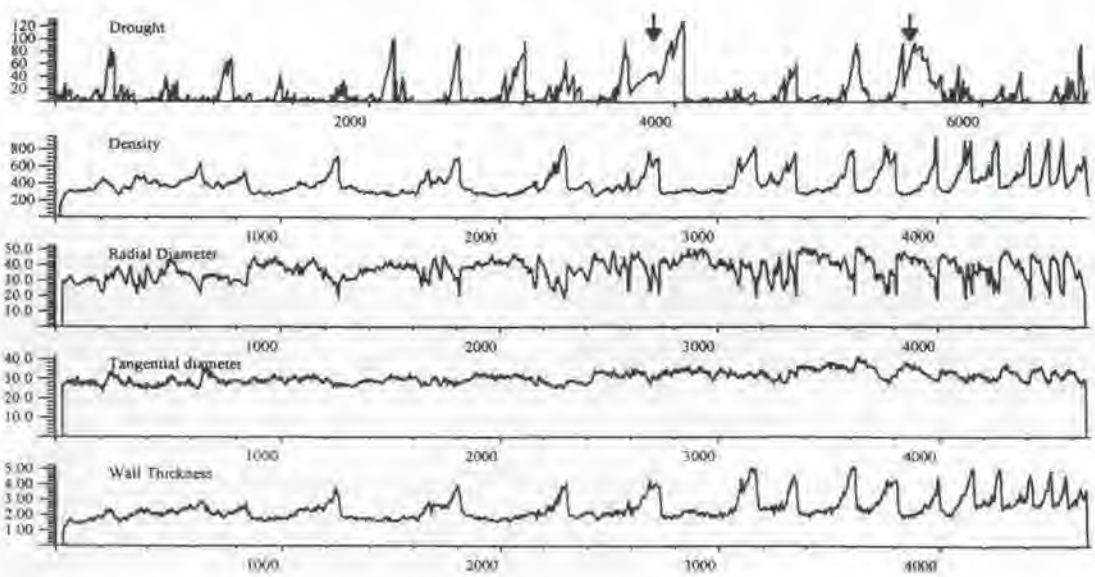
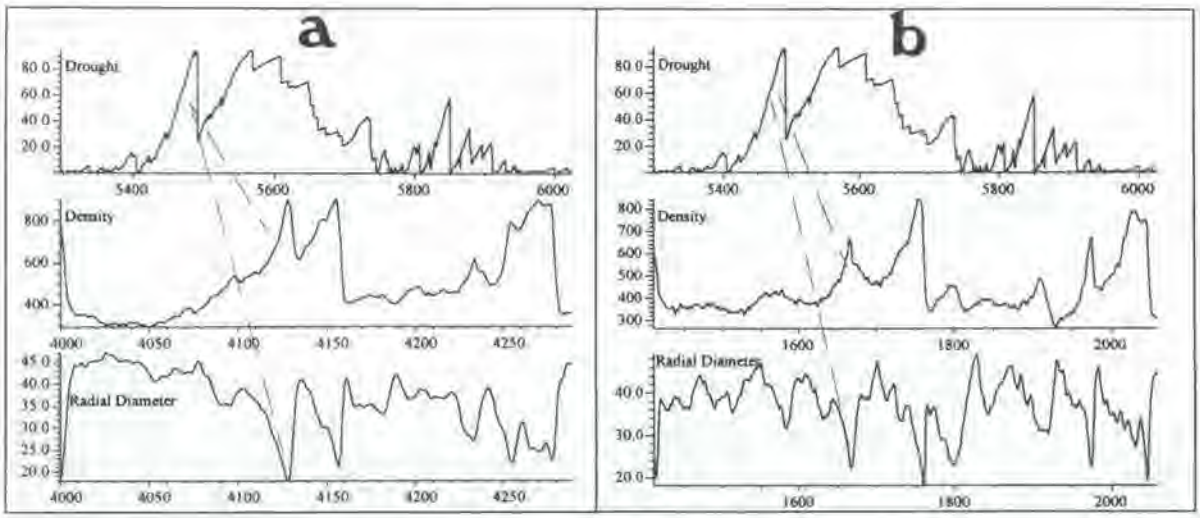


Figure 3. Drought index, density and radial cell diameter for the period August 1986 to August 1988 at (a) breast height and (b) 15 metres. The peaks in the density and radial diameter traces can be attributed to the increase in drought index as shown by the dashed line. Similar effects are observed at breast height and at 15m with the peak at 15m being better resolved owing to the faster rate of cambial division at this point. In most respects the traces obtained from the 15 metre height were more variable, with the trace at breast height having the smoothed appearance.



Correlations between environment and wood formation

Algorithms have been developed for extracting information from the continuous pith to bark traces to produce more manageable summaries of the data. The summaries contain information on the width of each ring, and the maximum, minimum and mean values for density, and radial and tangential cell diameter. Data from the two heights were examined by simple correlation analyses. Only some of the correlations evident will be discussed here.

No significant correlations were observed between the average yearly values for drought, rainfall or temperature and any of the wood characteristics determined at breast height. However if one looked at seasonal averages, several associations became evident (Figure 4). The average temperature of the spring period was positively correlated with the minimum wood density ($r=0.64$; $p<0.01$) as was minimum wall thickness($r<0.57$; $p<0.05$). However no correlation of any of the variables was found with maximum radial or tangential diameter. A positive correlation between the maximum drought index value in the spring period and minimum density was found ($r=0.52$; $p<0.05$) as was a negative correlation between maximum spring drought index and the average radial diameter for the whole growth period ($r=-0.54$; $p<0.05$). Taken together these data might suggest that a higher average spring temperature will favour photosynthate production and increase density by increasing wall thickness, whereas drought stress during this time will tend to increase density by reducing radial diameter. The association between increasing temperature and density is similar to that found in New Zealand (Cown 1991, Harris 1965).

Winter rainfall preceding the spring growth period was positively correlated with the minimum density values obtained in the earlywood, as was the minimum wall thickness and the average density of the complete annual ring. This initially appears counter intuitive in that one would expect increased water availability to lead to faster growth resulting from faster cell division, thinner walls and lower minimum densities. However looking at the winter rainfall over the growing period it is evident that this has been increasing steadily (Figure 5) matching the common increase in earlywood density as one examines rings further from the pith (Figure 6a).

The average drought index over the summer period was found to be negatively correlated with maximum density ($r=-0.58$; $p<0.05$), whereas total rainfall in the winter period was strongly, positively correlated with maximum density ($r<0.84$; $p<0.01$). The lack of correlation between winter rainfall and minimum radial diameter suggests that summer drought limits density increase by limiting cell wall production, either directly or indirectly.

Figure 4. a. The Spring temperature and the low density wood formed over this period were found to be significantly correlated at breast height ($r=0.64$; $p<0.01$). b. The average drought index over the spring period was also significantly correlated with the average radial diameter over an entire annual ring ($r=-0.54$; $p<0.05$). The majority of the large diameter fibres are produced in the spring period. Both plots show a tendency for the data to "spray" out as other influences become limiting to the change in the property.

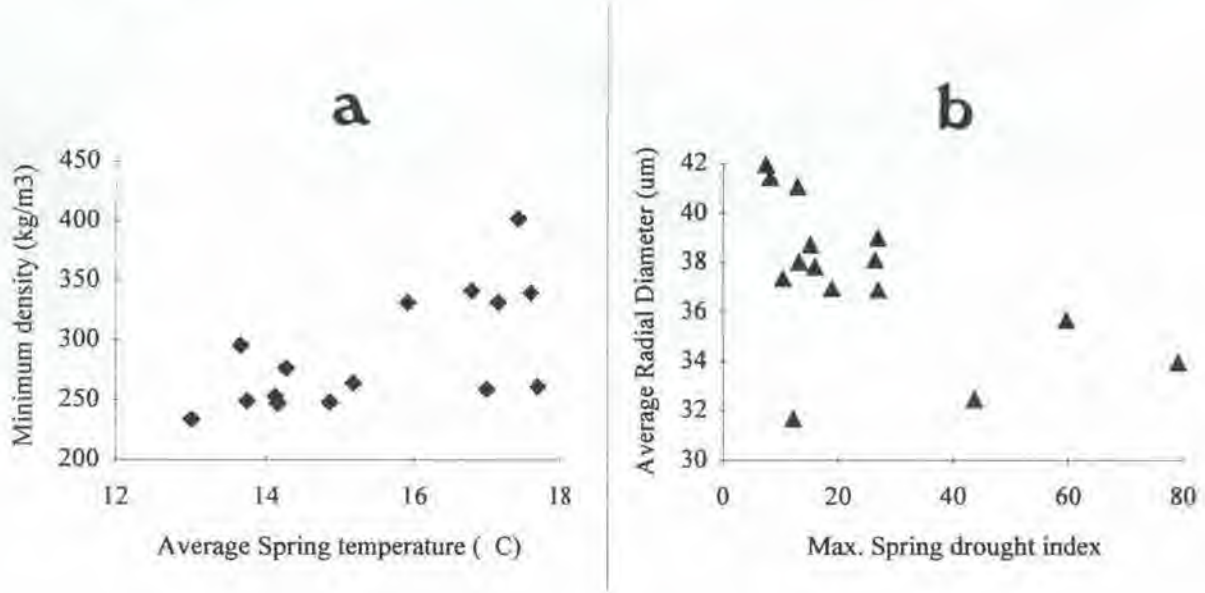


Figure 5. Over the 19 years of plantation growth annual rainfall showed marked fluctuations but appeared to oscillate around a mean value. In contrast the winter rainfall over the period showed an increasing trend. Thus many wood characteristics that normally show an increasing or decreasing trend across a radius, such as average density, also tended to exhibit correlations with winter rainfall.

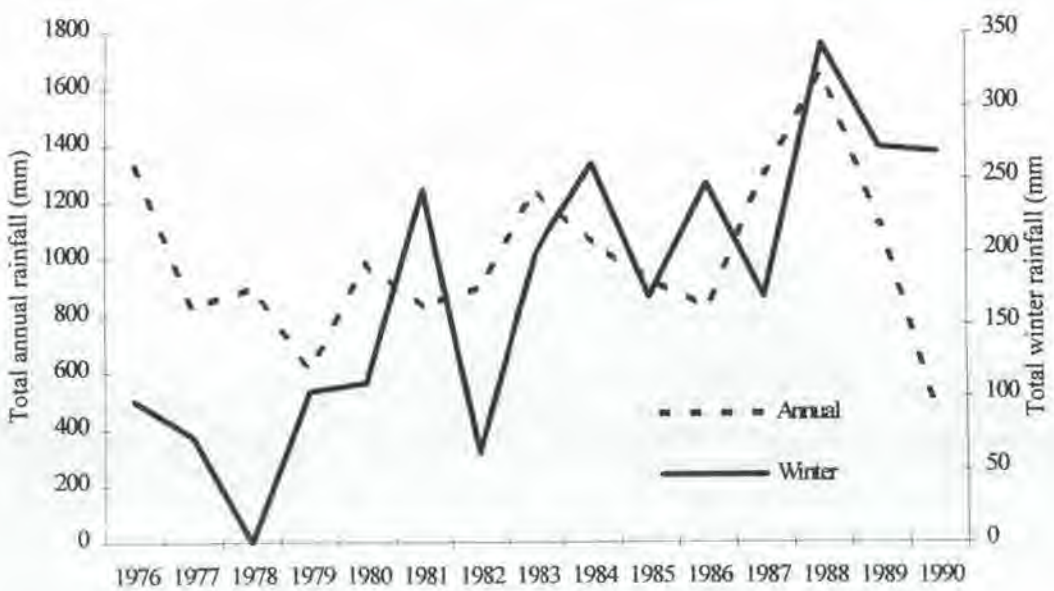
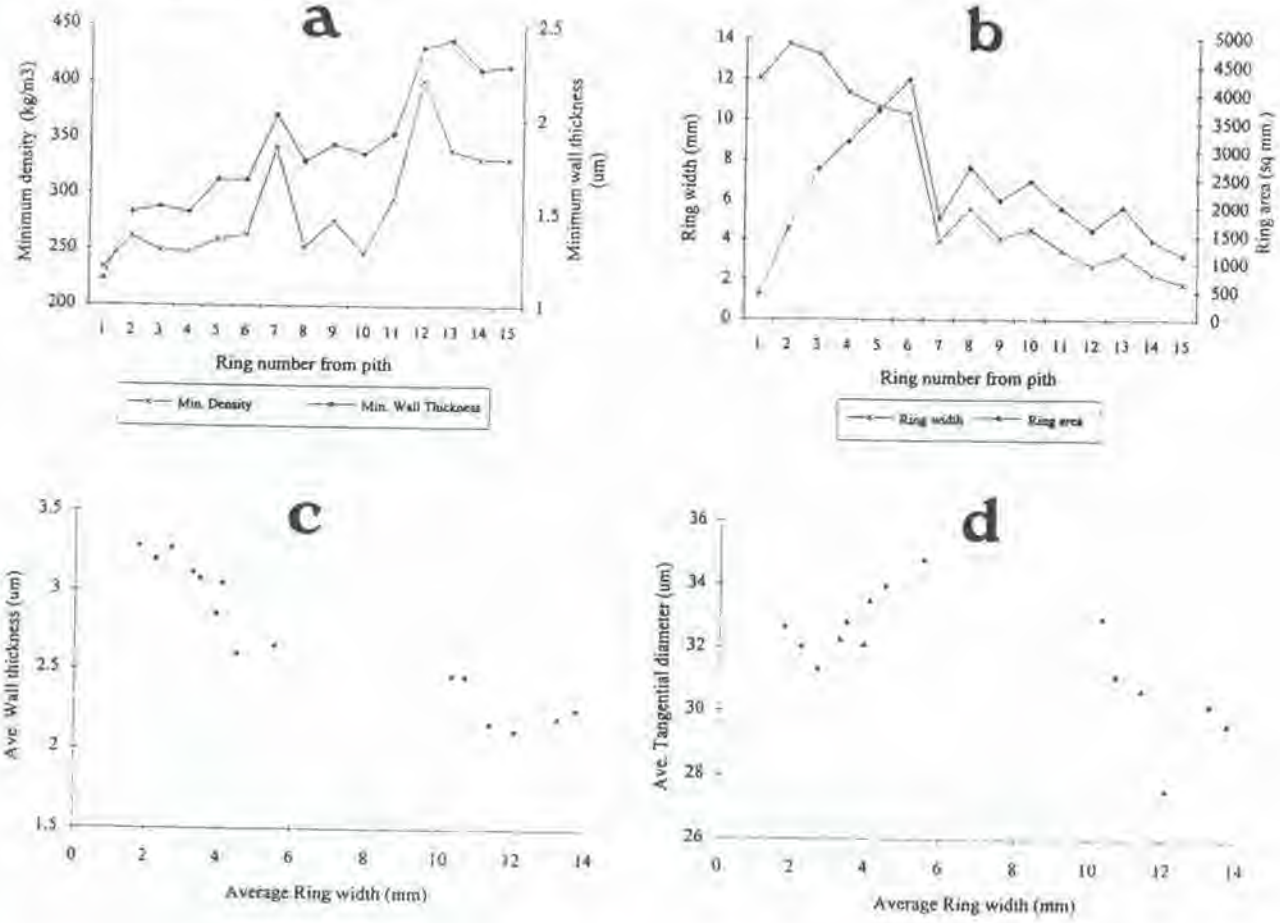


Figure 6. Many wood characteristics are known to vary consistently across the stem radius. (a) Minimum earlywood density tends to increase from the pith, and the wood analysis indicates this is largely attributable to increases in wall thickness. (b) Ring area and ring width plots indicate differences in the first 6 growth rings, probably as the plantation approaches canopy closure. The effect of this on wood properties is seen in plots c & d where the data from the first 6 rings appears to behave as a separate population. These trends are probably indicative of the differences between mature and juvenile wood.



Correlations between different wood characteristics

Wood characteristics vary from the centre of the tree to the cambium, and from the base of the stem to the apex. Figure 6a&b displays some of the relationships between variables at breast height expressed as a function of ring number. It is evident that minimum earlywood density increases from the pith, a trend which is not evident in radial cell diameter. Therefore density increase must be due to increasing wall thickness. The influence of the two major drought periods on increasing minimum density can be seen in this graph. The effect of the juvenile wood produced over the first six growth increments can be seen in Figure 6b, with ring area increasing up to canopy closure, and then decreasing in a similar trend to ring width. The data from these first six rings appears to behave as a separate population as is evident in the relationship between ring width and average tangential diameter (Figure 6d). On the basis of this plot it could be argued that tangential diameter increases with ring width if one excludes the data from the first six rings. An opposite conclusion might be drawn if one considered the ring width data as a whole. Minimum wall thickness shows a marked negative correlation with ring width, including the 6 near rings near the pith (Figure 6c).

The nature of the physiological relationship between cell diameter, wall thickness and density.

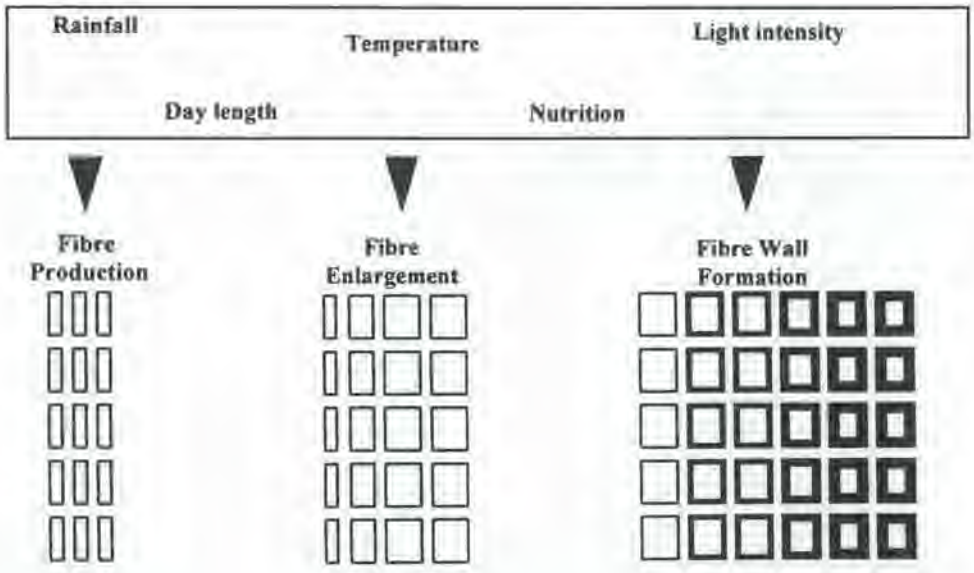
The data presented in this study represent information from a single tree only. Therefore no information is given as to the applicability of the reported relationships to other individuals. The intention was only to show the

relevance of the data output from the rapid analysis system, as reported in Evans et al. (1993), to physiological studies.

There are many internal and external influences acting on the cambium (Figure 1) which increase the noise, or reduce the strength, of simple comparisons of variables such as are produced by correlation analyses. Therefore correlations, or the lack of them, must be considered carefully. For instance the rainfall of the autumn/winter period preceding a growing season will influence the number of needle primordia produced in developing buds (Raison et al. 1992). This dictates the number of needles produced in the following season and hence effect the capacity to fix photosynthate. The length to which needles grow is influenced by the current season temperature conditions. Thus photosynthate may be more limiting to wood production in a year of good rainfall if, during the previous autumn, the tree experienced water stress. However correlation analyses are often useful as a starting point to examine associations between variables, and assist in generating hypotheses to test in future studies.

When one considers the factors controlling radial diameter and density variation it is evident that radial diameter will be influenced in the cambium within the zone of cell expansion (Figure 7). This process preceeds the time of secondary wall formation, with the expansion process being driven by turgor pressure within the developing tracheids (Barnett 1981). Thus it might be expected that this variable would be directly sensitive to water stress (Little 1975). Larson (1964) argues that the effects of water stress on fibre enlargement are indirect, arising primarily from influences of water stress on needle function, essentially influencing growth regulator fluxes.

Figure 7. The process of fibre development can be considered as a sequence of stages ending in cell death. Three stages of cell division, cell expansion and secondary wall development are predominant.



Density variation arises from changes in the number of cells within a given volume in combination with changes in cell wall thickness. Changes in cell wall thickness will operate in cells that have already enlarged, and be affected by the rate and duration of cell wall deposition (Skene 1969). If wall material is deposited at a faster rate one would expect density to increase. Similarly if cell wall material was deposited more slowly, but the cells spend a longer time depositing wall material one would also expect density to increase. This appears to be the situation in latewood production (Skene 1972). How trees regulate the cell differentiation process appears to become more complex the more closely one examines the system.

Cambial growth rates can be considered in terms of the organ as a whole, or in terms of the rate of division of an individual cambial initial. It is evident that annual ring width varies with distance from the pith (Figure 6b). Ring width is a direct reflection of the growth rate of each individual file of cells around the circumference of the stem. In contrast ring area is a reflection of the growth rate of the entire ring of the cambium enclosing the stem at any one point. The faster the cambial initials divide, the more rapidly the cambial tissue will move away from the differentiating cells it produced. The factors which control the longevity of differentiating fibres are still to be clearly identified, however one of the factors appears to be the flow of growth regulators from the crown (Aloni 1987). Factors controlling cell longevity will have a large impact on the amount of cell wall deposited. The entire process starting with cell division in the cambium and ending with cell death after secondary wall production can be considered as a process of controlled cell death. Research directed at understanding and manipulating this process may have some commercial applications in controlling wood quality, in the future.

Conclusions

The application of the Silviscan system will provide a major opportunity to develop our understanding of the factors involved in fibre development. A technology which allows more detailed and more rapid analyses of wood characteristics will be of great value in investigating factors which influence cambial development, allowing us to increase our understanding of wood production and utilisation.

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RAPID MEASUREMENT OF RADIATA PINE PULPWOOD QUALITY

Robert Evans, Geoff Downes, David Menz and Sharee Stringer
CSIRO Division of Forest Products
Private Bag 10, Rosebank MDC, Victoria, 3169

ABSTRACT

A new instrument, Silviscan, has been developed for the rapid analysis of radiata pine pulpwood. Silviscan is designed to automatically measure the variation in density and tracheid cross-sectional dimensions in samples prepared from increment cores. Weighted distributions of several important wood properties are reported, together with means and standard deviations. True radial profiles are obtained even when the core does not pass directly through the pith. Area-weighting and mass-weighting are optionally applied to the results. Ring widths may be obtained by inspection of the unweighted radial profiles. The analysis capabilities of Silviscan were demonstrated by mapping the variation in a number of wood and tracheid properties using sixty radial samples from a single tree.

INTRODUCTION

The papermaking properties of pulpwood are largely determined by the morphology of the constituent fibres. Characteristics such as length, transverse dimensions and fibril angle have long been recognised as controlling factors in pulp fibre quality and paper performance. Traditionally, density has been used with varying success as the major criterion for pulpwood quality. Density variation in softwoods depends mainly on tracheid wall thickness and tracheid diameter. These characteristics have not been measured routinely because of the slowness and labour-intensive nature of quantitative microscopy. This has prevented general application to the thousands of samples generated by tree breeding and silvicultural programs. Appropriate analysis methods should use small wood samples such as increment cores, involve automatic data acquisition, analysis and reporting, give reliable information and cost less than current pulpwood screening methods. This report describes Silviscan, the first automated system capable of meeting these criteria for plantation grown radiata pine (Evans, 1992). An example is given of its application to the detailed mapping of tracheid morphology variation within a single tree from a plantation at Tallaganda, near Canberra (Evans *et al.*, 1993). Within the CRC for Hardwood Fibre and Paper Science, the methods are being extended and new systems constructed to assist in the much more difficult assessment of wood from plantation-grown eucalypts.

In accordance with traditional terminology of the papermaking industry, 'fibre' is used in this report synonymously with 'tracheid'. All density values are those for dried and reconditioned wood.

EXPERIMENTAL

Sample preparation

Fifteen discs were cut from a single 19 year old NZ55 hybrid chosen for its interest to the industry. Each disc was cut from the bark to the pith on the north side to prevented cracking on drying. Radial samples were cut in the north, south, east and west directions with an automated twin-blade saw to give slices 6 mm in the longitudinal direction and 2 mm in the tangential direction. The cut samples were extracted with acetone for at least 18 hours then reconditioned to 23°C and 50% RH. Densities were determined gravimetrically from the dimensions and weights of the samples. One transverse surface of each sample was hand polished with 1200 and 4000 grit abrasive sheets to allow image analysis of the tracheid cross-sections. Fungal growth prevents light transmission and alters wood density. It was therefore essential that samples be dried soon after cutting them from the tree. Storage in ethanol prevented fungal growth, removed water and partially extracted resins from the samples.

Analysis system

A schematic diagram of the experimental arrangement is shown in Figure 1. Silviscan combines the techniques of x-ray scanning densitometry and image analysis to determine the cross-sectional dimensions of the tracheids. Video microscope images of the sample are acquired at the centre of rotation of the goniometer. These are processed to give continuous profiles of radial and tangential tracheid diameters for the sample. In addition, by measuring of the angle of the rings with respect to the sample, Silviscan automatically aligns the rings with the x-ray beam during densitometry. Nickel filtered copper radiation is used with a beam cross-section of 50 μm × 200 μm (horizontal × vertical) at the sample. Each x-ray densitometric profile is normalised to the average gravimetric density of the sample.

RESULTS AND DISCUSSION

A typical contrast-enhanced image is shown in Figure 2. The tendency of the cells to be circular in cross-section is consistent with the formation of mild compression wood reported in studies of NZ55 progeny (Nyakuengama, 1991). An example summary report for the north breast-height radius is given in Figure 3. The profiles and distributions have been area-weighted. Mass-weighted and unweighted summaries can also be produced. In addition to coarseness and wall thickness, the external specific surface area of the tracheids has been calculated. This is expected to correlate with the surface available for interfibre bonding and light scattering in paper. The contribution from the lumen surface could also be included, if required.

Long-term variation

The radial trends in the data were extracted by smoothing, and the results expressed in the form of grey-scale images. The result for east-west and north-south coarseness variation is given in Figure 4. Darker areas represent higher values. General tree structure is more easily visualised when the images are reduced to a few grey levels (Figure 5). The properties in Figure 5, including tree form, have been averaged circumferentially and displayed as a mirror image pair Each half-map contains all the

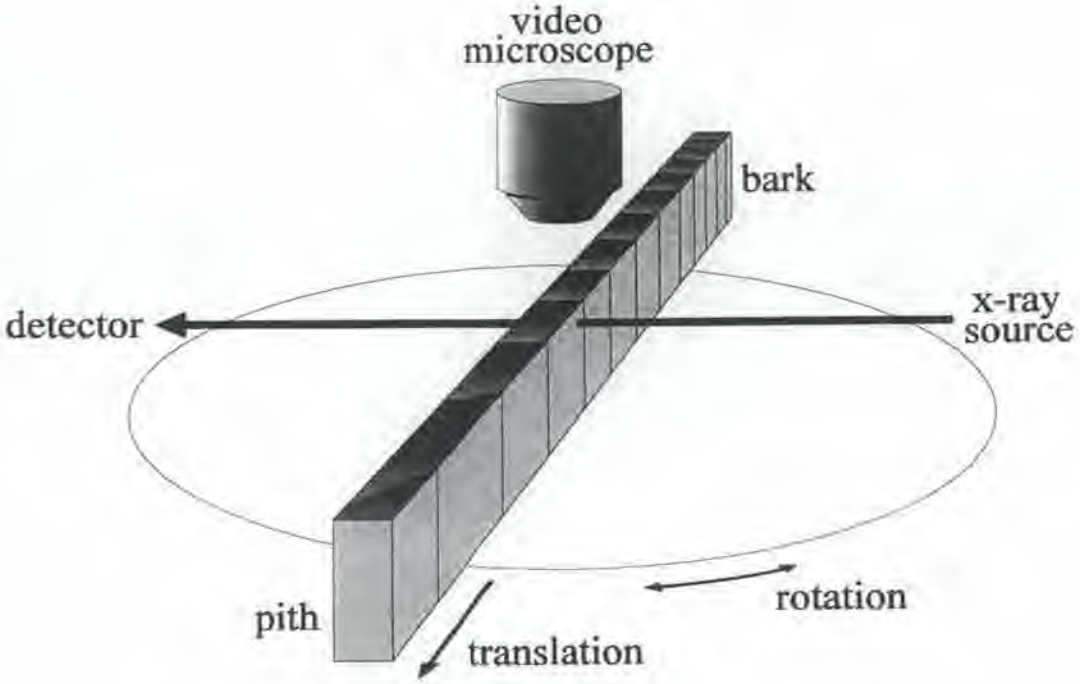


Figure 1 - Schematic diagram of the experimental arrangement

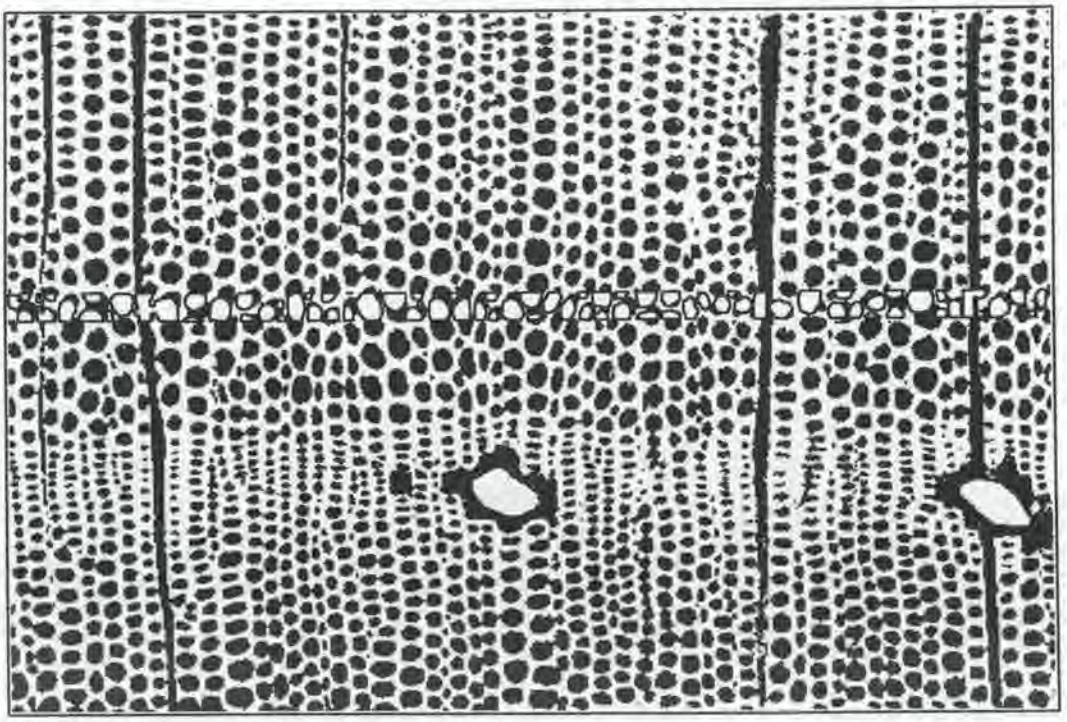
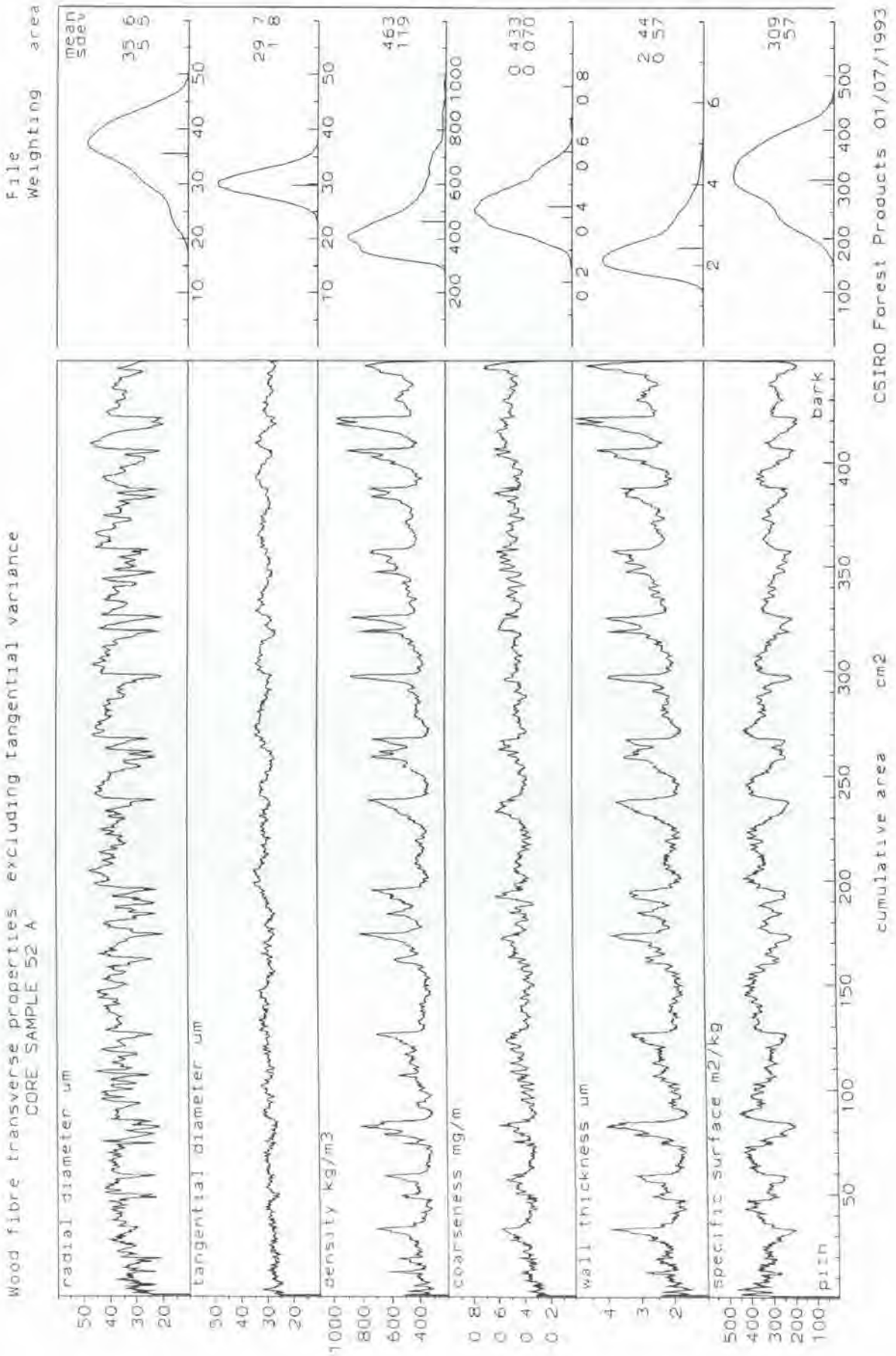


Figure 2 - Partially processed image of 1.5 mm x 1.1 mm section of polished transverse wood surface. The central band indicates the relative width of the x-ray beam.

Figure 3 An example of a report summary sheet



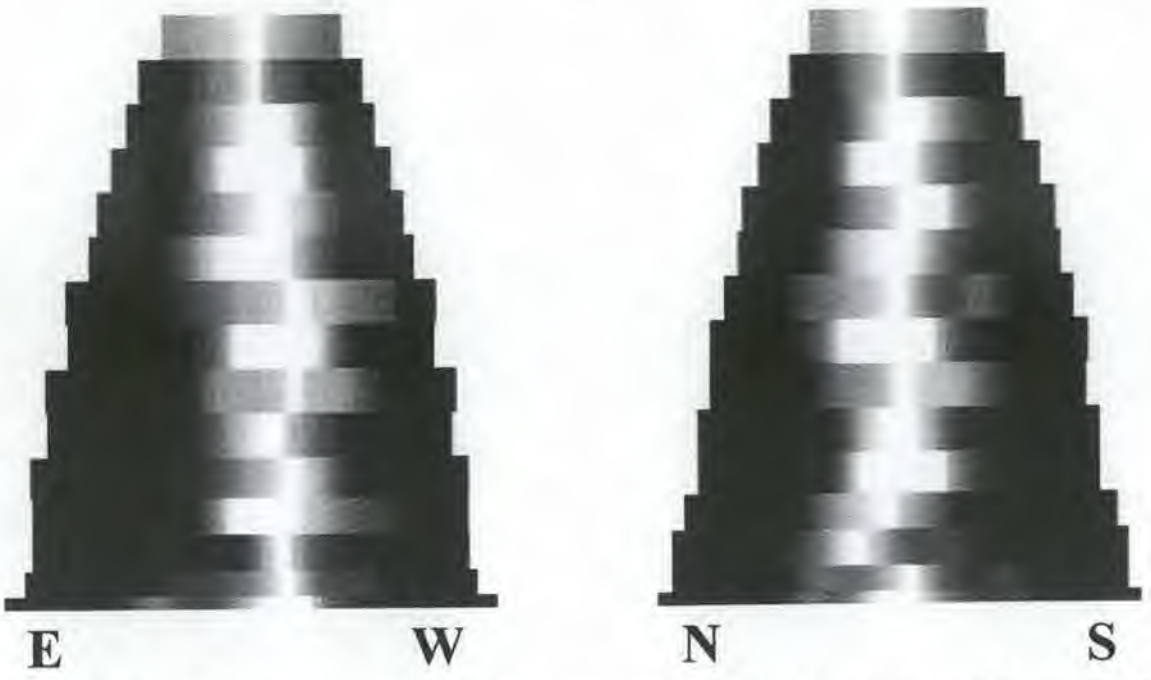


Figure 4 - Grey scale representation of coarseness variation in the east-west (a) and north-south transects of the tree. Each disc is represented according to its contribution to the height and diameter of the tree, with the horizontal scale exaggerated. Darker areas indicate higher coarseness.

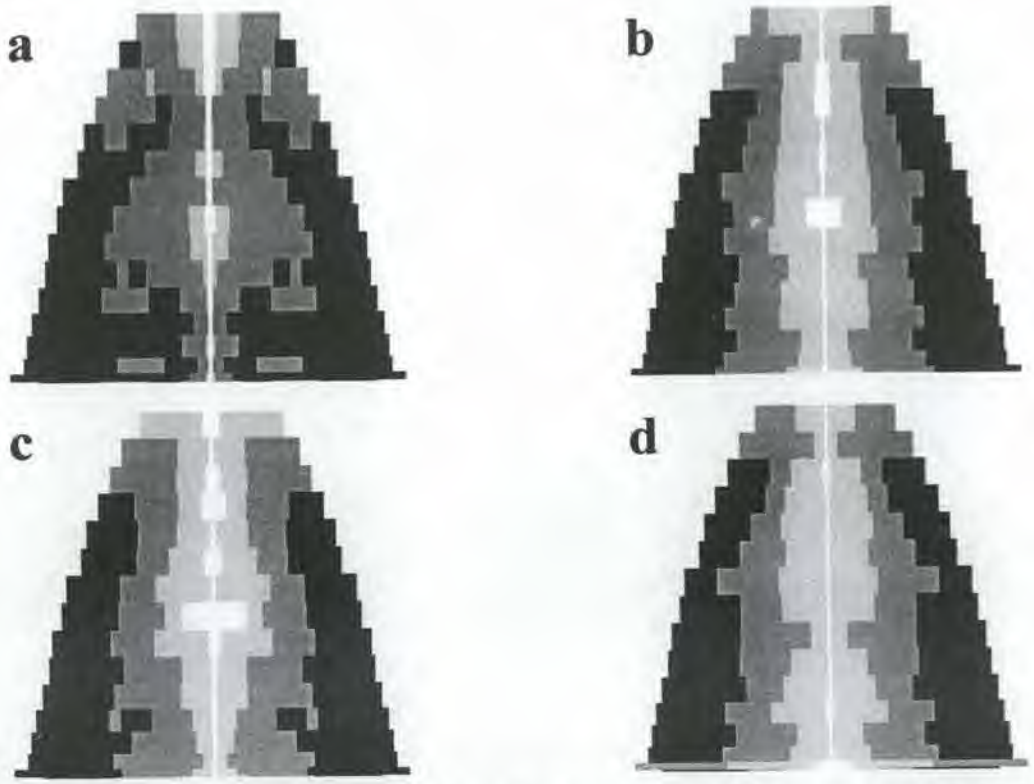


Figure 5 - Average maps of density (a), tracheid coarseness (b), tracheid wall thickness (c), and tracheid perimeter (d). Darker areas represent larger values. The tree has been modeled as radially symmetric.

information for that property. In this tree, spatial density variation was approximately cylindrically symmetric, although some evidence of the shell (ring) structure of the tree is still present in the density map. Variation in coarseness and wall thickness is even more cylindrically symmetric than is density. Except for the top and bottom discs, which had slightly smaller (5%) diameter tracheids, the average tracheid perimeter (or diameter) did not vary significantly (<1%) with sampling height. Average coarseness, wall thickness and density all decreased by 25% from the 0.8 metre level to the 20 metre level. Radial trends were even greater: at breast height, the increase in coarseness from pith to bark was 86% (0.35-0.65 mg m^{-1}). Density increased by 45% (380-550 kg m^{-3}) and wall thickness by 57% (2.1-3.3 μm). Tracheid perimeter increased by 20% (120-145 μm) over the first 5 years then decreased slightly (145-140 μm) to the bark.

In general, the results indicate that, in this tree, tracheid coarseness, wall thickness and density trends were approximately linear from the pith to the bark, and the rate of rise was similar at all sampling heights. Consequently, variation of these properties in the tree was approximately cylindrically symmetric. Theoretically, a conical tree with internal properties exhibiting cylindrical symmetry has the same average properties as those along a radius or diameter at the base of the tree. It is therefore reasonable to expect breast-height cores to correlate well with whole tree properties given the general cylindrical variation in properties. In the case of the more realistic paraboloidal tree form, the theoretical volume-weighted tree average is slightly higher for those properties which increase radially, but is still within a few percent of the unweighted core average. Note that this model applies better to young trees such as those currently used for pulpwood in Australia. Older trees tend to be more conically symmetric (Cown, 1980). Outerwood has been found to be more useful as a predictor of tree properties in the more mature New Zealand *P.radiata*.

Table 1. Comparison of tree properties with those of the disc and cores sampled at breast height.

	whole tree *	**breast-height disc** #	**east-west core**	**north-south core**
density kg m^{-3}	416	440	418	414
wall thickness μm	2.55	2.69	2.52	2.47
coarseness mg m^{-1}	0.491	0.510	0.474	0.460
specific surface m^2 kg^{-1}	288	276	292	296

*estimated from the volume-weighted set of 60 cores

#estimated from the area-weighted east-west and north-south breast-height cores

Table 1 compares selected properties of the whole tree with those of the breast-height disc and cores. The tree properties are volume-weighted, the disc properties are area-weighted and the core properties are

unweighted. The small contribution of the unsampled part of the tree above 20 metres was not estimated. In general, the unweighted core properties were closer to the tree properties. Coarseness was about 5% lower for the cores. These results are presented as illustrative examples; the significance of the comparisons can only be established by sampling many more trees. According to many previous studies (e.g. Zobel and van Buijtenen, 1989, Wheeler *et al.*, 1966), reasonable estimates of whole tree properties can be made based on measurements on breast-height core samples.

Short-term variation

Many genetic and environmental factors influence variation in wood properties. Some factors act over many years to produce slowly changing, or long-term variation such as that associated with the transition from juvenile wood to mature wood. These factors are responsible for the gross internal structure of trees as illustrated by models (Figures 4 and 5). Other factors cause short-term variation resulting in seasonal rings. During the transition from juvenile wood to mature wood, many properties change concurrently. Density increases together with tracheid length, diameter, wall thickness and coarseness. It is not surprising that there are strong long-term correlations between these properties. In the short term, however, these correlations break down. Note in the summary report (Figure 3) that there is little relationship between the short-term variation in wall thickness and that in coarseness. Annual ring structure is almost indiscernable in the coarseness profile. The wall thickness profile retains a strong resemblance to the density profile, with greatly reduced false ring structure. The very poor correlation over the short-term may be indicative of differences in the mechanisms by which cell diameter and cell wall thickness are attained (Timell, 1986). That cell expansion and secondary wall development are temporally distinct is sufficient reason to expect diameter and wall thickness to be largely independent. Tracheid diameter is determined in the first few days after cell division; wall thickness then accumulates over the lifetime of the tracheid. The accumulation of cell wall substance over a period of weeks tends to smooth out the effects of rapid environmental fluctuations. Tracheid diameter, however, is determined in such a short time that variation in this property tends to reflect the environmental variation.

Equipment performance

One of the purposes of the analysis was to estimate the sustainable performance of the system. The experimental section of this study, using 60 radial wood sections, took a total of 60 hours of labour (excluding tree felling and disc cutting) and 160 hours of analysis time. Analysis was dominated by image processing. A total length of 6.5 metres of radial wood section was examined at a rate of *ca* 40 mm/hour. The number of images processed was 6500, and the number of tracheids contributing to the analysis was approximately 8,000,000. This average analysis rate is equivalent to about 14 tracheids per second, which approaches that attained by commercial fibre length analysers. Analysis rates are limited by the computer processing speed. The current rate of development of microcomputers will allow the analysis rate to triple by the end of 1994.

CONCLUSIONS

An automated instrument has been developed which can estimate wall thickness, diameter, perimeter, wall area and coarseness of softwood tracheids in increment cores from *P.radiata* plantation-grown wood. Compensation is made for the effects of varying direction of radial cell growth and varying ring angle across the core. True radial profiles can be determined even where the core is not exactly radial. Weighted distributions can be estimated and the ring pattern reconstructed. Software optimisation and the installation of high speed hardware should eventually allow the analysis of 15-30 radial increment cores per day. Correlations between tracheid properties such as coarseness and wall thickness are strong when ring averages or long term trends are considered, but poor within individual tree rings. Understanding of short-term regulation will lead to more specific control of individual wood properties.

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PLANTATION EUCALYPTS - SURVIVAL OF THE FITTEST

MAX D. WILLIAMS

Experimental Scientist
CSIRO Division of Forest Products
Private Bag 10
Rosebank MDC
Clayton Victoria 3169, Australia

ABSTRACT

High-yield pulping studies were conducted on four young plantation eucalypt species from intensively managed sites of the Esperance Valley in SE Tasmania. Two provenances of three of the species, *E.regnans*, *E.globulus* and *E.nitens*, were selected from each of two sites of different elevation, and one provenance of *E.grandis* was selected from a further site.

Cold soda pulps were prepared using a Sunds Defibrator CD300 pilot plant refiner and paper handsheets made and evaluated. The effects of species, site and provenance on pulping and papermaking properties were examined.

The best handsheet strength properties were recorded by pulps from *E.nitens* and *E.globulus* trees grown at the lowest elevation. There were also greater differences between provenances at this elevation than at the higher elevation. The properties of pulps from *E.grandis* compared poorly with the other species. In general, the species with the thinner cell walls produced the better bonding strengths because of the ease of fibre collapse.

INTRODUCTION

Chemimechanical pulp from eucalypts is made commercially in Australia for local consumption as a component in products such as newsprint, telephone directory and coated magazine papers. Currently, regrowth eucalypt is the predominant raw material for chemimechanical pulp production, however, pulpwood acquisition from eucalypt plantations is becoming increasingly important because of the reduced access to native forests. Because of this, emphasis in the future will focus on improving the quality of the plantation wood resource through an understanding of the relationship between wood morphology and pulping and papermaking properties.

In the Esperance Valley of SE Tasmania, intensively managed eucalypt plantations were established in 1983 by CSIRO Division of Forest Research and the Tasmanian Forestry Commission to determine the seasonal growth and development patterns of various species (1). Samples were taken in September 1991 for both kraft and chemimechanical pulping studies.

This paper reports the latter work where the effect of species, site and provenance on pulping and papermaking properties was investigated.

EXPERIMENTAL

Wood samples

The 8 year old wood samples were randomly selected from sites 1, 2, and 3 at 60, 240, and 440 m elevation respectively in the Esperance Valley, S.E. Tasmania. Five trees from each of two provenances of *E.globulus*, *E.nitens* and *E.regnans* from both sites 1 and 3, and ten trees from one provenance of *E.grandis* from site 2, were felled, measured and cut into one metre billets. Each billet was tagged for identification.

The billets were chipped using a commercial chipper, and the woodchips from each tree lot remaining after sampling for chemical pulping were combined to create a composite mixture for the present mechanical pulping study. Each composite sample was made up of the 5 trees in the case of *E.globulus*, *E.nitens* and *E.regnans*, and 10 trees in the case of *E.grandis*.

The *E.regnans* A1 provenance sample from site 1 was contaminated with another sample during composite preparation and as such could not be included in the pulping phase of the study.

Table 1
Selected species and provenances

Sub-genus	Species	Code	Source	Altitude (m)
Monocalyptus	*E. regnans*	A1	Moogara, Tas.	550
		A2	Traralgon Creek, Vic	500
Symphyomyrtus	*E. globulus*	B1	Geeveston, Tas.	200
		B2	Otways, Vic.	125
	E. nitens	D1	Toorongo, Vic.	900
		D2	Errinundra, Vic.	1070
	E. grandis	F	Coffs Harbour, NSW	135

The provenances for the selected species are shown in Table 1. *E.nitens* provenance D2, is now known as *E.denticulata*.

Site factors

Turnbull *et al* (1) have documented various site factors. All sites were of average or above average site index classification, and were of similar topography. Each site was sprayed with a herbicide mixture prior to planting, and fertilizer was applied during tree growth. A regular insecticide spraying program was also carried out. The average temperature at 60 m (site 1) was about 6°C warmer than the average at 650 m (site 4). At this latter site, freezing temperatures and snow damage resulted in the severe curtailment of growth, or even death of *E.globulus* and *E.regnans*.

Woodchip pretreatment and refining

The woodchip samples were pretreated in a 20 g/L caustic soda solution overnight at ambient temperature, and then transferred to the hopper of a Sunds Defibrator CD300 single disc pilot plant refiner (3). Primary refining was carried out at ambient temperature. Secondary refining was conducted in a Sunds Defibrator ROP-20 open discharge refiner.

Replicate runs were carried out on each woodchip sample and pulp from each was evaluated.

Pulp evaluation

Latency was removed from the washed pulps according to Australian Standard AS1310.215s-89. Handsheets were conditioned at 23 °C and 50% relative humidity, and evaluated according to AS1301.208s-89 except that Gurley air resistance is reported as log s/100 mL rather than air permeance. The values for the papermaking properties given in the tables are averages of data from duplicate evaluations, expressed in terms of o.d. grammage. Results from the replicate refiner runs are included as separate entries in each Table.

Fibre length was measured with a Kajaani FS200 fibre analyser, and is reported as length weighted average.

RESULTS AND DISCUSSION

Anatomical properties of the wood

The cell wall thicknesses (Table 2) varied between the species. Pronounced differences can be seen for the earlywood and latewood of each species. Generally, the thicker the cell wall, the more difficult it is to collapse the fibre during refining. The greater the fibre collapse, the better is the fibre bonding, and the stronger is the product.

Table 2
Cell wall thickness (μm)

Species	*E. regnans*		*E. globulus*		*E. nitens*		*E. grandis*
Site/prov.	S1,A1	S1,A2	S1,B1	S1,B2	S1,D1	S1,D2	S2F
Earlywood	1.2	1.0	1.3	1.3	1.1	1.3	1.5
Latewood	2.1	2.1	2.7	1.9	2.2	2.6	2.2

Papermaking properties

Fibre fractions and pulp evaluation data are given in Tables 3-6. Figures 1-8 have been prepared to illustrate the effect of site, species and provenance on the pulping and papermaking properties.

(a) Effect of site

The graph of tensile index versus freeness (Fig.1) for *E.nitens* D2, shows that the tensile index at a given freeness is higher at site 1 than at site 3. It is evident from the Tables that with the exception of *E.globulus* B2, the other species also show a slight strength advantage at site 1.The Tables also indicate that at a given freeness, the bulk is the same at sites 1 and 3 for each species. Furthermore, there is no change in the relationship between air resistance and bulk. This suggests that site has no effect on the production of fines.

From the Tables it is also evident that for each species, fibre length at a given tensile index does not change from site 1 to site 3. Since fibre length is closely correlated with tearing strength (4), it is not surprising to find that there is no effect of site on the tear tensile relationship.

Table 3
Handsheet properties of chemimechanical pulps from *E. regnans*

Site no.	Prov. code	Free-ness (CSF)	Energy input (kWh/t)	Bulk (cm^3/g)	Tear index (mNm^2/g)	Tensile index (Nm/g)	Stretch (%)	Burst index ($kPam^2/g$)	Air resist. (Log s)	Fibre length (mm)*	Unbl. b/ness (% ISO)	Light scatt. coeff. (m^2/kg)
1	A2	502	961	2.26	3.6	28.9	1.3	1.0	0.5	0.76	52.9	54.2
		356	1212	2.07	4.3	38.5	1.7	1.6	1.0	0.70		50.9
		316	1274	2.03	4.2	39.9	1.6	1.7	1.2	0.69		53.3
		294	1207	2.01	4.3	42.8	1.7	1.9	1.1	0.69	50.6	49.6
		221	1431	1.88	4.7	49.5	2.0	2.4	1.3	0.68		49.0
		175	1647	1.81	4.4	53.4	2.3	2.6	1.7	0.66		50.9
		157	1677	1.81	4.9	53.7	2.2	2.5	1.7	0.67		52.1
3	A1	404	886	2.07	3.7	33.3	1.4	0.9	0.6	0.73	42.7	46.3
		353	981	2.09	4.1	35.7	1.6	1.0	0.9	0.73		46.9
		297	932	2.04	3.9	38.3	1.4	1.7	0.9	0.74		46.8
		249	1193	2.03	3.8	39.2	1.5	1.3	1.2	0.70		48.1
		172	1531	1.92	4.2	45.4	1.9	1.7	1.6	0.70		51.2
		150	1650	1.88	4.1	50.7	2.0	2.3	1.8	0.69		51.4
3	A2	425	945	2.20	3.6	32.4	1.4	1.3	0.8	0.73	44.2	48.6
		336	1117	2.02	4.2	36.6	1.5	1.5	0.9	0.71		47.5
		299	1107	2.03	3.8	38.0	1.6	1.6	0.8	0.70		49.1
		203	1484	1.84	4.4	44.6	1.9	2.1	1.6	0.67		48.2
		149	1743	1.83	4.7	49.6	2.2	2.4	1.8	0.65		49.6

* Kajaani FS200 length weighted average

For the graph of tensile index versus energy input (Fig.2), the plots for *E.regnans* A2, and *E.globulus* B1 show that more energy is required to refine to a given tensile strength at site 3 than at site 1. This effect is more pronounced at a higher tensile index value. From the Tables it can be seen that the other species, with the exception of *E.nitens* D1, also behave in this manner.

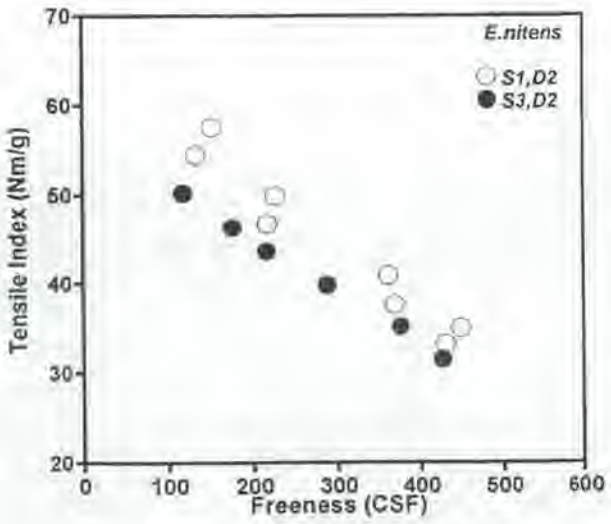

Fig. 1 - Tensile index versus freeness

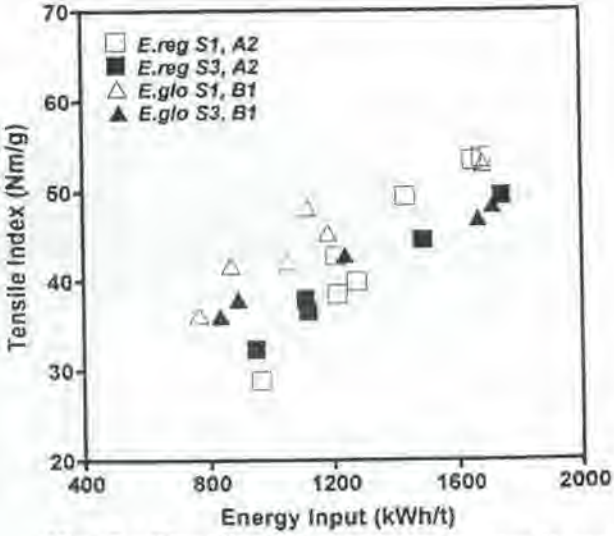

Fig. 2 - Tensile index versus energy input

The unbleached brightnesses on selected pulp samples for all species are given in the Tables. It is clear that the brightnesses for species is lower at site 3 compared with the same species at site 1. For example, the percent ISO brightnesses of *E.regnans* A2 and *E.nitens* D1 and D2 drop from the low 50's to the low 40's, for sites 1 and 3 respectively. Subsequent alkaline peroxide bleaching trials (5) have indicated that species with low initial brightnesses generally require more bleaching chemical to achieve the same final brightness than those with higher initial values.

Table 4
Handsheet properties of chemimechanical pulps from *E. globulus*

Site no.	Prov. code	Freeness (CSF)	Energy input (kWh/t)	Bulk (cm^3/g)	Tear index (mNm^2/g)	Tensile index (Nm/g)	Stretch (%)	Burst index ($kPam^2/g$)	Air resist. (Log s)	Fibre length (mm)*	Unbl. b/ness (% ISO)	Light scatt. coeff. (m^2/kg)
1	B1	427	765	2.07	4.5	35.9	1.7	1.4	0.4	0.82	48.2	41.5
		371	866	2.01	5.0	41.4	1.6	1.8	0.4	0.82		40.5
		318	1050	1.98	5.2	41.8	1.9	1.9	1.0	0.81		41.1
		254	1115	1.92	5.4	47.9	2.0	2.1	1.0	0.79		42.8
		242	1183	1.93	5.6	45.1	2.0	2.1	1.2	0.78		43.2
		126	1682	1.81	5.3	52.8	2.4	2.8	1.9	0.72		45.6
1	B2	425	692	2.14	3.9	34.1	1.5	1.2	0.4	0.81	46.6	40.9
		410	777	2.07	4.2	36.7	1.5	1.4	0.4	0.81		40.5
		316	854	2.15	4.1	35.9	1.5	1.3	0.8	0.79		42.4
		305	902	2.15	4.4	39.3	1.6	1.6	1.6	0.79		42.3
		219	1062	1.99	4.7	42.8	1.9	1.8	1.2	0.77		43.7
		171	1225	1.98	4.8	48.0	1.8	2.1	1.3	0.77		42.8
		116	1575	1.80	5.1	58.6	2.4	2.7	1.9	0.72		47.3
3	B1	420	832	2.06	4.6	35.8	1.4	1.5	0.5	0.80	43.7	40.4
		375	889	2.06	4.3	37.7	1.5	1.7	0.5	0.81		41.5
		269	1237	1.96	5.3	42.6	1.8	1.9	1.0	0.78		43.3
		198	1665	1.91	4.7	46.7	2.1	2.2	1.3	0.76		44.0
		147	1713	1.90	5.2	48.2	1.9	2.5	1.7	0.75		44.9
		99	-	1.80	5.4	54.3	2.1	2.6	2.1	0.75		45.4
3	B2	457	828	2.09	3.9	34.6	1.4	1.5	0.4	0.82		38.7
		356	990	2.16	3.7	36.7	1.4	1.4	0.7	0.81	39.3	45.7
		354	961	2.02	4.2	37.8	1.5	1.8	0.7	0.80		40.9
		272	1010	1.98	5.0	41.6	1.7	1.8	0.9	0.78		41.7
		156	1788	1.83	5.2	51.3	2.2	2.6	1.6	0.76		43.6
		154	1400	1.83	5.0	51.2	2.0	2.6	1.5	0.76		43.6
		121	1699	1.82	5.0	54.5	2.2	2.7	1.8	0.75		47.5

* Kajaani FS200 length weighted average

(b) Effect of species

To determine the effect of species on the pulping and papermaking properties, the better provenance from each species at site 1 has been compared. Included is *E.nitens* D1, *E.globulus* B1, and *E.regnans* A2. Since *E.grandis* is only found at site 2, it has also been included.

In the graph of tensile index versus freeness (Fig.3), it is clear that *E.nitens* has the highest strength at a given freeness, slightly higher than *E.regnans* and *E.globulus* which have similar properties. While it is obvious that *E.grandis* has very poor properties compared with the other species, it is not known whether this behaviour is an effect of species, of site, or a combination of both.

In the graph of bulk versus freeness (Fig.4), the bulk at a given freeness is about the same for *E.nitens* and *E.globulus*, and marginally higher for *E.regnans*. However, *E.grandis* has a significantly lower freeness at a given bulk, suggesting that a greater proportion of fines has been produced. The higher fines content is consistent with *E.grandis* having the highest cell wall thickness, since more fibre damage would result during refining because the thicker cells would require more work to develop conformability.

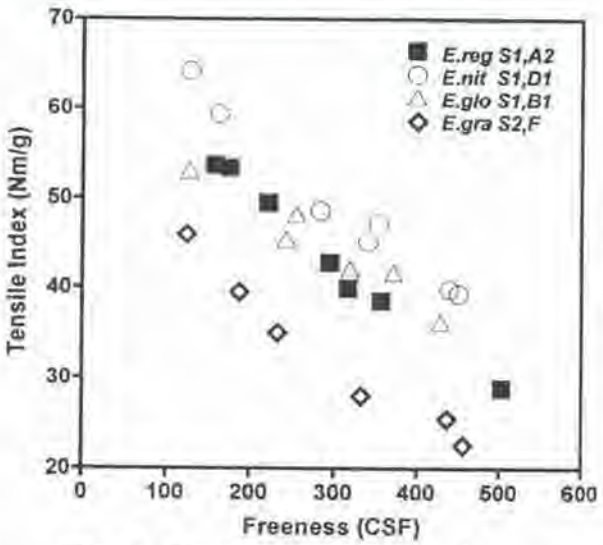

Fig. 3 - Tensile index versus freeness

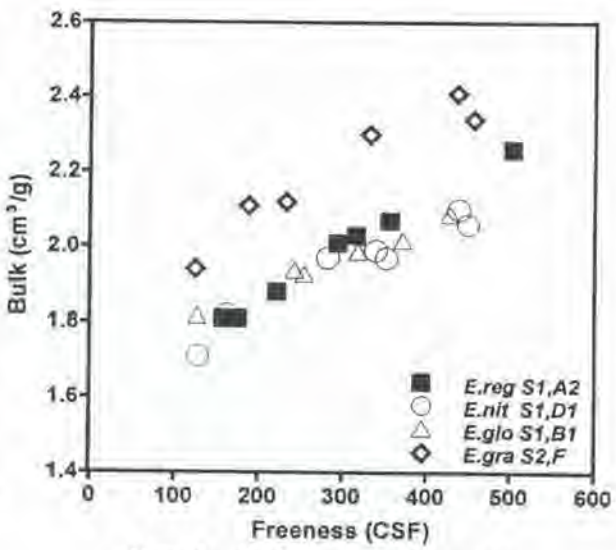

Fig. 4 - Bulk versus freeness

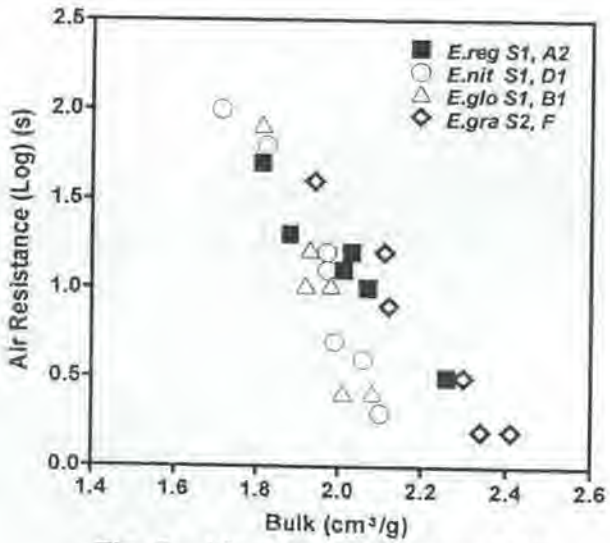

Fig. 5 - Air resistance versus bulk

The amount of fines produced for each species can also be assessed by the relationship of air resistance and bulk (Fig.5). At the same bulk, the air resistance is lower for *E.nitens* and *E.globulus* compared with *E.regnans* and *E.grandis*, particularly as the bulk is increased. This means a lower fines production for the former two species, and conversely a higher production for the latter two.

Table 5
Handsheet properties of chemimechanical pulps from *E. nitens*

Site no.	Prov. code	Free-ness (CSF)	Energy input (kWh/t)	Bulk (cm^3/g)	Tear index (mNm^2/g)	Tensile index (Nm/g)	Stretch (%)	Burst index ($kPam^2/g$)	Air resist. (Log s)	Fibre length (mm)*	Unbl. b/ness (%ISO)	Light scatt. coeff. (m^2/kg)
1	D1	449	1072	2.06	4.6	39.3	1.7	1.7	0.6	0.76	54.2	51.1
		438	794	2.10	5.1	39.8	1.4	1.6	0.3	0.78		45.5
		352	1176	1.97	4.8	47.2	1.9	2.0	1.1	0.74		48.7
		339	966	1.99	5.4	45.1	1.6	2.0	0.7	0.78		45.0
		282	1169	1.97	5.1	48.6	1.7	2.2	1.2	0.75		46.8
		162	1811	1.82	5.5	59.4	2.4	2.9	1.8	0.70		51.0
		127	1798	1.71	6.0	64.2	2.4	3.7	2.0	0.70		47.7
1	D2	448	849	2.16	4.8	35.0	1.4	1.7	0.4	0.77	49.4	45.6
		430	693	2.18	4.2	33.2	1.6	1.2	0.6	0.73		47.9
		369	872	2.15	4.5	37.7	1.5	1.2	0.7	0.73	51.6	49.3
		361	995	2.07	4.4	40.9	1.6	2.0	0.8	0.72		47.5
		226	1328	1.96	5.1	50.0	2.0	2.3	1.5	0.69		47.3
		217	1247	2.03	4.4	46.8	1.8	1.7	1.3	0.70		52.3
		152	1639	1.86	5.4	57.6	2.4	2.7	1.7	0.68		50.7
		133	1681	1.85	4.9	54.5	2.1	2.3	1.8	0.68		53.8
3	D1	451	665	2.01	4.6	38.7	1.5	1.6	0.6	0.79		41.7
		409	825	2.10	4.5	34.3	1.3	1.4	0.6	0.77	43.1	45.9
		355	1070	2.02	4.3	39.6	1.5	1.7	0.7	0.75		44.1
		213	1317	1.85	5.0	52.2	2.1	2.6	1.4	0.72		46.0
		164	1462	1.81	5.3	53.6	2.3	2.7	1.7	0.71		46.3
		160	1497	1.79	4.9	53.6	2.0	2.5	1.7	0.71		48.1
3	D2	426	950	2.19	3.8	31.5	1.5	1.3	0.4	0.72	40.7	47.7
		376	1024	2.11	4.2	35.2	1.6	1.5	0.6	0.71		45.5
		287	1250	2.05	4.2	39.9	2.0	1.6	1.0	0.69		46.6
		216	1300	2.02	4.2	43.7	2.0	2.2	1.3	0.68		52.7
		176	1491	1.96	4.7	46.4	2.1	2.2	1.0	0.67		46.1
		118	1873	1.92	4.8	50.3	2.3	2.6	1.7	0.66		52.5

* Kajaani FS200 length weighted average

The Tables show that for tensile index versus energy input, *E.grandis* from site 2 requires more energy to develop the same tensile strength than the species from site 1. This is consistent with the evidence that it has thicker cell walls compared with the other species. Conversely *E.nitens*, which is one of the thinner cell walled species, required a lower energy. However, *E.regnans* has the thinnest cell walls, and one would have expected this species to behave more like *E.nitens*. From the results it is evident that *E.regnans* requires less energy than *E.grandis* but substantially more than the other species to refine to the same tensile strength.

The relationship between tear and tensile indexes (Fig.6), shows that *E.grandis* has the lowest tearing strength at a given tensile index. This is more pronounced at lower tensile strengths. *E.regnans* shows a higher tearing strength than *E.grandis* at a given tensile index, but is less than for *E.nitens* and *E.globulus*. The graph of fibre length versus tensile index (Fig.7), shows clearly that *E.nitens* and *E.globulus* have the longer fibre lengths, compared with *E.regnans* and *E.grandis*. This is to be expected since the longer the fibre length, the greater is the tearing strength.

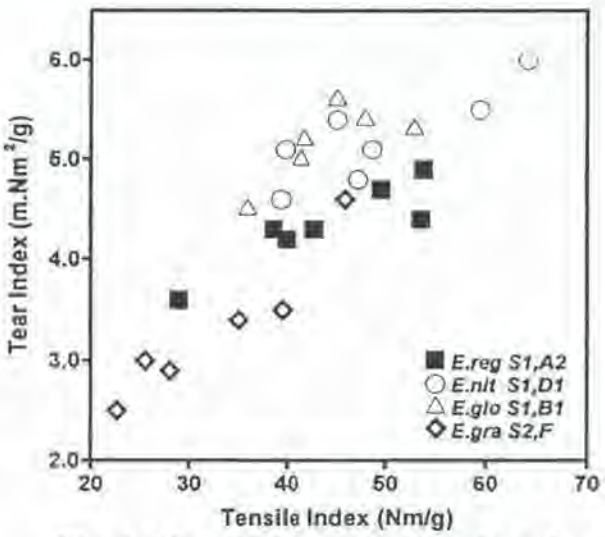

Fig. 6 - Tear index versus tensile index

The Tables show that the light scattering coefficients for *E.regnans* and *E.nitens* are in the general range of the high 40's to the low 50's, while *E.globulus* and *E.grandis* are in the low to mid 40's range. This means that for the latter two species, more filler may be required to improve sheet opacity in a commercial papermaking operation, particularly for products such as newsprint.

Table 6
Handsheet properties of chemimechanical pulps from *E. grandis*

Site no.	Prov. code	Free-ness (CSF)	Energy input (kWh/t)	Bulk (cm^3/g)	Tear index (mNm^2/g)	Tensile index (Nm/g)	Stretch (%)	Burst index ($kPam^2/g$)	Air resist. (Log s)	Fibre length (mm)*	Unbl. b/ness (% ISO)	Light scatt. coeff. (m^2/kg)
2	F	456	888	2.34	2.5	22.6	1.1	0.3	0.2	0.78	37.0	40.3
		436	815	2.41	3.0	25.5	1.0	0.8	0.2	0.72		40.2
		332	1098	2.30	2.9	28.0	1.3	0.7	0.5	0.75		45.1
		232	1331	2.12	3.4	35.0	1.6	1.1	0.9	0.73		50.4
		187	1342	2.11	3.5	39.5	1.7	1.2	0.72	0.69		44.5
		124	1641	1.94	4.6	45.9	1.9	2.1	1.6	0.78		45.9

* Kajaani FS200 length weighted average

(c) Effect of provenance

For provenance comparisons, the results show that for *E.regnans* it is difficult to assess the overall differences because A1 was not tested for site 1. However, it appears that A1 and A2 at site 3 have very similar pulping and papermaking properties (Table 3), and on the basis of these data it can be concluded that there is no difference between *E.regnans* provenances A1 and A2.

For *E.globulus*, the papermaking properties of provenance B1 appear to be better that those of B2 (Table 4). When compared at site 1, B1 gives a marginally higher tensile strength and a lower bulk at a given freeness, a slightly lower tensile at a given bulk, and a higher tearing strength at the same tensile index. For site 3, with the exception of tear index, where B1 was greater at a given tensile index, the papermaking properties for B1 and B2 were similar. However, at a given tensile index, a higher refining energy was required by B1. Both provenances exhibited similar fibre lengths at both sites 1 and 3.

For *E.nitens*, provenance D1 produced the better pulping and papermaking properties when compared with provenance D2 at sites 1 and 3 (Table 5). At about the same time as the samples were collected, an article by Cook and Ladiges (6) presented evidence that recognises the provenance of *E.nitens* from Errinundra (D2) in Victoria Australia, as *E.denticulata*. The authors claim that the seedlings of *E.denticulata* are much less frost resistant than those of *E.nitens*. They also claim that *E.nitens* grows at a much faster rate than does *E.denticulata*, indicating a competitive advantage to the former. Perhaps this may explain the differences in pulping and papermaking behaviour between the two.

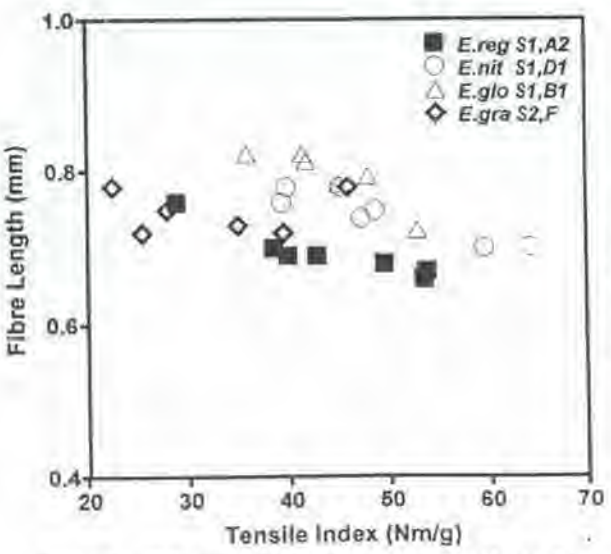

Fig. 7 - Fibre length versus tensile index

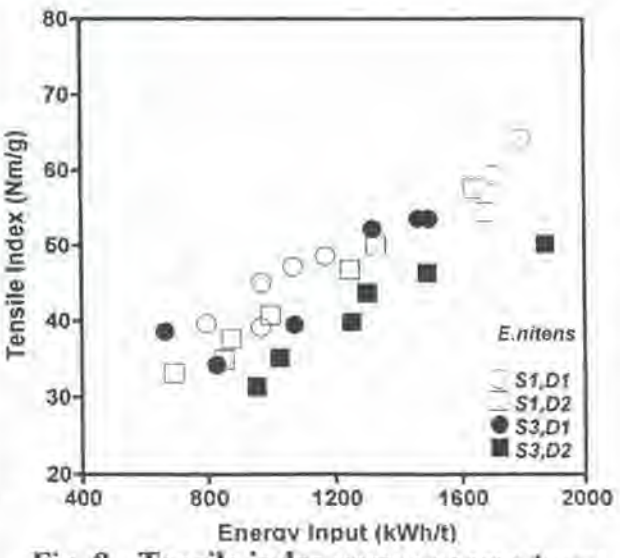

Fig. 8 - Tensile index versus energy input

To illustrate these differences, the graph of tensile index versus energy input (Fig.8) shows that the energy required to refine D2 from site 1 to a given tensile index, is marginally higher than D1 from the same site. However, at site 3 the energy requirement is significantly increased for D2 compared with D1.

CONCLUDING REMARKS

There is a definite effect of site on the pulping and papermaking properties of the various species with site 1 providing the best results. Compared with the site 3 species, the species at site 1 exhibit higher tensile strengths and require less energy to refine to a particular tensile. This latter feature does not appear to be a function of basic density, since the density of each species is similar at the different sites. There is a negligible effect of site on the production of fines, on bulk values, and on tearing strengths. It is concluded that there is a deleterious effect on the pulping and papermaking properties from trees planted at an elevation higher than at site 1 in the Esperance Valley region. This is particularly true for non-frost resistant trees planted at the higher altitudes.

There is a significant site effect on the unbleached brightness levels of all species, with the lower values coinciding with species from a higher elevation. It is suggested that environmental factors account for this behaviour.

The light scattering coefficients of *E.regnans* and *E.nitens* were greater than those of *E.globulus* and *E.grandis*. This suggests that more opacity improving additives may be necessary for the latter two species, particularly in printing grades of paper.

The relative performances of all species based on their pulping and papermaking properties was assessed. A numerical value was given to each species according to performance over all sites based on physical, optical, and morphological properties. The numerical values were added and a ranking given. This ranking is a guide only and it should be pointed out that it may change according to the altitude the species are grown at. *E.nitens* D1 rated slightly ahead of *E.globulus* B1, which was substantially ahead of *E.globulus* B2, followed by equally rated *E.regnans* A1, *E.regnans* A2, and *E.nitens* D2, followed last of all by a low ranked *E.grandis*.

Some basic knowledge has been obtained on the effect of the morphological attributes of eucalypts on the pulping and papermaking properties of chemimechanical pulps. Further studies will take place in the future to advance this knowledge.

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Stem deformation in plantation grown radiata pine

Geoff Downes.
CSIRO Division of Forest Products
Private Bag 10, Rosebank MDC, Victoria, 3169

Abstract

In the early to mid 80's it became government policy to stop the clearing of native forest for the establishment of radiata pine plantations. Much of the land then available for plantation establishment was ex-pasture which had a history of fertiliser application, and therefore higher residual fertility than most of the land previously used. On many sites, particularly in N.E. Victoria and southern NSW, symptoms of stem and branch deformity, similar to those exhibited by copper deficient pines, became apparent. Several research groups began examining aspects of the phenomenon, which had potentially serious economic consequences. This effort offered a range of genetic, silvicultural and nutritional approaches.

The research program into copper deficiency in *Pinus radiata* at the University of Melbourne, Forestry Section at Creswick was extended to examine the nutritional and structural reasons underlying the development of the deformation. Nutritional by environmental interactions were examined along with a study of the bio mechanics of the current growth of young pine stems. The focus of the research was to develop an understanding of the nutritional and structural physiology of the deformation symptoms, with a view to identifying trait(s) that could be used for the development of early selection criteria in seedlings..

Significance.

In any industry the quality of the primary resource has a major impact on the cost and quality of the manufactured product. In this regard any bends or twists in the stems of plantation timber is to be avoided if at all possible. The presence in a stem of any deviation from the vertical is commonly associated with the presence of reaction wood which has undesirable structural characteristics. Stem bending also has an influence on the apical dominance of the leading shoot which will influence the branching characteristics of the stem through bigger branches and/or the competition of branches with the leader. All of these influences adversely effect the quality and reduce the amount of merchantable wood produced.

Bent stems will result a reduction of choice for selection during thinning operations, and an increase in the costs of harvesting and processing. They are more difficult to cut and delimb mechanically; occupy more volume than necessary on trucks and are more difficult to debark and chip, increasing the occurrence of knife damage during chipping. The problem of deformation in fast growing stems must be one of prevention not cure. Once a deformation has become apparent, the structural characteristics of the tissue cannot be changed.

This paper will attempt to describe the research efforts that have been undertaken over the past 10 years, investigating the causes and control of the phenomenon of stem malformation occurring on fertile ex-pasture sites. The emphasis will be on research at the University of Melbourne, Forestry Section at Creswick, recognising however that several other groups within various research organisations in Victoria and New South Wales were also undertaking major research initiatives into the phenomenon.

Copper deficiency and stem deformation.

Stem deformation can occur from a variety of causes such as leader dieback, wind or snow damage, multiple leader production, trace element deficiencies to name a few. Trace element deficiencies have been encountered in many crop species throughout Australia. The history of the identification of trace element deficiencies in forestry is probably best known from the discovery of zinc deficiency, with trees growing near a galvanised fence exhibiting noticeably fewer symptoms than those further away. Stoate's involvement with zinc deficiency in

Western Australia in the late 1940's to early 1950's constitutes some of the earliest work on trace element nutrition in radiata pine in Australia.

Copper deficiency has been recognised in Australian forestry since the early 1960's, observed by Hall (1961) in a plantation established in deep stands at Longford, Victoria. This type of deformation is one in which the stems of trees deform as a consequence of an apparent inability of the stem to support the mass of tissue above it. It does not arise characteristically as a consequence of shoot dieback or some other similar event.

In the late 1960's plantation grown trees near Mt Gambier were observed to exhibit considerable stem deformity that could only be associated with low foliar copper levels(Ruiter 1969). Similar symptoms were described in New Zealand (Will 1972, Knight 1975). Research into stem deformation at the University of Melbourne began with the type of deformation associated with copper deficiency (Fig. 1), utilising an experiment established at Flynn Creek, Victoria in 1977 (Turvey et al. 1984). Deficiency symptoms were induced by the application of nitrogenous fertilisers. In cronic cases, where N was added in the absence of copper, seedlings either died or grew slowly, often exhibiting a prostrate growth habit. Applications of copper as low as 0.5kg ha^{-1} were sufficient to alleviate the symptoms and increase survival. Mortality was greatest when N was applied in the absence of copper. However even at the maximum rate of fertiliser application (13.5 kg ha^{-1}) deformity symptoms were still manifest in the treatments that received additional N.

Figure. 1 The deformed growth of a radiata pine growing at Flynn Creek near Traralgon, Victoria is shown.

Structural and histochemical investigations of the wood from these deformed, copper deficient pines revealed a qualitative reduction in the lignin content of the wood, particularly that produced early in the growing season and in compression wood (Downes and Turvey 1986). The observations were supported by chemical determinations of lignin content (Downes and Turvey 1990a), and when copper deficiency was induced in glasshouse grown seedlings, qualitative and quantitative reductions in lignin content were found (Downes and Turvey 1990bc, Turvey et al. 1992). Similar observations have been made in copper deficient non-woody plants (Graham 1976, Schutte and Mathews 1969, Bussler 1981), and eucalypts (Dell and Bywaters 1989). This situation, whilst physiologically interesting, is relatively easy to correct or avoid through the application of copper.

Fast growth and stem deformation

In 1984 Pederick et al. reported the development of stem deformation symptoms in a 6 year old progeny trial established at Toorour. The type of deformation was visually similar to that exhibited by copper deficiency (Fig. 2) except that foliar copper levels were not within what was considered to be the range of deficiency (< 2ppm). The addition of copper fertiliser to the affected sites did not alleviate the symptoms (Hopmans 1990). The term 'speed wobbles' had been coined earlier to describe the common phenomenon of sinuous growth in fast grown plantations (Will 1986), and Will argued that the reported deformation was of this type. Similar sinuous growth has recently been reported in the USA in Christmas tree plantations established on ex-pasture (Hinesley and Campbell 1992). However the extent of the deformation symptoms were considerably beyond what could be encompassed within the definition of 'wobble' (Fig. 2), although it was likely that the two observations had a similar basis. The great advantage of the report by Pederick et al. was that it was made in a progeny trial which showed a strong genetic control over the expression of the symptoms. These observations coincided with similar observations of deformity on many sites within N.E. Victoria and were a cause of considerable concern to forest growers. Extensive nutritional and structural studies were commenced by workers both at the University of Melbourne and the Department of Conservation and Natural Resources.

Figure 2 Stem deformation as it occurred in fast growing plantations established on ex-pasture was visually similar to that resulting from copper deficiency, but appeared to be nutritionally distinct.

Deformation symptoms were associated with fast growth rates, ex-pasture sites of high fertility and higher than usual levels of nitrification in the soil. In some plantations up to 90% of the trees were affected, a large proportion of these being unmerchantable (Carlyle et al. 1989). An extensive survey of sites was undertaken (Carlyle et al. 1989) which indicated that the deformation was clearly associated with previous land use rather than the soil being derived from a particular parent material. Comparison of plantations established on ex-native forest and ex-pasture indicated that where the soils on ex-native forest sites were essentially ammonifying, the ex-pasture sites were strongly nitrifying. In addition this study indicated that the deformation could not be associated with reductions of lignification in the woody tissue. It was concluded that although there were visual similarities, the nutritional basis of the deformity arising as a consequence of copper deficiency were different to those arising on the high fertility sites. The term "Toorour syndrome" was adopted (Carlyle et al. 1989) to distinguish this ex-pasture phenomenon from other types of stem deformations.

The nutritional basis of the Toorour syndrome.

With this distinction being made attention was given to identifying the nutritional basis of the deformation symptoms. Extensive breeding and clonal propagation trials were established by the Department of Conservation and Natural Resources to select the best performing families. In tandem with this work, others were identifying the nutritional characteristics of affected sites in order to develop a risk index so that the limited improved genetic stock could be directed preferentially to higher risk sites (Hopmans pers. comm.[1]). Within the New South Wales Forestry Commission the emphasis was on the nutritional characteristics of affected sites and their silvicultural management (Birk 1990, 1991). The emphasis at the Forestry Section of the University of Melbourne was placed on understanding the nutritional and structural basis of the phenomenon at the individual tree level.

Bail and Pederick (1989) reported the results of a progeny trial which showed clearly the distribution of susceptibility to deformation across a range of families and provenances. On the basis of these and earlier results, extensive cuttings programs were undertaken to obtain resistant material for establishment on high risk sites. An additional factor identified was that cuttings were more resistant to deformation than seedling stock exhibiting finer branching patterns. They conclude that 'extreme stem deformity appears to be a phenomenon of the juvenile growth period of trees grown on fertile sites.'

Nutritionally many hypotheses were generated to explain the deformation. Many of the sites affected were boron deficient. Sulphur deficiency was also raised as having a potential causal effect (Birk 1990). Nitrate and ammonium imbalance was considered a possibility, perhaps affecting the anionic/cationic balance in nutrient uptake. Nutritional work at sites in north east Victoria showed that deformity symptoms could be induced in plantations established on ex-native forest sites by the addition of N fertiliser (Hopmans and Flinn 1991). When N was applied at rates in the order of 200 kg ha^{-1} basal area increased with moderate stem deformity symptoms[2] increasing to around 10%. If N was applied at 600 kg ha^{-1} then basal area increased further and stem deformity symptoms affecting around 55% of stems (Hopmans pers. comm.). The higher the rate of N fertiliser induced nitrification in an otherwise ammonifying soil. In this study stem deformation was observed to occur predominantly in the years 3,4 and 5 as the height increased from around 3 to 9 metres; in essence the butt log. Birk (1990) compared growth of radiata pine on improved ex-pasture sites in comparison with ex-native forest sites, and found that despite the faster growth of trees on the improved pasture sites there was a reduction in the volume of merchantable timber produced. Birk (1991) reported that the severity of deformity symptoms in a plantation in Sunny Corner State Forest NSW was directly correlated with soil mineral-N concentrations.

Earlier work in the glasshouse had shown that families resistant to the Toorour syndrome were also resistant to copper deficiency (Downes and Turvey 1990b) and this was further shown in a study of the interaction of boron, manganese and copper (Turvey et al. 1992). Other investigators had argued that deformity symptoms were a consequence of boron deficiency (Crane and Boroughs 1987), whilst Carlyle et al. (1989) had established a possible link with levels of soil manganese. Birk (1991) reported a correlation between deformity symptoms and foliar manganese. In glasshouse grown seedlings manganese was found to enhance deformity symptoms in the absence of copper and enhance the ability of copper to alleviate deformity. This interaction was also evident in the lignin content of the stem tissue. Seedlings from the more susceptible family were both taller and thinner

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[1] Dr. Peter Hopmans is a Research Officer with the Department of Conservation and Natural Resources, 378 Cotham Rd. Kew, Victoria, Australia.

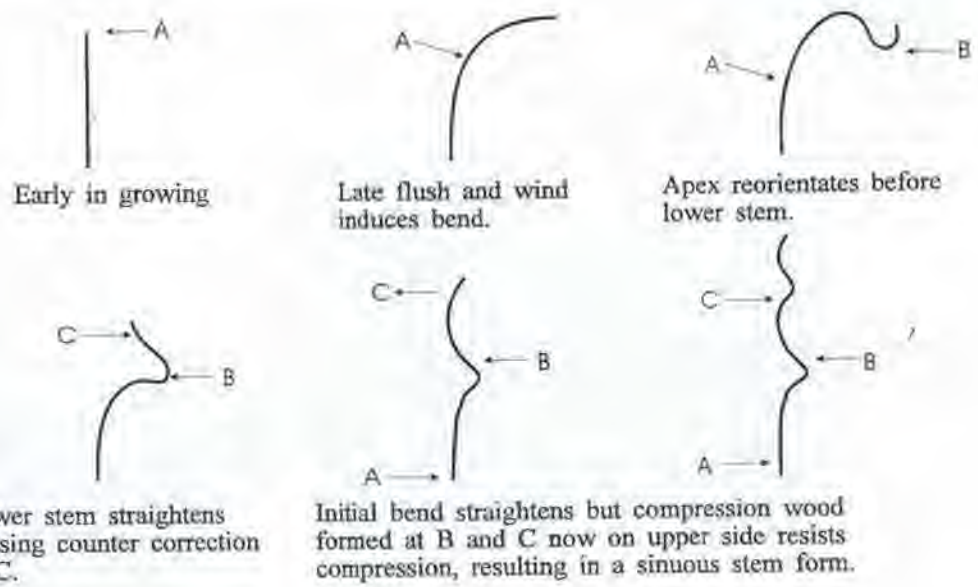
[2] Several indices of stem deformity have been developed (Birk 1991). In this study stem deformity was ranked on a 6 point scale with a ranking of 3 or higher representing stems were utilisation was significantly affected.

than seedlings from the resistant family. No link between boron and deformity symptoms was found in this glasshouse experiment or in fertiliser trials were boron deficiency symptoms have occurred in concert with stem deformation symptoms (Hopmans and Clerehan 1991). The experiment showed that if copper was available, manganese had no effect on stem form or the development of deformity symptoms.

Possible interactions between N source and seedling growth were also investigated in glasshouse grown seedlings. Ammonium and nitrate were supplied in a range of ratios and at 2 different levels of total N (2.0mM and 0.67mM; Carlyle unpublished). Seedlings were found to grow optimally when ammonium was the predominant N form, but still grew well when nitrate constituted 50% of the N applied. In this study 2 families were also used, one family being more susceptible to deformation based on the ranking given in Pederick et al. (1984). The most susceptible family was found to grow at a faster rate than the less susceptible family, particularly in the higher N environment (Downes 1987).

Extensive monitoring of a fertiliser trial near Myrtleford, Victoria was undertaken over the 1988/89 growing season in an attempt to identify some link between nutrition and the onset of deformity (Turvey et al. 1993). The site was an ex-pasture site and sustained considerable levels of deformation symptoms (Hopmans and Flinn 1991). Straight and deformed trees were compared in fertilised and unfertilised plots with leader growth and form being monitored photographically at two week intervals over the growing season. Extensive nutritional analyses of the foliage, buds and soils were carried out and environmental conditions were monitored on site. No clear nutritional link with deformity was found. Changes in nutritional levels appeared to be synchronous with deformation but not causal. Indeed the growth rates of the trees indicated that biomass was being accumulated at rapid rates and that no nutritional deficiency or imbalance was likely to be found. Monitoring of the weather conditions and rate of leader extension however indicated that the onset of the initial bending event coincided with a warm,wet, windy period. Following the movement of the leaders during and after the bending event indicated that the progress of the deformation and the subsequent recovery generally followed the pattern illustrated in Fig. 3. Greater or lesser initial leaning moments in the stem had a large impact on the nature of the recovery and the level of permanent deformation that became fixed in the stem.

Figure 3 The diagram illustrates the process by which permanent stem sinuosity often originated in stems growing on fertile ex-pasture sites. In many stems the region of the initial deformation straightens, and it is the corrective measures undertaken by the stem that become permanent.



Nutritional studies also looked at the N content of xylem sap both in terms of total N content and amino acid N. Concentration changes were examined over the spring-summer period of 1989. No clear nutritional differences

were found between straight and deformed stems, however the presence of high concentrations of glutamine in the xylem sap was noted (Downes and Turvey 1992), with this amino acid exhibiting sap concentrations in the order of 2 - 4 mM. Similar levels have also been reported in *Eucalyptus regnans* seedlings grown in a high nitrate environment (Adams and Atkinson 1991).

Structural basis of deformation

Given these observations research at the University of Melbourne addresses the anatomical and structural reasons which dictate the resistance or susceptibility of families. It is evident that permanent deformity can arise from 2 separate but related processes. The magnitude of the initial bend, and the nature of the recovery response. Subjective observation of the trees suggested that those individuals which deformed most were elongating at a faster rate than those individuals which were more resistant.

Thus initial glasshouse and field experiments endeavoured to compare the growth characteristics of resistant and susceptible families in terms of there stem characteristics prior to stem deformation. These studies included detailed descriptions of the stem anatomy and wood structure and how these variables related to stem bending strength as measured by stem lean at harvest and the modulus of elasticity in bending of a circular stem segment (Downes and Turvey 1990, 1993, Downes et al. 1993a). In these experiments the stems of both seedlings or trees examined in the field and glasshouse were supported to prevent the onset of bending, relative to unsupported controls. This support was necessary to be able to compare treatments on the basis of differences that were causal, and not produced as a reaction to deformation. Even straight stems have some characteristics of reaction tissue as a consequence of exposure to external influences such as wind. Supporting the stem reduced these effects on wood production and the wood was more a response to genetic/nutritional influences.

No structural or anatomical variable could consistently be associated with a genetic susceptibility to bending apart from the susceptible families producing taller thinner stems (Downes and Turvey 1990c,1993, Downes et al. 1993b). Several variables were related to differences in bending strength, but not to genetic origin. High N levels resulted in reductions in stem strength and these were attributed largely to proportional increases in the production of non-woody tissues, such as pith and bark. In the field study the variation in the three point bending strength of the stems was explained largely by variation in average microfibril angle and lignin content.

A further glasshouse study focussed on the behaviour of seedlings following a bending event, trying to identify differences in the abilities of families to recover the stem to the vertical (Downes et al. 1993b). Susceptible families elongated faster following bending, however both groups showed an ability to produce functional and effective compression wood, generating the forces necessary to lift and straighten the lower stem (Fig. 4). This experiment did lend support to the argument that the regions of obvious deformation observed in plantations are often greater in response to an initial bend, than in the region of the stem where the bend first became apparent (Fig. 4). A similar hypothesis was advanced by Harris (1977) observing patterns of compression wood formation in New Zealand grown radiata pine.

These results therefore suggest that susceptible families are those that are elongating at a faster rate than resistant families. This, at first appears to contradict the findings of Bail and Pederick (1989) who reported that the tree height of susceptible families tended to be less than resistant ones. However it should be noted that these measurements were made of tree height and not stem length, and on unsupported stems which were growing through cycles of bending and straightening. When susceptible seedlings were bent artificially their rate of elongation was reduced (Downes et al. 1993b) however not to the same extent as the resistant families. If the resistant families were not elongating as fast then the initial bend would tend to be smaller or non existent, therefore the rate of apical extension would not be slowed to the same extent as the more deformed trees. Therefore it could be argued that the observation reported by Bail and Pederick (1989) was a consequence of the trees susceptibility, and not a characteristic of their growth potential. This hypothesis needs to be proven on field grown material, perhaps by comparing tree growth prior to deformation , in young plantations that will deform. This was attempted in the experiment described in Downes et al. (1993a). Unfortunately the trees did not deform as it was hoped they would.

The other hypothesis that arises from this study is that there does exist a link between the Toorour syndrome and copper deficiency. The stem deformation arising from both phenomena occurs as a response to N addition. The consequential rapid rate of leader elongation then makes the trees susceptible to bending in response to wind or other external forces. The mechanism of resistance to this being changes in the rate of stem length to diameter increase in the leader. The additional complication of copper deficiency inhibiting lignification would tend to make a leader more susceptible to bending, lowering the threshold of resistance. More importantly reduced

lignification would impair the function of compression wood to straighten the stem, particularly the lower stem where the bend arose initially. Thus one might expect the families resistant to the Toorour syndrome would also be resistant to deformation arising as a consequence of copper deficiency.

Figure 4 The ability of seedlings to recover from a weighting treatment was examined in the glasshouse. No differences between susceptible and resistant families to straighten a bent region of the stem was found. In seedlings with a large initial bend, increase in stem diameter as a consequence of compression wood formation ultimately prevented the complete recovery of the stem.

Conclusions.

Considerable effort has been directed at understanding and controlling the phenomenon of stem deformation as it occurs in fast growing plantations established on fertile ex-pasture sites in north east Victoria and southern New South Wales. At present no nutritional abnormality or imbalance has been identified that results in stem deformation. The growth rate of the trees on affected sites indicated that biomass accumulation is not limited by any nutritional factor. It would also be expected that any increase in growth rate mediated by the application of N on ex-forest sites, will increase the level of deformity on the site if applications are in the order of 500 kg ha^{-1} or more.

The strong genetic control exhibited over the deformation has been utilised in the development of improved stock for establishment on sites likely to be affected. No structural abnormality in the wood produced by affected stems has been found. The only structural characteristic associated with deformation is a tendency for susceptible families to produce more slender stems than resistant families. This however still needs to be proven under field conditions. If true this characteristic could be used as an early selection criterion for selecting families of unknown susceptibility.

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ENVIRONMENTAL CONSTRAINTS ON GROWTH AND KRAFT PULP YIELD OF *EUCALYPTUS GLOBULUS* AND *E. NITENS*

Christopher L. Beadle, Charles R.A. Turnbull

Cooperative Research Centre for Temperate Hardwood Forestry
Locked Bag 2, Sandy Bay, Tasmania 7005

and

Geoffrey H. Dean

Associated Pulp and Paper Mills, Research and Technology Group
PO Box 201, Burnie, Tasmania 7320

ABSTRACT

The volume growth and kraft pulp yield of two provenances of eight-year-old stands of *E. globulus* and *E. nitens* were investigated at four plantations. The plantations were located at 60, 240, 440 and 650 m along an altitudinal gradient in the Esperance valley, south-east Tasmania. A significant decrease in pulp yield between the lower and upper sites was observed for both species though differences within provenances between sites did not exceed 3.8%. There were significant differences in pulp yield between provenances within species: across sites these yields were 55.8% and 51.5% for the better provenances of *E. globulus* and *E. nitens* respectively. In contrast, the better provenance of *E. nitens* was superior in terms of volume growth except at the 220 m site which had the highest minimum temperatures.

Given careful matching of provenance to site, planting of *E. nitens* is recommended for maximising pulpwood production except on frost-free sites at low altitude when the higher pulp yield of *E. globulus* favours this species.

INTRODUCTION

The genetic composition of a species sets its potential for growth; environmental constraints limit the expression of that potential. Is pulp yield, the proportion of dry mass recovered as pulp to total dry mass, regulated in the same way?

Progress towards resolving this issue has been slow. Matheson, Turner, Dean (1986) showed that there were significant differences in pulp yield between provenances of *E. obliqua* within a site; and the ranking of three provenances of *E. regnans* was the same at

two sites, though differences in pulp yield were small (Raymond, Balodis, Dean in press). One constraint is the large tree to tree variation in wood properties, including pulp yield, at a single site (Malan 1991; Raymond, Balodis, Dean in press). Another is the concern that site variables and their effect on pulp yield through the rate of development and growth of the tree, prevent extrapolation of results from one site to another (Turner, Balodis, Dean 1983; Balodis 1992). While there was some indication from the study of Turner and colleagues that rainfall was correlated with pulp yield of *E. globulus*, other variables like altitude, temperature and soil type have not been adequately addressed in this respect for eucalypts.

In this presentation pulp yield and related characteristics of *E. globulus* and *E. nitens* are examined in four 8-year-old plantations. Every attempt was made to ensure uniform silviculture at the sites so that the major variable determining growth rate was the weather. As the sites were separated by 200 m along an altitudinal transect, the variable of most importance was anticipated to be temperature.

MATERIALS AND METHODS

Site, species and environment

Four plantations were established in 1983 at 60, 240, 440 and 650 m in the Esperance valley, SE Tasmania. The trees were planted at 2 x 2 m spacings and several species of eucalypts and *Pinus radiata* were located at each site. All were managed uniformly with respect to fertiliser addition and pest control during the first four years of growth. (Turnbull, McLeod, Beadle, Ratkowsky, Mummery, Bird in press).

Two provenances of each of the species of interest here, *E. globulus* and *E. nitens* were included in the trial (Table 1). Survival was high at all sites (≥ 80%) except for *E. globulus* at 650 m (<45%) which is not considered further.

TABLE 1. SPECIES, PROVENANCES AND THEIR ORIGIN

Species	Provenance	Origin
E. globulus	Geeveston	Tas, 200 m
	Otways	Vic, 125 m
E. nitens	Upper Toorongo	Vic, 900 m
	Errinundra*	Vic, 1070 m

*now considered to be *E. denticulata* (Cook, Ladiges 1991)

Maximum and minimum screen temperature and rainfall were measured weekly at all sites to age 5 years and at the 60 m site to age 8 years.

Growth

Sixty-tree plots (or less depending on survival) were used to determine mean annual increment (MAI) at age 5 years. The height and diameter of each tree was measured and its stem volume under bark calculated using an equation developed for young eucalypts (Opie 1976). MAI at age 8 years was calculated from the same measurements made in a sub-plot of 20 or 23 trees. For comparison with the earlier measurement, the value for the sub-plot was multiplied by the ratio of the volumes estimated from the 60-tree plot:sub-plot at age 5 years.

Sampling procedure

Five sample trees were selected at random from each provenance at each site. Only trees from the upper 50% on the basis of volume, and free of pronounced lean, major stem malformations or defects were considered. The trees were felled and, for most samples, three 1 m billets cross-cut at 10, 30 and 70% of merchantable height (Fig.1). This was defined as 10 cm short-end diameter under bark (SEDUB). Merchantable length of the trees used in this study was more than 5 m except for the Errinundra provenance of *E. nitens* at the 440 and 650 m sites. SEDUB was reduced to 8 cm for these samples. The 10 and 30% billets were then combined to give two billets only per tree (Fig. 1).

25 mm discs were also cut adjacent to the billets for the determination of basic density (Fig. 1). The discs, with bark intact, were individually sealed into plastic bags. The billets from each tree were debarked, strapped together and transported to APPM Burnie for kraft pulping.

Basic density

Wood moisture content and density were determined on each disc according to Tappi standard T258 om-89. All bark and loose materials were first removed. Basic density was defined as the ratio of oven dry mass:green wood volume. The latter was measured by the suspended submergence method.

Kraft yield

The billets from each tree were chipped and combined. The chips were then air dried and kraft pulped in airheated, rotating pressure vessels to a constant H-factor under the following conditions: wood charge, o.d. basis, 300 g; sulphidity, 25%; temperature, 170°C; time to/at temperature, 90/90 minutes; liquor to wood ratio, 3.5:1; target Kappa number, 18; H factor, 2865.

The soda charge was varied for each wood sample so as to achieve a pulp with a resulting Kappa number as close as possible to 18; generally 16-18% NaOH was required.

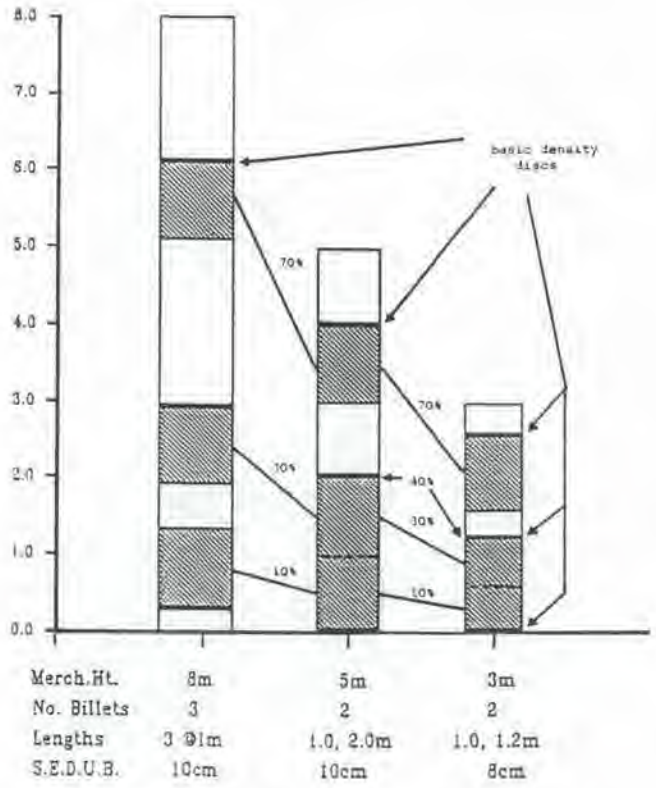

Fig.1 Billet sample locations for various tree sizes

From the results of these cooks, and using standard response curves established for trees with a wide range of pulp quality, yield at Kappa number 18 was estimated for each sample.

Either two or three replicate samples were done and mean pulp yields calculated for each tree.

Data analysis

Basic density was first expressed as the simple mean of the three levels evaluated for each tree. Pulpwood productivity (kg pulp m^{-3} wood) was calculated as the product of pulp yield and mean basic density. Analyses of variance were done for pulp yield, mean basic density and pulpwood productivity. The two species were considered separately using a model with terms for site, provenance and their interaction. For pulp yield only, a similar model was used to evaluate species differences for the 60, 240 and 440 m sites by considering the four provenances from the two species together.

RESULTS

Environment

The average weekly maximum temperature decreased with altitude and differed by 5 °C between the lowest and highest site (Table 2). In contrast, cold air drainage resulted in the 60 m site having the lowest average weekly minimum temperature. Annual rainfall, on average, exceeded 1000 mm at all sites but was highly variable.

TABLE 2. THE WEATHER IN THE ESPERANCE VALLEY*. TEMPERATURES ARE THE MEAN WEEKLY VALUES. FIGURE IN BRACKETS IS ONE STANDARD DEVIATION

Site (m)	Temperature (°C)		Annual Rainfall (mm)
	max	min	
60	21.1(0.6)	1.4(0.5)	1017(120)
240	19.5	3.7	1412
440	18.0	2.6	1924
650	16.1	2.0	1363

* for 240, 440 and 650 m sites, 1984-88; for 60 m site, 1984-91.

Growth

The MAI's of the Upper Toorongo provenance of *E. nitens* were inversely related to altitude at age 5 years, one year after the cessation of application of fertiliser (Table 3). Three years later, there was no clear relationship between MAI and altitude. For the Errinundra provenance, the maximum MAI was observed at the 240 m site. For both provenances of *E. nitens*, the relative growth at 650 m compared to the other sites increased between age 5 and 8 years. For *E. globulus* both provenances had higher MAI's at 240 m compared to the 60 m and 440 m sites at both ages (Table 3).

The Geeveston provenance of *E. globulus* had higher MAI's at the 240 m and 440 m sites, but a lower MAI at the 60 m site, than the Otways provenance. For *E. nitens*, the MAI's of Upper Toorongo were consistently higher than those of Errinundra provenance.

TABLE 3. MEAN ANNUAL INCREMENT OF STEM VOLUME ($m^3ha^{-1}a^{-1}$; OPIE 1976) AT AGE 5 YEARS, AND AT AGE 8 YEARS, JUST BEFORE SAMPLING FOR KRAFT YIELD

Species	Provenance	Age	Site(m) 60	240	440	650
E. globulus	Geeveston	5	11.6	18.8	9.1	-
		8	14.2	22.3	15.1	-
	Otways	5	15.1	19.7	8.5	-
		8	18.3	21.6	12.7	-
E. nitens	Upper Toorongo	5	23.4	20.4	15.4	13.6
		8	26.8	22.4	20.5	25.8
	Errinundra	5	13.1	14.3	8.0	5.4
		8	16.6	18.6	11.1	11.0

Pulp yield

There were significant differences between sites and provenances. The pattern was the same for both species (Table 4). Pulp yield at the lower sites was always significantly higher than at the upper site(s) but there were no significant differences between that at 60 m compared to 240 m and, for *E. nitens*, that at 440 m compared to 650 m. For provenance, Geeveston was significantly higher than Otways for *E. globulus;* and Upper Toorongo than Errinundra for *E. nitens*, at all sites.

Although the pulp yield of *E. globulus* was always higher across sites than that of *E. nitens,* this difference was not significant at the provenance level between Otways and Upper Toorongo for the lower three sites (Table 5). For *E. globulus* and the Errinundra provenance of *E. nitens* the highest pulp yields were observed at the 240 m site though differences within provenances between sites did not exceed 3.8%. The highest pulp yield was 57.6%, the lowest 46.6%, observed respectively for the Geeveston provenance of *E. globulus* at the 240 m site and the Errinundra provenance of *E. nitens* at the 440 m site (Table 5).

TABLE 4. ANALYSIS OF VARIANCE OF PULP YIELD FOR SITES AND PROVENANCES OF (a) *E. GLOBULUS* AND (b) *E. NITENS*

Source of variation	d.f.	mean squares	significance level
(a) *E. globulus*			
Site	2	25.73	<0.01
Provenance	1	77.76	<0.01
Site x Provenance	2	0.9160	0.67
Residual	24	2.277	
Total	29	6.404	
(b) *E. nitens*			
Site	3	18.00	<0.01
Provenance	1	100.9	<0.01
Site provenance	3	3.243	0.26
Residual	31	2.316	
Total	38	6.127	

TABLE 5. MEAN VALUES (NUMBER OF TREES, n=5) FOR PULP YIELD (%)

Species	*E.globulus*		*E. nitens*	
Provenance Site (m)	Geeveston	Otways	Upper Toorongo	Errinundra
60	56.0	53.0	52.6	49.4
240	57.6	53.7	52.2	50.2
440	53.8	51.1	51.3	46.6
All ex. 650 m	55.8	52.6	52.0	48.7
650	-	-	50.1	47.0*
All sites	55.8	52.6	51.5	48.4

* n = 4

Basic density

There were no significant differences between either sites or provenances for *E. globulus*. For *E. nitens*, the basic density of Errinundra provenance was significantly higher than that of the Upper Toorongo provenance at all sites. It was also significantly higher at 60 m than at 440 and 650 m, otherwise there were no significant differences between sites.

For both species and provenances, the minimum value of basic density tended to occur in the disc sampled from the billet at 30% merchantable height. The range of the means for *E. globulus* varied between 458 and 540 kg m^{-3} and for *E. nitens*, between 428 and 520 kg m^{-3} (Table 6).

TABLE 6. BASIC DENSITY (kg m^{-3}) OF THE BILLETS AT 10, 30 AND 70% MERCHANTABLE HEIGHT (SEE FIGURE 1)

Species	*E.globulus*						*E. nitens*					
Provenance	Geeveston			Otways			Upper Toorongo			Errinundra		
Site (m)	10	30	70	10	30	70	10	30	70	10	30	70
60	500	485	507	517	490	533	478	471	496	506	488	520
240	503	493	514	515	506	540	451	442	475	513	482	479
440	516	476	508	517	458	468	471	434	434	520	462	465
650	-	-	-	-	-	-	459	428	440	507	458	490

Pulpwood productivity

There were significant differences in pulpwood productivity between sites which precisely followed those observed for pulp yield. However there were no significant differences between provenances for either species. For *E. globulus*, values ranged between 246 and 290 kg m^{-3}, for *E. nitens* between 222 and 250 kg m^{-3} . As for pulp yield, the highest values for the two species were observed, respectively, at the 240 and 60 m sites.

TABLE 7. PULPWOOD PRODUCTIVITY (kg pulp m^{-3} wood) OF THE TREES (n=5) HARVESTED

Species	*E. globulus*		*E. nitens*	
Provenance Site (m)	Geeveston	Otways	Upper Toorongo	Errinundra
60	279	272	250	250
240	290	279	238	247
440	266	246	229	225
650	-	-	222	232

DISCUSSION

The major part of the plantation estate of eucalypts in Australia has been established to *E. globulus* and *E. nitens*. These results present evidence that pulp yield of these species can be a function of air temperature during growth. For *E. nitens*, a species which is resistant to the levels of frost experienced at the sites studied, pulp yield of the Upper Toorongo provenance was inversely related to altitude. For *E. globulus* and the Errinundra provenance of *E. nitens*, pulp yield and growth were both less at the 60 m than the 240 m site. *E. globulus* is susceptible to frost (Hallam, Reid, Beadle 1989) and the low minimum temperature at 60 m (Table 2) caused repeated crown damage during the winter periods: at the 240 m site frost was absent throughout the year. Rainfall at the 60 m site (Table 2) was also insufficient to ensure that growth rates were not limited by available soil water (Honeysett, Beadle, Turnbull 1992): at the other sites water did not limit growth. Available water, through rainfall, was highly correlated with pulp yield of provenances of *E. globulus* investigated *in situ*, probably through its limiting effect on growth (Turner, Balodis, Dean 1983; Balodis 1992).

The results from this study also confirmed that significant differences in pulp yield can occur between provenances of a species growing in a uniform environment (Table 4; Matheson, Turner, Dean 1986). The Geeveston provenance of *E. globulus* was superior in this respect to that of Otways but the difference was not significant in terms of pulpwood productivity even though there were no significant differences in basic density between the provenances (Tables 5, 6, 7). Differences in MAI (Table 3) however, point to Otways being better for pulpwood productivity on a per hectare basis at 60 m and Geeveston at 240 m and 440 m. Although both provenances originate from sites with similar annual rainfall, the higher mean temperatures in the Otways compared to Geeveston suggest adaptation to warmer and cooler sites respectively.

For *E. nitens*, the higher basic density of Errinundra offset the higher pulp yield of Upper Toorongo such that there were no significant differences in pulpwood productivity between provenances. The superiority of the Upper Toorongo provenance of *E. nitens* in terms of MAI however favour choice of this provenance and species for pulpwood on a per hectare basis except on frost-free sites at lower altitudes. Under these conditions, the similar growth rates of *E. globulus* in conjunction with its higher pulp yield and basic density compared to the Upper Toorongo provenance of *E. nitens* will maximise production of pulp on such sites.

ACKNOWLEDGEMENTS

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AUSTRALIAN STANDARDS FOR STRUCTURAL TIMBER

R.H. Leicester
CSIRO Division of Building, Construction and Engineering
PO Box 56, Highett, Victoria 3190

SUMMARY

This paper summarises the relevant standards and documents that are the current basis of reliability control for timber construction in Australia. The topics covered include the Limit States Design Code, definition and derivation of structural properties, stress grading, quality control and certification. From the viewpoint of product certification, many of the necessary standards are non-existent, and those that do exist do not appear to be written in any uniform format.

INTRODUCTION

Structural qualities, particularly reliability of timber construction relies partly on the industry infrastructure and partly on compliance with the various Codes and Standards that are called up by producers, regulatory authorities and clients. Australian Standards have evolved in a fairly unstructured and uncontrolled process, usually in response to a new product, industry or problem. The following is a summary of the relevant standards and documents that are the current basis of reliability control for timber construction in Australia. This is followed by some proposals for future standardisation.

LIMIT STATES DESIGN CODE

In the following, the notation WSD and LSD will be taken to refer to the 'working stress design' format and the 'limit states design' format respectively. Currently, there is a draft of the proposed LSD version of AS 1720.1, the Australian Timber Structures Code (1). The future LSD version is a 'soft conversion' of the existing WSD version. The term soft conversion implies that on average, similar design solutions would be obtained from the WSD and LSD codes. This is intended to ease the transition to the new LSD format.

The WSD code is in a stress format, i.e. the design criterion for strength is

$$F_d > F_d^* \qquad (1)$$

where F_d and F_d^* refer to the permissible design stress of the timber and the applied design stress (due to the design loads) respectively.

However, the LSD code is in a capacity format and the design criterion for strength is

$$R_d > R_d^* \tag{2}$$

where R_d and R_d^* refer to the design ultimate capacity and the design action effect (due to the design loads) respectively.

Despite this difference however, equations in the WSD code and LSD look very similar. For example, in checking the strength of a beam in bending, the permissible design stress in a WSD code is given by

$$F_b = k_1\, k_2\, k_4\, k_5\, k_6\, k_8\, k_{11}\, k_{12}\, F_b' \tag{3}$$

and in a LSD code

$$M_d = \phi\, k_1\, k_2\, k_4\, k_5\, k_6\, k_8\, k_{11}\, k_{12}\, [Z\, F_b'] \tag{4}$$

where k_1–k_{12} are strength modification factors, F_b' are specified stresses, ϕ is a capacity factor and Z is a section modulus. The specified stresses F_b' in the WSD code and LSD code differ. All the k modification factors are identical for the WSD and LSD codes except for k_1, the duration of load factor.

The k_1 factors are related by

$$k_{1(LSD)} = k_{1(WSD)}/1.75 \tag{5}$$

Equation (5) leads to the value $k_1 = 1.00$ in LSD codes for the case of short term loads of 5 minute duration.

The specified stresses of WSD and LSD codes are related by

$$F_{LSD}' = (2.36/\phi)\, F_{WSD}' \tag{6}$$

The proposed values of ϕ factors for the LSD codes are given in Table 1.

In rough terms, the specified stress F' in the LSD code is the five-percentile value of the short term laboratory test strength and hence is a property that can be checked by direct measurement. A detailed discussion on this matter, together with other aspects of the LSD code have been given in a previous paper (2).

TABLE 1.
Capacity factors for the Australian LSD Code

Structural element	ϕ
Sawn timber, poles and glulam	
all stresses	0.8
Plywood and laminated timber	
all stresses	0.9
Connectors	
nails	0.8
other	0.7

DEFINITION OF SPECIFIED PROPERTIES

For the case of sawn timber, there is a recent Australian standard AS 4063, 'In-grade Strength and Stiffness Evaluation' (3), which defines the specified values for properties parallel to the length of the timber. In rough terms, the strength is related to the five-percentile value and stiffness is related to the mean value. Furthermore, the five-percentile value of strength must be estimated with 75 per cent confidence; an acceptable formula for this five-percentile value $F_{0.05}$ is

$$F_{0.05} = \{1 - (2.7\ V/\sqrt{N})\}\ F_{0.05,data} \qquad (7)$$

where $F_{0.05,data}$ is the five-percentile measured directly from the data, V is the coefficient of variation and N is the sample size used to make the measurement. Sample sizes as small as N = 30 may be used, but from equation (7) it is seen that this will lead to a penalty in the design stress if the coefficient of variation is large.

It should be emphasised that any design properties derived through the application of AS 4063 refer only to the population which was sampled for the test. This population is usually a specific grade, graded by a particular process from a particular parent population.

The procedure in AS 4063 has also been applied to other structural materials such as LVL. Currently there is no Australian Standard that defines the properties in a direction perpendicular to the board; nor is there one that defines the design properties of connectors and joint systems. It is planned to draft relevant standards for these purposes in the near future.

DERIVATION OF DESIGN PROPERTIES

For the case of sawn timber, there are three procedures for the derivation of design values for properties parallel to the length of the timber. These are as follows:

(a) *From In-grade Tests:* Use of AS 4063 to obtain specific design properties.
(b) *From In-grade Tests:* Use AS 4063 to obtain an F-grade rating: This requires tests on structural size timber bending and tension properties only.
(c) *From Small Clears Tests:* Use AS 2878, Timber – Classification into Strength Groups (4), AS 2858 Timber – Softwood – Visually Stress-graded for Structural Purposes (5), and AS 2082 Visual Stress-graded Hardwood for Structural Properties (6). This leads to an F-grade rating. Note that AS 2878 requires tests only on a few small clear specimens for bending and compression properties only.

The basic philosophy in the above is that the use of in-grade tests to obtain specific design properties, coupled with good quality control systems, leads to reliable design values; whereas an F-grade rating, coupled with limited quality control procedures, leads to design values that have a degree of uncertainty that is quite satisfactory for domestic construction, but is not ideal for engineered design where the consequences of failure may be serious. This concept is reflected in the recent amendment to AS 1720.1 wherein a new application factor k_2 has been introduced (7).

Although not stated explicitly, an important implicit consideration in the above is that the type of grading used does not affect the validity of the outcome of in-grade tests. The in-grade procedure is valid for stress-graded timber derived through the application of any method of stress-grading to any parent population of timber; an extreme example of this would be an application to an imported timber that has been stress-graded according to an overseas procedure.

For the case of structural properties perpendicular to the length of a board, design values are given on the basis of strength grouping according to AS 2878 (4). As with the F-grades, the derivation of grouped properties is associated with limited reliability.

For the case of connectors, the Standard AS 1649, 'Basic Working Loads for Metal Fasteners for Timber', (8), provides a procedure for the derivation of design capacity for four standard connector types. However, this Standard should be applied with caution since the prescribed evaluation tests are related to only one of many potential failure modes. This Standard is often used in association with a joint grouping concept. For this purpose, joints are grouped according to the density of the timber used as indicated in Table 2. There are no Standards available for evaluating design properties either for connectors in general or for any joint systems.

TABLE 2.

Density criteria for joint grouping

Unseasoned timber		Seasoned timber	
Joint group	Basic density of timber* (kg/m^3)	Joint	Air dry density at 12% m.c.* (kg/m^3)
J1	750	JD1	940
J2	600	JD2	750
J3	480	JD3	600
J4	380	JD4	480
J5	310	JD5	380
J6	245	JD6	310

* mean value for the species

STRESS GRADING

The intent of stress-grading is to sort timber into groups (i.e. stress grades) that are associated with low variability in their structural properties; the lower the variability the more efficiently can the timber be used.

The concept of stress-grading is illustrated schematically in Figure 1. Here a grading parameter G (which may be a complex function of several other parameters) is used to estimate the value of structural properties such as the strength R. The efficiency of a stress-grading procedure is illustrated roughly by the relationship

$$V_{SG} = V_P \sqrt{1 - r^2} \tag{8}$$

where V_{SG} and V_P denote the coefficients of variation of the stress graded and parent populations respectively and r denotes the correlation coefficient between G and R.

Australian Standards that define stress-grading processes are AS 2858 (5) and AS 2082 (6) for visual grading, AS 1748 and AS 1749 (9,10) for mechanical stress-grading and AS 3519 (11) for proof grading.

QUALITY CONTROL

Rigorous quality control of stress-graded timber requires the use of three standards as follows:

(a) Full in-grade evaluation every decade or so according to AS 4063 (3);

(b) Limited verification of in-grade properties a few times each year according to the draft Standard AS YYYY (12); and

(c) Daily process control such as that of the new drafts of AS 1748 and AS 1749 (9,10).

The procedure is illustrated schematically in Figure 2. A good example of process control is that given in the draft Standard AS 1749 (10) which involves mechanical testing and a CUSUM charting procedure.

Australian Standards for the rigorous quality control of other structural properties of timber and of connectors have yet to be drafted.

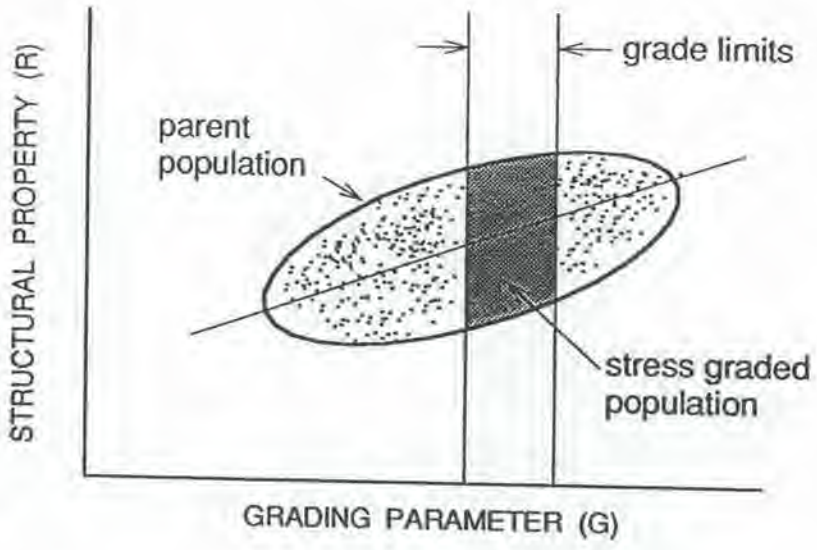

Figure 1. Schematic illustration of stress-grading.

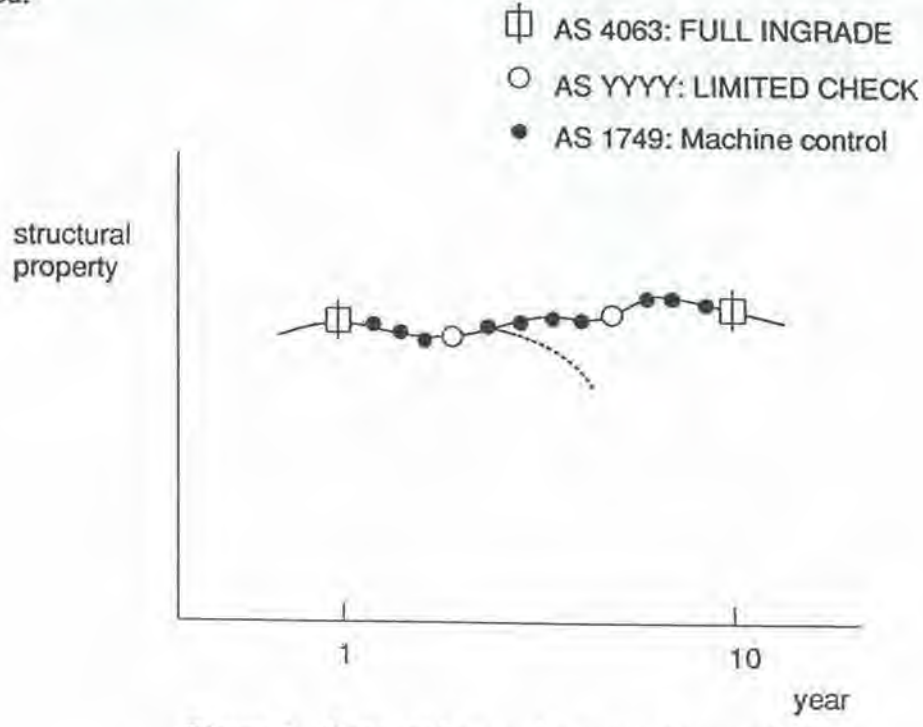

Figure 2. Concept for quality control procedures.

RELIABILITY

In the past, structural design properties were derived through a mixture of experience and intuitive application of probabilistic concepts. However, during the past two decades some very useful formal procedures, based on structural reliability concepts, have been developed. Some of the applications to Australian Standards are given in the references (2), (13) and (14). An example of one study is shown in Figure 3; this was considered in the derivation of the application factor k_2 for AS 1720.1 (7).

CERTIFICATION

Currently, the ultimate authority for product certification of structural products in Australia rests with 800 local government authorities; there is some sort of coordination via state and federal bodies as indicated in Figure 4, but the acceptable control procedures are more to do with the available schemes rather than with a formalised set of criteria.

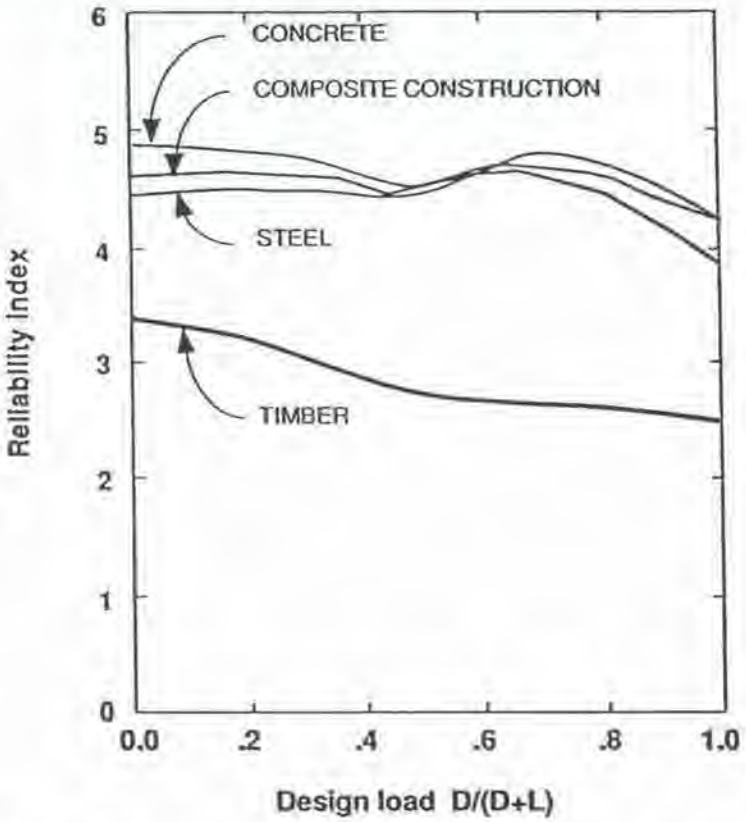

Figure 3. Assessment of reliability for design according to Australian Structural Standards.

However, in the future it is expected that most quality certification will be through JAS-ANZ, the Joint Accreditation System for Australia and New Zealand, (Fig. 5). This body will comply with international standards in its operations and will also have international linkages to, and recognition by, other national and regional bodies.

FUTURE

Currently, many standards that would be required for product certification and other aspects of structural quality are missing; and those that exist are not written to any uniform format. It is hoped to remedy this situation in the foreseeable future. Three types of standards as follows are envisaged:

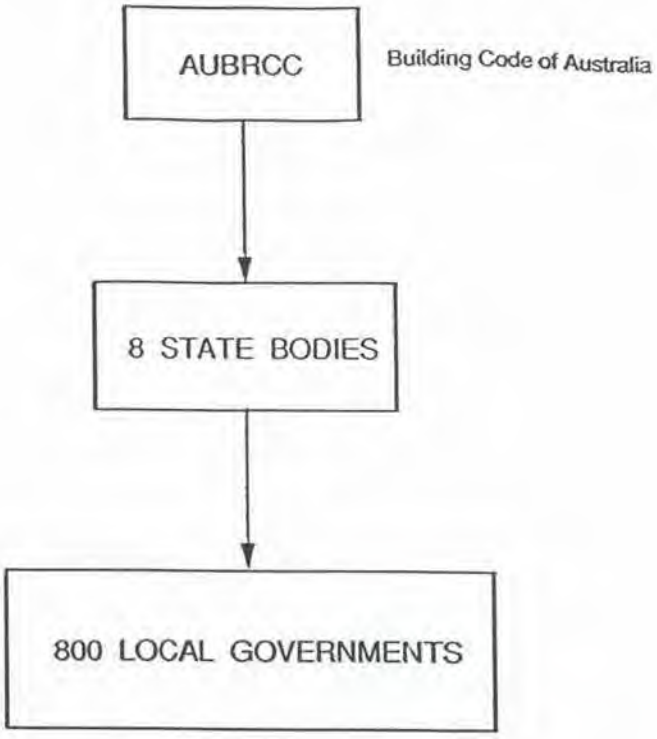

Figure 4. The AUBRCC ACCREDITATION System.

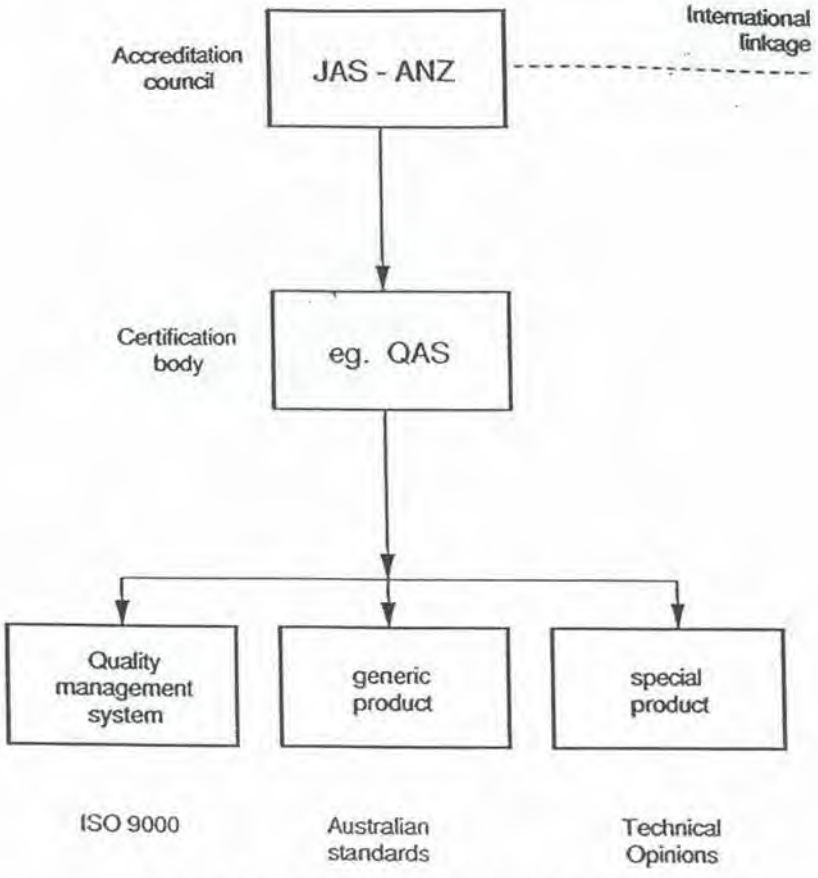

Figure 5. The JAS–ANZ Accreditation System.

(a) *Product Standards* These will describe products that are acceptable for a given end use; examples are floor joists, shear walls and transmission poles.

(b) *Material Standards* These will describe the specification and quality control of a material, the derivation of design properties; these design properties will be used in association with a design standard; examples of engineering materials would include sawn timber, poles and I-beams.

(c) *Design Standards* These would include standards for the design of single elements (e.g. a floor joist), composite elements (e.g. a shear wall) and total structures (e.g. a house).

It could be argued that there should be a fourth category of standards for *processes* (such as preservation and stress-grading) and a fifth for *test procedures*. However, it would make for a clearer presentation and understanding to place these standards as subsets of the basic three types proposed.

The use of a formalised procedure for developing standards and the associated quality assurance procedures, should facilitate the introduction of new products and marketing strategies. One example would be the development of special grading techniques for sawn timber to produce an end product (such as a floor joist) rather than a stress-grade (such as an F-grade). Another example would be the application of reliability theory to produce a design procedure where durability in biologically hazardous locations is an issue (15).

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THE EFFECT OF A PLYWOOD STIFFENER ON TOP PLATE UPLIFT PERFORMANCE

by Bob Clinch and Moses Virivolomo

Abstract

The use of solid top plates in domestic construction of the size 70 x 70 mm or 90 x 90 mm are not often practical. Typically, two sections of either 38 x 70 mm or 45 x 90 mm are used to create the full cross-section of the top plate. A possible alternative is the use of a continuous plywood strip nailed to studs and a 70 x 45 mm top plate.

1. Introduction

Timber wall frames in domestic construction normally have a horizontal member (ribbon top plate) on top of the studs. Roof trusses or rafters are fixed to the plate, usually by metal connectors. Wind forces on the roof produce uplift which is translated to the top plate. Typically, two sections of either 38 x 70 mm or 45 x 90 mm are used to create the full cross-section of the top plate. A possible alternative to this arrangement is the use of a continuous plywood strip nailed to studs and a 70 x 45 mm top plate, provided the required strength and stiffness can be maintained. The aim of this study was to investigate the effect of various depths of 7 mm thick plywood stiffeners, ranging from 150 mm to 300 mm deep. Since the aim was to determine the effect of the plywood as a stiffener of the top plate in a typical construction, no other stiffening materials, such as cladding or metal connectors, were to be used.

2. Literature Review

In a study by Ribinsky (1990) an attempt was made to investigate the problem using a similar model frame as in this study. Unfortunately, in Ribinsky's set-up, the loading configuration and method of supporting the model frame did not adequately simulate the in-service loading condition. Design methods involving plywood are based on AS 1720.1 and assume continuously restrained edges, whereas in this and Ribinsky's study, one edge is unrestrained except where it is attached to studs, every 600 mm.

3. Fabrication

Four test frames were made up of four short studs 70 x 45 mm and 1130 mm long, and a top and bottom plate each 70 x 45 mm and 1800 mm long. Each stud was nailed

to the bottom plate and top plate at 600 mm centres by two 3.75 mm diameter by 100 mm long plain shank bullet head nails driven through the plates into each end of the stud. Two threaded rods were fixed to the top and bottom plates on the outside of the outer studs to simulate holding-down bolts used in construction practice. Each threaded rod was anchored to the reaction frame through the bottom plate. The bottom plate was also fixed to the reaction frame midway between studs. In order to facilitate loading, the frame was inverted, with the bottom plate being attached to a heavy steel reaction beam as shown in Figure 1. Plywood was attached by nailing at 50 mm centres with 2.8 mm diameter galvanised clouts 30 mm long along the top plate and down each of the studs. A loading rig was fabricated to apply equal "uplift" loads to the top plate midway between studs, also shown in the figure.

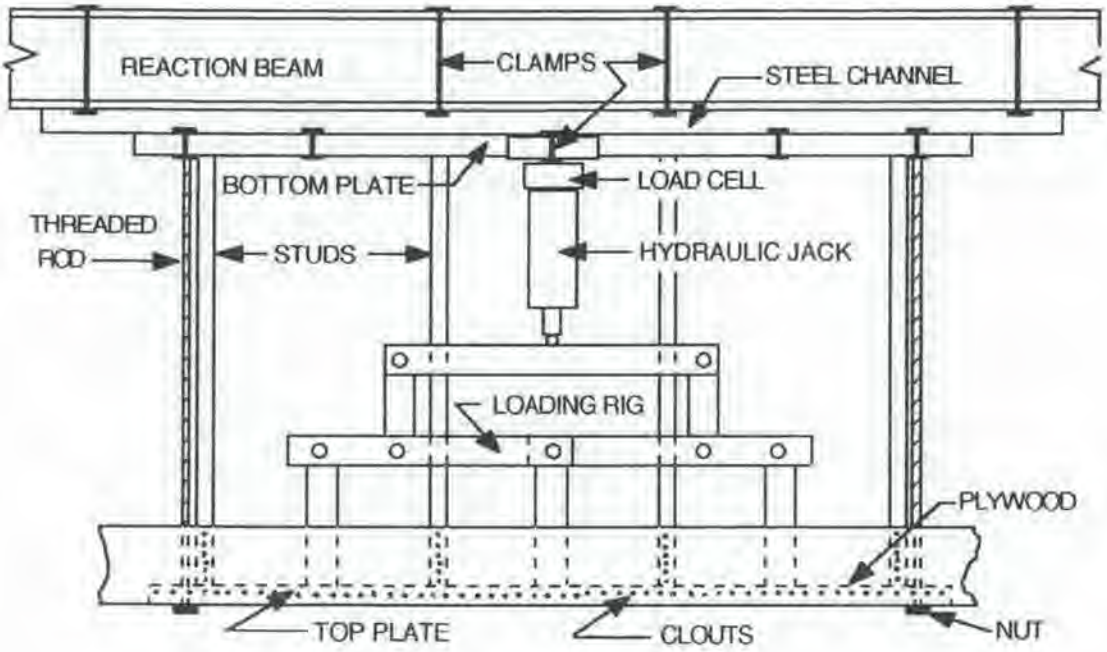

Figure 1
Loading set-up

4. Testing Program

In order to determine the effect on strength of the components, three different types of tests were carried out. These were: nail withdrawal from the end grain of stud material, loading each frame with no plywood stiffener, and, loading each frame with a plywood stiffener. Four depths of plywood stiffener were to be evaluated: 150 mm, 200 mm, 250 mm and 300 mm. Two tests (A and B) of each frame type were to be conducted.

Each of the four frame types was loaded without a plywood stiffener. Loading was discontinued when the deflection increased without an increase in load, typically at 10 mm deflection at mid-span. Since the nails in the end grain of the studs withdrew during loading, they were withdrawn completely by hand after load-deflection data had been obtained, and then new nails were driven into a solid area of the end of each stud. The plywood stiffener was then added and load was applied until failure, which occurred when the load could no longer be sustained.

5. Results

5.1 Nail Withdrawal

Using a nail withdrawal testing procedure based on a standard test procedure, two nails were hand-driven 45 mm into the end grain of six 70 x 45 mm stud off-cut test blocks and immediately withdrawn using a specially designed jaw in the universal testing machine. The results were as shown in Table I, with an average maximum load of 1.0 kN, representing a withdrawal rate of 22.2 N per mm for the two nails combined.

Table I **Maximum nail withdrawal loads for 2 nails in end grain**

Test No.	1	2	3	4	5	6	Ave.
Max. Load kN	0.82	1.20	0.73	0.86	1.46	0.92	1.0

5.2 Frame Loading

Frames types were identified as 150 (for 150 mm deep plywood stiffener), 200 (for 200 mm deep plywood stiffener), and so on. Table II shows the results of loading for frames without and with plywood stiffeners.

6. Discussion and Conclusion

From the results of the nail withdrawal test the average maximum load which two nails in the end of a stud off-cut could sustain was 1.0 kN, as in Table I. It is a reasonable to infer that the maximum load which could be applied to a frame without plywood would be twice that value, being shared between the two centre studs. Results from the frame test (Table II) without plywood reflect that inference, where the average maximum load is 1.85 kN, with a range from 0.59 kN to 3.13 kN.

Table II Maximum loads which frames could sustain - kN

Frame type	150	200	250	300	Ave
Test A: Without plywood	0.91	1.30	2.29	2.04	1.64
Test B: Without plywood	3.13	2.94	0.59	1.55	2.05
Average: Without plywood	2.02	2.12	1.44	1.80	1.85
Test A: With plywood	3.46	6.18	10.32	10.33	7.57
Test B: With plywood	7.16	7.39	5.71	7.93	7.05
Average: With plywood	5.31	6.79	8.02	9.13	7.31

Since all the frames were essentially similar in construction, the maximum loads should be similar, with nail withdrawal being the main variable. Areas of knotty material at the end of some studs could account for the variability of the loads.

The frames with plywood show a trend of increase in strength as the depth of the plywood stiffener increases, as shown in Table II. The anomoly in the sequence is with Frame Type 250, Test B, with a maximum load of 5.71 kN; however, without plywood its maximum load was low, at 0.59 kN.

The effect of a plywood stiffener on top plate uplift performance is significant, on the average producing a fourfold increase in strength in a 70 x 45 mm top plate.

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"NEW DEVELOPMENTS FOR STRESS LAMINATED TIMBER BRIDGES"

Author: Keith I Crews
Director of Timber Engineering Studies,
School of Civil Engineering - University of Technology, Sydney
PO Box 123 Broadway, NSW 2007

Synopsis:

Since early 1990, a major research and development program for stress laminated timber decks has been undertaken at the University of Technology, Sydney.

The purpose of this testing program is to develop an "engineered system" for both new and replacement bridge decks, using commercially available sizes of sawn timber. The technology provides a timber bridge deck which meets AUSTROADS design standards, and will be used by both state and local government authorities to construct new bridges and in the maintenance of some 10000 timber bridges that are currently in service on the east coast of Australia. In order for such new technology to gain acceptance, a thorough research and testing program is necessary to characterise the structural performance and undergird the basis of design procedures for stress laminated timber deck systems.

This paper presents an overview of serviceability and ultimate load testing of full sized decks under laboratory conditions and comments on the implications of the test results and analytical predictive models for preparation of limit states design procedures for stress laminated timber bridge decks for use throughout Australia.

1 - INTRODUCTION:

Historically, timber bridges have played a major role in the development of transport routes throughout most countries in the world, not the least of which has occurred in Australia. Traditionally, timber has been perceived by Engineers as an inferior material for use in exposed bridges, because of fears of deterioration due to decay or insect attack. This perception is not surprising, given the traditional neglect of timber structures and the fact that most of them have been in service for more than 50 years.

Despite the fact that maintenance on many existing timber bridges has often been under funded (and sometimes ignored), experience both in Australia and overseas has shown that in the majority of cases, the most significant cause of maintenance expenditure is degradation of the deck and wearing surface and of those structural elements which are unprotected from weathering. Often, the decking material and perhaps the girders will be in need of replacement, whilst the sub-structure (which is usually protected from weathering by the deck) is in relatively good condition despite its age.

Over the past few years, maintenance of the "Timber Bridge Asset" has become a major focus for most Road Authorities in Australia. In order to address this problem and develop new means of rehabilitating and upgrading load carrying capacity of timber bridges, a major Research and Development program has been under way since early 1990 at the University of Technology, Sydney, being sponsored by the Roads and Traffic Authority of NSW, the Forestry Commission of NSW and Pine Australia.

The main thrust of this research and development program has been the development of stress laminated timber bridge decks, using local hardwoods, radiata pine and (to a limited extent) imported douglas fir. Details of this technology and details of the testing program and prototype bridges are presented elsewhere.[1] The technology is now well established in Australia and is rapidly becoming a key factor in asset management strategies for road authorities and local government instrumentalities involved in the maintenance of timber bridges.

2 - TEST PROCEDURE:

2.1 - Scope:

As a part of the R & D program, a series of tests on full span, single lane width stress laminated decks have been undertaken in the Structures Laboratory to:

a) quantify serviceability behaviour for stress laminated bridge decks

b) quantify ultimate load behaviour of stress laminated timber decks.

c) quantify the serviceability and ultimate load behaviour of new forms of stressed timber construction, such as cellular decks, which utilise smaller end section sawn timber.

Whilst tests validating orthotropic plate behaviour in the service load range for stress laminated decks, have been undertaken both in Australia[2] and North America,[3] information on ultimate load and "post - failure" behaviour of full size decks, was unavailable. Testing of cellular decks has not been previously undertaken.

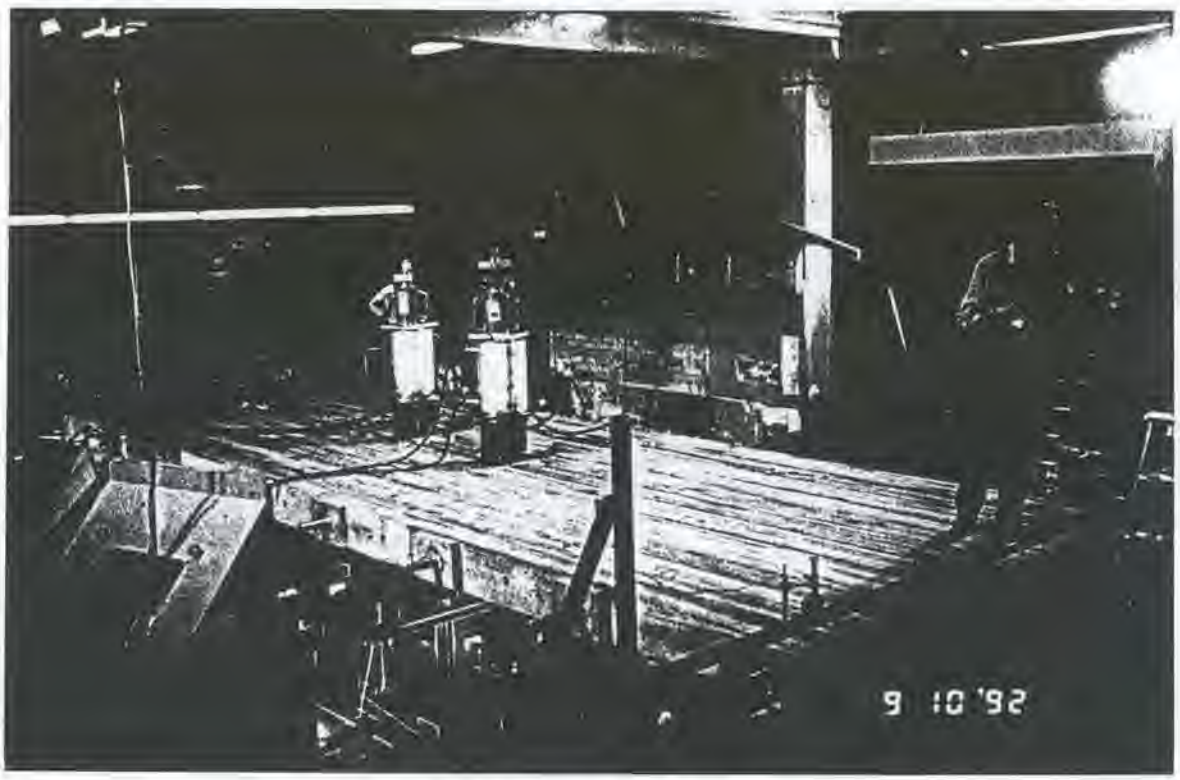

figure 1 - 8.5m span hardwood bridge deck

2.2 - Deck Construction:

To date, three "full scale" bridge decks have been constructed and tested in the laboratory. The first was a hardwood deck made from 290 x 45mm F27 laminates,[4] nominally 9m long and 3m wide, with a clear span (centre to centre) of 8.5 metres (refer **figure 1**). The second deck was made from 290 x 35mm F5 radiata pine laminates, with a nominal length 6.6m and a clear span of 6m (centre to centre bearing supports). Both decks were constructed using butt jointing patterns similar to those used in the prototype field structures.

The third deck tested in June 1993, was a cellular deck spanning 12.2m, constructed of 140*35mm F17 hardwood flanges, with 63*450mm F17 LVL webs at 483mm c/c. (refer **figure 2**)

Stressing was accomplished using Dwyidag post tensioning bars at 1200mm centres (26 mm diameter for the plate decks and 16mm diameter for the cellular deck) and pre-stress levels of 1200, 1000 (hardwood only), 700, 550 and 350kPa used for the determination of load carrying behaviour.

2.3 - Description:

The load tests for each deck were undertaken in two sequences. Firstly, the load deflection behaviour was measured for a series of loads in the elastic range at various prestress levels, to quantify the change of effective longitudinal stiffness with regard to prestress level. As a part of the serviceability tests, measurement of natural frequencies and damping responses were also taken on each of the bridges at different prestress levels.

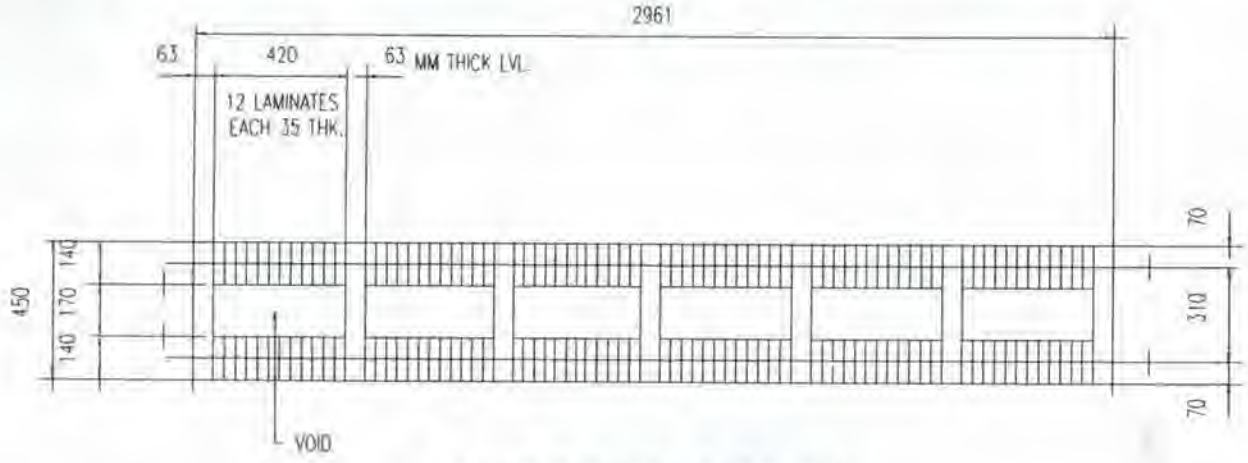

figure 2 - Section plan of cellular deck

The second set of tests involved stressing the bridge decks to a level representative of that likely to be encountered "in service" after a period of time, then loading the decks until failure of the laminates began to occur or until such time as the bridge deck could no longer take load.

For the plate decks, two point loads were applied, 1200mm apart at the centre of the deck, representing one wheel path, parallel to the laminates of the deck as can be seen in **figure 1**. The cellular decks were loaded at 4 points (representing 2 wheel paths, 1800mm apart) for the "serviceability" tests and two points (on the centre line) for the ultimate load tests.

Deck failure was defined (prior to testing) to have occurred when any of the following criteria were observed :-

- Failure of the laminates at or around the loading plates which would prevent any further significant test force increment.
- Increase in force within the stressing bars of the deck adjacent to the loading plates to 75% of UTS of the bar.
- Interlaminar shear failure of a magnitude that could induce significant "kinking" of the stressing bars. Kinking of the stressing bars may give rise to premature bar failure.

Instrumentation was provided at 25 (for the plate decks) and 50 (for the cellular deck) deflection points in order to characterise deflection profiles. The prestress level in the stressing rods was also monitored by use of a load cell placed on the centre stressing rod, which from past experience was recognised as the one which would have the largest increase in force due to deformation of the deck.

2.4 - Test Regime for Ultimate Load:

The anticipated ultimate load for the plate decks was expected to be in the range between 200 and 300kN per load point ie. a total of 400 - 600kN on the deck. The cellular deck was expected to take a load of approx 150 to 200 kN loaded at 4 points (2 wheel paths) and 250 to 350 kN loading at 2 points (for the single wheel path). The loading pads were 400 x 200mm x 20mm thick steel located on the centre line of the deck at 1200mm centres about the deck mid-span. The 200mm dimension of the plates was parallel to the deck length in accordance with the AUSTROADS standard vehicle configuration.

2.5 - Objectives of Ultimate Load Testing:

Whilst the current Australian design code for timber structures (AS1720.1 - 1988)[4] is still in working stress format, a limit state code is under preparation and the national bridge design code (AUSTROADS - 1992)[5] has recently been released in a limit states format, but without any provisions for design of timber structures.

The previously referenced testing of stress laminated decks had confirmed that linear elastic orthotropic plate behaviour could be expected at service loads, but the potentially complex interactions and behaviour at the Ultimate limit state were unknown and were not capable of being modelled analytically with any degree of confidence. A number of key questions concerning "unknowns" needed to be answered:

- is there any difference between the performance / behaviour of hardwood and softwood decks?
- what are the limits of linear elastic behaviour?
- is the failure mode brittle or ductile?
- does catastrophic failure occur?
- what is the likely mechanism of failure?
- what is the "post-critical" behaviour and what, if any, is the residual load carrying capacity of the deck once failure has occurred?

Noting the desirability of code developments moving towards reliability based design procedures, answers to the above questions are imperative for any high risk / high cost of failure structure, such as a stress laminated bridge deck.

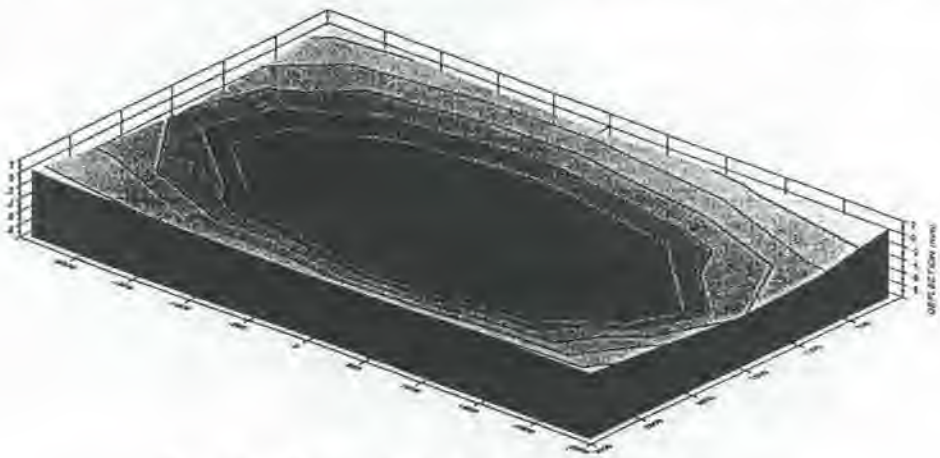

figure 3 -deflection plot for hardwood deck (simple plate)

2.6 - Summary of Results:

The serviceability loading cycles for both the hardwood and softwood plate decks demonstrated linear elastic behaviour up to load levels of at least three times the basic static design load of 48kN per pad, (refer Table 1), which represents a proof load for each deck that satisfies both strength and serviceability criteria.

deck type:	proportional limit (both pads)	ultimate load (both pads)
radiata pine	350 kN	450 kN
hardwood	450 kN	530 kN

Table 1 - Approximate Elastic and Ultimate Loads

deck type:	proof load limit (4 pads)	ultimate load (2 pads)
hardwood cell	760 kN	590 kN

Table 2 - Maximum Loads for Cellular Deck Test

Table 2 presents the maximum loads for 4 point and two point loading on the cellular deck. Deflection plots (refer **figure 3**) at load levels of 170 kN per load point (340kN total) confirm "typical" orthotropic plate behaviour.

Observations of the load deformation behaviour at mid span also indicated that the effective "stiffness" of each deck increases with increasing prestress force. From these results, the effective stiffness for various prestress levels relative to an initial prestress level of 1000 kPa (for hardwood) is as follows:

1000 kPa - 100% 700 kPa - 95% 550 kPa - 91% 350 kPa - 78%

Effectively, this means that a loss in initial prestress of 30% will increase instantaneous deflections by about 5%. The data from the serviceability load tests has been used to derive an expression for estimating distribution widths for the decks, which is presented elsewhere.[6]

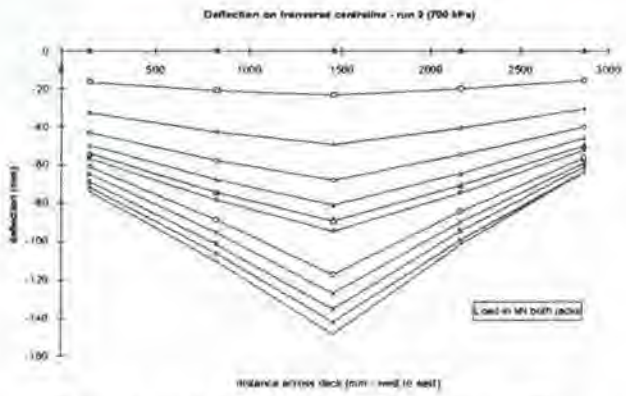

figure 4 - mid span transverse deflection profile - Hardwood

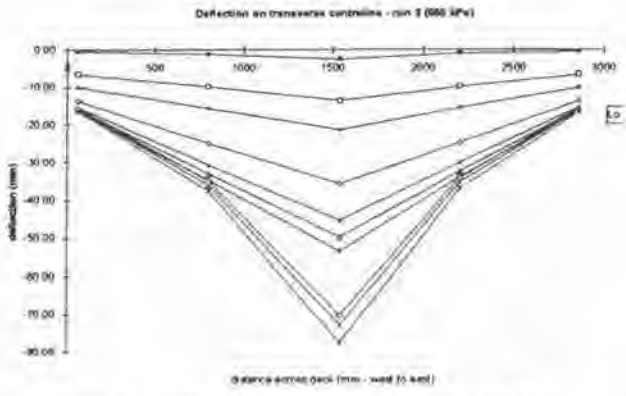

figure 5 - mid span transverse deflection profile - Softwood

3 - DISCUSSION OF ULTIMATE LOAD TESTS:

3.1 - Ultimate Load Response of Hardwood Plate Deck:

In the initial run on the hardwood deck, which was undertaken at a prestress level of 350kPa, interlaminate slip occurred in one location, at a load of approximately 170 - 180kN per jack. This slip was a matter of only a few millimetres. Subsequent to deck recovery, the deck was re-stressed to a prestress level of 700kPa. The load was then reapplied on both jacking positions and no distress was observed up until a load level of approximately 210kN per jack.

Upon reaching load levels of 200kN per jack load increments were taken up in 10kN increments. As can be seen in **figure 6**, the hardwood deck was able to achieve load levels of 240kN before significant failures in laminates started to occur. When this occurred, the bottom of the laminate visibly protruded from the bottom of the deck. This type of failure was propagated at a butt joint and although not fully visible at the time, it is believed to have been the result of longitudinal splitting of the laminate (horizontal shear).

This splitting is believed to have been caused from tension perpendicular to grain, induced by an interaction between the high degree of curvature and the prestress force between laminates and initiated by the discontinuity at the butt joint. This splitting failure was later confirmed in a post-mortem on each of the bridge decks when they were disassembled.

Despite these "failures", it was still possible to increase loads up to 260kN per jack, but as can be seen from **figure 6**, the behaviour of the deck is clearly non linear at this point. The large deflections at this load level resulted in the laminates inducing excessively high bar forces in the pre-stressing rods. As a result of this, the load was limited to 260kN (per jack).

3.2 - Ultimate Load Response of Radiata Pine Plate Deck:

The radiata pine deck had its first obvious failure in several of the laminates in line with the load points, at a load level of 200kN per jack. At 220kN (per jack) for the radiata pine deck, another laminate failed with the bottom visibly protruding from the bottom of the deck. As for the hardwood, this failure was in line with the point loads and was propagated from a butt joint. The failure occurred between the support and the first load point, extending into the loaded region. When this failure occurred, the load dropped to around 180kN and the measured maximum displacement of the deck, not including failed laminates was about 50mm.

Loading of the deck continued until a maximum load of 210 kN was reached. At this load level, what appeared to be a full punching shear failure occurred, when the loaded region slipped with respect to the adjacent decking on both sides.

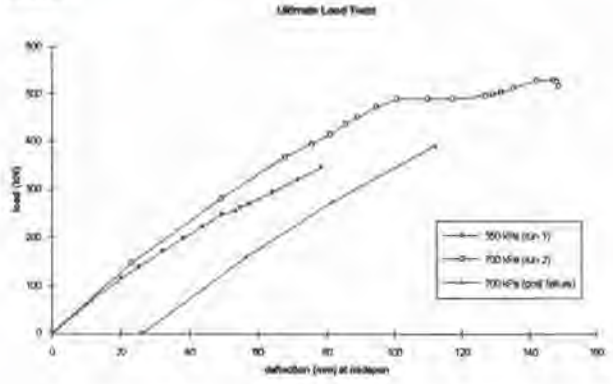

figure 6 - Ultimate Load Responses - Hardwood

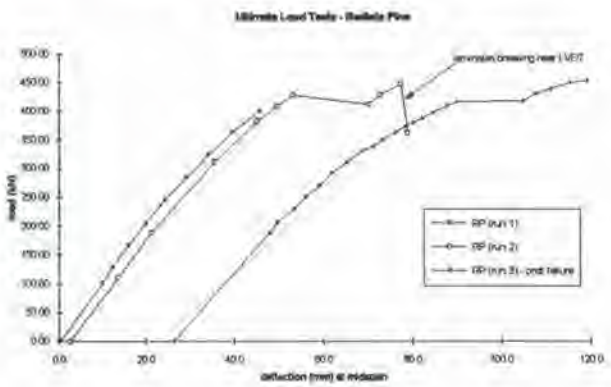

figure 7 - Ultimate Load Responses - Radiata Pine

It should be noted that there were no failed laminates outside the longitudinal lines defining the loaded region. In order to record additional detailed observations, the load level was maintained at this point and a closer inspection of the slip was performed. On top of the deck there was no visible distress of the laminates where failure had occurred below, except that the loaded zone had clearly slipped with respect to adjacent decking. No visible further increase in the crushing of the timber under the steel loading plates was observed at the jacking points, beyond that which was observed under seating loads.

For the hardwood, similar failures were observed to occur except that the load levels were considerably higher.

3.3 - Comparison of Hardwood and Radiata Pine

For both the hardwood and radiata pine decks, the non linear region produced increasing deflections for no significant increase in load, which resulted in the laminates inducing excessively high bar forces in the pre-stressing rods. As a result of this, the load was taken off the hardwood deck at a load of 260kN (per jack).

Both the hardwood and radiata pine softwood decks exhibited two predominant failure modes:

1. horizontal splitting at or near the neutral axis, propagated at butt joints
2. bending failures initiated as a result of slope of grain or defects such as knots.

In both cases, a tension perpendicular to grain failure resulted, (with extensive splitting) which resulted in a non-performance of the particular laminate.

3.4 - Hardwood Cellular Deck

Detailed analysis of both the serviceability and ultimate load carrying behaviour of the cellular deck is still being undertaken by the author at the time of writing and will be published over the next 12 months. Suffice to say the

cellular construction is considered to be a highly successful structural system, both in terms of its performance and cost effectiveness.

The deck tested had intentionally used a very shallow depth to span ratio, in an effort to induce curvature and encourage "failure" at a load level within the capacity of the reaction floor. The "normal" design depth for this span would have been 600mm, rather than the 450mm as tested.
One interesting phenomenon which was noted was the fact that even when all the LVL webs had fractured (in flexure) the deck still retained significant load carrying capacity (580kN per wheel path), albeit, with very large deflections. Only one of the hardwood flange laminates exhibited any signs of failure, although interlaminate slip was noticeable at some butt joints at high load levels.

3.5 - Post - "Failure" Behaviour:

All three decks were subjected to additional loading to evaluate their behaviour after failure.

The hardwood plate deck was allowed to recover and subsequently re-loaded in two cycles each up to 180kN. In both these cases the bridge performed adequately with no additional failures occurring. However, due to the excessively large deflections, the deck would be considered non- serviceable. Similar post failure behaviour and associated recovery was observed in the hardwood cellular deck, although the deflections were excessive (about 100mm), due to the amount of permanent set in the deck due to interlaminate slip.

Similar reloading cycles were applied to the radiata pine deck. Upon re-loading another failure slip occurred at a load level of 215kN. The load was then increased to 225kN and the post tensioning bar forces were observed to increase dramatically as they began acting like dowels. At 230kN concern regarding the bar forces prevented further loading and the deck was unloaded. Recovery was the same as before.

4 - DISCUSSION AND CONCLUSIONS:

4.1- General Observations:

The following points can be observed from the test data:

- The decks behave in an essentially linear and elastic fashion up to three times the design service loads ie. proof loading of the structure will fail to produce any significant failures in the bridge deck
- A comparison between elastic and non-elastic behaviour is clearly seen once failure of the laminates begins to occur. The onset of laminate failure appears to be sensitive to the location of butt joints and tension side defects.
- Increases in prestress levels and the subsequent effect on transverse stiffness is seen to increase the effective longitudinal stiffness of the deck.
- No interlaminar shear 'failure' could be induced at prestress levels above 350 kPa.

4.2 - Limit States:

It is necessary, as a result of these tests, to define or at least quantify, what we mean by "failure". The extreme deformation of the deck cannot be realistically considered as the ultimate loading. Two distinct loading conditions have to be considered; Serviceability Load responses and Ultimate Load behaviour.

Whilst serviceability criteria may be surpassed, the bridge can nevertheless recover after the load has been removed and actually remains in a condition that can still carry design loadings. It should be noted that the design pad loading is 48 kN per pad (static load), which is in turn increased by a dynamic effect / impact factor of between 1.1 and 1.4 An analysis of the data indicates that the distribution width and the moment deformation characteristics of the plate essentially behave as orthotropic linear elastic plates, up to a point when non-linear behaviour begins to occur. Details of this, along with the derivation of an equation for predicting distribution width in plate decks is presented in Crews, Bakoss, et al.[7]

During the ultimate load tests, a number of "stages" were observed, each of which might be defined as failure criteria. The first stage of the ultimate limit state was observed when horizontal shear failures began to occur at discontinuity's such as the butt joints, resulting in the deck behaving in a non-linear manner. This appears to have occurred at load levels less than the fifth percentile material strength under bending.

The second limit state stage may occur when bending failures as a result of tension perpendicular to grain are induced in the laminates by slope of grain or knots.

The third failure stage may be when the load level in the pre-stressing rods becomes unacceptably high due to the pre-stressing rods acting as dowels, due to the excessive deformations occurring in the deck.

The fourth and final stage of the Ultimate limit state may be deemed to occur at the point at which the deck can no longer continue to take load or at which excessive deformations continue to occur whilst the load is sustained, at a constant level. For the hardwood plate deck this would appear to be a load level of 265kN per jack or a total of 530kN per wheel path on the bridge deck.

Deck Type	Ultimate BM (kNm)	T44 ULS (kNm)	HLP320 ULS (kNm)
8.5m span Hardwood plate	967	545	862
6.0m span Softwood plate	540	293	445
12.2m Hardwood Cell	1622	1000	1740

Table 3 - Ultimate Load capacities compared to AUSTROADS Design ULS requirements (per wheel path)

4.3 - Conclusions:

The results summarised in Table 3, confirm that the capacity of stress laminated timber bridge decks meets full AUSTROADS design requirements. The expected capacity of a 600mm deep cellular bridge is expected to exceed 2500 kNm, well in excess of the HLP320 ULS requirement.

These tests have also demonstrated the high degree of resilience of this form of construction. When the decks appeared to have failed due to fracture of laminates and excessive deformation removal of load almost fully restored the original structural form; and despite being loaded significantly into the non-linear zone the decks had sufficient residual strength to carry three times the basic (unfactored) design load - a feat which is near impossible with any alternative building material.

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[4] SAA — *"SAA Timber Structures Design Code - AS1720.1 - 1988"* - Standards Australia, Sydney 1988

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[7] Crews, KI; et al — *ibid*

SOFTWOOD VERSUS STEEL FRAMING - A REVIEW

J. Georgiou. Deakin University

Introduction:

In 1974 the writer was employed by a national construction company contracted to build in excess of 100 houses in a town north of Melbourne. Some may remember the extreme shortage of labour during the housing boom of that period. As a result of the labour shortage, many people were sold on the virtues of prefabrication. At that stage the writer built houses using prefabricated frames out of timber, steel and a combination of steel and timber. Serious problems were encountered with the location of windows and set-out for the brickwork.

This paper compares softwood and steel prefabricated framing after almost 20 years of further development. The comparison is based on:-

(a) Experience of the Contractor
(b) Price
(c) Erection
(d) Other trades
(e) Conclusion.

The vehicle used is the construction of a 95 square metre weekend residence on a hobby farm north of Melbourne and within daily driving distance of the city. Construction of the residence is to be as an owner builder.

Experience:

Quotations were requested from timber and steel fabricators. Each fabricator was asked about the qualifications, experience and background of their personnel in the factory. all fabricators evaded the question. When pressed on the point of setting out windows and brickwork, the standard reply was that no mistakes were made in that area. The workers were supposedly experienced and the use of a computer eliminated the risk of error. Overall one was left with the impression the factory hands were only skilled labourers/process workers. Significantly, both timber and steel fabricators were keen to impress with the fact that they ran their plant with computers. No mention was made about the possibility of human error.

Price:

Competitive quotes received were as follows:

	Softwood	Steel
Supply and deliver trusses	2,700	3,300
Supply and deliver wall frames	2,700	3,100
Labour to erect above	1,000	1,000
Total	$6,400	$7,400

Erection:

The erection price for the timber frame was obtained by the fabricator from a carpenter known to him. But the owner-builder was advised that the carpenter would be employed by the owner-builder not by the fabricator. The steel fabricator also used sub-contract carpenters for erection but kept responsibility for employing them. An obvious advantage as responsibility is clear cut.

Framing carpenters known to the writer were also asked to price the erection of the frame but they were dearer. Some resistance was experienced if steel was to be used but this was overcome quickly due to the downturn in the industry. There does appear to be a shortage of carpenters experienced with steel framing. One view expressed was steel framing was specialised and that they would work with it during the downturn, but would return to timber framing with upturn in work. Carpenters were unanimous with their liking for softwood due to its' lightness.

Other Trades:

The following trades were consulted on their attitudes to the different types of framing:

Bricklayers
Plumbers
Electricians
Plasterers

Bricklayers consulted did not have specific preferences that would affect their price but they did express concern with set out problems they have had with windows. Similarly, plasterers and plumbers did not have a strong preference. Plasterers like the straightness of softwood and steel although the use of tec screws for fixing of plasterboard was viewed as a minor inconvenience. The plumbers were indifferent because they are used to working with metal. It made little difference to the electrician. There may be a

slight advantage with steel due to pre-punched holes which are used to run cables through them.

A cordless drill is used for the fixings regardless of whether the frame is of timber or steel. However, the advantage was not sufficient to allow for dollar savings.

Conclusion:

Although the investigation was narrow, the question of economy seemed to revolve around the cost of the framing itself. The writer did not encounter any items which would add to, or save in the cost of either framing material. An important item which arose with steel framing was that locations have to be precise for the trusses and other fixings, while service holes can be punched at random. This means the need for skilled and experienced personnel in the factory is more important.

The difference in marketing between the timber and steel people was very pronounced. The steel framers seemed to be geared exclusively for the owner-builder and endeavoured to help and guide as much as was asked of them. The timber fabricators were a mixture. One was very blase and indifferent while the other was courteous without really being overly helpful.

Although these conclusions were drawn from a narrow investigation, it is considered that these findings are typical of attitudes towards timber and steel framing systems.

TIMBER FRAMING VERSUS STEEL FRAMING IN HOUSING

DARRYL JONES, Timber Promotion Council of Victoria

INTRODUCTION

The Timber Promotion Council has shown intense interest in the matter of steel versus timber framing for many years. As far back as the mid 70's steel framing was mooted as a threat to the timber industry, and at that time bus advertising was undertaken to promote domestic timber framing.

In subsequent years various initiatives have been taken to ensure that timber retains its relative place in the market.

CSIRO has played an important part in the development of timber framing through their early work on the timber framing code. The continuing CSIRO research and development of timber products is of the utmost importance to the timber industry.

The main advantage that timber framing has over steel is price but there are many others. The amount of energy used to produce timber is far less than with steel. In timber production, no harmful chemicals or processes are used. Normal building practices can be retained and no special construction methods are required to build timber houses. Timber is a biodegradable natural material with a low social cost.

The chances of timber conducting electricity, even when wet are almost nil and greater heat loss occurs through metal than timber. Above all timber is from a renewable resource.

MARKET RESEARCH

Annual surveys of building materials used in dwellings in Victoria have been carried out since 1979. This work was originally initiated by the then Forests Commission. Since 1985 this activity has been the responsibility of the Timber Promotion Council. The methodology involves a 20% (approx) random sampling of each L.G.A. Seven Melbourne and ten country statistical regions of Victoria are surveyed for the March quarter of each year.

Private market research consultants are employed each year to conduct what is known as "Survey of Building Materials Used in Domestic House Construction - Victoria-March Quarter".

The actual field work is carried out by qualified staff who inspect actual plans and specifications relating to material usage in Class 1a buildings.

In 1986 a steel wall and roof framing facility was included on the field sheets. The results of surveys relating to the market share of steel framing are shown below:-

[Fig 1]

Market shares of steel used in Wall Frame - Victoria.

Year	Steel %
1986	0.8
1987	2.5
1988	2.6
1989	3.0
1990	4.0
1991	2.0
1992	2.0
1993	2.1

[Fig 2]

Market shares of steel used in Roof Frame - Victoria.

Year	Steel %
1986	1.9
1987	3.3
1988	3.5
1989	3.5
1990	5.0
1991	2.0
1992	2.0
1993	2.7

These figures indicate very little growth in steel framing market share in the past 8 years.

OPPOSITION

The timber industries main opposition is Nu-steel, Tran-Build and the National Association of Steel Framed Housing (NASH).

Also, we believe BHP is involved to some extent in advertising and promotion.

Their main focus is on denigrating timber framing and publicising misleading information about the cost of steel framing.

Nu-steel and Tranbuild advertisements often portray huge savings buy using steel framing but they do not have figures to back up their claims. What they may be doing is comparing a builder built timber home with an owner builder built steel house. In any comparison at all, the cost savings that they claim are not there.

In some cases the cost of materials for a steel kit home will be higher than a builder built timber home.

NASH also claim that a saving on house insurance can be obtained on a steel framed house. Doubting this claim, TPC staff carried out a survey of 10 insurance companies in Melbourne and the result was, none would offer a cheaper premium price on a steel framed house.

The opposition claims are often unbelievable, and it is our belief that this aspect of their marketing is very harmful to themselves.

TIMBER MARKETING

During the past seven years the TPC has initiated two streams of timber framing promotion.

1. General promotion of timber framing in all publications and exhibitions.

2. Promotion of timber framing using accurate cost comparisons.

In 1989 TPC retained a consultant to produce an accurate cost comparison between timber and steel framing. The result was a cost saving of up to $10,903 by using timber framing.

The costing included all labour and material to construct walls and roofs only. A conventional 149m^2 conventional house plan was used as the basis of the study.

To account for builders margin and overhead structures an on cost loading of 30% adopted. The details of this cost study are shown below:-

[Fig 3]

KEITH GRIFF & ASSOCIATES PTY LTD BUILDING MANAGEMENT & CONSULTING SERVICES

DOMESTIC WALL & ROOF FRAME COST STUDY JANUARY 1989

COMBINED WALL & ROOF FRAMING CAMPERDOWN (149M^2)

SUMMARY PRICE SCHEDULE TABLE NO 5

WALL FRAMING		ROOF FRAMING		TOTAL
		SITE CONSTRUCTION		
1. F8 UNSEASONED HARDWOOD	$3212	F8 UNSEASONED HARDWOOD	$3478	$6690
2. F5 RADIATA PINE	$3804	F8 UNSEASONED HARDWOOD	$3478	$7282
3. F17 SEASONED HARDWOOD	$4243	F8 UNSEASONED HARDWOOD	$3478	$7721
4. F7 OREGON	$4709	F8 UNSEASONED HARDWOOD	$3478	$8187
	PRE-FABRICATED CONSTRUCTION			
5. F5 RADIATA PINE	$4693	F5 RADIATA PINE	$5364	$10057
6. STEEL	$7783	STEEL	$9810	$17593

Prices calculated using a 30% on cost loading

In 1992 further costings were produced using the same methodology as in 1989. The only difference being the house size, which was 130m^2. The plan and specification was sent out to tender and the result was a saving of up to $13,421 on timber framing. The details are shown below:

[Fig 4]

WALL FRAMING		ROOF FRAMING		TOTAL
SITE CONSTRUCTION				
F8 Unseasoned Hardwood	$2,918	F8 Unseasoned Hardwood	$3,235	$6,153
F5 Radiata Pine	$3,437	F8 Unseasoned Hardwood	$3,235	$6,672
F17 Seasoned Hardwood	$3,801	F8 Unseasoned Hardwood	$3,235	$7,036
PRE-FABRICATED CONSTRUCTION				
F5 Radiata Pine	$3,681	F5 Radiata Pine	$2,977	$ 6,658
F17 Seasoned Hardwood	$3,996	F17 Seasoned Hardwood	$3,558	$ 7,554
Steel	$9,564	Steel	$10,010	$19,574

Prices based on: 1. Dwelling of 130m^2
2. All Labour and Material
3. Builders Margin included

A 4 size brochures and A1 size posters depicting the cost savings were produced and distributed throughout Victoria. Also, the results of the cost study were publicised through advertisements, press releases and the spoken word.

In September 1992 the NASH threatened legal action, strongly objecting to the cost study. Their argument being that TPC should not have compared on site construction with pre-fab.

The legal action never eventuated, but in any case by September the promotion was nearing completion. The high cost of domestic steel framing is well known by most builders in Victoria.

CONCLUSION

TPC has recently observed some radical new construction methods for steel framing such as the availability of individual components and the introduction of a non-welded joint.

New fixing methods have allowed easier installation of fitments and fixing materials.

In general, the steel industry is showing a willingness to observe product and construction problems and develop solutions to overcome them.

In the meantime the Timber Promotion Council will continue to closely monitor the steel industries activities.

Obviously, TPC future activities are highly dependant on trends occurring in market share and the marketing activities of the steel industry.

DARRYL JONES
[20-Sep-93]
DJ:242

A REVIEW OF DURABILITY DESIGN METHODS FOR TIMBER STRUCTURES

G.R. STRINGER, B.ENG.(HONS) A.I.W.Sc.
1993 GOTTSTEIN FELLOW
Hyne & Son Pty Limited
160 Kent Street, Maryborough
Queensland

ABSTRACT

Existing durability design methods for timber structures need to be reviewed. A number of general design considerations are summarized including, agents which can detrimentally affect structural performance, factors influencing these agents and other more general design factors. The main durability design methods used in Australia are summarised, as are three alternative methods. A number of desirable features of these main methods are collectively reviewed. These include natural timber resistance to agents, quantification of the effect of agents, performance criteria, factors influencing agents and the efficiency of resource utilisation. It is concluded that current durability design methods have limitations in meeting Australia's future needs. It is recommended that a new design method should be developed. Some research work to support such a method is discussed.

INTRODUCTION

Creating, maintaining and increasing the value of timber structures in our built environment requires many decisions to be made. These decisions are taken prior to and during construction, as well as throughout the service life of the structure. The initial designer of a structure has a responsibility to consider all factors which could potentially influence the intended performance of the structure. A set of rules or guidelines for making such decisions about structures can be referred to as a design method.

Designers of timber structures concerned with its resistance to imposed loads have a formalised design method available in AS1720.1-1988 "SAA Timber Structures Code". While this higher level design method is aimed primarily at structural engineers, less sophisticated design methods based on AS1720.1 are available for other designers of timber structures, particularly in residential design, e.g. AS1684-1992 "National Timber Framing Code". An assumption inherent in the AS1720.1 design method and most other Timber Structures Codes throughout the world is that timber elements within structures will maintain their load carrying characteristics for the intended life of the structure. In reality, timber structures are exposed to a wide range of environmental conditions which can reduce its ability to perform structurally. Most codes assume that appropriate action is taken to ensure the material and geometric properties of timber structural elements are not significantly

reduced during the structures life. Material properties refer to the inherent strengths and stiffness of the timber and geometric properties refer to the size and shape properties also used in structural design. The ability of a structure to resist environmental conditions can be referred to as structural durability. Decisions to achieve a level of structural durability appropriate to the structure's function and service life is an integral part of structural design, despite the conspicuous lack of advice on this matter in AS1720.1.

A number of durability design methods, which have generally developed in isolation from formalised structural design methods, are available to Australian timber designers. As a result of ongoing structural design method improvements and the increasing formalisation of durability design methods for other structural materials, most notably concrete (AS3600-1988), there is a need to review existing durability design methods for timber structures to assess their ability to meet the changing requirements of timber designers specifically, and society in general. A review of these methods is the subject of this paper and has been undertaken as part of a study programme supported by the J.W. Gottstein Memorial Trust Fund.

STRUCTURAL DURABILITY - GENERAL DESIGN CONSIDERATIONS

The durability design of timber structures will generally involve an analysis of environmental agents and factors influencing their detrimental effect on the structure. These considerations, together with other factors, will usually form the basis of the pragmatic decision making process called durability design.

A summary of the environmental agents which can cause a reduction in either the material or geometric properties of timber elements within structures is provided in Table 1. The specific type of agent, the effect on the timber and the main influence on the timber's material or geometric properties is indicated.

In addition to the individual agents given in the table, combinations of agents often occur. The most common of which would be weathering which can be considered as a combination of A3, B2, C2, and/or E2. (Refer Table 1 for codes.) Agents in combination can often reduce the structural durability more significantly than individual agents acting alone, e.g. Subterranean termite (D2(i)(a)) activity can encourage fungi (D1(i)) and visa-versa.

The extent to which the agents or combinations of agents may detrimentally influence structural durability can vary considerably. Initially the effect may begin at a microscopic level with no visual or structural impact. This may progress to a stage where it is quite obvious, and may reach the limits of acceptable aesthetic performance.

TABLE 1 SUMMARY OF ENVIRONMENTAL AGENTS

Environmental Agents Acting on Timber	Effect on Timber		
	Descriptive	Reduced Structural Properties	
		Material Properties	Geometric Properties
A. THERMAL			
1. Temperatures above combustion point	Burning	X	X
2. Temperatures below combustion above normal	Delignification	X	X
3. Temperatures & UV in normal environment	Delignification	X	X
B. CHEMICAL			
1. Special environments	Wood breakdown	X	X
2. Normal environments, eg sea, air, soil	Wood breakdown	X	X
C. PHYSICAL			
1. Initial changes in MC%	Splits, checks & heart shakes	-	X
2. Ongoing cycling of MC%	Surface checks	-	X
D. BIOLOGICAL			
1. Plant			
(i) FUNGI			
(a) Brown Rot	Cubical decay	X	X
(b) White Rot	Fibrous decay	X	X
(c) Soft Rot	Surface cracking	X	X
(ii) BACTERIA	Wood breakdown	X	X
2. Animal			
(i) INSECTS			
(a)Termites			
-Subterranean	Irregular Galleries	-	X
-Drywood	Irregular Galleries	-	X
(b)Borers			
-Lyctus	Many small holes	-	X
-Anobium	Many large holes	-	X
-Calymmaderus	Many small holes	-	X
(ii) MOLLUSCS			
(a)Teredinid	Medium holes	-	X
(b)Martesia	Large holes	-	X
(iii) CRUSTACEANS			
(a) Limnoria	Many small holes	-	X
(b) Sphaeroma	Many medium holes	-	X
E. MECHANICAL			
1. Application induced, e.g. rubbing on fender piles	Grooves, surface abrasion, splits etc.	-	X
2. Natural agents, i.e. water, wind	Abraded surface	-	X

An "X" indicates that there can be a reduction in this property by the corresponding agent, while a "-" indicates that there is generally no effect.

Finally, the effect of the agent may reach a stage where the ability of a structure as a whole or an element thereof is not capable of performing structurally, i.e. it cannot withstand loads with an acceptably low risk of structural failure. At this stage the structure could be considered to have inadequate structural reliability. An example of this progressive effect of environmental agents and their influence on different failure scenarios is shown in the results of a cypress decking trial in Queensland (Cause and Stringer 1993). The time scale over which the agent acts can also vary considerably, e.g. a fire event could occur in less than an hour while wood breakdown due to normal atmospheric chemical actions could occur over hundreds of years.

When designing a structure which is exposed to the agents given in Table 1 it is usual to consider factors which may influence the magnitude of the potential reduction in material or geometric properties. These would generally be agent specific and could include any of the following:

- Geographical extent of agents
- Climatic influences on the agents
- Construction practice which eliminates or reduces the agents
- Natural or treated timber resistance to agents
- Protective options to reduce the effect of agents
- Influences on agents due to other materials, e.g. corrosion in fasteners
- Maintenance practices to repair or replace failed timber elements and/or reduce the effects of agents
- Structure and/or orientation influence on agents
- Natural habits or features of biological agents
- Produce type, size, grade and shape influences
- Moisture content fluctuations and timber response characteristics
- Uses of structure which may influence agents
- Architectural influences on agents

In addition to the above agent related design considerations there are also other matters for designers to integrate into their decision making process. These include:

(i) Design life of structure, which is mainly dependent on the use of the structure or future use of the land on which the structure is located.

(ii) Structural reliability, which depends primarily on the consequences of a failure and the resulting implications on human safety and costs of repair or replacement.

(iii) The cost of the structure, which depends not only on initial construction costs, but also on any maintenance costs which may occur over the life of the structure.

(iv) Aesthetic, health or amenity performance requirements, which will generally be controlled by architectural rather than engineering considerations.

The published design methods currently available to Australian designers will be collectively reviewed in light of the general design considerations given above.

EXISTING DURABILITY DESIGN METHODS

Engineers, architects, builders, carpenters and structure owners all make decisions that influence the ongoing structural durability performance of timber structures. In practice each person has their own personal durability design method which usually involves one or all of the following, depending on the structure itself.

(i) Personal knowledge based on first hand experience, including the use of practices proven through trial and error,

(ii) Knowledge of colleagues who may assist,

(iii) Legislative requirements, and

(iv) The general rules for durability design given in appropriate publications.

The formalised durability design methods are those suggested in (iii) and (iv). They are generally the basis of the decision making process and the more significant methods are summarised in Table 2.

Most of these design methods are prepared by different groups who often have different objectives and make different assumptions about the expectations and needs of timber designers and/or users of timber structures. As a result there are inconsistencies between design methods which create confusion, uncertainty and ultimately reduce the confidence of timber designers in the durability performance of timber products. By comparison the structural design method is covered in a motherhood document (i.e. AS1720.1) with simplified design methods based on same.

Prior to the above documented durability design methods the durability knowledge base which existed amongst timber tradesmen was the mainstay of timber structures durability performance. With the general decline in specialist trade knowledge, the increasing commoditisation of Australian timber products and the increased emphasis on timber structure cost rather than quality, the once substantial knowledge base of tradesmen is being lost. No doubt in years to come the lessons that our forefathers did not have the opportunity to pass on will be relearned. Despite the tremendous advances made in improving timbers resistance to biological organisms in the last 40 years, the general knowledge of timber designers/users has undoubtedly declined. This is similar to the decline in timber knowledge that native cultures experience when exposed to the supposedly more advanced western technology for using timber.

TABLE 2 SUMMARY OF CURRENT AUSTRALIAN DURABILITY DESIGN METHODS FOR TIMBER STRUCTURES

Method	Legal Status (excluding Contractural Specification)	Agents Covered (refer Table 1 for codes)	Where Used	Other Details
AS1720.4	Via BCA, Spec. A2.3	Fire A1	Aust	Single element design only
Timber Utilisation and Marketing Act (TUMA)	Queensland Act	Lyctus D2(i)b	Qld	Treated timber similar to AS1604
Timber Marketing Act (TMA)	NSW Act	Lyctus D2(i)b	NSW	Aust. Stds. called up
AS1604	None except via TMA-NSW	Biological D	Aust	Treated timber only
AS1694	Via BCA, B1.3	Sub Termites D2(i)a	Aust	Physical barrier systems
AS2057	Via BCA, B1.3	Sub Termites D2(i)a	Aust	Chemical barrier systems
NAFI datafile P4	None	All	Aust	Part of NAFI Timber Manual
AS1684	Via BCA, B1.3	Biological D, some Mech.E.	Aust	Aust. Std. called up
Tech. Pam. 1	Via BCA, Qld B1.3	Biological D, some Mech.E.	Qld	Extensive species schedule
Cookson 1986	None	Marine Borers D2(ii) & (iii)	Aust	Specific to piles
CSIRO, TRADAC, TPC, NSWFC, QFS, TAHMA, FIFWA & other Industry Publications (Not referenced)	None, unless called up in registered products or state variation to BCA	Generally as above	Aust	Generally based on the above design methods

Three other durability design methods which have either been used in the past or suggested for the future are summarised in Table 3.

TABLE 3 ALTERNATIVE DURABILITY DESIGN METHODS

Method	Agents Covered	Other Details
Langlands & Thomas 1939 Pearson et al 1958 AS1720-1975	Biological and weathering, except marine	Integrates durability and structural design, using Exposure Factors to adjust working stresses. Recently calibrated for bridge girders (Law and Morris 1992).
Cokley 1973	Biological, except marine	Improved geographical and climatic identification of agents proposed. To be based on survey of existing structures and reliability principles.
Leicester & Barnacle 1990	Biological	Prediction method for determining beam and joint strength performance is proposed. Reliability approach suggested.

REVIEW OF DURABILITY DESIGN METHODS

As there are many similarities between the current design methods a collective review of a number of desirable features will follow.

Natural Timber Resistance to Agents

The CSIRO natural durability rating system (Tamblyn 1966) is used in most methods, with some modifications due to specific state data. Unfortunately the limitations for use of these ratings have not always accompanied the system into the design methods. As a result the extreme variation in heartwood durability performance, the fact that suggested service lifes relate to inground sawn fence posts only and are not necessarily applicable to aboveground applications has not been adequately conveyed to designers. This tentative system is itself coming up for review as a result of the CSIRO inground durability trial which is nearing completion. The presentation of the trial results in a form, readily useable by structural designers, is essential.

Another aspect of natural durability which is promoted in all systems is the lack of durability of the untreated sapwood of all timbers. In practice however sapwood does perform adequately in many structures where the design methods suggest it should not, e.g. fence palings, pergola members, cypress decking (Cause & Stringer 1993).

Quantifying the Effect of Agents

The only existing method which quantifies the effect of an agent on structural performance is AS1720.4 where both the loss of timber through burning and the loss of material properties of adjacent timber through elevated temperatures is rationalised to a thickness of timber on the affected surfaces. This allows post fire event geometric properties to be determined and used in structural calculations to determine the structures performance under post fire event loads.

No other existing methods provide a means for determining either the reduction in geometric or material properties as a result of the environmental agents. Quantification of such effects is essential if structure performance over time is to be estimated.

Stated Performance Criteria

None of the methods adequately state the performance criteria which will be achieved through application of the particular method. There seems to be some implied assumptions underlying many of the methods, i.e.

1. "Good Building Practice, based on the traditional use of Timber" (QFS 1991)

2. Timber structures should provide very high levels of durability performance.

3. Owners of timber structures should not be faced with extensive maintenance.

4. Agents causing an effect on timber will occur everywhere and at their most extreme regardless of the presence of influencing factors.

In particular, none of the methods state the expected structural reliability or design life which will result from using a method. Most methods use a relative rather than an absolute approach to this issue, i.e. the performance of one species or specific factors influencing durability is higher or lower than another option. AS1720.4 however in conjunction with AS1720.1 does allow the AS1720.1 level of reliability to be achieved.

The magnitude of safety factors used to determine say preservation levels is not stated, although such information would allow designers to better estimate the risk of a structural failure. The current AS1604 debate concerning heartwood treatability is a good example of the increasing need for engineers to have statistically valid data which allows structural reliability to be determined. The current approach adopted in AS1604 is no longer sufficient for engineers who want to design reliable timber structures.

Factors Influencing Agents

Most methods do not recognise the wide range of factors which can influence the activity of agents on the timber, e.g. there is no advice given on the geographic or climatic influences of an agent occurrence or level of activity. There appears to be an assumption, probably based on the wide variation in durability performance, that factors apart from basic material resistance have a relatively negligible influence on performance. This is disproven by examination of the performance of real structures. The Queensland decking trial highlights the importance of sapwood orientation, sun exposure and brush on preservatives (Cause and Stringer 1993) all of which currently receive no recognition in existing design methods.

Efficiency of Resource Use

The inherent conservatism of some of the design methods is undoubtedly a direct consequence of trying to achieve a simple design method, e.g. AS1604 and the rationalisation of hazards, retentions and penetrations. The result of such conservatism is that resources, be they timber, chemical or human, are not always efficiently used, e.g. the labour involved on a Victorian building site (low termite risk) to install physical termite barriers capable of protecting buildings in tropical Australia (high termite risk) is wasteful, because AS1694 does not distinguish between the different agents on either site. The legislative endorsement of design methods, either directly or indirectly, effectively makes it difficult for any innovative durability system to be approved. In this regard the current methods effectively discourage the pursuit of ideas that help improve durability performance or resource utilisation, e.g. AS1604 and TUMA (QFS 1987) by establishing minimum retention and penetration levels discourage specific customisation of treatments for particular applications exposed to particular agents.

CONCLUSIONS

The current durability design methods have served Australian society adequately in the past. However, they are in general,

(i) Inflexible and stifling of innovative solutions to enhancing structural durability.

(ii) Not adequately meeting the needs of structure designers who need quantifiable information about the reliability of various durability enhancing options.

(iii) Not keeping pace with advancements in structural design methodology.

(iv) Represented by a disorganised series of publications which are collectively discouraging confidence in the durability performance of timber structures.

(v) Not encouraging the efficient use of Australia's timber and associated resources.

(vi) Not strongly influenced by the needs of structural timber designers.

Australian timber designers and society in general would benefit if current design methods were to evolve into a more co-ordinated suite of documents, which promoted innovation, recognised the wide range of known factors influencing durability performance and quantified as much as possible the many factors involved.

RECOMMENDATIONS

Based on the information presented in this report it is recommended that,

1. The development of a more sophisticated durability design method is required. It should ideally have the following features:

   (a) Include all agents.
   (b) Separate aesthetic, health, amenity and structural failure scenarios.
   (c) Information which will allow the effect of agents or combination of agents on structural and geometric properties to be quantified.
   (d) Information which either directly or indirectly allows an estimate of the structural reliability to be determined.
   (e) Guidelines which allow designers to optimise the resources involved in achieving a required level of durability performance.
   (f) A framework which can accommodate and actively encourge innovative approaches to durability performance.

It would seem that the methods summarised in Table 3 and particular features of the AS1720.4, NAFI and Cookson methods, are worthy starting points for the development of such a method. The evolution of improved design methods should primarily be designer driven rather than researcher or legislator driven, as is the situation currently.

2. Extensive refocussing of current durability research programmes will be required to support the design method proposed above. Particular areas where increased emphasis and improved information is required are,

   (a) Geographic extent of agents
   (b) Influences on agent activity
   (c) Natural or treated timber resistance to individual agents
   (d) Methods for predicting the effect of agents on structural or geometric properties
   (e) The interaction of agents
   (f) Uniform presentation of results so that they can be readily interpreted for structural design purposes
   (g) Product type, size, grade and shape influences.

Durability research should be broadened considerably to more actively involve the design and building professions. Increased surveys of existing structures coupled with supportive laboratory work, are required.

3. Based on the design method suggested above, a prescriptive design method with criteria appropriate to residential construction should be developed for use by residential designers, builders and home owners throughout Australia.

The development of a proposed durability design method and more detailed information of the required research work is currently being investigated by the author.

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THE APPLICATION OF JOHANSEN'S YIELD THEORY TO AUSTRALIAN NAILED TIMBER JOINTS

G R STRINGER, B.ENG.(HONS) A.I.W.Sc.
Hyne & Son Pty Limited
160 Kent Street, Maryborough
Queensland

ABSTRACT

A theory for predicting the performance of laterally loaded nailed timber joints has been accepted by researchers and code writers in Europe and North America. This paper reports on a study using this theory with Australian produced timber and nails. Material properties appropriate to the theory are established, and five joints are tested. The theory conservatively predicted the performance of three joints. It was concluded that the theory has the potential to provide a fundamental and reliable basis for the determination of laterally loaded nailed timber joint performance. A limit state joint design method based on the theory is provided.

INTRODUCTION

In recent years nailed timber joints have received increased interest from structural engineers due to simple installation, low slip and superior cost efficiency (NAFI 1989). As a result of reports on innovative nailed connections (Yttrup et al 1989 and Day 1989), CSIRO carried out a reappraisal of nailed timber joint design loads (Lhuede 1990). In doing so a theory, developed in Europe by a Danish scientist, Johansen, was used to examine the performance of hardened nails and metal side plates in joints. This theory can be applied to any dowel type joint and has been adopted as the basis for design in Europe, Canada and the USA. It has been suggested (Leicester and Young 1991) that the development of internationally accepted theories for predicting the structural performance of generic connection types is an urgent matter. Johansen's Yield Theory has been previously examined by Australian researchers (Mack 1960 and 1962, Lhuede 1988 and 1990), however has not been adapted by the authors of AS 1720 "Timber Structures Code", who have preferred an empirical model (Mack 1966) which incorporates a safeguard against excessive joint deformation. Since the development of this empirical model, the types and properties of Australian timber products and nails have changed considerably. A more fundamentally based design procedure capable of more readily adapting to changing materials is required. Johansen's theory is one such option and this paper summarises work on this matter carried out by the author at the Queensland University of Technology. (Stringer 1991).

2.

JOHANSEN'S THEORY

Johansen (1949) examining bolted joints, identified two effects which contributed to the "function" of a dowelled connection, i.e.

"1. The dowel effect of the bolt, which depends on its resistance to bending and the resistance of the wood to embedding.

2. The tensional effect of the bolt, which depends on its resistance to tension and friction between the abutting surfaces."

Johansen assumed no tension effect, no frictional effect and that the wood and nail are ideally stiff up to a yield point beyond which they are ideally plastic. Refer Figure 1. A range of expressions were developed for predicting various failure modes and ultimate load capacities for both single and double shear joints. Testing verified the assumptions and the relationships expressed in these formulae. The theory has been developed by Moeller (1951) for nails, Meyer (1957) for dowel friction, Larsen & Reestrup (1969) for screws and Aune (1966) for joint deformation. The theory has been validated by many researchers, most recently and comprehensively by Hilson et al (1989) and Aune and Patton Mallory (1986). Predictions within 10% of ultimate strength are typical.

Eurocode No. 5 (1990) gives a suite of formulae for predicting the characteristic resistance of the joint (R_k), based on the theory. These are shown in Table 1 below with slightly modified notation.

TABLE 1 EUROCODE NO. 5 EXPRESSIONS

$$R_k = \min. \begin{cases} f_{e.1} t_1 d & \text{MODE 1} \\ f_{e.1} t_2 d\beta & \\ \dfrac{f_{e.1} t_1 d}{1+\beta} \left(\sqrt{\beta + 2\beta^2 (1 + \alpha + \alpha^2) + \beta^3 \alpha^2} - \beta (1 + \alpha) \right) & \text{MODE 2} \\ \dfrac{f_{e.1} t_1 d}{2+\beta} \sqrt{2\beta (1+\beta) + \dfrac{4\beta (2+\beta) M_y}{f_{e.1} d t_1^2}} - \beta & \text{MODE 3} \\ \dfrac{f_{e.1} t_2 d}{1+2\beta} \sqrt{2\beta^2 (1+\beta) + \dfrac{4\beta (1+2\beta) M_y}{f_{e.1} d t_1^2}} - \beta & \\ \sqrt{\dfrac{2\beta}{1+\beta}} \sqrt{2 M_y f_{e.1} d} & \text{MODE 4} \end{cases}$$

FAILURE MODES

where the material property parameters are:

M_y	- the moment at which full plastic behaviour occurs in the nail (N.mm)
$f_{e.1}$, $f_{e.2}$	- the wood's resistance to embedment of a dowel in the side and main joint members, respectively. (N/mm^2)
β	- the ratio of $f_{e.2}$ to $f_{e.1}$

and the joint geometry parameters are:

d	- nail diameter (mm)
t_1, t_2	- the thickness of the side and main joint members respectively (mm).
α	- the ratio of t_2 to t_1.

MATERIAL PROPERTIES

Wood Embedment Strength (f_e)

Six test methods were reviewed (Stringer 1991) and a modified Nordtest Method, NT Build 135 (1981) was selected because of its simplicity. The modifications made to this test were similar to those made by Aune and Patton-Mallory (1987). The following influences on embedment strength were reviewed (Stringer 1991) i.e. Moisture Content, Compressive Strength, Nail Diameter, Density, Grain Direction and Nail Predrilling. The test equipment and procedures are reported elsewhere (Stringer 1991). The densities of the timbers represented in the test program were established and are shown in Table 2. The mean load-deformation relationship from the tests is shown in Graph 1, while a summary of the embedment strength test results are shown in Table 3. A relationship (R^2 = 0.88) between density and embedment strength was established for 3.06 mm diameter nails using the results from solid Radiata, Slash, Messmate, Spotted Gum and from Radiata LVL. This relationship is shown in Graph 2.

Nail Bending Strength (M_y)

Threepoint (Nordtest 1981), fourpoint (Nordtest 1989) and a cantilever (White et al 1990) bending test methods were reviewed (Stringer 1991), as was a standard tensile test (AS 1391 - 1974 "Methods for Tensile Testing of Metals"). Nail diameter and the carbon content of the steel nail were the two factors influencing nail strength which were reviewed (Stringer 1991). The nail test program decided on is shown in Table 4. The test design equipment and procedures are reported elsewhere (Stringer 1991). The yield strength distribution of wire used to manufacture the nails was obtained from BHP quality control data and is shown in Table 5. The mean load-deformation relationship for threepoint nail bending is shown in Graph 3. The moments at which plastic failure occurred in the nails are summarised in Table 6 for the tensile and bending tests. Plastic moments based on BHP mean wire yield stresses are also given, i.e. M_y = yield stress (f_y) x plastic modulus ($d^3/6$).

JOINT STRENGTH

Joint tests were carried out in accordance with AS 1649 "Methods for the determination of basic working loads for metal fasteners for timber". The joint test program is summarised in Table 7. The test design, equipment and procedures are described elsewhere (Stringer 1991). The mean load-deformation relationship from the tests is shown in Graph 4. The characteristic joint strength was determined from the expression:

$$R_k = (N/27)^{V_R} R_{min.} \quad \text{(Leicester 1990)}$$

The mean performance of the joint (R_{mean}) was compared with the theoretical performance (R_t) using the plastic moments from the tension tests and adjusting the embedment strength for slightly different wood densities. Table 8 shows this comparison.

To use the theory to estimate a characteristic joint strength (R_{kt}) suitable for design purposes, it was determined that characteristic embedment strength could be estimated using the five percentile model shown in Graph 2, i.e.

$$\text{Characteristic } f_e = 10.67 + 0.08x \text{ (mean density)} \quad ....(i)$$

Because of the low variation in M_y it was decided to adopt the mean M_y as an estimate of the characteristic M_y. Table 9 compares the actual characteristic performance of the joint with the theoretical characteristic performance.

DISCUSSION OF RESULTS

Wood Embedment Strength

Based on the Slash Pine results, it appears that plywoods have a higher embedment stress than solid wood of the same species. This may be due to veneer orientation. It also appears that the higher embedment stress for Radiata LVL compared to solid Radiata may be explained by the higher density rather than any veneer effect. The relatively high variation in density and embedment stress in solid Slash Pine may be explained by the orientation of the nail to the growth rings. Where results with nails parallel to growth rings were excluded from the data, a 15% increase in embedment stress was determined. Eurocode No. 5 (1990) suggests the following model for determining characteristic embedment stress, i.e.

$$\text{Characteristic } f_e = 0.09 \times d^{-.36} \times \text{(5\%ile density)} \quad ....(ii)$$

This compares reasonably well with the model for 3.06 mm nails presented in equation (i).

Nail Bending Strength

Yield stresses determined from simple tension tests on the nail wire stock appear to be sufficient for determining the plastic moment. The Eurocode No. 5 (1990) equation for estimating the yield stress of common round steel wire nails is:

$$f_y = 50\ (19 - d)$$

This equation provides estimates for f_y of the 0.08% carbon content steel nails which accord well with actual results. It does however underestimate the strength of 3.33 mm dia 0.17% carbon content steel nails.

Joint Strength

The theory appears to be most accurate for joints not containing 7 mm plywood. Aune and Patton-Mallory (1986) tested joints using 12 mm thick Douglas Fir plywood and reported ratios of 1.07 to 1.12. Chipping of the face veneer is one explanation for the lower than expected strengths. The 0.8 mm gap between joint elements recommended by AS 1649 means the inner face veneer is not fully supported during nailing. The instability of the joint itself is one other explanation for the low performance, as the joint configuration and small nail to plywood contact area make the joint sensitive to any minor eccentricity during loading. Slipping of the plywood on the nail was observed during the testing.

CONCLUSIONS

- Embedment stress is proportional to wood density.
- Hyspan LVL manufactured from Radiata Pine veneers has a resistance to embedment more typical of solid wood than plywood.
- Johansen's Yield Theory can be used to reliably predict the mode of failure of a laterally loaded nailed timber joint.
- Johansen's Yield Theory can be used to conservatively predict the mean joint capacity of a laterally loaded joint, which consists of solid wood or Slash Pine plywood (24 mm or thicker) and 3.06 mm diameter nails.
- The lateral load capacity of a nailed timber joint may be reduced significantly where the nail is driven parallel to the growth rings and the nail is located in earlywood. This is more likely to occur in species which have a large density variation between earlywood and latewood and also where the width of growth rings is large.

- Johansen's Yield Theory is less reliable at predicting the lateral load capacities of test joints constructed from thin plywood due to frictional effects between the nail and plywood, stability affects due to the test configuration and splintering effects due to nail installation.

- The characteristic resistance of laterally loaded joints consisting of solidwood and 3.06 mm diameter nails can be conservatively predicted using Johansen's Yield Theory.

- Johansen's Yield Theory has the potential to provide a more fundamental and reliable basis for the determination of characteristic resistances in laterally loaded nailed timber joints.

RECOMMENDATIONS

1. Standards Australia should consider adopting a design procedure based on Johansen's Yield Theory for use in AS 1720 "Timber Structures Code".

2. Further research work is required on a range of matters associated with the adoption of Johansen's Yield Theory in Australia. A summary of proposed research projects is given elsewhere (Stringer 1991).

3. Designers should consider using the following proposed limit state joint design method which is based on the research work from this study.

PROPOSED LIMIT STATE DESIGN METHOD

Scope

The following design method applies to joints constructed of the following products:

- Australian grown seasoned softwood and/or hardwoods with a mean density at 12% moisture content of not less than 400 kg/m^3 and not more than 1200 kg/m^3.

- Slash Pine Plywood which is at least 17 mm thick.

- Australian Nails manufactured from BHP Wire Stock produced in either the Newcastle or Sydney Mill with BHP product numbers 10144 and 10143, i.e. 2.87 mm and 3.06 mm diameter nails with 0.08% carbon content.

Characteristic Resistance

The short duration characteristic resistance (q_k') of a single nail in a laterally loaded nailed timber joint may be determined using the expressions given in Table 1, i.e. $R_k=q_k'$ The following materials properties shall be used in these expressions.

(i) Solid Wood
f_e (MPa) = -10.7 + 0.08 (mean density (kg/m^3))
Mean densities can be determined from Table 2.

Where nails are installed parallel to growth rings in woods which have growth rings in excess of 6 mm wide and prominent earlywood/latewood bands, f_e should be reduced by 10%.

(ii) Slash Pine Plywood (min 17 mm thick)
f_e = 44.0 MPa

(iii) Nails
2.87 mm diameter M_y = 3090 N.mm
3.06 mm diameter M_y = 3760 N.mm

Modification Factors

The characteristic resistance (q_k') shall be modified by the following factors where required:

(i) Load Duration Factor K_1^*, given by the values in Tables 2.5 of AS 1720.1 - 1988 divided by 1.75.

(ii) Multiple Nailed Joint Factor K_{17} as given in Tables 4.2 (A) and (B) of AS 1720.1 - 1988.

Spacing and Edge Distances

The minimum nail spacings and edge distances in AS 1720.1 - 1988 shall also apply.

Summary

In summary the characteristic resistance (q_k) of a nailed timber joint can be estimated using the following expression:

$$q_k = q_k' \times K_1^* \times K_{17}$$

where q_k' and K_1^* and K_{17} are determined as described above.

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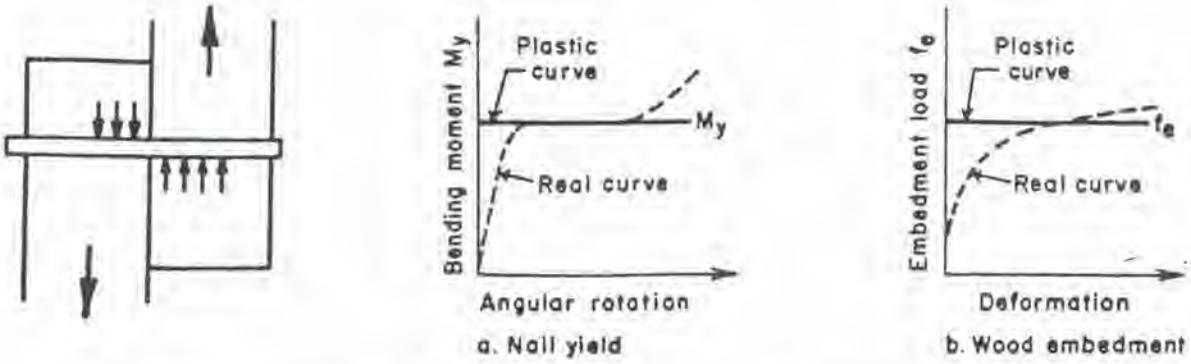
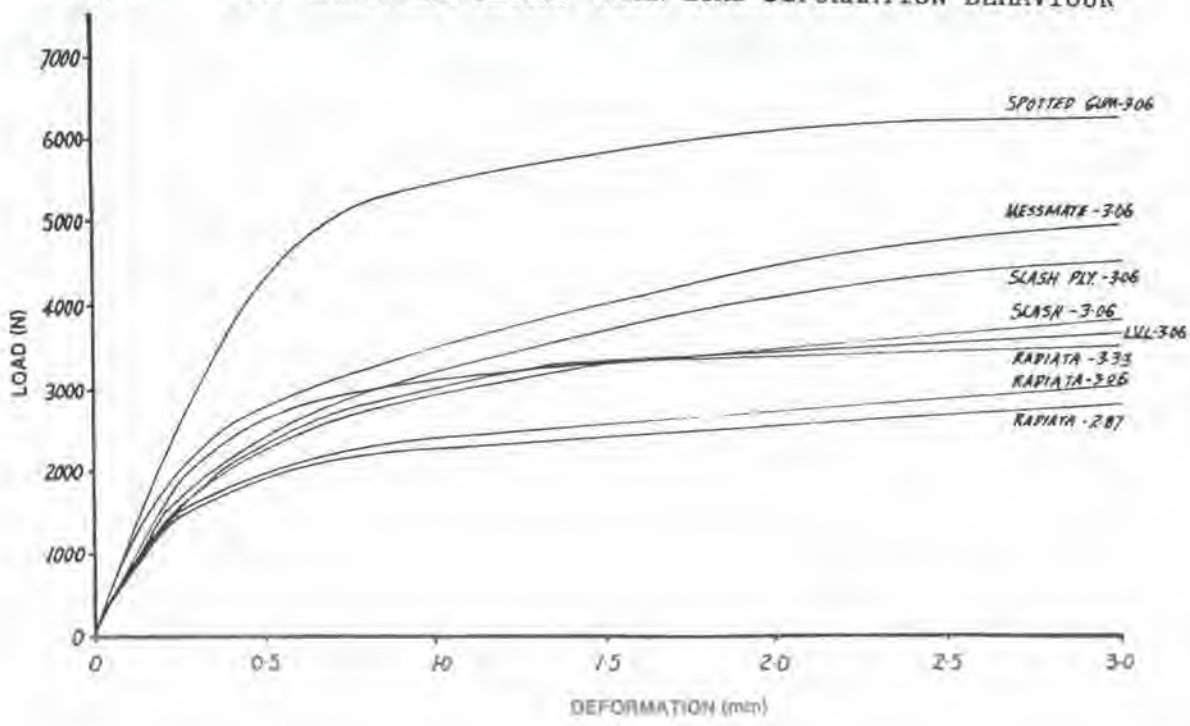


FIGURE 1 TYPICAL DOWEL JOINT AND ASSUMED MATERIAL BEHAVIOUR

TABLE 2 WOOD DENSITY INFORMATION

SPECIES	PRODUCT TYPE	OTHER DETAILS	DENSITY					REFERENCE
			Sample No	Mean kg/m³	S.D. kg/m³	COV %	5%	
Radiata Pine	Solid	MSG 90x35 F5	232	493	49	10	412	Leicester et al 1988
		MSG 90x35 F8	231	535	43	8	464	Leicester et al 1988
		MSG 90x35 F11	229	587	47	8	510	Leicester et al 1988
Radiata Pine	LVL	IPL	NA	610	18	3	580	PAA 1991
Slash Pine	Solid	MSG Framing F5	1163	560	63.7	11.4	451	QFS 1991
		MSG Framing F8	1171	615	67.4	11.0	504	QFS 1991
		MSG Framing F11	193	650	66.6	10.2	540	QFS 1991
Slash Pine	Plywood	7 mm	8	685	39.2	5.7	621	This Study
		12 mm	15	634	28.1	4.4	588	This Study
		17 mm	12	638	47.7	7.5	560	This Study
		24 mm	6	637	27.2	4.3	592	This Study
Spotted Gum	Solid	Clearwood	21	993	87	8.8	850	Bolza & Kloot 1963
Messmate	Solid	Clearwood	31	785	65	8.3	678	Bolza & Kloot 1963

GRAPH 1 WOOD EMBEDMENT TESTS. MEAN LOAD-DEFORMATION BEHAVIOUR



GRAPH 2 WOOD DENSITY - EMBEDMENT STRESS RELATIONSHIP

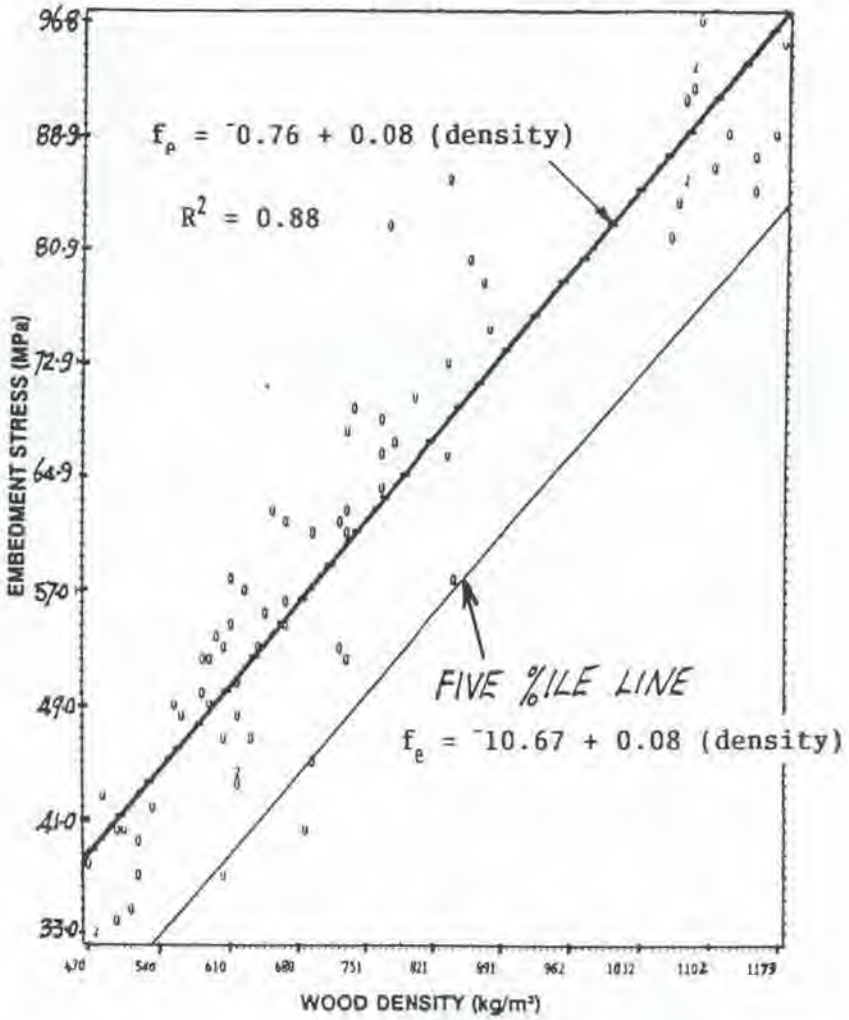


TABLE 3 WOOD EMBEDMENT TESTS. SUMMARY OF RESULTS

Test Series No.	Wood Type	Nail Dia mm	No. Tested	Density Kg/m³		Embedment Stress MPa		
				Mean	COV[1] %	Mean	COV[1] %	5%
1	Radiata/ Solid	2.87	15	517.8	12.7	43.0	21.3	27.9
2	Radiata/ Solid	3.06	14	529.6	7.3	43.0	16.1	31.6
3	Radiata/ Solid	3.33	15	492.3	9.7	45.9	14.4	35.0
4	Radiata/ LVL	3.06	15	623.9	4.7	51.4	9.2	43.6
5	Slash/ Solid	3.06	15	666.5	14.0	53.7	27.0	29.8
6	Slash/ Plywood	3.06	15	644.7	6.2	62.6	14.3	47.8
7	Messmate/ Solid	3.06	15	791.9	7.3	68.2	8.6	58.5
8	Spotted Gum/Solid	3.06	15	1103.2	3.3	89.0	4.9	81.9

Notes: 1. Coefficient of Variation.

2. the lower five percentile value assuming a normal distribution.

TABLE 4 NAIL STRENGTH TEST PROGRAM

Test No	Test Type	Test Method	Nail Dia	No. of Tests
NT1 - NT5	Tensile	AS 1391	2.87	5
NB1 - NB10	3 Point Bend.	Nordtest 136	2.87	10
NC1 - NC10	Cant Bend.	White et al	2.87	10
NT6 - NT10	Tensile	AS 1391	3.06	5
NB11 - NB20	3 Point Bend.	Nordtest 136	3.06	10
NC11 - NB20	Cant Bend.	White et al	3.06	10
NT11 - NT15	Tensile	AS 1391	3.33	5
NB21 - NB30	3 Point Bend	Nordtest 136	3.33	10
NC21 - NC30	Cant Bend.	Nordtest 136	3.33	10

TABLE 5 NAIL YIELD STRENGTH INFORMATION

	Wire Dia. mm	Steel Grade	Carbon Content %	BHP Mill[1] Location	No. Sampled	Yield Stress N/mm²		
						Mean	S.D.	COV%
*	2.87	WC1008	0.08	Newcastle	8	785	24.5	3.1
	2.87	WC1008	0.08	Sydney	N.A.	810	24.0	3.0
*	3.06	WC1008	0.08	Newcastle	92	788	25.9	3.3
	3.06	WC1008	0.08	Sydney	N.A.	798	29.0	3.6
*	3.33	WC1017	0.17	Newcastle	4	890	7.1	0.8
	3.33	WC1008	0.08	Sydney	N.A.	768	76.8	3.6

An * indicates the steel grade used in the tests.

Note: 1. The nails tested in this study were manufactured from wire produced at the Newcastle BHP mill.

2. N.A. means this data was not available.

GRAPH 3 NAIL TESTS.
MEAN LOAD-CURVATURE BEHAVIOUR

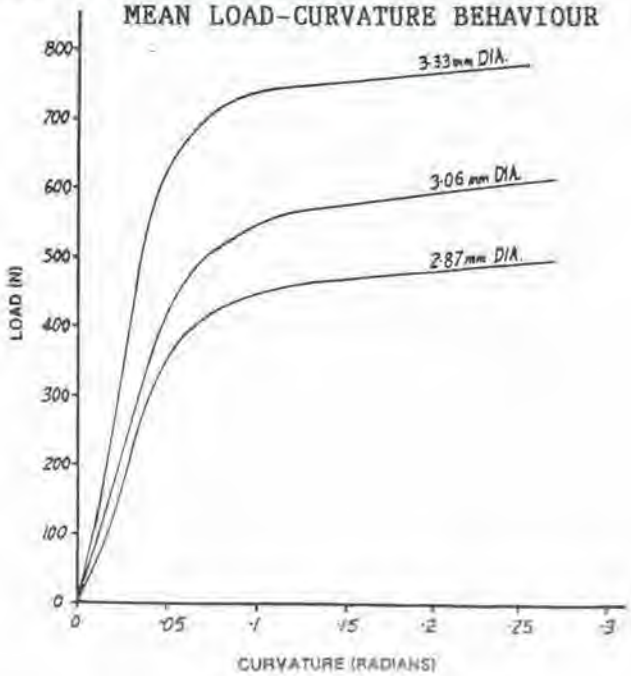


TABLE 6 NAIL STRENGTH TESTS. SUMMARY OF RESULTS.

Nail Dia mm	Plastic Moment N.mm					
	Tensile Test		3 Point Bending Test		BHP Tensile Test	
	Mean	S.D.	Mean	S.D.	Mean	S.D.
2.87	3205	10	3354	27	3158	99
3.06	3991	46	4192	66	3800	125
3.33	5384	23	5631	110	5527	44

TABLE 7 JOINT STRENGTH TEST PROGRAM

Test No	Main Member		Side Member		Nail Dia. mm	No of Tests
	Wood Type	Product Type	Wood Type	Product Type		
J1 - J15	Radiata	Solid	Radiata	Solid	3.06	15
J16 - J25	Radiata	LVL	Slash	24mm Ply	3.06	10
J26 - J35	Radiata	Solid	Slash	7mm Ply	3.06	10
J50 - J59	Messmate	Solid	Radiata	Solid	3.06	10
J60 - J69	Slash	Solid	Slash	7mm Ply	3.06	10

GRAPH 4 JOINT STRENGTH TESTS.
MEAN LOAD-DEFORMATION BEHAVIOUR

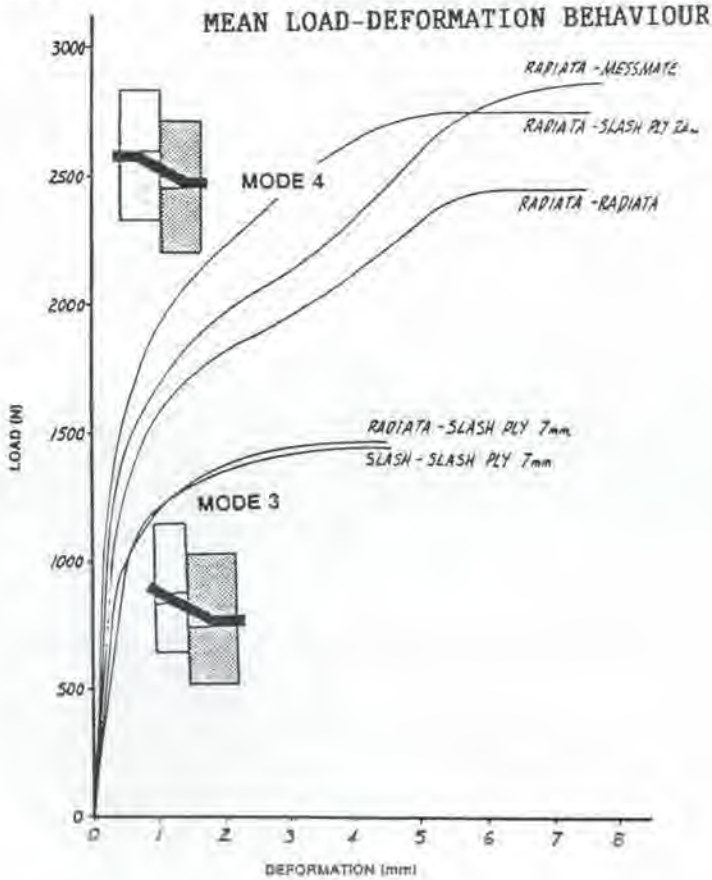


TABLE 8 MEAN JOINT PERFORMANCE. ACTUAL AND THEORETICAL

Joint Details						$\frac{f_{e.2}}{f_{e.1}}$	THEORETICAL PERFORMANCE		ACTUAL PERFORMANCE		Ratio
Main Member			Side Members				R_t		R_{mean}		
Wood & Type	MEAN Density kg/m³	$f_{e.1}$ MPa	Wood & Type	MEAN Density kg/m³	$f_{e.2}$ MPa	β	Newtons	Fail Mode	Newtons	Fail Mode	$\frac{R_t}{R_{mean}}$
Radiata solid	491	40.09	Radiata solid	491	40.09	1.00	989	4	1224	4	0.81
Radiata LVL	622	50.98	Slash ply-24	705	66.11	1.29	1185	4	1376	4	0.86
Radiata solid	472	38.50	Slash ply-7	693	65.40	1.69	770	3	732	3	1.05
Slash solid	682	55.96	Slash ply-7	684	64.87	1.16	873	3	716	3	1.22
Messmate solid	751	61.69	Radiata solid	487	39.76	0.64	1086	4	1432	4	0.76

TABLE 9 CHARACTERISTIC JOINT PERFORMANCE. ACTUAL AND THEORETICAL

Joint Details						$\frac{f_{e.2}}{f_{e.1}}$	THEORETICAL PERFORMANCE		ACTUAL PERFORMANCE		Ratio
Main Member			Side Members				R_{kt}		R_k		
Wood & Type	MEAN Density kg/m³	CHAR. $f_{e.1}$ MPa	Wood & Type	MEAN Density kg/m³	CHAR. $f_{e.2}$ MPa	β	Newton	Fail Mode	Newton	Fail Mode	$\frac{R_{kt}}{R_k}$
Radiata solid	491	29.10	Radiata solid	491	29.10	1.0	843	4	1027	4	0.82
Radiata LVL	622	39.71	Slash ply-24	705	64.44	1.62	1095	4	1063	4	1.03
Radiata solid	472	27.56	Slash ply-7	693	63.57	2.31	688	3	599	3	1.15
Slash solid	682	44.57	Slash ply-7	684	61.98	1.39	800	3	571	3	1.40
Messmate solid	751	50.16	Radiata solid	487	28.78	.57	943	4	1124	4	0.84

THE WOOD STRENGTH OF REGROWTH BLACKBUTT OF FOUR AGE GROUPS FROM 25 YEARS TO 70 YEARS OLD

P. Chapman
Research Division, State Forests
P.O. Box 100, Beecroft, New South Wales 2119

ABSTRACT

Five trees were selected from each of four even-aged regrowth blackbutt stands of ages 25, 40, 55 and 70 years. The sites were selected as being as representative and as uniform as practicable. Clear wood test specimens were obtained from logs cut from each of these trees and tested for strength in the green and air-dry conditions. Differences in strength properties were apparent between the age groups but not necessarily following an increasing age increasing strength pattern. These differences were attributed to environmental factors coupled with variability within the species.

From a practical viewpoint, the intrinsic strength of clear wood from regrowth blackbutt trees over the age range 25 years to 70 years did not essentially alter the strength group classifications of S2 and SD2 that are normally achieved for green and air-dry mature blackbutt respectively. Therefore other factors such as structural grading rules will predominantly determine the potential usage of young regrowth blackbutt.

INTRODUCTION

Blackbutt (*Eucalyptus pilularis*), is an important timber producing species in the commercial forests of eastern Australia. It represents about 17 percent of the total annual log cut of hardwood grown on Crown land in the State of New South Wales (Forestry Commission 1991). Blackbutt grows on sites with suitable soils and microclimate between the coast and the Great Dividing Range from south-eastern New South Wales to south-eastern Queensland (Boland *et al.* 1984). Because of its fast growth, blackbutt tends to dominate the stands in which it occurs and is the major timber producing species in these forests.

Most blackbutt forest is readily accessible and hence almost all has been logged with a large proportion silviculturally treated to promote regeneration over the past 60 to 70 years. Future blackbutt timber is expected to be cut from this regrowth forest. It is estimated that the proportion of timber provided by (mainly non-blackbutt) hinterland forests will decline in future and the importance of the timber from coastal regrowth blackbutt forests will further increase (Forestry Commission 1976, Phillis 1981). Logging will tend to concentrate on younger, smaller diameter trees with utilization aimed at producing maximum returns based on the concept of short rotation intensive forestry. The purpose of this study is to assess the basic strength properties of the wood from blackbutt trees which may be expected to be logged in the future.

Studies on the strength properties of regrowth blackbutt are sparse. Crockett (1955) examined the density and some strength properties of 8 year old blackbutt thinnings and found that the mean values of strength and density were some 30% to 50% lower than those for mature blackbutt. He also found a rapid increase in strength and density as distance from the pith increased up to a diameter of about 9 cm.

Bootle (1982) in a resume of Divisional studies on regrowth blackbutt between 1961 and 1977 quotes some test results from Kloot (CSIRO) on 85 trees of 15 year old blackbutt from Kenilworth, Queensland. The material from these trees gave strength and density figures some 10% to 30% lower than those for mature blackbutt. In similar work, Gerhards (1966), in tests on clear wood from an even-aged stand of 42-43 year old

blackbutt in Hawaii found the material less dense and hard and also weaker in bending and compression than wood from the same species grown in Australia. However, the Hawaiian grown wood had essentially the same stiffness and shearing strength as the wood native to Australia.

South Africa also has plantations of blackbutt and Banks (1957) found that the air-dry wood was somewhat lower in average density and strength than that of Australian-grown timber. However, he noted that the oldest (41 years) locally-grown material tested gave values comparable with Australian data.

This study aimed to extend knowledge of the age effect in regrowth blackbutt by examining the strength properties of clear wood from New South Wales grown trees ranging in age from 25 years to 70 years old.

MATERIAL

Even-aged blackbutt forests were sampled in four localities of known age. The four localities were natural regeneration following heavy logging or wildfire and were selected from a list of potential locations provided by foresters familiar with the areas concerned such that their site qualities could be considered reasonably similar. The four sampling locations were in a region extending over 400 km, from Taree in the south to Murwillumbah in the north (i.e. within the maximum growth development area of the species). The four locations could be described as typical moist sclerophyll blackbutt forests. Blackbutt was dominant to pure and more or less even-aged in these stands. Basal area of 40 m^2 per hectare was estimated for all four samples locations.

The chosen age groups were 25, 40, 55 and 70 years. Five trees, sampled to represent the range of merchantable trees, were felled such that one of the largest, one of the smallest and three intermediate sized trees were taken from each locality. This is the minimum number of trees recommended to be sampled for the purposes of determining strength properties (CSIRO 1969, SAA 1986). Two logs of minimum length 2.7 m were cut from each selected tree - one from the butt and one from the head - at average heights of 0.6 m and 9 m above the ground.

METHOD

To determine basic wood strength, test specimens for the various mechanical properties were machined to size and tested according to standard procedures (Mack 1979). Test specimen sizes were based on the 50 mm square cross-section standard. The material was tested green (unseasoned) and after air-drying.

Two diametrical flitches, extending from bark to bark and including the centre,were sawn from each log - one flitch being further sawn to obtain unseasoned test specimens, the other being further sawn to obtain seasoned test specimens. Each flitch was sawn into smaller sticks, of approximate size 60-65 mm square, the sticks from one flitch being stacked for air-drying and later machining, the sticks from the other flitch being dressed to the final cross-section size of 50 mm square from which the various unseasoned test specimens could be cut to the required length and tested immediately. The number of test sticks obtained from each flitch varied with the diameter of the log and also on the quality of the material in the core of the log which was sometimes too poor to obtain test specimens.

The basic mechanical properties of the clear wood were determined for each age group as the mean of tree means (CSIRO 1969), with the emphasis being placed on those mechanical properties of importance for the strength grouping of the material i.e. bending strength and stiffness and compression strength parallel to the grain. All test results from each tree were pooled to obtain tree mean values of properties.

RESULTS

The main results from this series of tests are given in the accompanying Table 1 which summarises the tree mean results for the properties determined for each age group and includes reference values for blackbutt for additional comparison. These reference values are taken from Bolza and Kloot (1963) which is normally considered as a benchmark for the mechanical properties of Australian Timbers as determined from small

clear specimen testing. The air-dry density values quoted in Table 1 were obtained from density measurements on the static bending specimens, as these being by far the largest test specimens were considered to be most representative of the bulk of the material. All results obtained from tests on seasoned material were corrected to 12 percent moisture content using the mean correction values given by Mack (1979).

Table 2 gives, for the four age groups, the significance of intercomparisons between those mean property values normally considered of greater importance, on the basis of the 't' test.

Table 3 shows for each age group the preliminary strength group classifications for the unseasoned and seasoned material respectively following the procedure established in Australian Standard AS 2878 - 1986 "Timber - Classification into Strength Groups".

The positive strength group classification for each age group is also given in Table 3 following the procedure in the aforementioned Australian Standard based on the combination of classifications when the three critical strength properties do not all indicate the same classification.

DISCUSSION

Undoubtedly, the single most important factor to emerge from this study is that irrespective of the age of the regrowth blackbutt, within each age range examined the strength group classifications remain almost entirely unaffected at S2 and SD2 for the green and air-dry material respectively (SAA 1986), i.e. the basic wood properties appear to be only marginally affected as tree age changes from 25 years to 70 years. This is clear from Table 3 which gives the positive strength group classifications for both the unseasoned and the seasoned material of the different age groups.

The age of the trees from which the quoted reference values in Table 1 were obtained (Bolza and Kloot, 1963) is not explicitly stated, but this source has always been intended to represent the properties of material from mature trees sampled substantially over its geographical range of availability. In the case of blackbutt, mature trees are generally considered to be 70 years and greater in age and these are the trees from which the majority of NSW production comes at present. Trees in the 30-40 year age range are normally regarded as thinnings while trees 150 years plus would be regarded as old growth - these are not formal categories but rather loose age classifications evolved from common usage.

It would be universally accepted that there is a direct relationship between the strength of wood and its density. It is also clear that, in general, for trees grown under essentially similar conditions, the younger and hence smaller diameter trees will contain a greater proportion of juvenile wood; this being lower in density and correspondingly lower in strength than mature wood. It follows therefore that, other conditions being equal, the mean strength of younger trees should be less than that of more mature trees, i.e. the mean strength properties of trees could be expected to follow a trend of increasing strength with age. If this is so then, in this study, a perusal of the summary Table 1 would indicate that the material from the 40 year old trees is somewhat weaker than expected and the material from the 55 year old trees is somewhat stronger than expected. This observation is also borne out by the significance Table 2, which shows that when the 40 year material is compared with the 25 year material, then its strength properties are, in general, either significantly lower or not significantly different. Similarly, the 55 year material when compared with the 70 year material has strength properties that are, in general, either significantly higher or not significantly different.

The above observations also become apparent when the positive strength group classification is made in Table 3: the unseasoned material from the 40 year age group trees being classified as strength group S3 and the seasoned material from the 55 year age groups trees being classified as strength group SD1.

Blackbutt is normally classified as belonging to strength groups S2 and SD2 in the unseasoned and seasoned conditions respectively (SAA 1986). The two previous departures noted from these groups, namely, S3 for 40 year old unseasoned material and SD1 for 55 year old seasoned material, could be due to different provenances, site effects, environmental influences, genetic diversity, etc, even though it was attempted to select the

trees and sites as carefully as possible such that these factors would be minimised. Wilkes (1988) states that Eucalyptus species are characterised by substantial genetically predetermined within - and between - tree variations in wood anatomical features and that this effect of genotype outweights that of growing conditions.

If the increase in strength on drying that occurs in those properties that determine strength groups classification is examined it can be seen that the 40 year and 55 year old age groups exhibit a generally greater strength increase than the 25 year and 70 year old age groups. The effect is evident in the preliminary strength group classifications and in the final positive classifications of Table 3 where both the 40 year and 55 year seasoned material are placed one strength group higher than their corresponding unseasoned strength group. As it seems unreasonable to attribute any substantive differences in strength increase on drying to differences in anatomical aspects of the 40 year and 55 year intermediate age groups as compared with the 25 year and 70 year boundary age groups, than these differences are probably a reflection of natural variability within the species and, as such, too much emphasis should not be placed on a deviation in strength group classification of one group, such as the S3 for the 40 year old unseasoned material and the SDI for the 55 year old seasoned material. These deviations are unlikely to be of consequence if the logs are to be sawn and structurally graded. Hence, regrowth blackbutt 25 years and older may, for practical purposes, still be considered as belonging to strength groups S2 and SD2 in the green and seasoned conditions respectively.

As part of a somewhat similar study to the present, Bolza (1978) determined the properties of mature and immature spotted gum trees sampled from various Queensland localities from as wide a range as possible to cover variations in growth conditions. The results were obtained from 11 mature trees and 25 immature trees, however, the ages of the trees sampled were not specified. Bolza also tested the statistical significance of differences between means for the properties of this mature and immature spotted gum with the results showing similar values in the unseasoned condition and a tendency for the strength properties of the immature seasoned material to be generally significantly higher. Bolza concluded that immature spotted gum is able to produce as strong and as tough timber as the mature tree from the same area and that the differences observed between the strength of mature and immature samples could well be an effect of some factor other than maturity.

The present study gives strong indications that regrowth blackbutt trees as young as 25 years are capable of producing wood that satisfies the normal strength group classification for blackbutt. Such wood has average strength properties that would not preclude its normal structural use even though at this age it is still questionable as to whether what may be considered mature wood cells are being laid down (Bamber and Curtin 1974). Wilkes (1988) in examining a variety of new growth eucalypt forest considered that the reputed differences in wood quality between regrowth/plantation stands and old growth forests is founded on non-anatomical feature, or reflects simply the greater proportion of juvenile wood in small, rapidly grown stems. It thus appears that factors other than wood quality (e.g. the type and size of defects that become evident on sawing) may be the ones that determine the structural efficacy of young regrowth blackbutt.

Material in structural sizes was not sawn from the trees tested and it is the recovery of such material which, when graded to an appropriate structural standard, will determine whether this usage is economically appropriate.

CONCLUSIONS

Within the age group ranges (25 years to 70 years) of the regrowth blackbutt studied, significant differences in some properties did occur between some age groups. These differences did not, however, follow what might be the expected path of monotonic increasing strength properties with increasing age. Nevertheless, and irresepctive of the differences in strength properties between the age groups, these differences were not, in general, sufficient to materially alter the positive strength group classification of this regrowth blackbutt when compared with mature blackbutt which is classified in strength

groups S2 and SD2 in the green and air-dry conditions respectively. Hence other factors such as structural grading rules will predominantly determine its potential usage.

ACKNOWLEDGEMENTS

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Table 1. Summary of Mechanical Property Tests on Regrowth Blackbutt.**

Test Type	Property	Moisture Condition	Age Group					
			25 yrs.	40 yrs.	55 yrs.	70 yrs.	Ref.*	Value
Static Bending	Stress at P.L.(MPa)	Green	51.7 (1.4)	53.9 (4.4)	67.7 (2.1)	67.5 (4.6)	54.8	(3.0)
		12%	96.2 (1.9)	99.7 (2.3)	90.0 (1.8)	93.2 (3.1)	96.6	(3.5)
	Modulus of Rupture(MPa)	Green	90.8 (1.2)	85.5 (3.4)	95.9 (1.7)	100.3 (3.0)	86.9	(2.5)
		12%	138.9 (2.5)	139.6 (4.8)	157.4 (2.2)	132.6 (4.4)	144.1	(2.8)
	Modulus of Elasticity(GPa)	Green	14.6 (4.7)	12.8 (4.4)	17.8 (2.2)	16.6 (3.9)	15.0	(2.8)
		12%	19.1 (2.8)	19.3 (6.0)	23.8 (2.7)	19.5 (4.3)	18.9	(2.8)
Compression Parallel to Grain	Stress at P.L.(MPa)	Green	28.9 (2.7)	21.4 (11.4)	35.1 (2.4)	27.2 (3.7)	38.4	(4.3)
		12%	46.3 (2.5)	53.5 (2.8)	69.8 (1.2)	53.6 (4.1)	52.6	(4.8)
	Maximum Stress(MPa)	Green	43.0 (3.4)	37.7 (5.0)	43.2 (3.0)	43.1 (1.7)	47.5	(2.0)
		12%	74.8 (2.2)	70.9 (2.8)	92.0 (1.5)	76.0 (2.3)	77.2	(2.3)
	Modulus of Elasticity(GPa)	Green	15.6 (4.0)	15.5 (6.2)	18.5 (1.5)	16.8 (3.0)	17.4	(3.3)
		12%	19.8 (4.1)	20.9 (3.9)	26.7 (2.2)	20.5 (4.6)	21.2	(3.5)
Compression Perpendicular to Grain at 2.5mm.	Radial Stress (MPa)	Green	12.2 (4.9)	11.0 (9.7)	15.0 (4.2)	15.1 (4.4)	15.0	(5.5)
		12%	19.3 (3.8)	21.6 (6.6)	26.7 (1.9)	26.8 (6.3)	25.8	(4.3)
	Tangential Stress(MPa)	Green	12.7 (4.1)	11.5 (7.9)	15.3 (3.8)	13.9 (4.8)	13.9	(4.8)
		12%	19.5 (4.0)	20.3 (5.8)	23.8 (1.3)	24.1 (6.3)	22.1	(3.8)
Hardness	Radial Load(kN)	Green	5.9 (3.8)	6.4 (7.7)	6.2 (4.7)	7.4 (3.8)	6.3	(3.5)
		12%	8.7 (4.0)	8.7 (6.4)	9.8 (2.6)	9.5 (8.4)	8.8	(3.8)
	Tangential Load(kN)	Green	6.1 (2.9)	6.7 (7.6)	6.7 (4.2)	7.7 (4.7)	6.6	(3.3)
		12%	9.1 (4.8)	9.9 (5.9)	10.5 (3.3)	9.8 (8.2)	8.9	(4.0)
	End Load(kN)	Green	6.5 (4.6)	6.5 (6.3)	6.3 (3.5)	7.4 (4.4)	6.5	(2.5)
		12%	9.2 (4.1)	9.8 (6.8)	11.5 (2.1)	10.8 (5.9)	9.6	(3.5)
Impact	Izod(J)	Green	19.7 (5.2)	20.8 (4.2)	19.3 (12.5)	21.9 (3.8)	21.3	(4.5)
		12%	23.5 (9.5)	22.8 (1.6)	27.0 (4.9)	25.4 (9.0)	20.3	(6.8)
	Toughness(J)	Green	22.7 (6.4)	18.9 (8.3)	22.5 (9.4)	22.6 (5.7)	21.1	(4.0)
		12%	23.6 (5.3)	23.1 (2.4)	30.0 (5.2)	27.2 (8.4)	22.5	(5.5)
Shear	Radial Stress(MPa)	Green	11.9 (3.7)	10.8 (6.1)	11.6 (2.1)	12.3 (3.2)	9.4	(5.0)
		12%	17.0 (5.1)	15.1 (4.1)	16.9 (3.6)	17.8 (5.1)	14.7	(4.0)
	Tangential Stress(MPa)	Green	12.0 (1.9)	12.0 (3.7)	12.7 (4.0)	13.5 (4.3)	10.9	(3.3)
		12%	19.3 (2.1)	19.9 (2.7)	22.4 (3.2)	20.2 (3.4)	15.7	(3.5)
Density	Air-dry(kg/c.m)	12%	811 (3.3)	842 (2.6)	922 (2.0)	886 (3.4)	886	(1.8)

** Mean value followed by (bracketed) percentage standard error of mean.

* Bolza and Kloot, 1963.

Table 2. Significance* of differences between means of age groups.

Property	25- 40yrs.		25- 55yrs.		25- 70yrs.		40- 55yrs.		40- 70yrs.		55- 70yrs.	
	G	D	G	D	G	D	G	D	G	D	G	D
MoR	N.S.	N.S.	1%>	0.1%>	1%>	N.S.	0.1%>	1%>	0.1%>	N.S.	N.S.	0.1%<
MoE	5%<	N.S.	0.1%>	0.1%>	1%>	N.S.	0.1%>	0.1%>	0.1%>	N.S.	1%<	0.1%<
Comp.Parl.	0.1%<	N.S.	N.S.	0.1%>	N.S.	N.S.	0.1%>	0.1%>	0.1%>	1%>	N.S.	0.1%<
Comp.Perp.	1%<	5%>	0.1%>	0.1%>	0.1%>	0.1%>	0.1%>	0.1%>	0.1%<	0.1%>	5%<	N.S.
Shear	5%<	1%<	N.S.	1%>	5%>	5%>	5%>	0.1%>	1%>	0.1%>	1%>	N.S.
Density	-	N.S.	-	0.1%>	-	5%>	-	0.1%>	-	5%>	-	5%<

* (1) Significant at 0.1%, 1% or 5% levels of probability or else not significant (N.S.).

(2) The < > symbols indicate the sense of the difference for the older group (O) with respect to the younger group (Y),i.e. Omean < Ymean or Omean > Ymean, with the latter being the sense intuitively expected.

(3) G -- denotes unseasoned (green); D -- denotes seasoned (air-dry at 12% M.C.).

Table 3 Strength group classification

Tree Age Group (yrs)	Preliminary Strength Group Classification						Positive Strength Group Classification	
	Mean Static Bending				Mean Compressive Strength parallel to grain (MPa)			
	Modulus of Rupture (MPa)		Modulus of Elasticity (GPa)					
	G	D	G	D	G	D	G	D
25	91 S2	139 SD2	14.6 S2	19.1 SD2	43 S2	75 SD2	S2	SD2
40	86 S2	150 SD1	12.8 S3	19.8 SD2	38 S3	71 SD2	S3	SD2
55	96 S2	164 SD1	17.8 S1	24.1 SD1	43 S2	92 SD1	S2	SD1
70	100 S2	144 SD2	16.6 S1	20.2 SD2	43 S2	76 SD2	S2	SD2

Note G denotes unseasoned (green); D denotes seasoned (air-dry @ 12% M.C.)

STRUCTURAL SOFTWOOD TIMBER MODEL

H.O. Breitinger
(CSIRO Division of Building, Construction and Engineering)

SUMMARY

The nominal bending strength of timber beams varies with the span length and loading configuration; to explain this, a statistical model based on a Weibull model is developed. In this, timber is represented by clear wood with discrete defects embedded therein and the strength within a stick of timber is assumed to be correlated. The practical applications of the model, including the effects of grade, are discussed.

INTRODUCTION

Timber being an natural material with orthotropic strength properties requires more effort on the part of the user to understand its structure, and the way it copes with loads applied. Many features affect the strength of timber; loading configuration, rate of load application, quality of sawn timber, species associated properties, to name a just a few.

Original Weibull Theory (1) model describes the strength of brittle material using the 'weakest link' approach, as shown in Figure 1. This model does not handle the effect of discrete defects, or strength correlations occurring along the length of a stick of timber.Weibull theory describes the statistical properties of a test length taken at random from a stick. Madsen and Buchanan (2) and Leicester (3) have measured the effect of span length and loading configuration on the bending strength of timber using modified Weibull theories.

The Statistical Timber Strength Model developed by Leicester and Breitinger (4) modifies the Weibull Theory approach by considering the effects of span length, loading configuration, within stick correlation, and discrete defects spaced at intervals along a stick, as depicted in Figure 2.

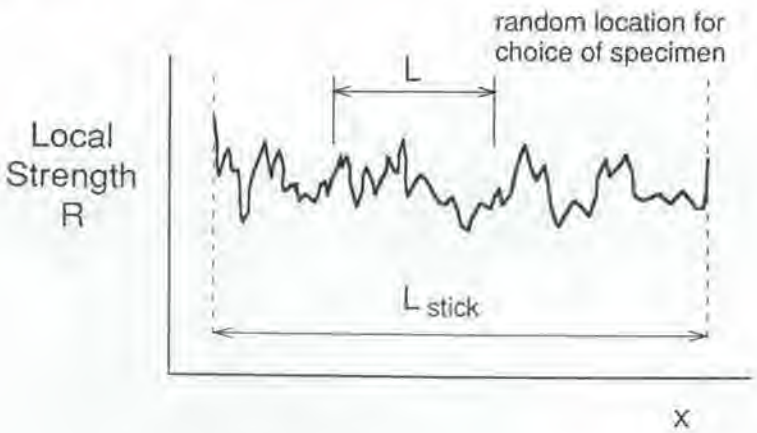

Figure 1: Weibull Theory

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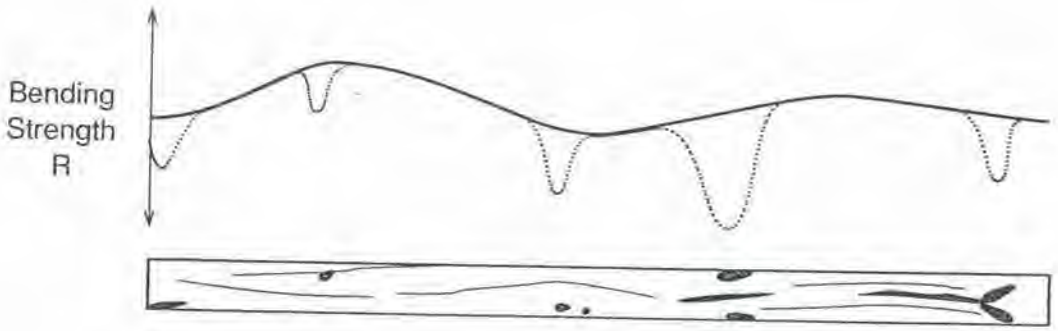

Figure 2: Bending Strength along stick

PROPOSED MODEL FOR A STRUCTURAL SOFTWOOD TIMBER

The proposed model is illustrated schematically in Figure 3. It comprises of clearwood, in which are embedded discrete defects spaced at variable intervals. The spacing of defects follow a Poisson distribution. The timber strength is measured by testing two test specimens from each stick, loaded as shown in Figure 4. The distance between the load points can be any percentage of the span, L. The specimens are taken from random locations and are separated by a distance D.

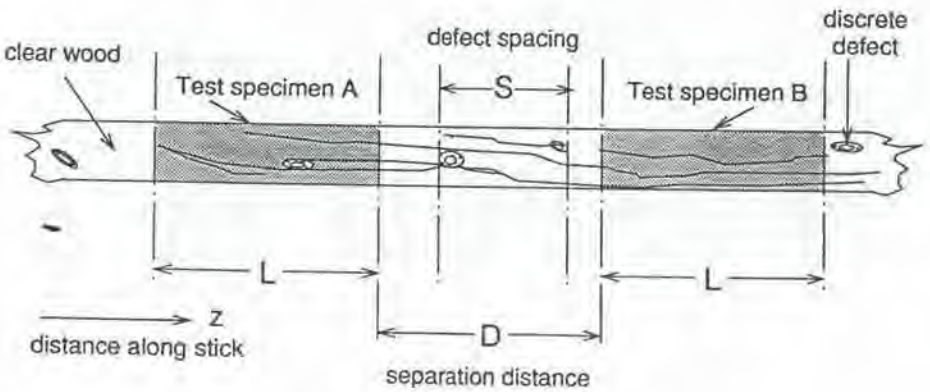

Figure 3: Schematic diagram of a softwood stick

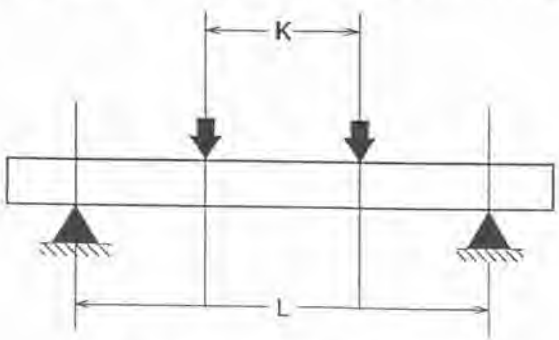

Figure 4: Loading Configuration

Clearwood Strength

The variable clearwood strength along a stick is approximated to one value per test length, and given by

$$R_c = R_o \times R_w \qquad (1)$$

where R_o and R_w are independent random variables. The variable R_o is taken from a distribution where, $\overline{R}_o$ is the mean clearwood strength obtained from a population of test pieces under a given loading configuration, refer to Figure 5, and R_o is constant for a particular stick. The variable R_w is taken from a distribution where, $\overline{R}_w$ takes into account variable loading configurations, and variable span lengths, and R_w is constant for a test length, refer to Figure 4. The associated coefficients of variation are V_o and V_w respectively.

$$\overline{R}_w = \left[\frac{1+m_w}{L+Km_w}\right]^{1/m_w}$$

where L = test span length, m.
K = loading configuration effect
m_w = Weibull variable ($m_w = V_w^{-1.085}$)

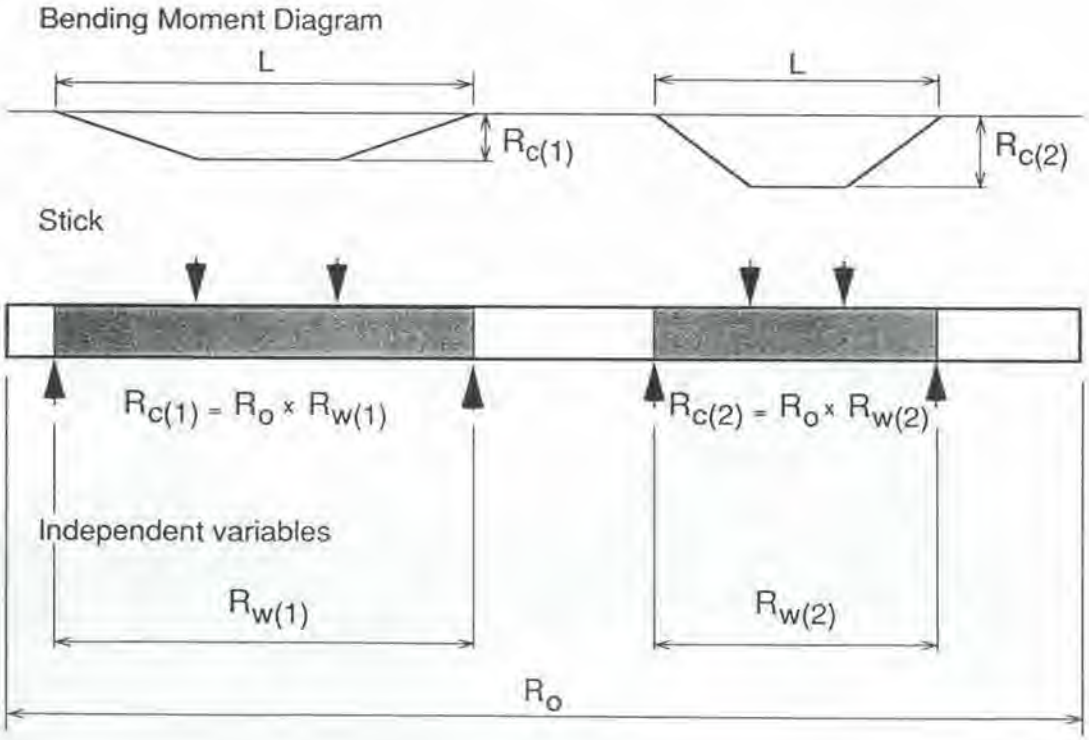

Figure 5: Model Clearwood Strength Approximation

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Defect Strength

The resultant defect strength is given by

$$R_d = R_o \times R_k$$

where R_o and R_k are independent variables. The variable R_o is explained as before. The variable R_k is taken from a distribution where $\overline{R}_k$ is expressed as a fraction of the clearwood strength mean, and R_k varies from defect to defect. The associated coefficients of variation are V_o and V_k respectively.

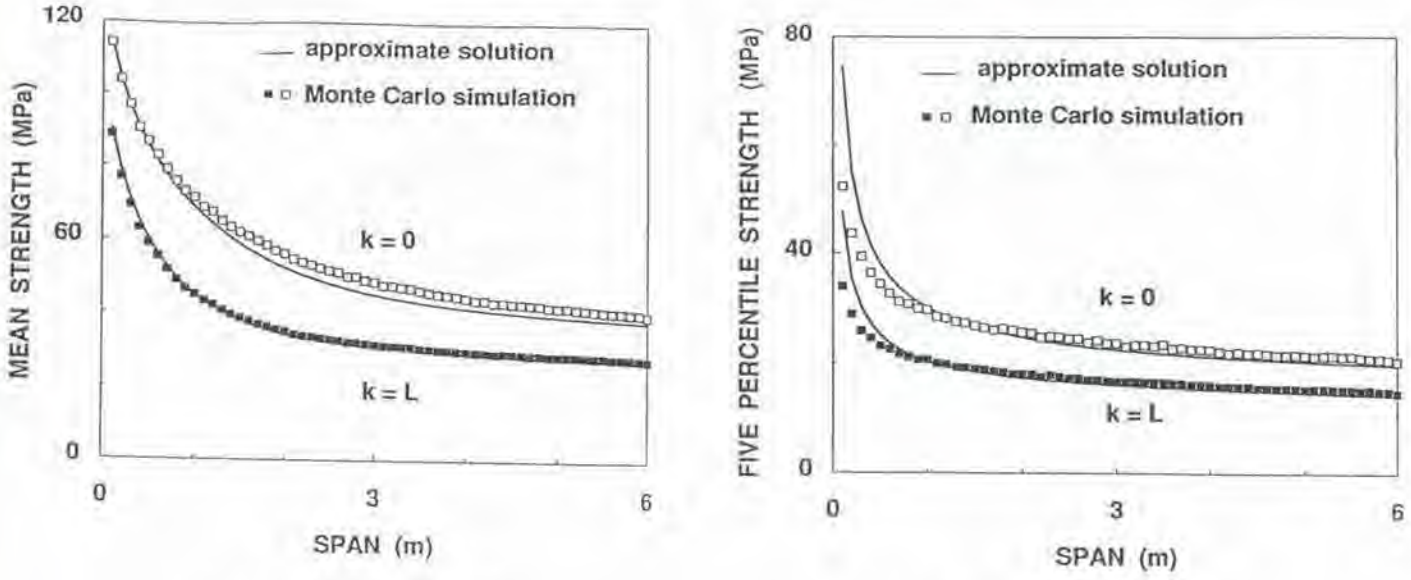
EXAMPLE

The example chosen is based on the properties of F5 grade radiata pine for the defect strength and F11 grade radiata pine for the clear wood strength (5). The following parameters are used;

$\overline{S} = 600$ mm $\quad R_o = 80$ MPa $\quad R_k = 0.5$

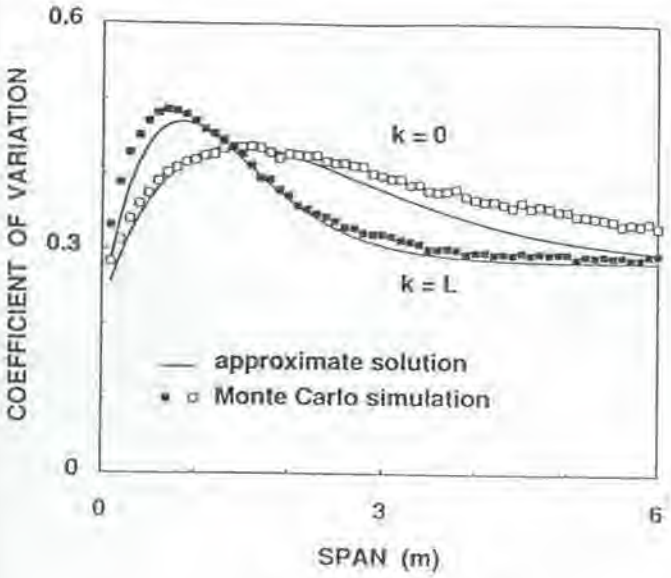
$V_o = 0.2 \quad V_k = 0.2 \quad V_w = 0.1.$

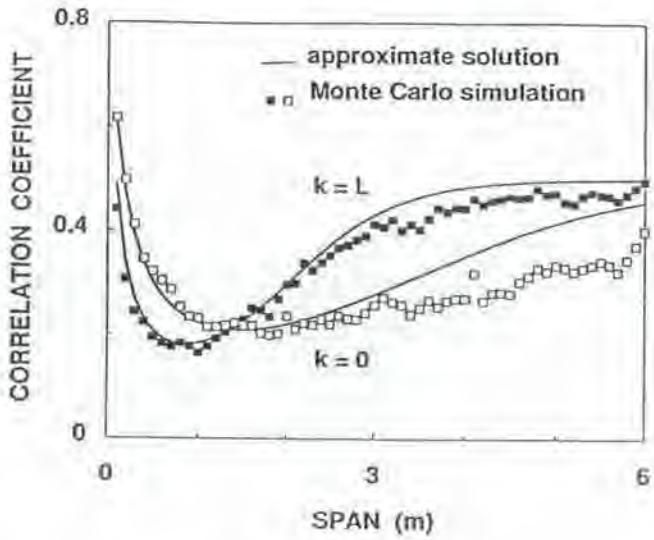
All distributions are taken to be Weibull distributions, Figure 4 shows some of the effects of span length and loading configuration computed by Monte Carlo simulation. Included also is the closed-form approximate solution which is seen to reproduce the model characteristics reasonably well.



(a) Average Strength, $\overline{R}$ (b) Five Percentile, $R_{0.05}$

Figure 5: Span length and Load configuration effects





(c) Coefficient of Variation, V (d) Correlation coefficient, r

Figure 5: Span length and Load configuration effects

DISCUSSION

In using the model to simulate structural timber, the effect of grade can be examined by adjusting the strength ratios of R_d/R_c. A simple method of choosing parameters for the model would be to use a select grade as the equivalent 'clear material'; the defects not acceptable to this grade would then be treated as the discrete defects of the model.

Applications for the model would be;

- to use the model as a base to develop design rules for span length , and loading configurations effects.
- to calibrate the timber strength model for export timber species. This would require a small testing program to find out the relationships between clearwood and defects; and visual assessment of the occurrence of defects along the stick length. Once the model parameters are established then the testing methods of the importing country could be imposed and an estimate of timber strength given.
- to asses the timber strengths of limited samples of timber, as an example, for low grades it may be most effective to measure the strength of a pair of defects selected at random from each stick.

Further developments of this model would be;

- to extend the model for use with hardwood timber; in this, the effects of many of the hardwood defects such as kino veins could well be modelled by the use of defects that have a finite length.

- to incorporate the effect of grading methods, as an example, the lengths in which timber is graded has an effect on the measured strength; this matter has been discussed by Lam and Varoglu (6).

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STRENGTH AND DEFORMATION DUE TO MECHANO-SORPTIVE EFFECTS

Dr J.P. Lu
CSIRO Division of Building, Construction and Engineering
PO Box 56, Highett, Victoria 3190

SUMMARY

Mechano-sorptive effects are known to contribute significantly to the deformation and strength under long duration loads. To apply this in practice, simple models are required. In this paper, climate parameters are represented by a set of sine waves. This leads to a closed form solution for moisture effects and simple models for estimating creep and strength under long duration load conditions.

1. INTRODUCTION

In most practical situations, wood or wood-based materials used in structures are subjected to variations in environmental conditions. Therefore, the long-term deformation and load duration behaviours of structural timber elements are significantly contributed by mechano-sorptive effects.

This paper follows earlier investigations of the effects of shape and size on the mechano-sorptive deformation of beams [1,2,3,4]. Fick's law is used for predicting the moisture content within beams. Climate parameters are represented by a set of sine waves. This leads to a closed form solution for moisture effects and simple models for estimating creep and strength under long duration load conditions.

2. CLIMATE

The climate condition surrounding timber structures can be interpreted in terms of parameters such as temperature, relative humidity, equilibrium moisture content (EMC), vapor pressure, air velocity and so on, which can be obtained from local bureau of meteorology. This data can then be reduced to a set of functions that vary with time in a series of sine waves by employing a standard mathematical operation. For any given external climate, the environment for various parts of a building can be determined by applying different micro-climatic models. For example, the temperature (T) and absolute humidity (AH) in the south wall cavity of a Brisbane house in April can be predicted from external climate by the following equations [5]:

$$T_t = 0.76\ TE_t + 0.33\ TE_{t-9} \quad (1)$$

$$AH_t = 0.349\ (2.3\ AHE_t + AHE_{t-12}) \quad (2)$$

where subscript t signifies time in hours, TE is the external temperature and AHE is the external absolute humidity. This kind of technique enables us to imitate the true induced climate in real buildings for a long period of time (e.g more than 20 years), based on data from local bureau of meteorology.

Figure 1 shows a typical example of the variations in the temperature and relative humidity of a thermally insulated underground room in Italy [6]. Another example of a typical daily cycle and an annual cycle of real data in an unsealed shed in Melbourne, Australia, is shown in Figure 2 together with the equivalent sine cyclic variations about the average value.

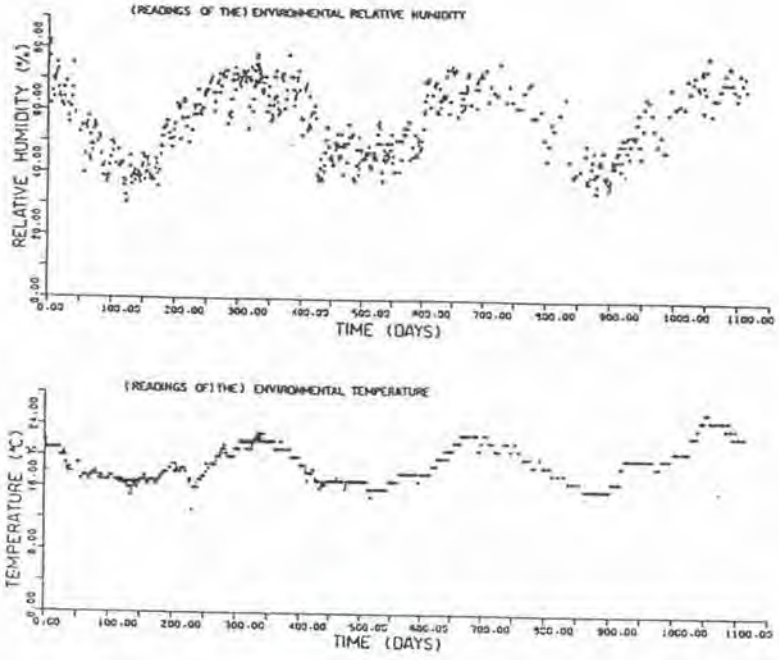
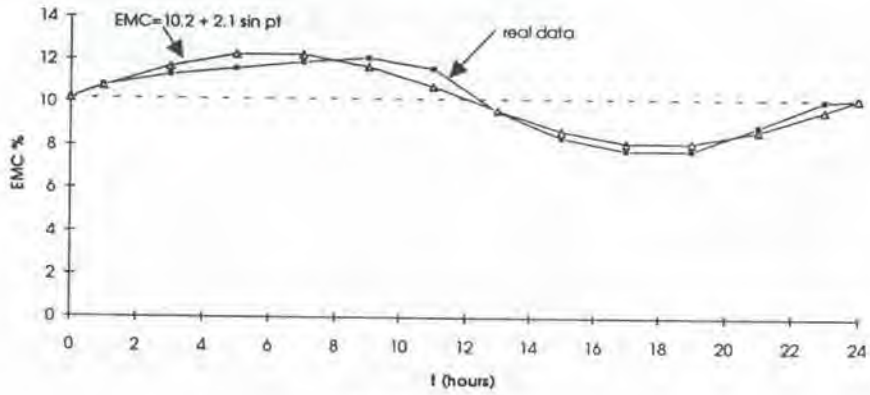
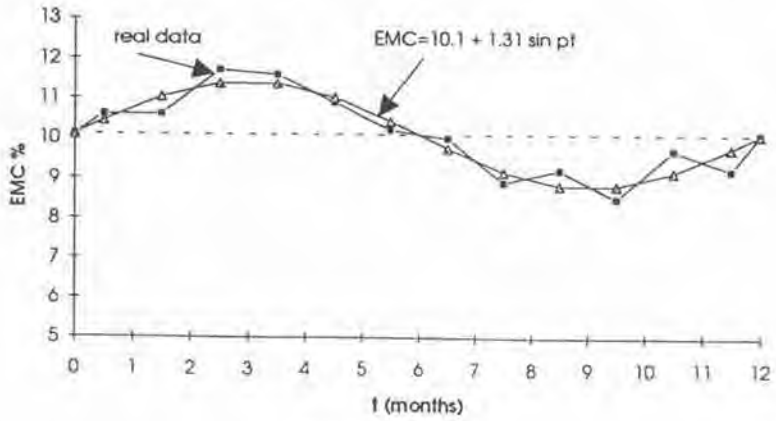


Figure 1. The distribution of the relative humidity and temperature in a thermally insulated underground room in Italy[6].



(a) Daily cycle



(b) Annual cycle

Figure 2. EMC of the air in an unsealed shed in Melbourne, Australia.

3. MECHANO-SORPTIVE MODEL

The mechano-sorptive model used is illustrated schematically in Figure 3. Each fibre of wood is assumed to comprise an elastic element and a mechano-sorptive element connected in series. The total strain ε of the fibre is given by

$$\varepsilon = \varepsilon_1 + \varepsilon_2 \tag{3}$$

where ε_1 denotes the elastic strain and ε_2 denotes the mechano-sorptive strain.

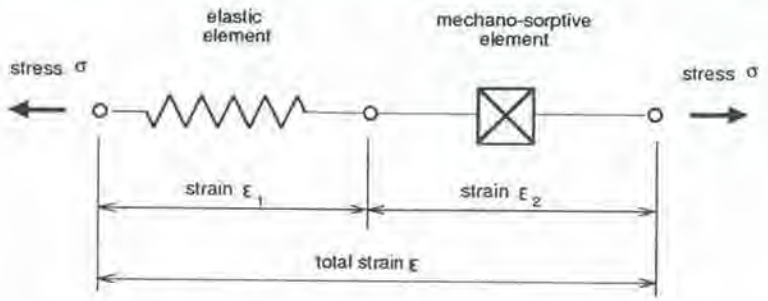


Figure 3. Schematic illustration of a wood fibre.

During a time increment Δt, the stress σ on the element is assumed to increment by $\Delta\sigma$. The increment in the elastic strain is $\Delta\varepsilon_1$, given by

$$\Delta\varepsilon_1 = \frac{\Delta\sigma}{E} \tag{4}$$

where E denotes the modulus of elasticity. If during that period there is a change in moisture concentration, then there will be a change in mechano-sorptive strain $\Delta\varepsilon_2$ given by

$$\Delta\varepsilon_2 = (\sigma/E) \,.\, \Delta\alpha \tag{5}$$

where $\Delta\alpha$ denotes the incremental creep factor.

For the case of a monotonic decrease or increase in moisture concentration as illustrated in Figure 4 (a) and (b), the incremental creep factor is

$$\Delta\alpha = -(A_f.\Delta m_f + A_m.\Delta m) \tag{6}$$

For compression stress:

$$A_m = F(\sigma) \,.\, f(m)$$

$$A_f = \beta \,.\, A_m$$

For tension stress:

(a) structural timber

$$A_m = \alpha \,.\, F(\sigma) \,.\, f(m)$$

$$A_f = \alpha \,.\, \beta \,.\, A_m$$

(b) clear wood

$$\alpha = 0$$

where A_m and A_f are experimentally evaluated constants and Δm is the change in moisture content and Δm_f is the change in moisture content not previously attained during the loading history.

In the above equations, f(m) and F(σ) are two functions of moisture content and applied stress levels. From the limited mechano-sorptive creep data in literature [7], it shows that mechano-sorptive creep diminishes to zero at low moisture content whereas increases greatly at high moisture content. The effect is more pronounced for high stress levels and less so for low stress level. They can be estimated by the equations in the forms of the following:

$$f(m)=0 \qquad m \le 0.05$$

$$f(m) = [5(m - 0.05)]^7 \qquad m > 0.05$$

$$F(\sigma) = 1 \qquad \frac{\sigma}{\sigma_u} \le 0.4$$

$$F(\sigma) = 1 + \left[5.8\left(\frac{\sigma}{\sigma_u} - 0.4\right)\right]^3 \qquad \frac{\sigma}{\sigma_u} > 0.4$$

in which σ_u is the ultimate short-term strength.

To validate these functions, considerably more long-term creep data at high stress levels and at different moisture content is needed than is currently available. Further investigations on these areas are in progress.

If the moisture change in the fibre has a cyclic variation as illustrated in Figure 4(c),

$$m = m_{av} + m_o \sin pt \tag{7}$$

then the incremental creep factor is

$$\Delta\alpha = -(A_f + A_m).2m_o \,.\, \Delta N \tag{8}$$

where ΔN denotes the number of cycles of moisture change within the time increment Δt.

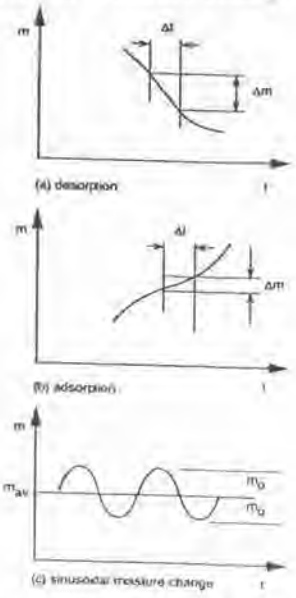


Figure 4. Notation for sorption in a wood fibre.

If several types of moisture cycles occur simultaneously, then it will be assumed that the incremental creep factor is given by

$$\Delta\alpha = -(A_f + A_m)(2m_{o1} \cdot \Delta N_1 + 2m_{o2} \cdot \Delta N_2 + \ldots) \quad (9)$$

where m_{o1}, m_{o2}, ... and ΔN_1, ΔN_2, ... denote the parameters m_o and ΔN associated with moisture cycles of type 1, type 2, ...

4. MOISTURE CONCENTRATION

4.1 Procedure

The estimate of moisture concentration in the timber will be based on Fick's law which is

$$\frac{\partial m}{\partial t} = D_x \frac{\partial^2 m}{\partial x^2} + D_y \frac{\partial^2 m}{\partial y^2} \quad (10)$$

where D_x and D_y denote diffusion constants. The boundary condition used will be

$$m = m_{air} \quad (11)$$

where m_{air} is the equilibrium moisture concentration for the temperature and relative humidity conditions of the air around the timber [8].

4.2 Cyclic moisture conditions, edge effects

The surface moisture condition will be written

$$m_{air} = m_{av} + m_A \sin(pt) \quad (12)$$

For a semi-infinite solid, bounded by $x = 0$, the application of equation (10) and (12) leads to the moisture concentration.

$$m = m_{av} + m_A e^{-H_x x} \sin(pt - H_x x) \quad (13)$$

where $H_x = \sqrt{p/2\,D_x}$. Equation (13) is illustrated schematically in Figure 5.

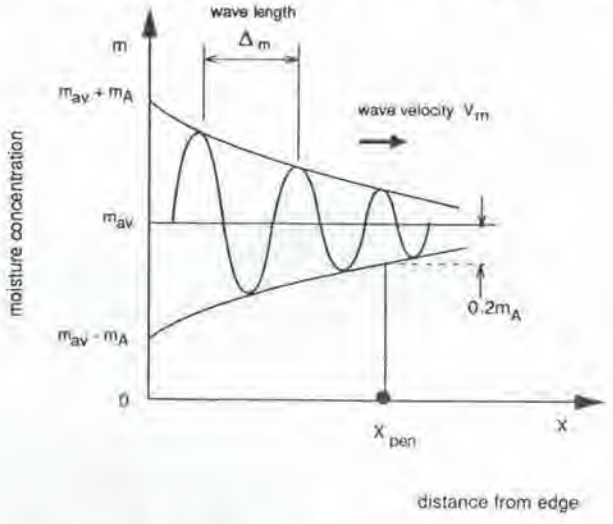


Figure 5. Edge moisture concentrations due to cyclic variations at the boundary

From equation (13), the half range m_o of a cycle at an internal wood fibre is given by

$$m_o = m_A e^{-H_x x} \tag{14}$$

Equation (13) indicates that the moisture cycle has the form of a travelling wave with velocity V_m given by

$$V_m = p/H_x \tag{15}$$

4.3 Cyclic moisture conditions, rectangular section

The application of the boundary condition of equation (11) applied to Fick's law equation (10) leads to the moisture concentration distribution as follows,

$$m = \sum_{m=1,3,\ldots} \sum_{n=1,3,\ldots} B_{mn} \sin\left(\frac{m\pi x}{a}\right) \sin\left(\frac{n\pi y}{a}\right) \tag{16}$$

where $$B_{mn} = \frac{16\, m_A}{mn\pi^2} \frac{(Q^2 + 1)}{[Q \sin(pt) - \cos(pt)]}$$

and $$Q = [(m\pi/a)^2 D_x + (n\pi/b)^2 D_y] \left(\frac{1}{p}\right)$$

At any given point, the exact moisture range parameter corresponding to m_o of equation (7) can be obtained from a plot of 'm' *vs* 't' based on equation (16). However, for most practical purposes, for the case of an ambient cyclic boundary condition

$$m_{air} = m_A \sin pt \tag{17}$$

m_o can be obtained with sufficient accuracy from the following approximate solution

$$(m_o/m_A) = (m_x/m_A) + (m_y/m_A) - (m_x/m_A)(m_y/m_A) \tag{18}$$

where

$$(m_x/m_A) = e^{-H_x x_A} + e^{-H_x x_B} - e^{-H_x x_A} e^{-H_x x_B} \tag{19}$$

$$(m_y/m_A) = e^{-H_y y_A} + e^{-H_y y_B} - e^{-H_y y_A} e^{-H_y y_B} \tag{20}$$

where the notation $H_x = \sqrt{\rho/2\, Dx}$, $H_y = \sqrt{\rho/2\, Dy}$ and the distances x_A, x_B, y_A, y_B are defined as shown in Figure 6.

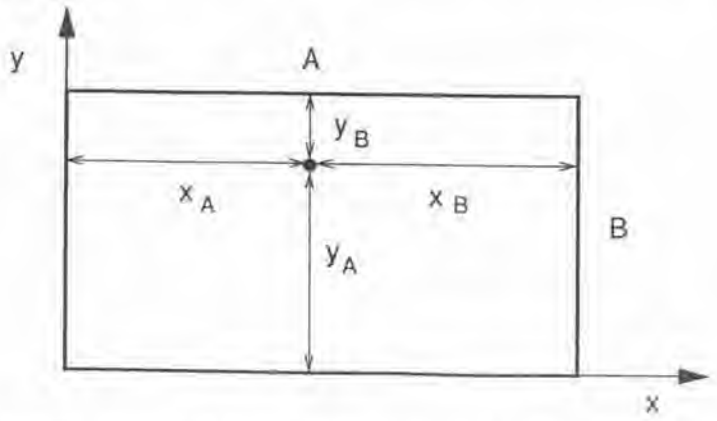


Figure 6. Notation for coordinates used in Eqs.19 and 20.

5. AN OUTLINE OF THE ANALYSIS PROCEDURE

In this analysis, the beam is subdivided into elements, and the notation A(i), σ(i) and y(i) are used to denote the area, stress and distance to the neutral axis of each element. For a beam of rectangular cross-section under a constant moment M_o, an outline of the numerical analysis procedure is summarised as follows:

(a) compute the moisture range parameter from the approximate solution given in Eq. 18;

(b) compute the initial elastic stress $\sigma(i) = M_o\, y(i)/I$, where $I = \Sigma\, A(i)\, .\, y(i)^2$ is the second moment of area;

(c) at any time increment, compute the increment of bending moment
$\Delta M = \sum_i \sigma(i) \cdot \Delta\alpha(i)\ \ \bar{y}(i) \cdot A(i)$ due to a relaxation in stress equal to $\sigma(i) \cdot \Delta\alpha(i)$, where $\Delta\alpha(i)$ is obtained from Eqs 8 and 9;

(d) calculate the incremental stress in each element by $\Delta\sigma(i) = (\Delta M/I) \cdot \bar{y}(i) - \sigma(i) \cdot \Delta\alpha(i)$ and the surface strain $\Delta\varepsilon_o = (\Delta M/EI) \cdot \bar{y}_o$, where $\bar{y}_o$ is the distance from the neutral axis to the extreme fibre;

(e) update the total stress by $\sigma(i)\,|_{t+1} = \sigma(i)\,|_t + \Delta\sigma(i)\,|_t$ and the total surface strain by $\varepsilon_o\,|_{t+1} = \varepsilon_o\,|_t + \Delta\varepsilon_o\,|_t$;

(f) store the current creep factor $\alpha = \dfrac{\varepsilon_o\,|_{t+1}}{\varepsilon_e}$ and the current stress distribution $\sigma(i)\,|_{t+1}$, where ε_e is the initial elastic surface strain;

(g) start a new time step by returning to Step (c) above.

6. EXAMPLE

To demonstrate the type of effects predicted by the aforementioned mechano-sorptive model , the computation was made for the case of two beams of rectangular cross-section and subjected to a constant bending moment for 20 years.

It was assumed that the parameters fitting the existing data for the mechano-sorptive effects were:

(a) for daily cycles
$A_m = 0.2$
$A_f = 0$
$m_{o1} = 0.02$

(b) for annual cycles
$A_m = 0.2$
$A_f = 20$ (for the first year; $A_f = 0$ for the following years)
$m_{o2} = 0.02$

The diffusion constants were taken to be $D_x = D_y = 2 \times 10^{-10}$ m^2/sec.

The computed results for creep and strength under long duration loads are given in Figures 7 and 8 respectively. It can be seen that there are large differences in the predicted creep rates and stress ratios. Creep rates are greater and stress ratios are lower for smaller beams.

From the earlier studies, it indicates that for practical cases, mechano-sorptive deformations are primarily due to edge effects and the creep rate close to the surface layer is higher than that in the middle of the cross-section. This leads to the relaxation of stress at the surface and the accumulation of stress in the middle of the member. Therefore an increasing portion of the load will be carried by the inner part of the material subjected to a constant loading. This stress redistribution in the beams perhaps gives part of the reason why the strength of timber member under long duration loads is lower than the short-term strength. As shown in Figure 8, for a 50 x 200 beam subjected to a constant load under natural climate conditions, the strength reduces to 50% of the ultimate short-term strength at 20 year's time.

For comparison purposes, the stress ratio data from duration of constant bending load experiments[9] are also included in Figure 8. Although the stress ratios predicted in this study are about 15% higher than those of test results, with the limitation of the assumption used, it can be expected that the trend of the curves gives some insight into the strength loss due to mechano-sorptive effect. Furthermore, there might be some time rate effects interact with the mechno-sorptive effects. Whether or not the mechano-sorptive creep for tension near a strength controlling knot (in test results) is half of that for compression (assumption in this study) is not known at this stage.

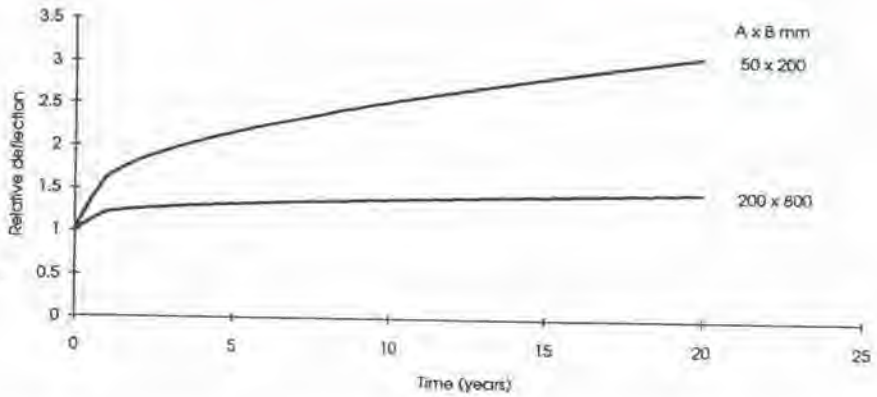


Figure 7. Computed mechano-sorptive deformations for rectangular beams (the dimension A and B are defined in Figure 6).

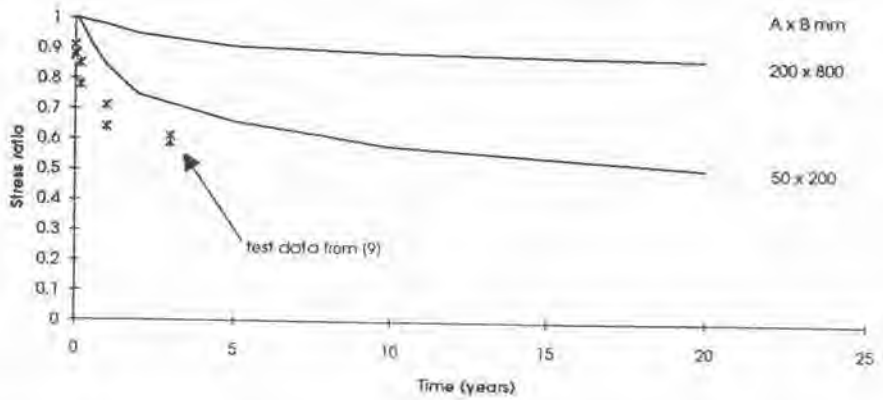


Figure 8. Computed strength due to mechano-sorptive effects for rectangular beams (stress ratio is the ratio of applied constant stress to ultimate short-term strength)

It should be noted that the parameters used above are only rough estimates from past experience. To obtain true 'constants' for the above theories and also to find the conditions under which the 'constants' can be assumed to be constant, a set of environmental chambers are being designed and built. This computer-controlled equipment can provide an environment for accelerated testing of timber products by controlling the temperature and the relative humidity to imitate the true induced temperatures and humidities in various parts of real buildings in a range of climatic zones in Australia.

7. CONCLUSIONS

A simple mechano-sorptive model has been used to estimate creep and strength under long duration load conditions. It indicates that for practical cases, mechano-sorptive effect contributes significantly to the deformation and strength under long-term loading and the size has a considerable effect on the relative creep and strength of beams.

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THE DESIGN OF RAFTER OVERHANGS.

M. J. Syme, L. Pham and R. H. Leicester
(CSIRO Division of Building, Construction and Engineering)

ABSTRACT

Three new modification parameters are proposed for use in the design of rafter overhangs. These modification parameters account for the lateral load distribution provided by the fascia, the effect of the birdsmouth notch on strength and the effect of the birdsmouth notch on stiffness of the rafter overhang. The proposed modification parameters represent an improvement on the factors currently given by AS 1720.1 and other sources. A new general design procedure was developed. Design in accordance with the new procedure is compared with design using current timber framing manuals.

INTRODUCTION

Rafters are currently sized using the span tables from either the AS 1684 supplements (ref. 2) or various timber trade publications such as the TPC Timber Framing Manual (ref. 1). The span of a rafter overhang (or eaves overhang) can dominate the selection of a rafter size when the overhang becomes relatively long and the back span (or internal span) is relatively small.

Fascia, batten and purlin and soffit bearer members contribute to the strength and stiffness of rafter overhangs by providing load sharing with, and lateral load distribution to other rafters within the roof framing.

Whilst the aforementioned span tables are believed to allow for load sharing, lateral load distribution and birdsmouth notching in rafter overhangs, and have provided overhangs that have performed satisfactorily, there are difficulties interpreting the criteria upon which these tables are based. There are therefore, difficulties in reproducing engineered designs which accord with the aforementioned span tables.

The objective of this study was to produce a design procedure that accounts for load sharing, lateral load distribution and birdsmouth notching, given the strengthening and stiffening effects of current eaves construction techniques. An example of current eaves construction techniques is shown in Figure 1 below. The proposed design procedure is presented in Appendix A of this paper. To formulate the design procedure, the following investigations were carried out:

(i) Status of current design procedure.
(ii) Experimental investigation of birdsmouth notch effects and framing system effects.
(iii) Theoretical modelling of framing system effects.

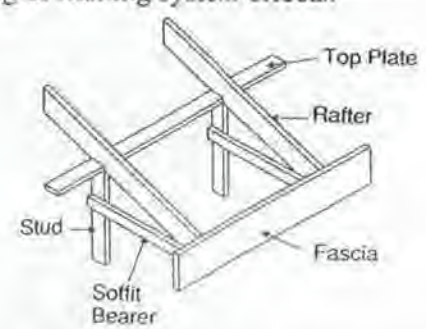

Figure 1. Example of current eaves construction.

Improvements to the three modification parameters listed below are proposed for use in design.

(i) $g_{43fascia}$ (lateral load distribution)

(ii) g_{40bird} (notch geometry factor)

(iii) g'_{bird} (birdsmouth notch stiffness factor)

The soffit bearer effect is also discussed

SUMMARY OF RESULTS

The results of this investigation have provided improvements to three modification parameters for use in the general design procedure proposed in Appendix A of this paper.

Lateral load distribution provided by the fascia is allowed for by use of the proposed factor $g_{43fascia}$. This factor is given by:

$$g_{43fascia} = 0.20\log_{10}(K_r/K_f) + 0.69 \quad (1)$$

where $$K_r = g'_{bird}E_rI_r/Lo^3 \quad \text{and} \quad K_f = E_fI_f/s^3 \quad (2)$$

Note: K_r/K_f must be greater than 0.01 for the above relationship to hold

The fascia has much greater influence on the lateral load distribution than batten or purlin members. It was therefore decided to take account only of the fascia member. If a fascia is not included in the design, as is sometimes the case, the properties of the tilt batten supporting the lowest row of tiles, or the purlin supporting the end of roof sheeting could be used in place of the fascia properties. Equation (1) above was derived from plots of the theoretical framing system study mentioned in the introduction.

The strength of a rafter overhang is effected by the geometry of the birdsmouth notch. The current notch geometry factor given by AS 1720.1 is not suited to birdsmouth type geometry. A new factor; g_{40bird}, which is related specifically to birdsmouth notches is given by:

$$g_{40bird} = 18/d^{0.333} \quad (3)$$

This factor is essentially double the factor given by AS 1720.1 for a l_{notch}/d_{notch} ratio of 2. With the notation adopted in Figure 2 below the l_{notch}/d_{notch} ratio never exceeds 2, and equals 2 for 45° birdsmouth notches.

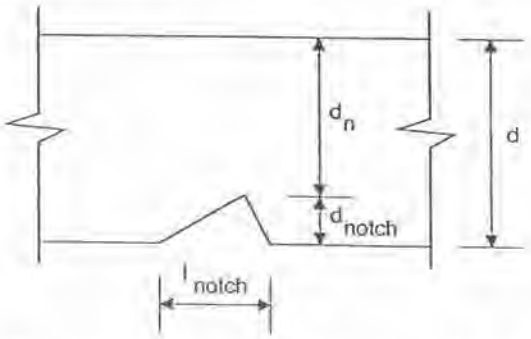

Figure 2. Assumed birdsmouth notching notation for use with AS 1720.1.

Stiffness of the rafter overhang is effected by the rotation of the rafter at the birdsmouth notch. The proposed factor g'_{bird} given below is an improvement on the factor given by Ryan (ref. 4) previously.

$$g'_{bird} = 1 - (5.7d_{notch}/L_o) \quad (4)$$

Design to the proposed procedure given in Appendix A gave allowable rafter overhangs up to 20% less than given by documents such as the TPC Timber Framing Manual (ref. 1). Notwithstanding this finding, the above span tables have provided eaves overhangs that have performed satisfactorily. It is believed that the soffit bearer effect (which is not accounted for in the current span tables) in addition to other less significant system effects has contributed greatly to the satisfactory performance of rafter overhangs.

The experimental and theoretical studies showed the soffit bearer effect to be significant, with load effect reduction factors of between 0.31 and 0.46. Although the soffit bearer effect was found to be significant it was decided that there were so many complicating factors that impinge upon the effect of the soffit bearer in practice, (such as discontinuity of studs at windows, stud height, etc.) that it was considered impractical to devise a general design procedure that would account for all these factors. If it was desired to take advantage of the soffit bearer effect, it is recommended that this be done on a case by case basis by a complete structural analysis.

CONCLUSIONS

Three new modification parameters are proposed. These modification parameters account for the lateral load distribution provided by the fascia, the effect of the birdsmouth notch on the strength and stiffness of the rafter overhang. The proposed modification parameters represent an improvement on factors currently given by AS 1720.1 and other sources. A general design procedure was developed and presented in complete mathematical form.

The current span tables give rafter overhangs up to 20% longer than the values determined by the proposed design procedure. Rafter overhangs based on the current span tables have been performing satisfactorily mainly due to the effect of the soffit bearer. It is advised that the inclusion of the soffit bearer effect in design is best done on a case by case basis by full structural analysis. Incorporating the effect of the soffit bearer in a general design procedure would be too cumbersome due to the many factors that impinge upon the effect of the soffit bearer.

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APPENDIX A
Proposed Design Procedure

The following design procedure is recommend.

1. Establish material properties F'_b, F'_s, F'_{sj} and E from AS 1720.1 or in grade studies

2. Establish modification parameters from equations (1), (2), (3) and (4) or AS1720.1 as follows:

$$g_{43fascia} = 0.20\log_{10}(K_r/K_f) + 0.69$$

K_r/K_f must be greater than 0.01

Note: These modification factors have been derived as a result of this study.

where $K_r = g'_{bird}E_rI_r/Lo^3$ and $K_f = E_fI_f/s^3$

$$g_{40bird} = 18/d^{0.333}$$

$$g'_{bird} = 1 - (5.7d_{notch}/L_o)$$

k_1:

dead load	1.0
live load	1.65
wind load	1.75

$$k_9 = 1.24 - 0.48\ (s/2L_o) \qquad (5)$$

j_2:

Dead load	≤ 15% moisture content	2.0
	≥ 25% moisture content	3.0

Note: Moisture content is at time of load application. For moisture contents between 15% and 25%, linear interpolation should be used.

Live load	1.0

3. Establish loads as follows:

Dead load $w_D = 0.1, 0.2, 0.4, 0.6,$ or 0.9 kPa as appropriate

Live load $W_L = 1.1$ kN

$$w_L = (1.8/2sL_o) + 0.12 \text{ kPa} \qquad (6)$$

Wind load $w_w = 1.1 + 0.63g_{43fascia}$ kPa (7)

4. Check design criteria as follows:

(a) Bending strength under dead load

$$M_{app} \le M_{cap} \qquad (8)$$

where $M_{app} = (w_D s L_o^2/2)$ (9)

$M_{cap} = k_1 k_9 F'_b (b d_n^2/6)$ (10)

$d_n = (2/3)d$ (11)

(b) Bending strength under dead plus live load

$M_{app} \leq M_{cap}$ (12)

where $M_{app} = (w_D s L_o^2/2) + g_{43fascia} W_L L_o$ (13)
and $(w_D + g_{43fascia} w_L L_o) s L_o^2/2$ (14)
which ever is greater

$M_{cap} = k_1 k_9 F'_b (b d_n^2/6)$ (15)

$d_n = (2/3)d$ (16)

(c) Shear strength under dead load

$V_{app} \leq V_{cap}$ (17)

where $V_{app} = (1 - (1.5 d_n/L_o)) w_D s L_o$ (18)

$V_{cap} = k_1 F'_s (2 b d_n/3)$ (19)

$d_n = (2/3)d$ (20)

(d) Shear strength under dead plus live load

$V_{app} \leq V_{cap}$ (21)

where $V_{app} = (1 - (1.5 d_n/L_o)) w_D s L_o + g_{43fascia} W_L$ (22)
and $(1 - (1.5 d_n/L_o))(w_D + g_{43fascia} w_L) s L_o$ (23)
which ever is greater

$V_{cap} = k_1 F'_s (2 b d_n/3)$ (24)

$d_n = (2/3)d$ (25)

(e) Fracture strength under wind minus dead load

$0.3 f_b + f_s \leq g_{40bird} k_1 F'_{sj}$ (failure criterion) (26)

where $f_b = M_{app} (6/b d_n^2)$ (27)

$f_s = V_{app} (3/2 b d_n)$ (28)

$M_{app} = (w_W - 0.6 w_D) s L_o^2/2$ (29)

$$V_{app} = (w_W - 0.6w_D)sL_o \quad (30)$$

$$d_n = (2/3)d \quad (31)$$

(f) Deflection due to dead load

$$\Delta_{DLcomp} = j_2 w_D s L_o^4 (3n^3 + 4n^2 - 1)/(2g'_{bird} n^3 E_r b d^3) \quad (32)$$

where $$n = L_o/L_{bs} \quad (33)$$

(g) Deflection due to live load

$$\Delta_{LLcomp} = 4g_{43fascia} W_L L_o^2 (L_o + L_{bs})/g'_{bird} E_r b d^3 \quad (34)$$

NOTATION

b	= member width
d	= member depth
d_n	= net section depth at birdsmouth notch (refer fig. 2)
d_{notch}	= notch depth (refer fig. 2)
E_f	= modulus of elasticity of fascia
E_r	= modulus of elasticity of rafter
f_b, f_s	= applied stress in bending and beam shear
F'_b, F'_s, F'_{sj}	= basic working stress values in bending, beam shear and shear at joint details
g_{40bird}	= proposed notch geometry factor specific to birdsmouth notches
$g_{43fascia}$	= proposed lateral distribution factor for the effect of the fascia
g'_{bird}	= proposed modification factor for overhang stiffness due to birdsmouth notch
I_f	= second moment of area of fascia
I_r	= second moment of area of rafter
j_2	= creep factor
K_f	= fascia stiffness
K_r	= rafter stiffness
k_1	= duration of load strength factor
k_9	= load sharing factor (statistical effect)
L_o	= overhang span (horizontal dimension)
L_{bs}	= backspan length (horizontal dimension)
l_{notch}	= notch length (refer fig. 2)
M_{app}	= applied bending moment
M_{cap}	= design bending moment capacity
s	= spacing between rafters (centre to centre dimension)
V_{app}	= applied shear force
V_{cap}	= design shear capacity
w_D, w_L, w_w	= intensity of distributed loading for dead, live and wind loads
W_L	= magnitude of concentrated live load
Δ_{DLcomp}	= computed nominal dead load deflection
Δ_{LLcomp}	= computed nominal live load deflection

Design of Flooring with Sheet Decking

J. Yang, L. Pham and R. Leicester

1.Introduction

The current design method for timber joist floor system of domestic construction has been based upon the design for a single joist. It has assumed that each component of the floor act independently. Interaction between the joists and floor decking which increases the stiffness and strength is ignored in this method. It is considered to be conservative and inadequate.

A comprehensive study on developing a improved design method for joist timber floor systems has been carried out by CSIRO and Forest Research Institute, NZ. The aim of this work was to derive a design procedure for timber joist floor system sheathed with board or sheet materials in domestic construction. The procedure accounts for the interaction between the joists and the floor decking including the effects of non-rigid connection and gaps in the floor sheeting. Experimental work and Finite Element modelling was used to analyse the performance of floor systems under both concentred load and uniformly distributed load.

2. System Effects on the Floors

The structural analysis to the timber joist floor is very complicate due to various system effects. There are three major factors which affect the strength and stiffness of the timber joist floor systems. They were:

(i) Effective deck. A T-beam with simple supports was assumed to be the basic structural unit in developing analytical model incorporated composite action between deck and joists for timber joist floor system. As shear lag may occur in the flange of the T-beam, it is not accurate to assume that the width of the flange is equal to the centre-to-centre spacing of the joists. To insure that the elementary beam formula can be applied with sufficient accuracy in the analysis, evaluation of effective width of sub-floor flange is necessary.

(ii) Interlayer slip between joists and floor decking. Nails are commonly used as connector to composite the floor deck to the joists. There is relative displacement between joist and sheeting when connection is not rigid due to shear force occurred. The T-beam with partial composite action does not act as efficiently as a rigidly connected T-beam , however is stiffer than the joist acting alone. The stiffness of the connectors at the sheeting-to-joist interaction is the key parameter that affects the degree of composite action in floor systems. The behaviour of nailed joint can be express by a function of both the properties of the fastener and the materials of components joined in the vicinity of the fastener.

(iii) Discontinuities in the deck due to gaps between sheeting pieces. The presence of gaps between pieces of floor sheeting produces a discontinuity in the axial

displacement and force in the decking. It reduces the amount of composite action. Gap effect to floor behaviour is difficult to quantify as gap pattern is a random variable. In this analysis, the study of gap effect was based on the common gap pattern used in typical floor constructions.

3. Theoretical Modelling and Experimental Work

3.1 Developing analytical model

In this project, Finite Element analysis technique was used to qualify the system effects mentioned above based on the parametric study of a wide range of floor systems. The work of FE analysis was divided into three phase corresponding to each of these effects. Parametric studies were used to analysis the effects of material variability and system configuration upon the deflection and stress response of the systems in each phase of modelling. The FE model of floor systems was assumed to be simply supported at both ends of each joists. The floor deck was subjected to both concentrated load and uniformly distributed load.

The FE model used was verified by experimental work conducted by Forest Research Institute, NZ. This experiment included evaluating of the properties of the materials and joints used in floor construction and testing of the floor systems. The properties of the components and floors could then be used to calibrate and validate the analytical model. The comparison of FE modelling and testing results shows that the FE model does give a reasonable estimation of various effects to the timber joist floor systems.

3.2 Results of FE analysis

Based on the FE analysis, following results are obtained:

- The primary variable having influence on the effective flange width of the deck is the joist spacing while other variables have a minor effect. The ratio of the effective flange width to the joist spacing obtained is in the range of 0.52 to 0.83.

- The slip modulus has the major effect on the composite action of the joist and deck flange. Incomplete composite action is indicated for values of slip modulus between 100 to 10000N/mm. Both significant composite action and slip between joist and deck flange occur in this region. Most of currently used connectors lie in this range.

- The results indicates that the gaps across the joists have significant influence on the composite action of the floor. The presence of these gaps increase the deflections 16 to 34 percent and the stresses 14 to 30 percent. The gaps along the joists have little influence on the floor performance. The maximum deflections and stresses increase by only 1 to 3 percent by taking these gaps into account.

4. Proposed Design Procedure

It is proposed that the design procedure should still be based on the computation of a single joist as in the existing procedure but with additional modification factors to account for the interaction effects between the decking and the joists. The new procedure involves the use of design charts and tables to determinate system effects which included decking effect if there is no gap and full composite action between the deck and the joists, effect of the nailing and the gaps in the decking. The details of this design method is given in Appendix.

In general, a increase of approximate 2-6 % in strength and 5-15% in stiffness can be achieved with the new procedure for static design of the timber joist floor systems. It indicates that adoption of the new design procedure will give significant increasing for stiffness but increasing in strength is negligible. However it must be borne in mind that dynamic performance may control the design of long span floors.

5. Effect of Ceiling

The stiffening effect of ceilings on the floor system did not include in FE modelling due to uncertainties of the wide variety of ceiling types. But an assessment of the effect of the ceiling based on the test data was conducted. The significant result is that the measured stiffness at the midspan of the centre joist in weaker direction, i.e across the joist, is increased approximately by 2 and 5 times corresponding to two concentrated load conditions for this specific case. It is implicated that increasing the stiffness of the floor system in weaker direction would be significant for improving the dynamic performance of the floor system.

6. Conclusion

A simple static design procedure for timber joist floor systems has been proposed to account for the strength and stiffness of floor decking contributed to the floor system. The effects of non-rigid connection between the decking and the joists and gaps in the floor sheeting have been considered in the new design model.

The new procedure for static design of the timber joist floor systems will give significant increasing for stiffness but increasing in strength is negligible. However it must be borne in mind that dynamic performance may control the design of long span floors. The assessment of the effect of the ceiling based on the test data results that increasing the stiffness of the floor system in weaker direction would be significant for improving the dynamic performance of the floor system.

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8. Appendix: Proposed Design Procedure of Timber Joist Floor System

8.1 Design procedure

The procedure can be expressed in mathematical terms as follows:

$$\sigma_b = m_s \ \sigma_{bo} \quad \text{and} \quad \delta = n_s \ \delta_o \tag{1}$$

where

σ_{bo} & δ_o — the bending stress and the deflection calculated based on the properties of the joist only.

σ_b & δ — the bending stress and the deflection of the joist to be used in design.

m_s & n_s — the system effect modification factors for the bending stress and the deflection respectively.

The factors m_s and n_s can be written as

$$m_s = m_t \ m_c \ m_g \quad \text{and} \quad n_s = n_t \ n_c \ n_g \tag{2}$$

where

m_t & n_t — factors to account for the decking effect if there is no gap and full composite action between the deck and the joists for the bending stress and the deflection respectively.

m_c & n_c — factors to account for the effects of the nailing for the bending stress and the deflection respectively.

m_g & n_g — factors to account for the effects of the gaps in the decking layout for the bending stress and the deflection respectively.

8.2 Determination of m_t and n_t

(i) Determine the effective flange width b' from Table 1.

Table 1. Recommended effective flange width for timber joist floor systems

Joist spacing Sj (mm)	Effective flange width, b' (mm)
450	340
600	420

(ii) Determine m_t from Fig.1 using input $(EA)_j / (EA)_f$ for typical constructions.

where

$(EA)_f = E_f \times t \times b'$, the axial stiffness of the flange of the T-beam;
$(EA)_j = E_j \times d \times b_j$, the axial stiffness of the joist;

E_f - deck modulus of elasticity, E_j - joist modulus of elasticity;
b'- effective flange width, t - floor thickness;
d - joist depth; b_j - joist width,
(see Fig. 2)

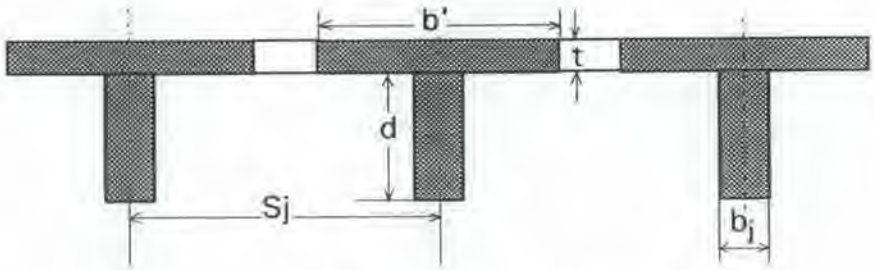


Fig. 2 T-beam with deck flange and joist web

(iii) Determine n_t from Fig 3 using input $(EA)_j / (EA)_f$ for typical constructions.

8.3 Determination of m_c and n_c

(i) Determining m_c from Fig 4 using inputs of R_s and k'_{sm}.

where $R_s = 1/m_t$
k'_{sm} is given in Table 2.

Table 2 Slip modulus for common nailed joints (using 50.8mm x 2.87mm, plain steel Senso GC21 gun nails)

Floor type	joint stiffness k_{sm} (N/mm)	nail spacing S_n(mm)	k'sm (= k_{sm}/S_n) (N/mm^2)
Particleboard on F17 joist	1800	200	9
Particleboard on F5 joist	1600	200	8
F14 Plywood on F17 joist	1800	300	6
F14 Plywood on F5 joist	1670	300	5.6
F11 Plywood on F17 joist	1600	300	5.3
F11 Plywood on F5 joist	1570	300	5.2

(ii) Determine n_c from Fig 5 using inputs of R_d and k'_{sm}.
where: $R_d = 1/n_t$

8.4 Determination of m_g and n_g

(i) Determine m_g from Fig 6 using input R_s.

(ii) Determine n_g from Fig 7 using input R_d.

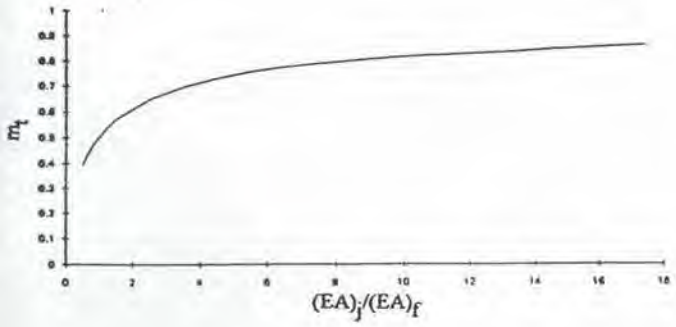


Fig.1 Determination of m_t

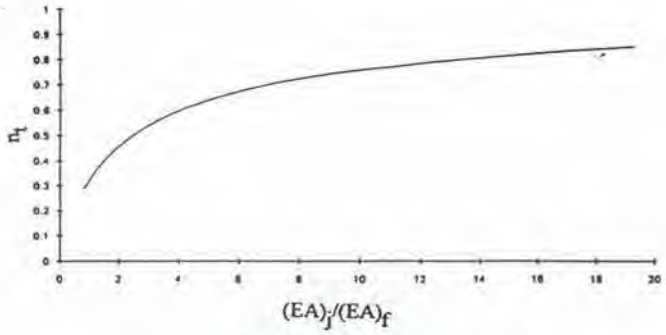


Fig.3 Determination of n_t

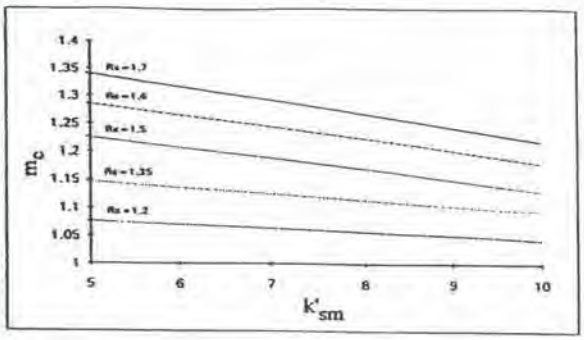


Fig.4 Determination of m_c

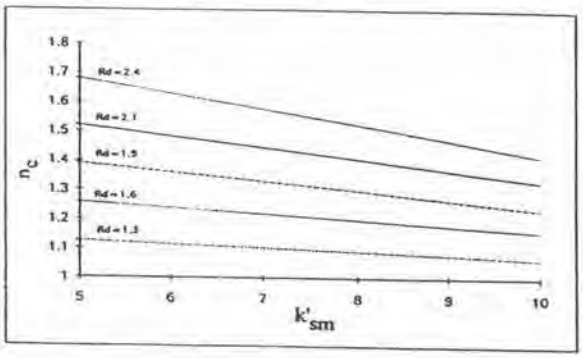


Fig.5 Determination of n_c

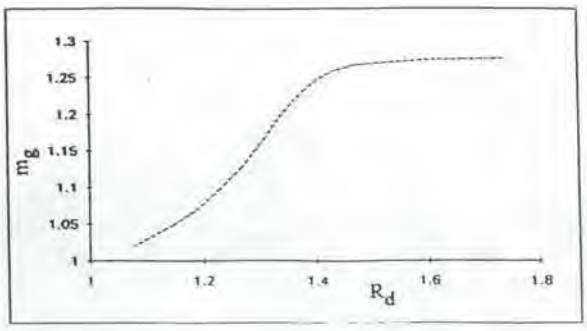


Fig.6 Determination of m_g

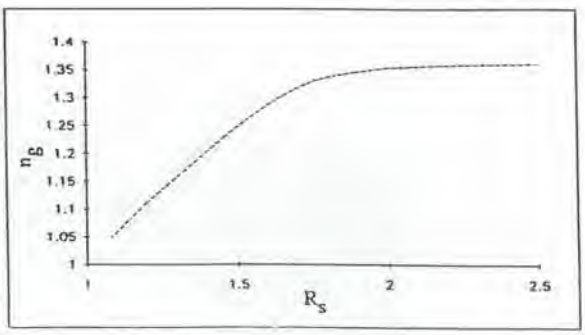


Fig.7 Determination of n_g

Quality of Surface Measures for Concrete Formwork Constructed from Timber Components

H R Milner, BE, MEngSc, PhD, FIEAust, CPEng
Executive Director, Monash Timber Engineering Centre
P Nio, BE
Research Student, Department of Civil Engineering, Monash University, Victoria

Abstract

Australian Standard AS3610, 'Formwork for concrete', specifies Quality of Surface (QoS) criteria which limit the level of imperfection of a concrete surface. Depending on the target quality of surface finish sought, one of Class 1 - Class 5, all QoS measures are assigned one or another limit stated in a statistical format. The imperfections arise because of the deflections induced in the formwork components by concrete loading, initial curvature of the timber (spring) and construction errors. Because of the statistical format of the QoS criteria, formwork designers are placed in a situation which makes considerable demands on their analytical skills; most structural engineers are not equipped to carry out the task. This paper contains details of a mathematical model by which such analyses can be performed. It also contains statistical tables which can be used as design aids and shows how these can be used in conjunction with span tables to develop concrete formwork designs.

1 Introduction

Concrete formwork systems formed using timber framing have three types of structural component. Firstly, there is a panelling layer which is in immediate contact with the concrete. The panelling is most commonly constructed from plywood but steel panels are also commonly used. Supporting the panelling are up to two layers of timber framing. The inner layer consists of a series of equally spaced parallel members known as 'joists' for horizontal or soffit forms and 'studs' for vertical or wall forms. In wall forms, the 'studs' may be horizontal or vertical, see Fig 1. The outer support layer consists of a series of equally spaced parallel members which are described as 'bearers' in horizontal formwork and as 'wales' or 'walers' in vertical formwork. It appears that the term 'waler' is used more commonly in Australia whereas 'wale' is the term used in the UK.

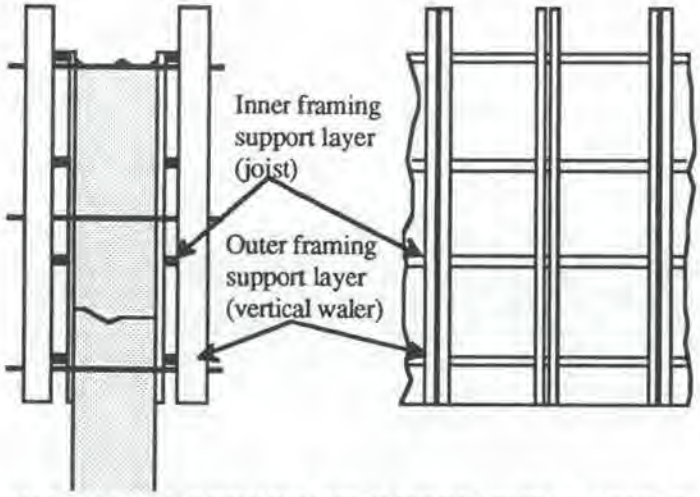
The introduction of Australian Standard AS 3610, 'Formwork for concrete', brought with it unprecedented difficulties in relation to the structural analysis of concrete formwork systems. The design of formwork against structural collapse is relatively straightforward but design to meet the statistically defined Quality of Surface criteria is difficult if undertaken with any degree of precision. Approximate, conservative approaches are possible but these impose severe limits on the choice of formwork components.

2 Quality of Surface (QoS) Classes and Measures

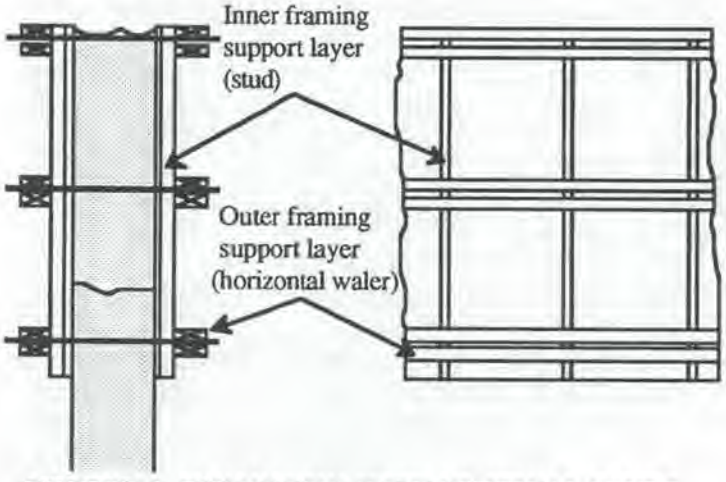
AS 3610 defines five QoS Classes denoted as Class 1, Class 2, ..., Class 5. Class 1 is of the highest quality ranging down to Class 5 at the low end of the scale. Class 1 is only used for the very highest quality of work and requires paying close attention to both design and construction supervision; it is difficult to achieve a Class 1 surface. Class 5 is not normally used for structural purposes and will receive no further attention herein.

The QoS measures are related to the visual qualities of the surface as affected by deflection of the formwork components and errors in construction. These measures are defined in AS3610 as follows.

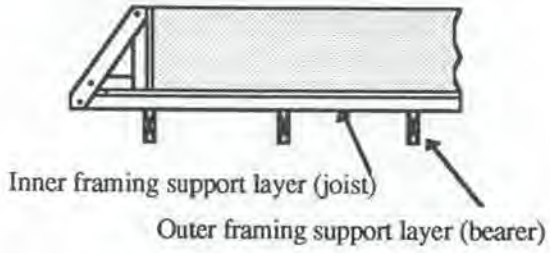
a) Form Face Deflection (FFD) refers to visually undesirable regular surface waves having wave lengths characteristic of the span or spacing of one of the formwork components such as the panelling, joists or bearers. The waves reach undesirable levels through a failure to control deflections within the FFD limits specified in AS 3610 - Table 3.4.2; see Table 1.



VERTICAL FORMWORK WITH HORIZONTAL JOISTS
& VERTICAL WALERS



VERTICAL FORMWORK WITH VERTICAL STUDS
& HORIZONTAL WALERS



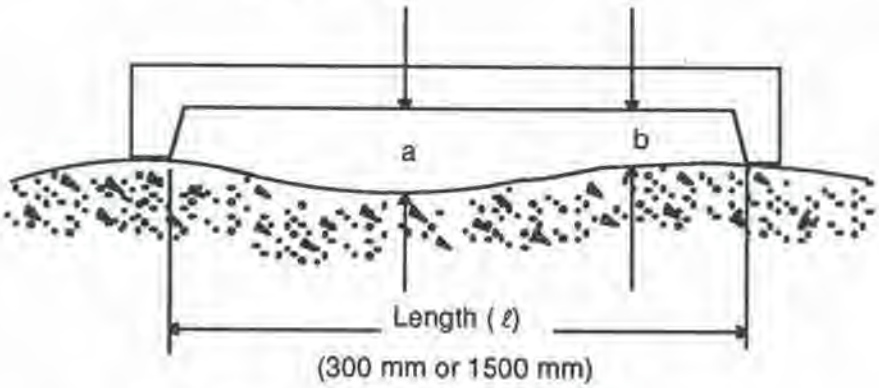
HORIZONTAL FORMWORK

Fig 1: Typical concrete formwork construction

b) Surface Undulations (SUs) are irregular imperfections (deviations from a perfectly flat surface) caused by the combined effect of panelling, joist/stud and bearer/waler deflections

and spring as well as construction errors. Construction errors are those arising from the inaccurate locating of the bearer/waler support points, variations in the size of framing members, load take-up due to poor workmanship, inconsistent tightening of tie bolts etc. SUs are defined in AS 3610 as the difference between the maximum and minimum offset readings measured from the underside of a straightedge to the surface; see Fig 2. For a particular surface, AS 3610 specifies that the straightedge be placed randomly at a minimum of 30 trial positions and that two sets of readings shall be taken. One set is taken under a $300mm$ long straightedge and the other under a $1500mm$ straightedge. For both sets AS 3610 specifies that 100 percent of the undulation readings shall be less than one limit and, depending on the QoS Class, that a percentile of readings shall be less than another limit; see Table 1.

$$U = a - b \qquad 1$$



(a) Measurement of surface undulations

Fig 2: Method of measuring surface undulations. The surface undulation = a - b.

c) Two flatness measures are described in AS3610, Clause 5.6.2.2(e), both taken using offset string lines or an equivalent device. The first measure is taken over a $1.25m \times 1.25m$ grid, see AS 3610 - Clause 5.6.2.2(e) and Fig 3, and the second over $10m$ segments. Because timber formwork components span considerably less than $10m$ in normal circumstances, the second flatness measure is associated more with a failure to exercise adequate supervisory control. Because this paper is more concerned with formwork design, it is not considered any further. The first flatness measurement taken over the $1.25m \times 1.25m$ grid is measured from a reference plane approximately parallel to the target surface. Assuming that the grid has c columns of grid lines parallel to the x axis, r rows parallel to the y axis and measurements are designated by m_{ij}, the flatness is given by

$$F = \max(m_{ij}) - \frac{\sum_{i=1}^{c}\sum_{j=1}^{r} m_{ij}}{rc} \qquad 2$$

Unfortunately this is a poor measure of flatness as it is affected by the method of measurement, especially the angle of tilt of the reference plane; see Appendix B. It is supposed to take on a zero value when the concrete surface is flat but this does not occur. It is possible to use eqn 2 unambiguously only if the m_{ij} values are interpreted as readings taken from a reference plane parallel to the ideal plane which cannot be located in practice.

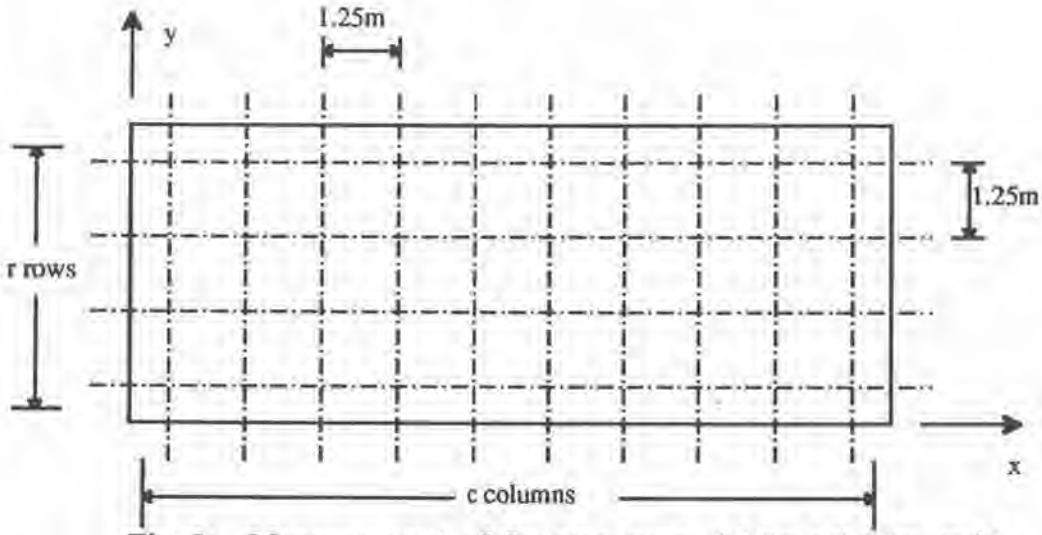


Fig 3: Measurement of flatness over *1.25m x 1.25m* grid.

Quality of Surface	Class 1		Class 2		Class 3		Class 4	
Form face deflection	Lesser of 2mm or L/360		Lesser of 3mm or L/270		Greater of 3mm or L/270		Greater of 3mm or L/270	
	TOLERANCES IN mm							
% of readings	95	100	90	100	80	100	70	100
Surface undulations								
(a) $l = 300$	1	2	2	4	3	4	5	7
(b) $l = 1500$	2	4	3	6	5	7	8	10
Flatness								
(a) 1.25m grid	4	5	6	7	7	10		
(b) at 5m over 10m	5	7	7	10	10	15		

Table 1: Quality of surface requirements specified in Australian Standard AS3610; Table 3.4.2 (in part).

3. Mathematical Modelling and Simulation

The proposed method of deflection analysis is based on mathematical modelling of surface geometry and Monte Carlo simulation. This technique provides the required statistical characteristics of the QoS measures directly. It is not necessary to make any distinction between horizontal and vertical formwork in performing the analysis.

3.1 Surface Description

Let L_1 = span of the panelling = spacing of joists/studs

L_2 = span of the joists/studs = spacing of bearers/walers

L_3 = span of the bearers/walers = prop or tie spacing

The ideal or perfect surface is assumed to lie within an $x-y$ plane and deviations, w, are measured from it in the z direction. An expression is required for the out-of-plane displacement of point P having coordinates (x,y) and lying within the panel EFGH; see Fig 4. The panelling spans in one way bending parallel to the x axis over span length L_1. Joists/studs span parallel to the y axis span over span L_2, (eg EH and FG) and the bearers/walers span parallel to the x axis over length L_3. In Fig 4, bearer/waler support

points are marked with a black circle and do not necessarily coincide with the joist-bearer intersections.

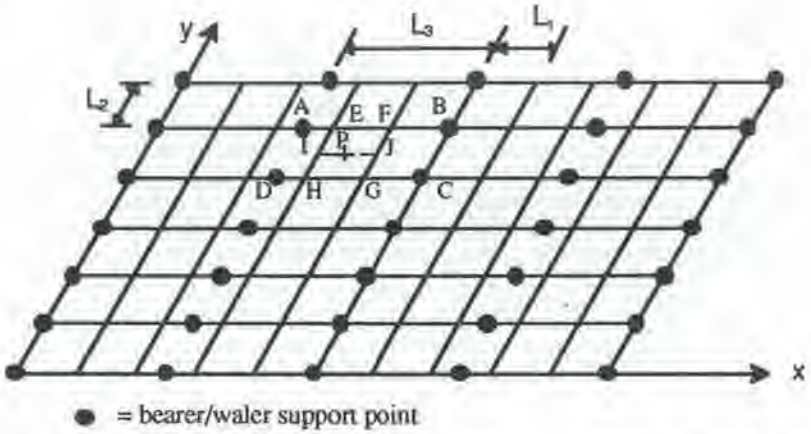


Fig 4: The model of the concrete formwork system for horizontal and vertical formwork.

The panel, EFGH, lies within the larger zone ABCD defined by bearer/waler supports. Points ABCD are allocated random values of the construction tolerance designated w_A, w_B, w_C, w_D. It will be assumed that the panelling, joist/stud and bearerwaler deflection are all given with sufficient accuracy by the absolutes of half sine waves. Hence the deflections of the points EFGH are given by

$$w_E = w_A\left[1 - frac\left(\frac{x_{EH}}{L_3}\right)\right] + w_B\left[frac\left(\frac{x_{EH}}{L_3}\right)\right] + w_b^{AB}\left|\sin\frac{\pi x_{EH}}{L_3}\right| \qquad 3a$$

$$w_F = w_A\left[1 - frac\left(\frac{x_{FG}}{L_3}\right)\right] + w_B\left[frac\left(\frac{x_{FG}}{L_3}\right)\right] + w_b^{AB}\left|\sin\frac{\pi x_{FG}}{L_3}\right| \qquad 3b$$

$$w_H = w_D\left[1 - frac\left(\frac{x_{EH}}{L_3}\right)\right] + w_C\left[frac\left(\frac{x_{EH}}{L_3}\right)\right] + w_b^{CD}\left|\sin\frac{\pi x_{EH}}{L_3}\right| \qquad 3c$$

$$w_G = w_D\left[1 - frac\left(\frac{x_{FG}}{L_3}\right)\right] + w_C\left[frac\left(\frac{x_{FG}}{L_3}\right)\right] + w_b^{CD}\left|\sin\frac{\pi x_{FG}}{L_3}\right| \qquad 3d$$

In these expressions, the function *frac* is the fractional part of the quantity in brackets immediately following; this is automatically available in some computer languages. The terms w_b^{AB}, w_b^{CD} are the mid-span deflections of the bearers/walers AB, CD whose values are related statistically to a, designer chosen, nominal deflection limit. Individual bearers/walers will deflect different amounts because of piece to piece variations in the modulus of elasticity. x_{EH}, x_{FG} are the x coordinates of the lines EH and FG given by $x_{EH} = L_1 \bmod(x/L_1)$ and $x_{FG} = x_{EH} + L_1$.

The deflections of points I and J on the joists/studs are given by

$$w_I = w_H\left[1 - frac\left(\frac{y}{L_2}\right)\right] + w_E\left[frac\left(\frac{y}{L_2}\right)\right] + w_J^{EH}\left|\sin\frac{\pi y}{L_2}\right| \qquad 4a$$

$$w_J = w_G\left[1 - frac\left(\frac{y}{L_2}\right)\right] + w_F\left[frac\left(\frac{y}{L_2}\right)\right] + w_J^{FG}\left|\sin\frac{\pi y}{L_2}\right| \qquad 4b$$

Finally the deviation of point P is given by

$$w = w_I\left[1 - frac\left(\frac{x}{L_1}\right)\right] + w_J\left[frac\left(\frac{x}{L_1}\right)\right] + w_p^{EFGH}\left|\sin\frac{\pi x}{L_1}\right| \qquad 5$$

The values of w_J^{EH}, w_J^{FG} are the mid-span deflections of the joists EH, FG and w_p^{EFGH} is the mid-span deflection of the panel EFGH. The panel acts in one-way bending.

3.2 Use of the Mathematical Model

The method of formwork deflection analysis involves the following steps.

For a single surface of known overall size ie, L_x and L_y known

3.2.1 The QoS Class will be either stated in contract documents or nominated by the formwork designer.

3.2.2 To use the simulation model a trial formwork layout has to be selected including values of deflection limits and construction errors, specifically,

- nominal values of panelling, joist/stud and bearer/waler deflection limits,
- nominal construction error,
- the spans of panelling, joists/studs and bearers/walers.

Actual deflections of individual components will vary due to variations in the modulus of elasticity as will the construction errors of individual bearer/waler supports.

3.2.3 The surface modelling eqns 3 - 5 can be used to determine the deviation of the surface from perfect flatness at individual points. This information can then be used to compute the QoS measures defined in AS 3610 and check against the QoS targets given in AS3610, Table 3.4.2.

For a series of surfaces of unknown dimensions

3.2.4 Alternatively, 'standard solutions' can be prepared and tabulated, as has been done in the Appendix A, for representative surfaces. In the simulation runs used to generate these solutions, the overall surface dimensions, L_x and L_y, vary implicitly although the solutions are tabulated explicitly for different L_1, L_2 and L_3 values.

3.3 Choosing Nominal Values, their Statistical Characteristics and Construction Errors

For the panelling and support framing deflections normal, log-normal, Weibull, gamma and other distributions can be used as a basis for assigning values to individual components. As the final results differ very little with the different distributions, a decision was taken to choose the Weibull.

3.3.1 Choosing w_{pnom}

The most commonly used form of panelling is plywood. Plywood has a modulus of elasticity (MOE) assigned as a result of testing and Stress Grading procedures. From a

knowledge of the Stress Grade, the designer may obtain the MOE from AS 1720.1 - Table 5.1. The value quoted in AS 1720.1 is the mean MOE; a coefficient of variation, V, of 0.08 has been adopted. Other forms of panelling have not been considered.

Span tables have been published for panelling by the Plywood Association of Australia (PAA) which show that commercially available plywoods can span, at most, around 900mm although spans of 600mm or less are more common. By choosing plywood for formwork panelling from the PAA booklet, the designer can be satisfied that Form Face Deflection (FFD) criteria associated with the panelling are met. In keeping with normal timber engineering design practice, the PAA booklet spans are based on average MOEs which implies that the designs will not meet the AS3610 FFD criteria in approximately 50 percent of cases. Given the relatively low coefficient of variation of plywood, the adoption of this practice for selecting the panelling for concrete formwork design is reasonable.

	w_{pnom}	V
Class 1	lesser of L1/360 and 2mm	0.08
Class 2	lesser of L1/270 and 3mm	0.08
Class 3	greater of L1/270 and 3mm	0.08
Class 4	greater of L1/270 and 3mm	0.08

3.3.2 Choosing w_{jnom} and w_{bnom}

Stress Graded sawn timber also has a MOE which is assigned as a result of testing and stress grading activity; mean values are given in AS 1720.1 - Table 2.3. For sawn timber, V is taken to be 0.2 on the basis of tests by Leicester et al (1988) on Radiata Pine. Adhesive bonded timber products such as laminated veneer lumber (LVL) have MOE values which can be obtained from the manufacturer but V values are not usually cited. For LVL, V will approximate the value cited for plywood. For glued laminated timber (GLT) the MOE is available from suppliers and is of the order of 0.12. For the 'standard designs' $V = 0.2$ has been used.

3.3.3 Choosing w_{cnom}

The construction error needs to be estimated by the formwork designer according to the level of supervision to be exercised. Construction errors would normally be expressed in the form $\pm xmm$ where x is chosen by the formwork designer. The actual distribution of errors in construction is not known but is likely to follow classical observation error theory, ie, values will be distributed normally with a mean of zero. It is further assumed that 98 percent of all construction errors will lie within the specified range ie within 2.33 standard deviations. The normal distribution will be characterised by having a mean, $\mu = 0$, and standard deviation, $\sigma = x/2.33$.

4 Details of the Simulation Model Algorithm

The production of the standard designs for a range of surfaces is undertaken as follows.

4.1 The lengths of plywood, joist/stud, bearer/waler span, (L_1, L_2, L_3), are chosen as designated on each of Tables 2 and 3 given in the Appendix A. The L_1 values cover those listed in the PAA booklet. The L_2 and L_3 values have been taken from private communications from McAdam (1992) and are based on extensive experience in the design of concrete formwork systems.

4.2 The length, L_x, of the trial surface parallel to the x axis is given by $L_x = n_3 L_3$, ie as an integral number of bearer/waler spans. For the undulation simulation n_3 is chosen

randomly as a whole number in the range of 1 to 8. The length, L_y, of the trial surface parallel to the y axis is given by $L_y = n_2 L_2$, ie as an integral number of joist/stud spans. For the undulation simulation n_2 is also chosen randomly as a whole number in the range of 1 to 8. A check is next made to ensure that the trial surface has minimum dimensions of $2m$ in both the x and y directions. This ensures that the straightedge will always fit on the surface. The number of plywood panels needed to span the length L_x is computed to the nearest whole number using $n_1 = trunc(L_x/L_1)$ and the length L_1 adjusted so that $L_1 = L_x/n_1$. This ensures that there is an integral number of plywood panels in the trial surface.

4.3 The construction errors are next assigned to all bearer/waler support points.

4.4 The values of nominal deflection limits for individual joists/studs and bearers/walers are then chosen randomly using the Weibull distributions described above with α and β calculated to provide the correct mean and standard deviation.

4.5 For the first trial surface the undulation values are computed for the 30 trial straightedge positions. The coordinates of end 1 of the straightedge are chosen randomly as $x_1 = random * L_x$, $y_1 = random * L_y$ ensuring that one end lies somewhere on the surface. Next, the angle, θ, of the straightedge to the x axis is chosen as $\theta = random * 2\pi$. The coordinates of end 2, (x_2, y_2), are computed and checked to see if end 2 lies on the surface. If it does not, another value of θ is chosen randomly and the process is repeated until end 2 also lies on the surface. The assumption is made that this method meets the requirements of Australian Standard AS3610 - Clause 5.6.2.2(d) of positioning the straightedge "systematically over the whole face of the element to ensure reasonably even coverage"

4.6 The height w above the (x,y) plane is computed at the two straightedge ends and at the 19 intermediate points. The maximum and minimum of the 21 values are subtracted to provide the undulation measure, $U = w_{max} - w_{min}$. Once the 30 undulation values have been obtained for the 30 straightedge positions, see AS 3610 - Clause 5.6.2.2(c), they are arranged in descending order, U_1^{1500}, U_2^{1500}, ... U_{30}^{1500} (the superscript is the straightedge length and the subscript the rank order). The relevant percentiles defined in AS3610 - Table 3.4.2 are calculated as follows where the subscript is now also used to indicate a percentile.

$U_{100}^{1500} = U_1^{1500}$ $\quad U_{95}^{1500} = 0.5(U_1^{1500} + U_2^{1500})$ $\quad U_{90}^{1500} = U_3^{1500}$

$U_{80}^{1500} = U_6^{1500}$ $\quad U_{70}^{1500} = U_9^{1500}$

4.7 Steps 4.1 to 4.6 are repeated for the 500 trial surfaces in the simulation and finally the means and standard deviations are computed for each of the percentiles. Assuming that these are normally distributed, the QoS undulation measures can be met with a confidence level chosen by the formwork designer when using the simulation program individually or automatically built into 'standard designs'.

The above analysis must be repeated for the flatness QoS measure by generally similar procedures.

5 Presentation of Standard Designs

The results for a series of standard designs are given in Tables 2 and 3.

Form Face deflection (FFD) can be affected by the choice of joist/stud and bearer/waler combinations of deflection limit and span. The choice of these combinations must meet the the AS3610 - Table 3.4.2 criteria, eg, for a Class 2 QoS and joist deflection limit of $3mm$, the joist span should be not less than $810mm$. All 'standard designs' given in the Appendix A automatically meet the FFD criteria.

Each of Tables 2 and 3 applies to specific choices of L_2 (joist/stud span) and L_3 (bearer/waler) span and refers to combinations formed using:

- panelling selected from the PAA booklet,
- nominal joist/stud and bearer/waler deflections,
- construction errors

A confidence limit of 75 percent has adopted in arriving at the standard designs. Because all QoS measures produced in the simulation have been found to be normally distributed, the design values are calculated as

$$X_{des} = X_{av}(1+0.7V) \qquad 6$$

6 Observations and Conclusions

6.1 Examination of Tables 2 and 3 shows that, for fixed nominal deflections of joists/studs and bearers/walers, designs which employ longer spans provide a wider variety of design solutions. For instance, in Table 3 ($L_2, L_3 = 3000mm$) there are more feasible solutions available than exist in Table 2 ($L_2, L_3 = 600mm$).

6.2 The use of Appendix A Tables, together with a set of Span Tables, can be employed to select the components of concrete formwork systems to meet the requirements of Australian Standard AS3610. In this context, it is pointed out that a set of Concrete Formwork Span Tables is currently in the course of preparation.

6.3 Tables 2 and 3 apply to designs involving the use of equal joist/stud and bearer/waler spans. For designs involving the use of different spans reference should be made to the Tables involving the lesser of the two spans.

7 References

Australian Standard AS3610-1990, 'Formwork for concrete', Standards Association of Australia.

Leicester, RH, et al, 'Structural Engineering Properties of Machine Stress-graded, Australian-grown Radiata Pine', Technical Report TR88/1, Division of Construction and Engineering, CSIRO, 1988.

McAdam, PS, Private communication, 27 November, 1992.

Plywood Association of Australia, Plywood in Concrete Formwork.

APPENDIX A: STANDARD DESIGNS MEETING AS3610 QUALITY OF SURFACE CRITERIA

TABLE 2: STANDARD DESIGNS FOR JOIST/STUD AND BEARER/WALER SPANS BOTH GREATER THAN 600*mm*

CLASS 1 FORMWORK

		Construction Error	
		±1*mm*	±2*mm*
Joist/Stud Spacing (*mm*)	Bearer/Waler Deflection (*mm*)	Joist/Stud Deflection (*mm*)	Joist/Stud Deflection (*mm*)
225	0.5	0.5	-
225	1.0	0.5	-

CLASS 2 FORMWORK

		Construction Error			
		±1*mm*	±2*mm*	±3*mm*	±4*mm*
Joist/Stud Spacing (*mm*)	Bearer/Waler Deflection (*mm*)	Joist/Stud Deflection (*mm*)	Joist/Stud Deflection (*mm*)	Joist/Stud Deflection (*mm*)	Joist/Stud Deflection (*mm*)
225	0.5	1.0	1.0	0.5	-
300		1.0	0.5	-	-
400		1.0	0.5	-	-
225	1.0	1.0	1.0	-	-
300		1.0	1.0	-	
400		1.0	-	-	-
225	2.0	0.5	-	-	-

CLASS 3 FORMWORK

		Construction Error			
		±2*mm*	±3*mm*	±4*mm*	±5*mm*
Joist/Stud Spacing (*mm*)	Bearer/Waler Deflection (*mm*)	Joist/Stud Deflection (*mm*)	Joist/Stud Deflection (*mm*)	Joist/Stud Deflection (*mm*)	Joist/Stud Deflection (*mm*)
600	1.0	2.0	-	-	-
900		2.0	1.0	-	-
600	2.0	1.0	-	-	-
900		2.0	0.5	-	-
600	3.0	1.0	-	-	-
900		2.0	0.5	-	-

CLASS 4 FORMWORK

		Construction Error			
		±5*mm*	±6*mm*	±7*mm*	±8*mm*
Joist/Stud Spacing (*mm*)	Bearer/Waler Deflection (*mm*)	Joist/Stud Deflection (*mm*)	Joist/Stud Deflection (*mm*)	Joist/Stud Deflection (*mm*)	Joist/Stud Deflection (*mm*)
900	3.0	3.0	3.0	3.0	3.0

TABLE 3: STANDARD DESIGNS FOR JOIST/STUD AND BEARER/WALER SPANS BOTH GREATER THAN 3000*mm*

CLASS 1 FORMWORK

		Construction Error	
		±1*mm*	±2*mm*
Joist/Stud Spacing (*mm*)	Bearer/Waler Deflection (*mm*)	Joist/Stud Deflection (*mm*)	Joist/Stud Deflection (*mm*)
225	0.5	2.0	1.0
400	0.5	2.0	1.0
225	1.0	1.0	1.0
400	1.0	1.0	0.5

CLASS 2 FORMWORK

		Construction Error			
		±1*mm*	±2*mm*	±3*mm*	±4*mm*
Joist/Stud Spacing (*mm*)	Bearer/Waler Deflection (*mm*)	Joist/Stud Deflection (*mm*)	Joist/Stud Deflection (*mm*)	Joist/Stud Deflection (*mm*)	Joist/Stud Deflection (*mm*)
225		3.0	3.0	3.0	3.0
300		3.0	3.0	3.0	3.0
400	0.5	3.0	3.0	3.0	3.0
225		3.0	3.0	3.0	3.0
300		3.0	3.0	3.0	3.0
400	1.0	3.0	3.0	3.0	3.0
225		3.0	3.0	3.0	3.0
300	2.0	3.0	3.0	3.0	2.0
400		3.0	3.0	3.0	2.0

CLASS 3 FORMWORK

		Construction Error			
		±2*mm*	±3*mm*	±4*mm*	±5*mm*
Joist/Stud Spacing (*mm*)	Bearer/Waler Deflection (*mm*)	Joist/Stud Deflection (*mm*)	Joist/Stud Deflection (*mm*)	Joist/Stud Deflection (*mm*)	Joist/Stud Deflection (*mm*)
900	3.0	3.0	3.0	3.0	3.0

CLASS 4 FORMWORK

		Construction Error			
		±5*mm*	±6*mm*	±7*mm*	±8*mm*
Joist/Stud Spacing (*mm*)	Bearer/Waler Deflection (*mm*)	Joist/Stud Deflection (*mm*)	Joist/Stud Deflection (*mm*)	Joist/Stud Deflection (*mm*)	Joist/Stud Deflection (*mm*)
900	3.0	3.0	3.0	3.0	3.0

APPENDIX B: FLATNESS MEASUREMENT

A fundamental problem exists with the AS3610 definition of surface flatness as given by eqn 2, $F = \max(m_{ij}) - \dfrac{\sum_{i=1}^{c}\sum_{j=1}^{r} m_{ij}}{rc}$.

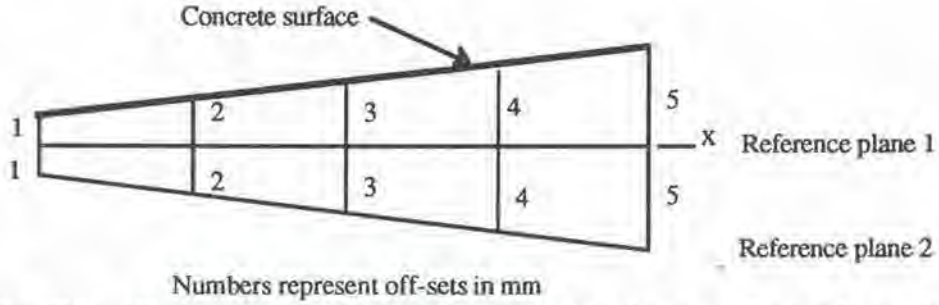


Fig B1: Diagram for Example showing how a flat plane is described as otherwise under AS3610.

Consider flat concrete surface and two choices of reference plane labelled 1 and 2. In the transverse direction assume that the reference planes are parallel to the flat surface, ie, in eqn 2, $B = 0$.

For reference plane 1

$F = 5 - \left(\dfrac{1+2+3+4+5}{5}\right) = 5 - 3 = 2mm$. Note that adding $500mm$ to all dimensions does not change the result.

$$F = 505 - \left(\frac{501+502+503+504+505}{5}\right) = 505 - 503 = 2mm.$$

For reference plane 2 all the offsets double as does the AS3610 flatness parameter.

$$F = 10 - \left(\frac{2+4+6+8+10}{5}\right) = 10 - 6 = 4mm.$$

Hence, according to the AS3610 definition, the flatness takes on a value which depends on the tilt of the reference plane relative to the correct absolute location of the surface. Under the AS3610 definition, even for a perfectly flat surface when F should be zero, a non-zero value can be calculated, ie, it is concluded that a flat surface is not flat.

SIMULATION OF GLUED LAMINATED TIMBER BENDING STRENGTHS USING LAMINATION TENSION TEST DATA

by R Nestic and H R Milner

Summary

The simplest method of assessing the strength characteristics of glued laminated timber involves converting lamination test data into beam strength values by computation. This paper describes a simulation procedure which can be used to test the accuracy of simplified conversion formulas. The motivation for the paper is based upon the needs of the Australian glued laminated timber industry which requires a low cost method of evaluating beam properties in a situation where the existing conversion formulas are grossly inaccurate. The techniques have been especially developed to deal with the difficulties associated with laminating hardwoods.

1 Introduction

The concept of mathematically modelling glued laminated timber appears to have originated with Wilson and Cottingham (1947) who developed a method which has become known as the I_k/I_g method; it is summarised in ASTM D 3737 (1991). Foschi and Barret (1980) were the first to apply modern modelling methods in which a digital computer was employed along with Monte Carlo simulation. Their motivation was to provide a means by which variability in beam strength and stiffness could be predicted using a digital computer. A number of further models have stemmed from the original Foschi and Barret model which have been summarised by Hernandez *et al* (1992). There is reference to a "Karlsrhue calculation method" attributed to Ehlbeck *et al* (1985a, b, c) which includes allowance for the effect of end joints and allowance for progressive failure. Govindarajoo (1986) developed a model which used a stochastic timber properties model developed by Kline *et al* (1986). The Kline model correlated timber properties with localised MOE data. Other models developed by Bender (1989) were used to model the finger joints.

2 Mathematical Model

The authors' objective was to develop a model whereby the strength of glued laminated timber beams could be estimated from lamination tension strength test data. Consequently, it is not necessary to develop models which evaluate the tension strength from clear wood data since lamination strength is the basic input to the model.

2.1 Lengthwise Beam Modelling

Glued laminated timber is manufactured by laminating segments of a length characteristic of the laminating stock. Some laminators dock out defects which also affects these characteristic lengths. Let the beam longitudinal axis be x, as shown in Fig 1, and the length of an individual segment be l_{ij} $((i=1\rightarrow N, j=1\rightarrow S)$. The segment lengths and their corresponding material properties E, F_c, F_{tlam} are assigned randomly. F_{tlam} represents the lamination tensile strength properties in the absence of finger joints. The finger joints connecting the laminations have strengths, F_{tfj} assigned randomly.

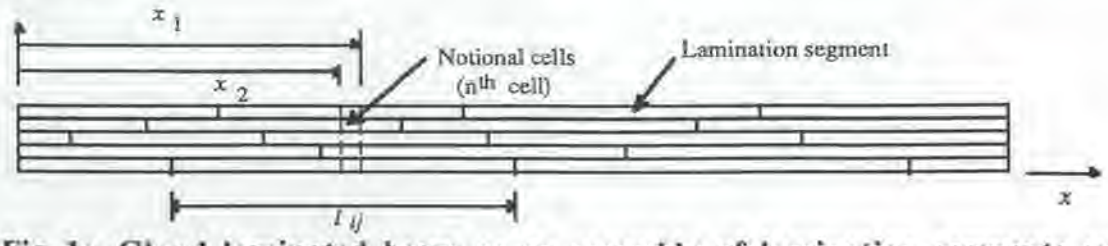


Fig 1: Glued laminated beam as an assembly of lamination segments and notional cells.

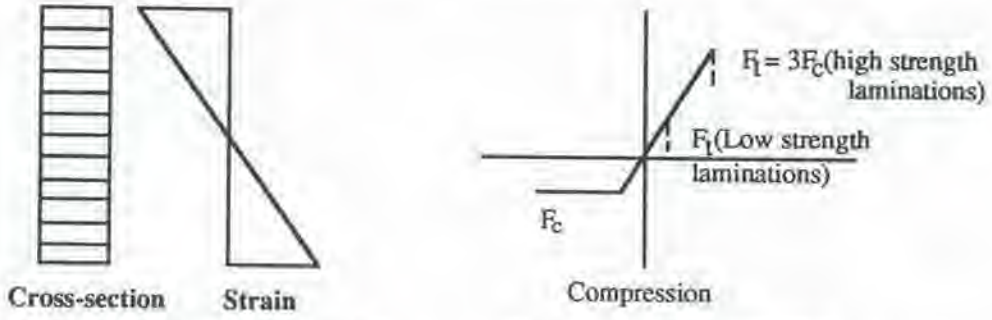
For computational purposes the beam is notionally subdivided into n_c cells as first proposed by Foschi and Barret (1980), with a cell length approximately $100mm$.. The n^{th} cell is defined from the left hand side by the co-ordinates x_1 and x_2. The cells are assumed to have constant material properties assigned as follows.

Case (a) Where a cell does not contain a finger joint E, F_c, F_t are the values of E, F_c, F_{tlam} of the laminating segment in which the cell lies.

Case (b) Where a cell contains a finger joint E, F_c are taken as the lowest of the adjacent laminting segments. The value of F_t is the least of F_{tlam} for the laminations on either side of the finger joint and the finger joint strength F_{gj} contained within the cell.

2.2 Moment-Curvature Relationship

The moment-curvature relationship is based on Kirchoff's assumption that, during bending, plane sections remain plane; see Fig 2(a). As the bending curvature increases the stress distribution has a shape controlled by the stress-strain curve shown in Fig 2(b).



(a) Cross-section and strain distribution (b) Stress-strain relationship

Fig 2: Stress distribution and stress-strain curve used in the mathematical modelling

In solid clear timber, compression yield usually occurs at stress F_c and tension rupture at stress $F_t = 3F_c$; at failure the stress distribution is as shown in Fig 3(a) with a fully developed compression yield zone. Compression yield in clear wood involves a type of constrained buckling at the cellular level in which the post-buckling strength is maintained and a plastic plateau develops as shown in Fig 2(b). On the other hand, structural timber and glued laminated timber, containing natural and/or manufacturing defects, rupture at much lower tension stresses and, as a consequence, may not capable of mobilising the compression yield phenomenon. Such timber has either the stress distribution shown in Fig 3(b) at rupture or less well developed compression yield of the type shown in Fig 3(a). The algorithms used herein allows either type of stress distributions to develop as appropriate depending on the lamination segment strength. It also permits individual laminations to have independent E, F_t, F_c values which means that the stress distribution will vary step-wise across a glued laminated timber section in accordance with the lamination E value; see Fig 3(c)

(a) Clearwood and high strength structural timber

(b) Structural timber containing significant defects

(c) Glued laminated timber with both strong and weak tension laminations

Fig 3: Approximate stress distributions at failure of high tensile (clear), low tensile structural wood and glued laminated timber at failure.

Algorithm for beams under constant moment

In performing the simulation, the curvature, ϕ, of each cell is set initially at 1×10^{-6} and progressively increased in steps of 1×10^{-6} until such time as a finger joint or lamination fractures, usually at around a curvature of 5×10^{-5}. As a consequence the corresponding curvature is determined to an accuracy of better than 2%. The bending moment for this curvature is computed for the cell. The cell with the smallest bending moment is taken as the point of initial failure. The failure of a lamination with in a particular cell will not necessarily trigger overall collapse as thee beam may continue to support additional load with the failed lamination. For subsequent load increments the laminating segment in which the failure occurred is assigned zero strength. The curvature is then increased and the whole process repeated until such time that the bending moment of the cell with the smallest bending moment decreases. The simulation is capable of analysing other loading configurations other than constant moment, see fig 5.

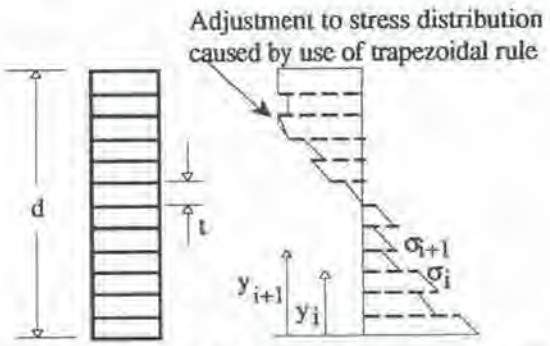


Fig 4: Stress distribution and variables employed to evaluate the bending moment capacity by quadrature.

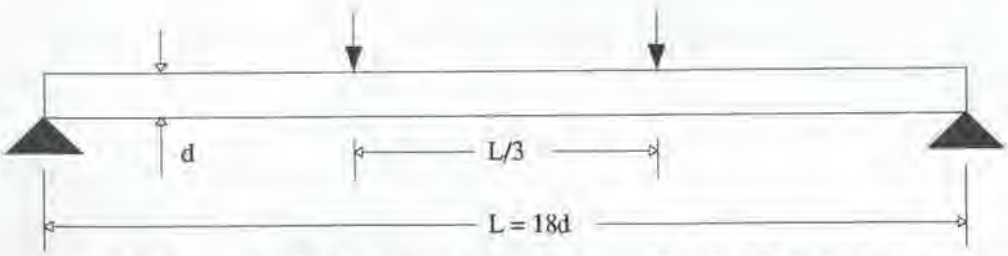


Fig 5: Standard loading pattern used for the simulations.

3 Lamination Engineering Properties

3.1 Statistical Distributions

A two parameter Weibull distribution is assumed to represent the variation of all lamination engineering properties with sufficient accuracy. The distribution has the probability density function

$$p = \alpha\beta x^{\beta-1} e^{-\alpha x^{\beta}} \qquad 1$$

and a cumulative probability function

$$P = 1 - e^{-\alpha x^{\beta}} \qquad 2$$

The parameters α and β are selected so that the mean and standard of the Weibull distribution matches that of the experimental data.

3.2 Statistical Parameters

The authors' interest has been focussed specifically on the performance of glued laminated timber beams manufactured from native Australian hardwoods. Tension testing shows that finger jointed laminations have a bi-modal behaviour associated with failure of the finger joints on the one hand and failure of the unjointed lamination on the other. The specific parameters of interest are the means and standard deviations of E, F_t, F_c.

Unjointed Laminations

With unjointed laminations the values of E, $F_t(=F_{tlam})$, F_c are taken to be correlated. In the authors' simulation, a probability is selected randomly and applied to the each of the distributions for E, F_t, F_c. This means that a low E value is associated with low F_t and F_c values.

For the Mountain Ash glued laminated timber with which the authors were working the engineering properties shown in Table 1 have been adopted. In this test series, which is typical of hardwood behaviour, the separation of finger joint and lamination strengths was straight forward because the finger joint strengths were much lower than the lamination segments without finger joints. The two sets of strengths were obtained from separate test series.

Property	Mean (MPa)	V
E	18500	0.20
F_c	-85.0	0.15
F_{tlam}	84.8	0.40
F_{tfj}	42.6	0.13

Table 1: Engineering properties of laminations used in simulation. Test data applicable to Mountain Ash.

Jointed Laminations

With jointed laminations it is assumed that, between finger joints, E, $F_t(=F_{tlam})$ and F_c are correlated as was the case for the unjointed laminations. The tension strengths as limited by the finger joint strength, F_{tfj}, are uncorrelated with the other properties and are obtained from the tension test data by eliminating any tension results where failure occurs at other than the finger joint. Fig 6 is a graphical representation of the actual test data fitted to a Weibull distribution.

For one Australian glued laminated timber manufacturer with whom the authors have been associated the properties shown in Table 1 are applicable.

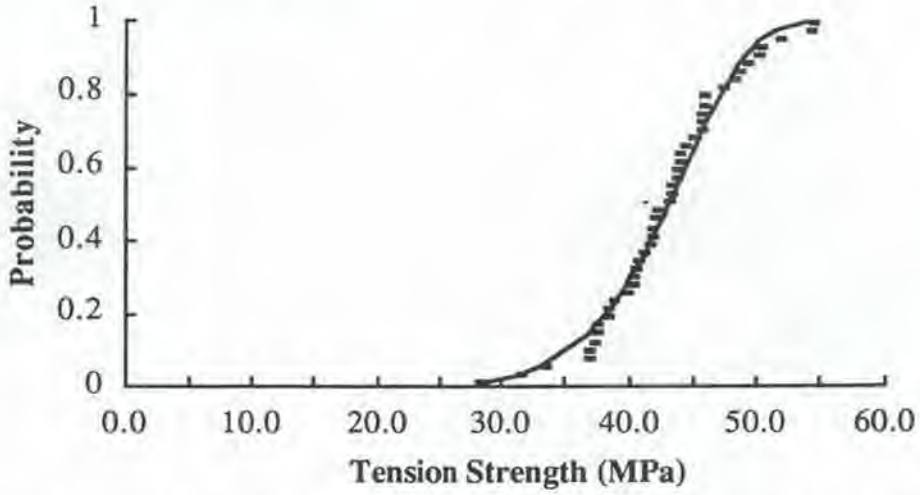


Fig 6: Strengths of finger jointed lamination segments tested in tension. Dashes are observed data points and solid line is a two parameter Weibull distribution with the same mean and standard deviation.

3.3 Lamination Strength Modification Factors

Within the simulation the strength of the laminations as given by tension tests needs to be modified in accordance with the reinforcing and size factors k_r and k_s detailed below. The strength of the laminations is taken as given by

$$F_{ilam} = k_r k_s F_{ilam(test)} \qquad 3a$$

$$F_{ifj} = k_r F_{ifj(test)} \qquad 3b$$

4 Physical Test and Simulation Results

In a series of destructive tests on an Australian hardwood glued laminated beams and laminations grade from (Mountain Ash - *e regnans*) the results given in Table 3 were obtained. In evaluating the design strengths, F', the coefficient of variation (CoV) of the test data has been made to fit the tail of a Weibull distribution, Leicester (1993).

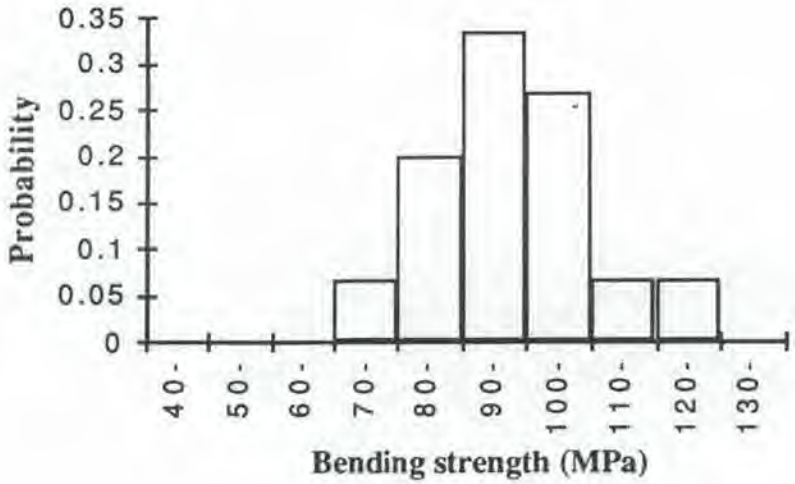
Test	F_{av} (MPa)	V (overall statistics)	$F_{0.05}$ (MPa)	F_b' (MPa)
Glulam beams without finger joints	96.7	0.12	78.7	29.8
Glulam beams with finger joints	69.5	0.24	43.2	17.7
Laminations in tension without finger joints	84.8	0.40	41.8	13.9
Laminations in tension with finger joints	42.6	0.12	31.6	12.9
Laminations in bending without finger joints	115.6	0.16	83.5	29.9
Laminations in bending with finger joints	75.4	0.16	54.9	19.8

Table 3: Strength parameters for Mountain Ash glued laminated timber and laminations obtained by physical tests. Results are based on 15 tests.

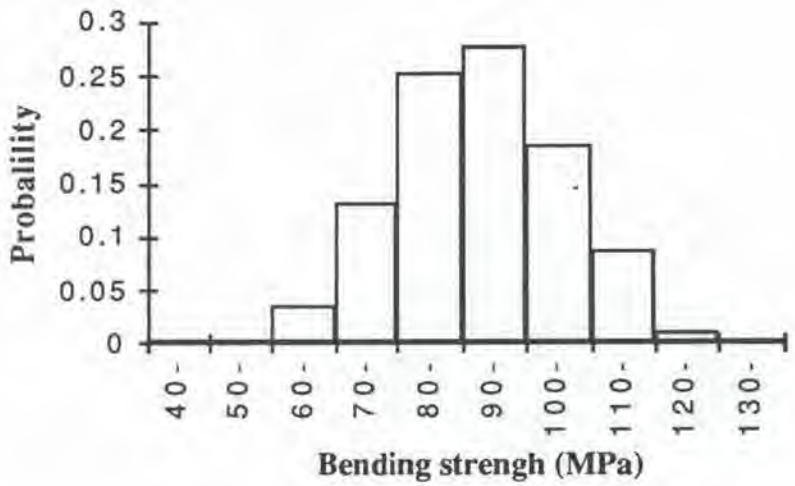
The glued laminated timber members manufactured without finger joints exhibited a basic permissible strength in bending, $F_b' = 29.8MPa$, approximately equal to that of the laminating stock. All members failed in the tension zone with some members exhibiting compression yield and a relatively small co-efficient of variation, see Fig 8(a) and Table 3.

Glued laminated timber containing finger joints, series(b) in Table 3, has a mean modulus of rupture between the mean failure stresses in tension of laminations with and without finger joints, see series (c) and (d). If test series(b) is treated as uni-modal data, as has been done, the computed co-efficient of variation is quite high because of the real bi-modal nature of failure. In some beams, no finger joints were present in the high moment section and/or the outer tension laminations and these had high failure loads whereas, in others, the outer tension laminations contained one or more finger joints and these tended to have sharply lower failure loads. The bi-modal behaviour is obvious in Fig 9(a) for the test data and, to a lesser degree, in the simulation, see Fig 9(b). The sample size of the test data was fifteen, it may not be considered a large enough sample for statistical purposes but it highlights the bi-modal behaviour of glulam. The observed modes of failure in the tests were also either noticeably finger joint or lamination related and related, respectively, to low or high failure loads.

In the test series(b), the low modulus of rupture is a reflection of the low finger joint strength. Because of the low finger joint strengths, it follows that, if shorter lamination segments are used, the probability of encountering a low strength finger joint is correspondingly higher. Hence the beam bending strength is affected by the length of the lamination segments.



(a) Test data



(b) Simulation results

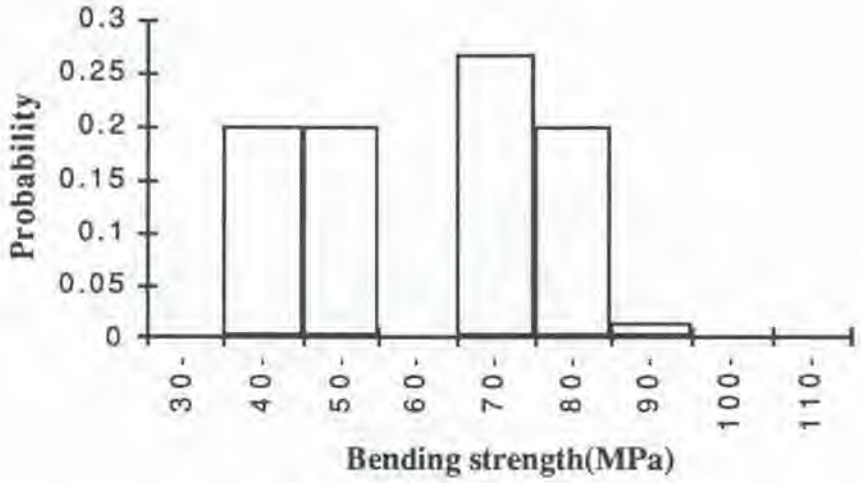
Fig 8 Histograms of (a) test data and (b) simulation results for members without end joints.

The histograms for the distribution of bending strengths of beams both without and with finger joints are shown in Figs 8 and 9, respectively. In Fig 8 the test data histogram, Fig 8(a), and the simulation histogram, Fig 8(b), have similar means and spread of results. A similar observation can be made of the Fig 9 histograms.

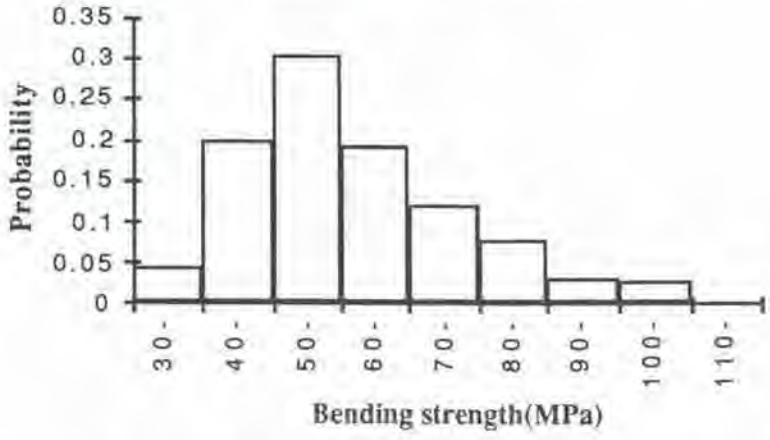
The results given in Table 4 were derived from the lamination strength data given in Table 3 through the use of Monte Carlo simulation with a sample size of 500.

Lamination Details							Beam Strength Details from Simulation			
F_{tav} (MPa)	V	F_{tjav} (MPa)	V	l (mm)	V	k	F_{bav} (MPa)	V	$F_{b0.05}$ (MPa)	F'_b (MPa)
85.0	0.25	-	-	4000	0.2	-	92.1	0.15	69.9	28.1
85.0	0.25	-	-	4000	0.2	5	84.5	0.14	65.2	26.4
85.0	0.25	42.6	0.10	1000	0.2	-	46.6	0.12	37.6	15.3
85.0	0.25	42.6	0.10	3000	0.2	-	79.1	0.24	47.9	18.1
85.0	0.25	42.6	0.10	1000	0.5	-	48.2	0.16	35.8	14.2
85.0	0.25	60.0	0.10	1000	0.5	-	63.8	0.16	46.9	18.6
85.0	0.25	60.0	0.10	3000	0.5	-	82.2	0.19	56.2	21.9
85.0	0.25	42.6	0.10	3000	0.5	5	70.8	0.24	43.1	16.3
85.0	0.25	42.6	0.10	2000	0.5	5	59.2	0.27	33.2	12.4

Table 4: Strength parameters for Mountain Ash glued laminated timber derived from lamination strength test data (Table 3) by Monte Carlo simulation and eqn 15. Beam simulation involved 9 laminations of size 30 x 65 in a beam 270 x 65.



(a) Test data



(b) Simulation results

Fig 9. Histograms of (a) test data and (b) simulation results for members with end joints.

5 Development of an Approximate Expression for Beam Strength

Under the provisions of Australian Standard AS 1328, the basic permissible bending stress (under permanent load) of glued laminated timber in bending is given by

$$F'_{b(glulam)} = \frac{F_{bfj(min)}}{2.3} \qquad 4$$

where $F_{bfj(min)}$ is the minimum strength obtained from 50 bending tests undertaken on the finger jointed laminations. Four point loading is applied to the lamination lying on the flat having a finger joint located in the constant moment region. As an option, AS1328 permits a manufacturer to assign beam strengths on the basis of lamination tension test data obtained from 50 specimens containing a single finger joint. The basic permissible tension strength (under permanent load) is given by

$$F'_{t(glulam)} = \frac{F_{tfj(min)}}{2.3} \qquad 5$$

Given that Australian Standard AS1720.1 - 1988, Timber Structures Code implies that the nexus, $F'_t = 0.6F'_b$, exists, it follows that, any manufacturer choosing to assign beam strength, $F'_{b(glulam)}$, on the basis of lamination tension testing, will obtain a basic permissible bending stress given by

$$F'_{b(glulam)} = \frac{F_{tfj(min)}}{2.3 \times 0.6} = \frac{F_{tfj(min)}}{1.38} \qquad 6$$

The use of this pre-testing to obtain beam properties has come to be known in Australia as qualification testing; individual manufacturers use this procedure to obtain their structural properties. Unfortunately, there is doubt concerning the accuracy of eqns 4, 5 and 6 on two counts.

1 The use of lamination bending strength data to deduce beam strengths using eqn 4 is of doubtful validity in that the stress distribution at rupture is dissimilar to that which occurs in the outer tension laminations of glued laminated beams at rupture.

2. The use of eqn 6 with a divisor of 1.38 seems to provide optimistic estimates of the permissible bending strength of glued laminated timber. The stress distribution at rupture in the outer tension laminations approximates pure tension and it is difficult to accept that a safety factor of 1.38 provides an adequate safety margin even after making an allowance for reinforcing effects.

The simulation program has been used to provide better estimates of the strength of glued laminated timber members for a range of average finger joint strengths (F_{fjav}), see fig 10. Results are shown for $F_{fjav} = 42.6MPa$ (corresponding to test data), $55MPa$, $70MPa$ as well as for beams without finger joints. The dashed horizontal line represents the performance of a glued laminated beam with unjointed laminations and provides an upper strength limit. For the finger jointed lamination simulation, the coefficient of variation was held constant. As the finger joint strength increases, ie, as F_{fjav} approaches F_{tlamav}, the effect of lamination segment length on the beam lower fifth percentile strength, $F_{b0.05}$, declines. The curve for a fixed F_{fjav} value asymptotically approaches the upper limit for shorter average lamination segment length. When $F_{fjav} = F_{tlamav}$ the strengths of beams made from laminations with finger joints approaches those of beams made from laminations not containing finger joints.

In developing a simple formula to describe this behaviour, it was considered desirable that the raw data come from a single tension test series. In a situation where a manufacturer progressively improved finger joint strength the bi-modal lamination behaviour evident in lamination tests containing relatively weak finger joints would eventually become uni-modal; it would become progressively more difficult to isolate

the two data sets. The following formulae are recommended for the conversion of short term lamination tension strengths to glued laminated timber bending strengths.

For permissible stress design.

$$F'_{b(glulam)} = k_{lam}\left[\frac{1-\frac{2.7V_{fj}}{\sqrt{n}}}{1.75\left(1.3+0.7V_{fj}\right)}\right]R_{fjt0.05} \le F'_b \qquad 7(a)$$

$$k_{lam} = 1+0.01\left(\frac{\bar{l}}{300}\right)\left(\frac{R_{b0.05}}{R_{fjt0.05}}\right) \qquad 7(b)$$

where

$F'_{b(glulam)}$	=	basic working stress in bending of glued laminated timber
F'_b	=	basic working stress in bending of lamination stock
$R_{fjt0.05}$	=	fifth percentile value of tension strength of finger jointed laminations obtained from a qualification test sample of size n
$R_{b0.05}$	=	fifth percentile value of bending strength of unjointed laminations obtained from a qualification test sample of size n_1
k_{lam}	=	modification factor for average lamination segment length and reinforcement effects
$\bar{l}$	=	average lamination segment length(mm) in outer 20% of the tension zone
n	=	number of finger jointed laminations tested in tension by the glued laminated timber manufacturer
n_1	=	number of unjointed laminations tested in bending by the glued laminated timber manufacturer or lamination stock supplier

The k_{lam} factor is based on a standard depth of 300mm. The factor k_{11} given in A1720.1-1988 is additionally applicable.

In Fig 11 the approximate formulae are overlaid on the simulation results.

6 Conclusion

The model presented provides an accurate method for predicting the strength of glued laminated members, especially those fabricated from Australian native hardwoods for which fingers joints are almost always initiate failure. Current methods of evaluating the bending strength from individual lamination tests given in Australian Standard AS1328, either by tension or bending, over-estimate the strength.

Eqns 17 and 18 provide a more accurate estimate of the permissible design stress. Expressions derived from simulation studies have been compared with limited test data. The k_{lam} factor takes into account the average lamination segment length as well as the reinforcing effect. The fact that short average lamination segments are penalised is a reflection of the fact that, in a system composed of finger joint linked tension segments, the overall strength can be no greater than that of the weakest link (finger joint). The more finger joints, the greater is the likelihood of premature failure.

The advantage of the model is that the basic input data is obtained from in-grade tension testing, whereas some other models use modified clear wood data. Input data includes finger joint and lamination segment tension strengths and lamination

compressive strength.

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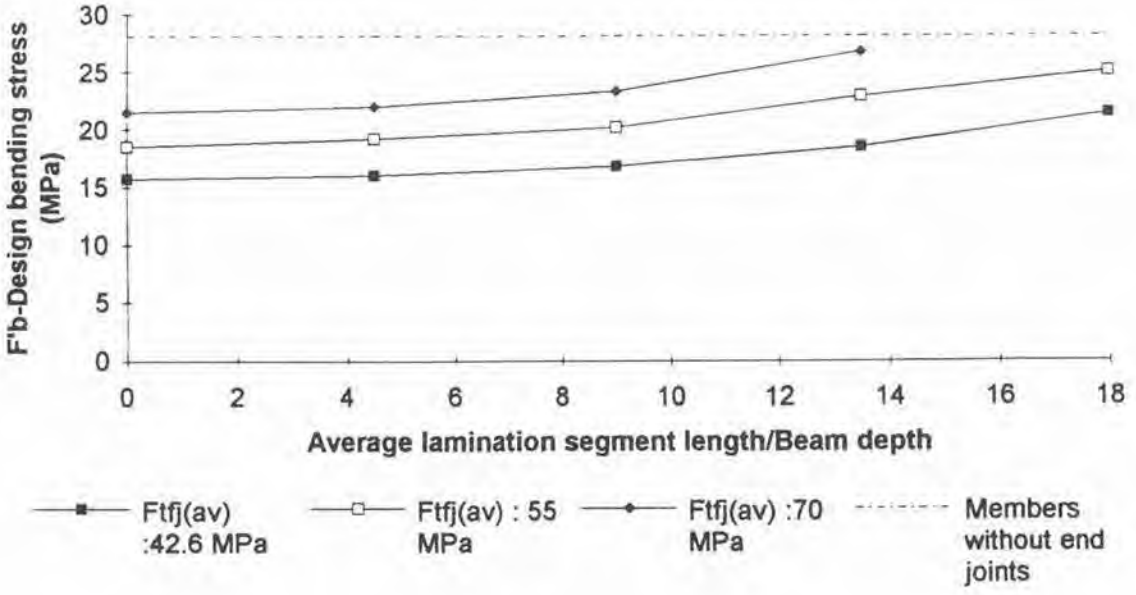

Fig 10. Simulated design stress of glued laminated beams

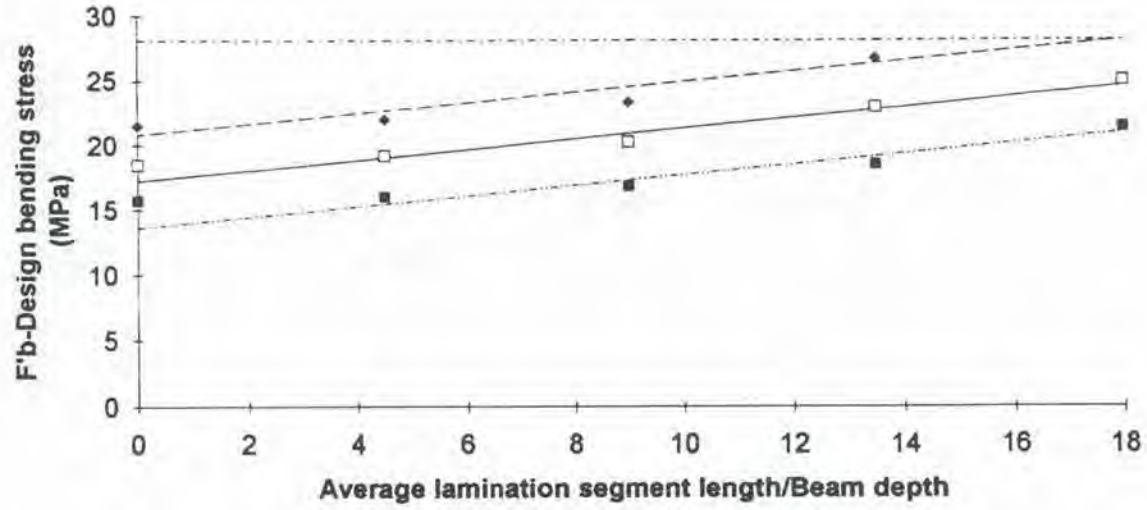

Fig 11. Comparison of equation 17 and simulated data.

NAILED PLYWOOD GUSSET KNEE JOINTS IN PLYWOOD WEB BOX-BEAM PORTAL FRAMES

Alastair C. Woodard
BE (Civil), MIE (Aust), CPEng
Postgraduate Research Student
Monash Timber Engineering Centre
Monash University

Henry R. Milner
BE, M Eng Sc, PhD, FIE (Aust), CPEng
Executive Director
Monash Timber Engineering Centre
Monash University

ABSTRACT

This paper describes the structural behaviour of a nailed plywood gusset knee joint of a timber portal frame made using plywood web box-beam rafter and column members. It includes the description of an experimental study of a photoelastic stress analysis of a small-scale model and a conventional strain gauge analysis of a full-scale knee joint. The study was carried out to determine whether existing design formulae for nailed plywood knee connections for glued laminated timber portals are applicable to plywood web box-beam portals.

INTRODUCTION

Recently a number of portal frames have been designed and constructed in Australia using plywood web box-beam sections for the rafter and column members. These portal frames utilise nailed plywood moment connections at the knee and apex joints. While considerable research has been undertaken on the design of the beams virtually no research has been done, and little advice is available, for design of the nailed moment connections. As a consequence, designers have been forced to use moment connection design theories developed from research involving solid or glued laminated rafter and column sections.

It is the authors view that the connection design theories applicable to glued laminated portals are not applicable to plywood web box-beam portals. The purpose of the research reported herein was to evaluate existing design theories for nailed plywood knee connections in glue laminated timber portal frames and to asses their applicability to the design of knee joints for plywood web box-beam portals. An experimental testing program was undertaken to investigate the behaviour of nailed plywood gusset knee connections for plywood web box-beam portals, with specific focus on the following.

a) Determination of the gusset size and thickness, which is dependent on:
   - the position of the " line of critical stress ".
   - the stress distribution along this line, and
   - the choice of the Permissible Design Stress type: F_b or F_t.

b) Determination of the load distribution in the joint connectors.
   Examination of the load carried by individual nails, within a knee joint nail group, to determine if this varies with the radial distance from the

nail centroid in accordance with Appendix D of AS1720.1-1988, SAA Timber Structures Code .

c) Examination of the effectiveness of the accepted concept of a " nail ring " pattern as a means of computing the joint moment capacity.

d) Investigation of the type of failure of the knee connection and its point of initiation to determine if there is a unique failure mode when plywood web box-beams are used.

BACKGROUND TO CURRENT DESIGN THEORIES

In timber portal frames the knee connection can be formed from any one of a number of different joint-member configurations. Two popular types are mitred joints or the more commonly used form where the rafter passes over the top of the column, the latter being the joint configuration studied in this research project. The basic design sequence remains the same regardless of the type of joint configuration used.

1. Design the nailing pattern.
2. Design the plywood gusset.

General

The performance of nailed plywood gusset knee joints joining solid or glued laminated members has been investigated by Pneuman (c.1964), Petry (1968), Wardel & Weller (1968), Burgess (1970), Mc Kay (1974), Batchelar (1982, 1983, 1984a, 1984b), Kermani & Lee (1991) and Kermani (1992), however, there has been little research carried out on the performance of the joints of box-beam portals. Pneuman (c1964) carried out two tests on mitred box-beam joints as an adjunct to a larger testing program involving solid members; his conclusions did not include a comparison between the solid and box-beam members. Cavanagh (1983) undertook experimental work on a series of mitred nailed plywood gusset knee connections for "plybox" sections. He investigated the effect of varying nail fastener numbers, gusset thickness, gluing of the assembly and proposed a design method for estimating gusset joint sizes and fixings.

Current Theories for Plywood Gussets

Design of plywood gussets involves two steps: selecting the in-plane dimensions and calculating an effective plywood thickness. The joint design actions are determined from a rigid frame analysis based on rafter and column centre line dimensions.

Batchelar (1984) carried out a number of tests on nailed plywood gussets joining glued laminated members and identified the critical section for gusset design as a horizontal line through the intersection of the underside of the rafter and column centre line perpendicular to the outside edge of the gusset, which he termed the *"line of critical stress"*. He proposed the idealised stress/strain distribution shown in Fig 1.

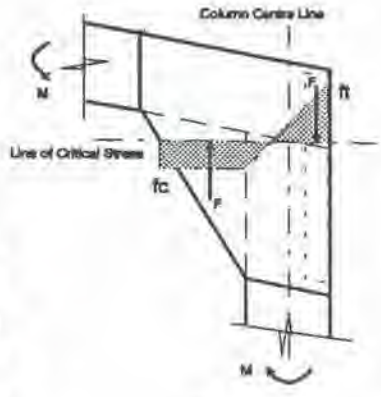

Fig 1
Batchelar's (1984) idealised stress/strain distribution

Batchelar's idealised stress distribution has consequently been adopted by a number of different researchers including Milner (1988), Walford (1989) and Bier (1989) as the basis of their respective gusset thickness design formulae though there has been some inconsistency as to what permissible stress value should be adopted; Walford and Bier suggesting that f_t should not exceed F_b while Milner suggests F_t should be used. The choice of this limiting value is a major matter for future research.

Hutchings (1989) presented a simplified procedure, assuming pure elastic beam theory with symmetrical, triangular compressive and tensile stress blocks. He proposed that the maximum calculated stress should not exceed the permissible bending stress, which is the product of the basic working stress in bending, F_b', and the size factor k_{11} taken from AS1720.1. This choice, like the previous choices, lacks any formal justification

Current Theories for the Nailed Connection

Design of the nailed connection is extremely tedious and time consuming when attempted manually in accordance with the non linear load displacement relationship given by Equation 4.3 of AS1720.1, equation 4.3 is reproduced in Appendix A of this paper.

Consequently a number of simplified hand methods have been proposed including Milner (1989) and Hutchings (1989) which utilise a smearing approximation for design of these large complex nail groups.

Time saving computer programs such as " Gusset ", developed at the Monash Timber Engineering Centre, are also available which, after being provided with primary member dimensions and applied forces, proceed to generate a nailing pattern with an un-nailed central region.

The aforementioned methods require the designer to choose an appropriate joint nailing pattern. In most cases a staggered hollow rectangular nailing pattern consisting of a number of "nail rings" is used. This ensures that as many nails as possible are placed at a maximum distance from the nail group centroid thereby maximising the contribution to the total nail group capacity. From this theory it also follows that a nail in the horizontal leg of the nail ring and a nail in the vertical leg would be subject to a load of the same magnitude if they had the same radial distance from the nail group centroid.

FULL-FIELD PHOTOELASTIC STRESS ANALYSIS

A photoelastic stress analysis was undertaken on a small-scale knee joint to obtain a complete picture of the stress distribution in the gusset.

The test model was fabricated using 60mm deep box-beam sections (one-tenth of the full-scale test model) consisting of 13 x 4 mm Spruce flanges and 3 mm thick plywood webs. The gussets used were 3 mm thick, 5 ply Finnish Birch. A 3 mm thick photoelastic coating was bonded to one gusset and the joint was loaded in the closing mode by the use of a turnbuckle; the load magnitude was monitored by a tension load cell.

Examination of the isochromatic fringe patterns through a reflection polariscope revealed three distinct stress concentration points in the gusset. A tension stress concentration was observed on the outside edge of the gusset at approximately the point where the bottom flange of the rafter intersects the gusset edge and two compressive stress concentration points were observed along the haunch edge at either end of the haunch strut.

FULL-SCALE TESTING

Box-Beam and Gusset Design

A 600 mm deep box-beam member was chosen for a full-scale test which approximates the size required for a 16.5 m span portal frame at 6m spacing with a 4m eaves height and a roof pitch of 10° constructed in wind region A as defined in Australian Standard AS1170.2-1989. The beam consisted of two 130 x 45 mm LVL flanges separated by 7mm thick (F11) structural ply webs, see Fig 2. The flange/web nailing consisted of 2.8mm diameter nails at 60mm centres staggered in two rows. The current design theory (Batchelar 1984) indicated that two 25mm thick (F14) structural ply gussets were required. The gussets were orientated with the face grain ply parallel to the outside edge of the column. The joint nailing pattern consisted of 3.05 mm diameter nails at 45 mm centres in a two row staggered pattern with a total of 142 nails per nail ring (51 in each flange, 20 in each stiffener) with a total of approx 570 nails for the connection. All the nails were installed using a pneumatically operated nail gun, the nails being driven slightly proud of the surface then driven flush by hand.

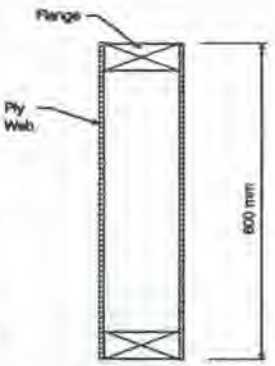

Fig 2 : Cross-section of test box-beam.

Testing Arrangement

The knee joint tested comprised the section of the 16.5 m portal between the pinned base of the column and the point of contraflexure of the rafter as this gave the closest representation, when loaded, of the force/moment combination which would be experienced in the actual full portal frame structure.

The joint was loaded using a 10 tonne capacity hydraulic ram housed in a specially fabricated loading rig. The test load was applied to the box-beams through steel footplates designed to transfer the resolved axial load component directly into the box-beam flanges and the transverse component directly into the webs. The test load was monitored using a 10 tonne

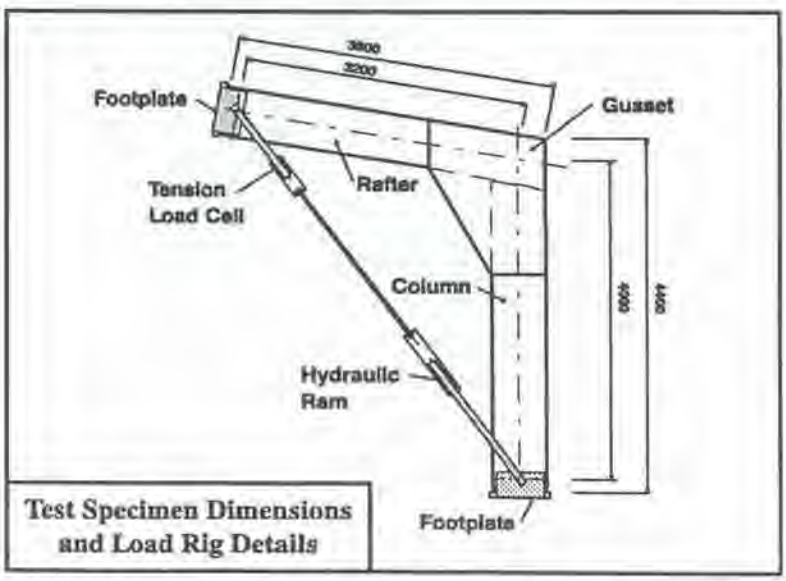

Fig 3. : Knee joint details and test arrangement.

capacity load cell fitted to the loading rig, see Fig 3.

The design moment due to dead load and live load for the joint was 50 kNm giving a test ram load required of 22 kN. The Equivalent Test Load (ETL) at the ram required to satisfy the prototype testing provisions of AS1720.1 Appendix A, Equation A2, was 58 kN. Deflections were recorded at the ram using an analog dial indicator.

Strains in the box-beam components were measured by means of 10 mm gauge length single element electrical resistance strain gauges. Strain data was recorded using a Datataker 200 and down loaded to a portable computer.

Observations made on the small-scale photoelastic test model were used to position three 12 mm wide photelastic strips 300 mm long on the full-scale model at those positions identified as stress concentration areas.

DISCUSSION OF RESULTS OF FULL-SCALE TESTING

Position of The Line of Critical Stress

The position of the "line of critical stress" was isolated using the photoelastic strips bonded to the upper surface of the gusset, see Fig 4. This line joins the point of maximum tensile stress concentration on the outside edge of the gusset and one of the points of compressive stress concentration on the inside haunch edge of the gusset. This corresponds to the location first identified by Batchelar (1984).

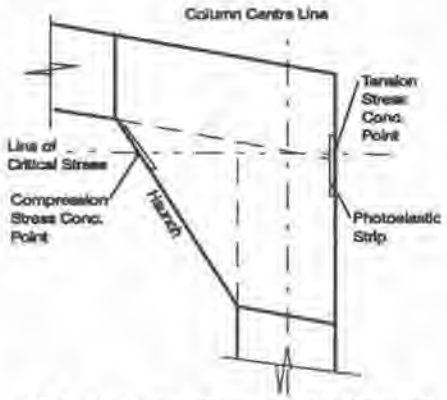

Fig 4 : Location of the line of critical stress.

Stress Distribution Along Line of Critical Stress

Five, 45° strain gauge rosettes were positioned along the line of critical stress. Examination of the measured strain distribution parallel to the face grain of the gusset, see Fig 5, shows strain concentrations occurring at the gusset edges with high strain gradients around these points confirming the small-scale test observations. The strains through the central portion of the gusset are proportionately low and consistent in magnitude (mapping the directions of principal strains from the small-scale photoelastic testing as well as resolution of the strain gauge rosette results indicates that the principal strains through the central portion of the gusset lie at approximately 45° to the direction of ply).

The stress distribution shown in Fig 5 leads to a requirement for a gusset thickness greater than the stress distribution shown in Fig 1. When used in conjunction with the basic working stresses for in-plane tension given in AS1720.1 Table 5.1 the resultant thicknesses are shown in experiments to be excessive. While the observed stress distribution is an undeniable reality the level of stress which should be permitted is somewhat less clear.

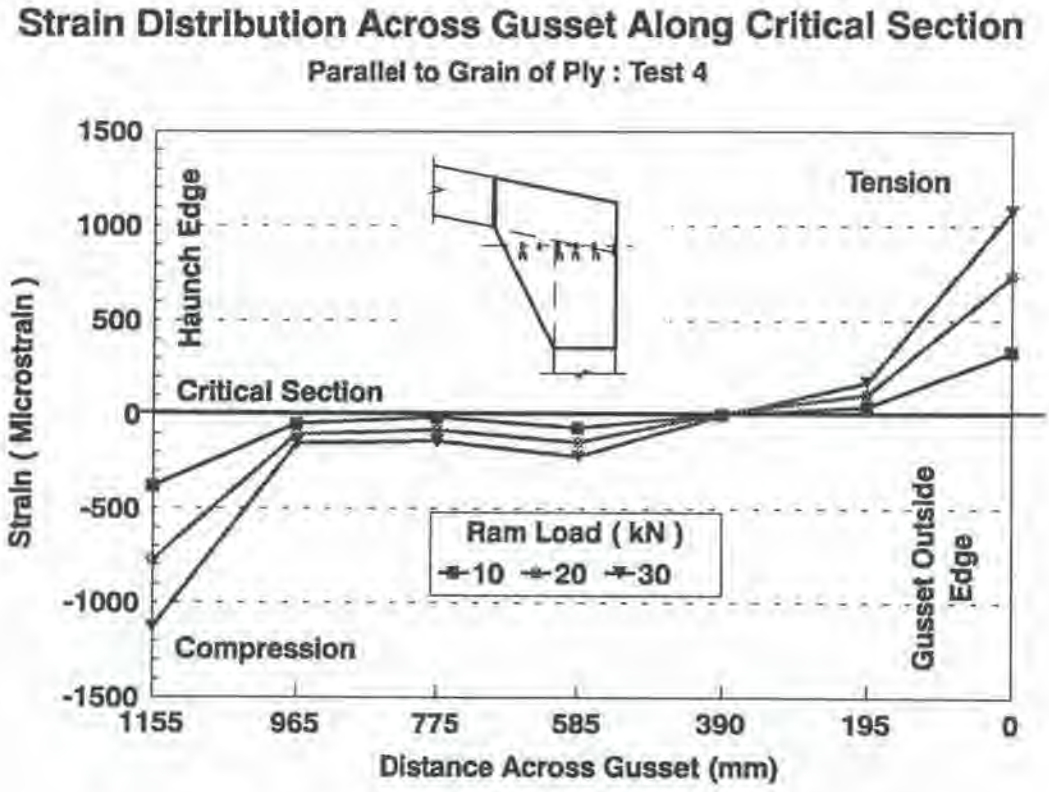

Fig 5 : Variation of strain normal to line of critical stress.

Choice of Permissible Design Stress Type: F_b or F_t

The gusset stress distribution measured along the critical section does not correspond at all to the stress distribution described by Leicester et al. (1975) for the test specimens from which the basic working stress values of AS1720-1975 were derived. This is not surprising as these distributions were derived from tests on small clear, square or rectangular beam sections with low aspect ratios while the plywood gusset is a high aspect ratio section with a large depth to thickness ratio.

Examination of Fig 5 clearly indicates that, at the extremities, isolated tensile and compressive stress concentrations occur. It therefore seems reasonable to assume that basic working stress values in bending given in AS1720.1, which have been derived from test samples having a stress distribution completely different to that measured, are not applicable to plywood gussets.

The presence of localised stress concentration points within the gusset indicates that it is far more appropriate, in the absence of more realistic in-grade test results, to use either the permissible tension, F_t, or compressive stress, F_c, values for design.

It is considered that a special design stress is applicable where a high stress gradient occurs in an isolated portion of an otherwise lightly stressed component. Preliminary Monte Carlo simulations have suggested that, where the maximum stress is confined to a relatively small part of the total critical section, elevated stresses can be permitted. Further simulations are

currently being undertaken combined with tension testing of plywood samples with the aim being to determine suitable modification factors that can be applied to the current AS1720.1 structural plywood values for the basic working stress in tension.

Flange / Gusset Load Shedding

Strains were recorded along the box-beam flanges to determine the pattern of load shedding to the gusset and the magnitude of the load in individual nails.

Fig 6 shows the stress distribution along the top flange of the rafter for a ram load of 22 kN and a theoretical curve based on calculation of the component of nail force parallel to the flange, derived using the non linear load-displacement equation for the joint given in AS1720.1 Appendix D : $P = k\Delta^{0.5}$. The theoretical and test curves both indicate the load is shed in a relatively linear fashion.

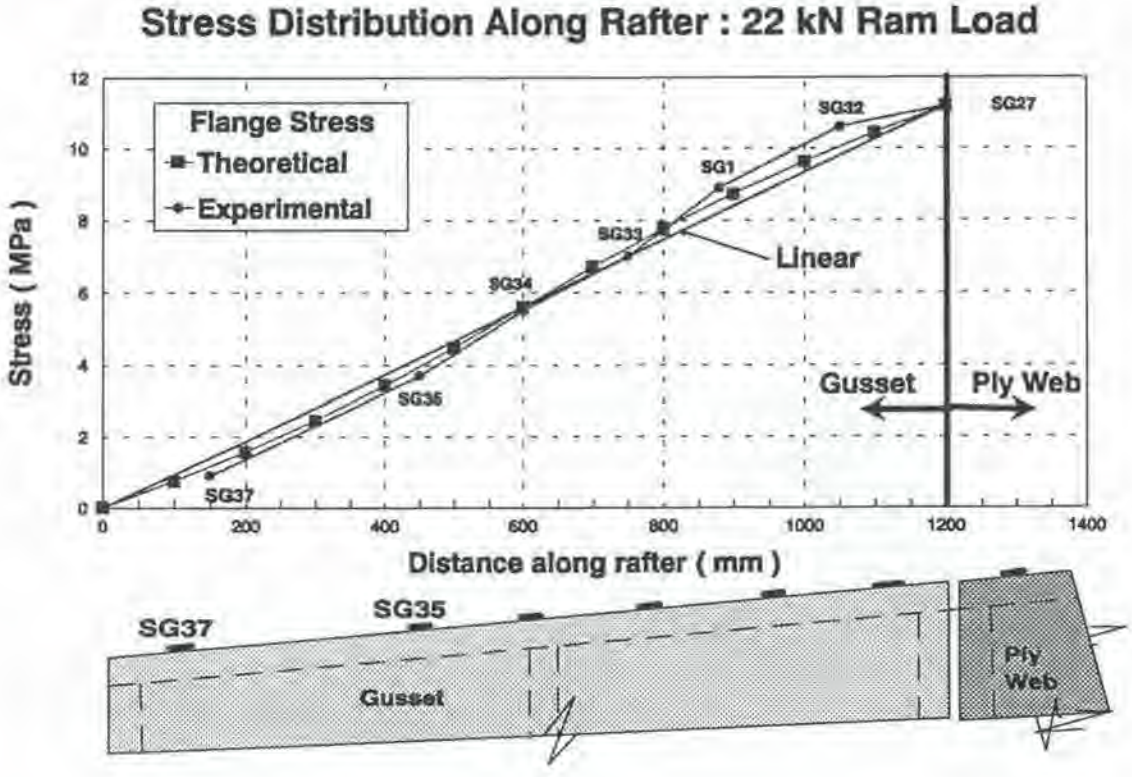

Fig 6 : Variation of flange tension stress over gusset length.

Nail Ring Concept

Fig 7 is a plot of the strain in the four members that comprise the rafter flange and stiffener ring for a range of ram loadings. Design of the nail ring to the requirements of AS1720.1 Equation 4.3, implies that a nail in the stiffener and a nail in the flange with the same radial distance from the nail group centroid will be subject to the same load. This graph clearly illustrates that the strains in the stiffeners are negligible compared to those in the flanges. With respect to the AS1720.1 equation, the radial distance to the point on the flange, is 2/3

rds the radial distance to the point on the stiffener, therefore if this equation was to apply and the stiffener was to be an effective member of the nail ring then the strain values given for the stiffener should be higher than those shown for the flange, not markedly lower.

The results indicate that the nail " ring " concept is not applicable to plywood web box-beams. The stiffeners have no restraint and therefore the loads applied to them by the gusset cannot be resisted. The actions due to the moment applied at the joint are transferred totally into the gusset through nails in the flanges.

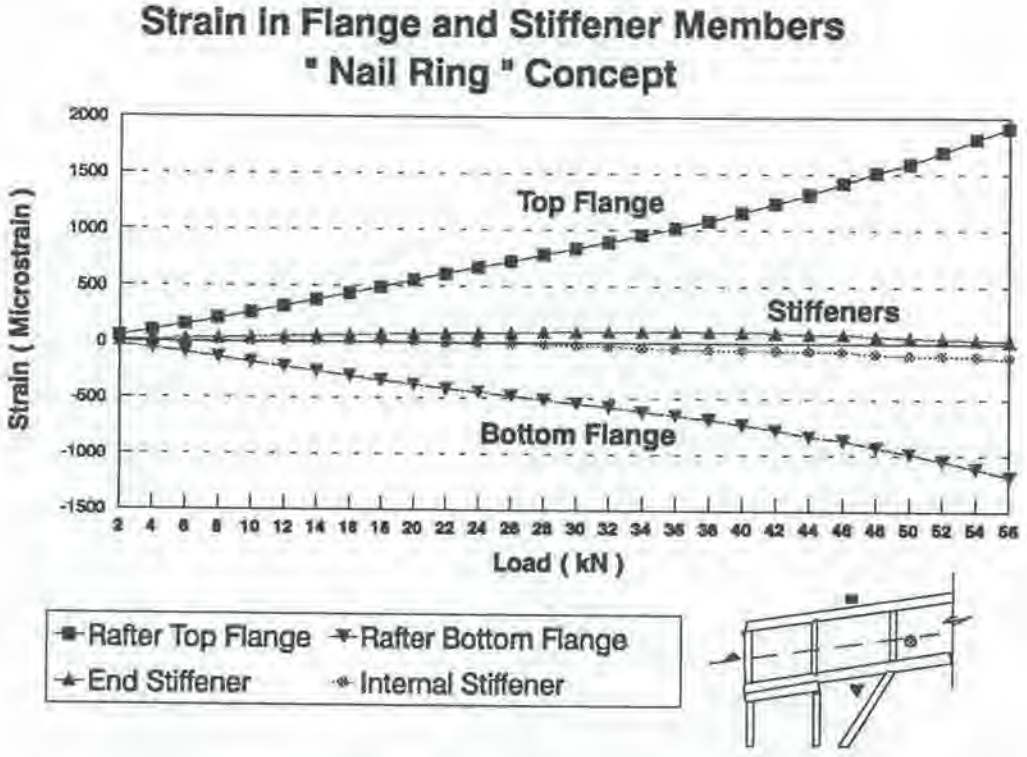

Fig 7 : Variation in strain at points shown in rafter top flange, bottom flange and stiffeners in knee joint.

Joint Failure Mode

Failure of the knee connection occurred in the box-beam rafter at a point on the top face of the rafter flange, at the first nail through the web away from the gusset, due to the combination of bending, axial tension and high local shear forces. The failure was brittle in nature occurring suddenly without any forewarning at a ram load of 5.8 tonne or 2.6 times the design load which coincidentally was the ETL for the joint. This represents a failure stress of the LVL flange of approximately 40 MPa. This failure mode appears quite unique to box-beams as, in previous testing involving glued laminated members, the failure was more ductile and occurred in either the plywood gusset or in the joint nails.

CONCLUSIONS

Results of this testing have indicated that some of the design theories proposed for nailed plywood knee connections derived from research on solid or glued laminated portals are not applicable to plywood web box-beam portals.

1. The shape of the gusset stress distribution along the line of critical stress was found to differ from that previously reported. The stress concentrations recorded suggest that, for gussets of high aspect ratio, a Permissible Design Stress of F_t or F_c should be used in design in preference to F_b.

2. The nails fixing the stiffeners provide little contribution to the overall moment resistance capacity of the joint. A " nail ring " concept is therefore not applicable to the design of connections of plywood web box-beams.

3. The load shedding from the flange to the gusset occurs at more or less a constant rate. The test results show good correlation with theoretical results derived using the non-linear load-displacement equation given in Appendix D of AS1720.1.

4. The brittle nature of the failure of the top flange of the box-beam rafter suggests that, when designing the connection using currently accepted theories, the design of the gusset thickness and nailing requirements is conservative compared with the design of the box-beam members.

A simpler modified design procedure has been formulated incorporating the results of this testing. This modified procedure was used in the design of a further knee connection utilising 300 mm deep plywood web box-beam sections which is currently being tested as part of an ongoing investigation of box-beam portal knee joints.

APPENDIX A : EQUATION 4.3, AS1720.1-1988

AS1720.1-1981, Clause 4.2.1.2, equation 4.3, states that for rotational joints the design in-plane moment capacity of a nail pattern can be determined from the following formula:

$$M_n = Q\, r_{max} \sum_{i=1}^{n} \left(r_i / r_{max} \right)^{3/2}$$

M_n = design in-plane moment capacity of the joint.
Q = permissible lateral nail load.
n = the number of nails in the joint.
r_i = the distance from the ith nail to the centroid of the nail group.
r_{max} = the maximum value of r_i .

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VOLUME 2

VOLUME 2

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(iii) Fire Resistance Research - Dr R.H. Leicester

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(ii) Abstracts

LIST OF DELEGATES

PAPERS NOT IN VOLUME 1

2/8 A decade of Australian research into the fire performance properties of forest products
W.D. Gardner, State Forests of NSW.

2/10 Performance of copper-based preservative-treated timber under tropical in-ground and out-of-ground conditions of exposure at sites in north Queensland and Hawaii.
A.R. Moffatt and K.J. Archer, Queensland Primary Industries and Chemical Specialties/Laporte (USA). This paper was presented by Kevin Archer, but no written version has been supplied.

2/12 A preliminary above-ground wood decay index map of Australia.
J. Carter, M. Cause and A. Moffat, Queensland Primary Industries.

2/16 Novel pressure processes for timber treatment and current research in wood preservation at the University of Melbourne.
P. Cobham and P. Vinden, Forestry School of University of Melbourne.

2/23 Wood fibre for the surface of race tracks.
M.A. Tighe and G.C. Johnson, CSIRO Forest Products.

3/19 The application of modern process control theory to improve the timber drying process.
J.P.S. Viljoen, University of Stellenbosch, South Africa.

5/6 The wood properties of progeny NZ55 with superior TMP energy and optical characteristics differ significantly from standard radiata pine.
J.G. Nyakuengama and P.D. Evans, Department of Forestry ANU.

6/3 Assessment of the structural properties of mechanically stress graded Australian pine.
S.A. Bolden, P.F. Walsh, D.J. Grant, R.H. Leicester, F. Young and C. Seath, Pine Australia, Wood Technology Australia and CSIRO DBCE.

6/17 An investigation of factors influencing nail deviation and nailing induced splitting in Australian grown slash pine.
G.R. Stringer, Hyne & Son Queensland.

Addendum to Paper 2/21 (An accelerated field simulator study of the natural durability of heartwood from mature and regrowth trees, by G.C. Johnson, J.D. Thornton and N-K Nguyen), necessary to show results obtained from statistical analysis.

FOREST PRODUCTS RESEARCH CONFERENCE COMMITTEE MEMBERS.

24th Forest Products Research Conference

Opening Address by Dr Warren Hewertson, Chief, CSIRO Division of Forest Products

Welcome to the 24th Forest Products Research Conference. The next Forest Products Research Conference will celebrate the half century of these proceedings. During that time there have been vast changes in the forest products industry and in the research that has supported it. Most of you in this room were not born when that first Forest Products Research Conference was held in 1946. The questions of sustainable development were being asked by only the very perceptive members of some of the State Forest Services. They had an intricate knowledge of the demands placed on the forest after the Second World War. Also, the scope of the conference has broadened from a fairly general conference that was concerned mainly with State/Federal interaction, to one that is now much more concerned with detailed papers, much more concerned with interchange of research data between colleagues practicing in the field.

Huntly Higgins and Ted Hillis were young researchers when that first Forest Products Research Conference was held and Stan Clarke was Chief of the Division of Forest Products of the then CSIR. The pulping industry was still in its infancy as a major world class operation, though there had been smaller ventures before then. It was only between 1938 and 1942 that companies like ANM, APPM and APM got established large pulping operations. So in 1946 these companies were yet to celebrate their 10th anniversary. Prior to that, paper was made largely from recycled material and imported pulp. The range of board products, between 1946 and now, has increased phenomenally to compete with plywood which was, by and large, the only major board product at that stage. The first mature exotic pine plantations had just started to yield products, prior to that

thinnings were the only products available from investments in plantations. The industry and research organisations were carrying out valuable research into the processing of pine into very high value products. The range of preservatives available to the industry for treatment of timber began to come under some sort of attack, either scrutiny with regard to safety, or attack on environmental grounds; and the range of allowed treatments has been limited in the 47 year period. The legislative difficulty of introducing new treatments has increased at the same time. So for those of us involved in research on preservation we are forever having to be watchful about threats to those products that are on the market now and to the difficulties of getting new products accepted as old ones are withdrawn; so the degree of difficulty is twofold.

Understanding of the drying processes in both softwoods and hardwoods has also increased phenomenally in the period. High temperature drying has been introduced for softwoods largely due to Australian initiatives. Improved adhesives have been developed for a whole range of species and products, again often from Australian research efforts. These adhesives have been based both on natural products and on synthetic products from the petrochemical industry.

Similarly chemi-mechanical pulping technologies have been evolved, resource assessment techniques have been refined and the potential of acacias for pulpwood has been unearthed and shown to have great attraction. Each of these developments had their origin in the Division of CSIRO. Much greater attention to the growing of material for particular end uses has come about. This will be witnessed by the CRCs established in both Hobart and Melbourne of which you will hear more over the next few days.

This conference has progressively broadened to include forestry aspects as well as forest products aspects. It has also broadened to include industry members being present and in this conference broadened further to include industry personnel presenting papers.

Structural applications of timber have also undergone many changes since 1946. There is now greater understanding of the role and fundamental properties of wood and structures. The question of mechano-sorptive effects particularly in reconstituted products has been highlighted, again largely from Australian work. I was at a conference in UK recently where pulp and paper technologists were talking about mechano-sorptive effects in paper and reference was made to the early discoveries by Australians of the phenomenon in wood. Competition between timber and steel, particularly in framing, not only of commercial buildings but also for residences, has increased over the years. Competition between timber and concrete has also increased, and timber has shown quite a resilient fightback against invasion. Competition between timber and plaster, between timber and aluminium is very strong, but the industry has learned to become more sophisticated to deal with these aspects. Development of carbons for special purposes such as gold extraction, air purification and water clean-up have been notable advances.

Recently the Resource Assessments Commission has reported, following years particularly the last 10 years, of very strong environmental-industrial conflict. That RAC report, I think, is a source of great strength for the industry in that it has come out very strongly in terms of a balance between the use of land, both native and plantation, for timber production as well as for good conservation practices.

The world picture has become much more complex in that 47 years. The whole question of supply and demand which is central to any industry is strongly in favour of demand at the moment largely because of population increases, concern about environmental issues and the love that people have for natural products.

There has been a large restructuring of the forest products industry in this country, not just in the softwood industry that we have been aware of for a long time, but also in the hardwood industry with a reduction in the number of small hardwood sawmillers and the formation of fewer very large hardwood sawmillers. Very recently, in the pulp and paper industry, the largest company bought out the next largest company. That integration will not stop, it will continue, particularly as Australian companies increase their expansion into overseas production.

Finally I would like to thank the organising committee, Dr John Thornton, Chairman, Harold Breitinger, Noel Clark and Bill Keating for their untiring work which started some seven or eight months ago organising this conference. I now declare the conference open.

24th Forest Products Research Conference

Keynote Address by Dr Robert Bain, Executive Director, National Association of Forest Industries

Thank you for the opportunity to speak to you this morning. It is nice, even for a short time, to be part of this research group and this review of research; partly because my background is in research, but also because the industry is often cast as not being very research-oriented or being very progressive. It is good to see a gathering that puts a lie to those sorts of claims. Dr Hewertson has gone over the changing demand, the shifting markets, and the shifting technology that has characterised the industry in recent years. This is likely to speed up in the future rather than slow down so it is very important to keep up the research effort. That is what I wish to talk to you about.

With a bit of luck the Senate will pass the necessary legislation on Friday of this week to establish the Forest and Wood Products Research and Development Corporation. Given how the Senate is behaving you cannot be 100 per cent certain but seeing as the legislation is supported by both major parties I am hopeful it will go through. It is coming at a time that is tough for the industry in some ways. However, the Industry Commission report on value-adding is due out on 22 November and I would hope that people in the research stream will take a good look at it. Clearly, value-adding is one of the ways in which we will progress both economically and in our public awareness campaign. Taking people around the industry as I do, politicians and public servants, one of the key points they always refer to is, how much value adding is taking place. It has become a bit of a catch cry, but one to which we need to respond.

I think we are going to have a difficult time this summer for those people who work in the forest industries. We are expecting a pretty vociferous round of demonstrations to

start as soon as the university examinations are over. I see there has already been some debate in 'The Age' about logging in East Gippsland. When you see those debates going on please do not anticipate that Steve Guest, Robert Bain or whoever will be dealing with them, that we will write the letters to the paper, that we will do the things that are needed; we really rely on everybody who is associated with the industry to not merely grizzle about misrepresentation, but to actually sit down and write off a couple of paragraphs and make sure the industry does get represented. If you get cross about something but would like a few more facts give us a call. We are very happy to provide you with the information.

We also anticipate more involvement from the Federal Government now that we have an international treaty on biodiversity which gives the Federal Government the overriding power over State Governments on land use. One of the reasons I need to return quickly today is that we have a wood chip boat sitting off a port waiting to start loading at midnight tonight, but we still do not have a licence to load. For the first time Commonwealth endangered species legislation has been used to hold up granting of the licence. That legislation was only passed in December 1992. Unfortunately problems of this type will continue to be with us.

What I would now like to do is to go through this Research and Development Corporation in some detail. I hope very much that by about the middle of next year it will be injecting more funds into forest, forest products and forest industries R and D than is available today. I would like to go through the mechanics of it and respond to any questions.

[From this point Dr Bain spoke to a series of six overhead slides, reproduced on the following pages. A spirited discussion, both during and after his presentation, ensued.]

FOREST AND WOOD PRODUCTS RESEARCH AND DEVELOPMENT CORPORATION

CHOICE AND MONITORING OF RESEARCH PROJECTS

1. R&D BOARD ADVERTISES FOR SUBMISSIONS SETTING OUT ITS PRIORITIES

2. RESEARCH PROVIDERS - INSTITUTIONS, FIRMS, ASSOCIATIONS, INDIVIDUALS - SUBMIT PROJECTS TO THE BOARD

    - THE CORPORATION WILL NOT CARRY OUT ANY RESEARCH ITSELF

3. R&D BOARD SELECTS THE PROJECTS IT WISHES TO SUPPORT AND ALLOCATES FUNDS ACCORDINGLY

4. RESEARCH PROVIDER SUBMITS REGULAR REPORTS ON PROGRESS AND RECEIVES ONGOING FUNDING

5. COMPLETION OF PROJECT. R&D BOARD MAY ASSIST IN DISSEMINATION OF RESULTS

NAFI
November 1993

FOREST AND WOOD PRODUCTS RESEARCH AND DEVELOPMENT CORPORATION

SELECTION OF RESEARCH PRIORITIES

1. INDUSTRY SECTOR GROUPS IDENTIFY THEIR RESEARCH PRIORITIES

    - THESE CAN COVER VIRTUALLY ANY FIELD OF RESEARCH OR DEVELOPMENT RELEVANT TO THE FOREST INDUSTRIES, E.G. FROM TREE BREEDING TO BUILDING CODES

2. NAFI R&D COMMITTEE COMBINES THE PRIORITIES INTO A SUBMISSION TO THE BOARD OF THE R&D CORPORATION

3. OTHER ORGANISATIONS, GROUPS, FIRMS OR INDIVIDUALS MAY ALSO CONTACT THE R&D BOARD DIRECT

4. R&D BOARD DECIDES ON AND ADVERTISES THE RESEARCH PRIORITIES IT INTENDS TO PURSUE OVER A PERIOD OF TIME

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November 1993

FOREST AND WOOD PRODUCTS RESEARCH AND DEVELOPMENT CORPORATION

ESTABLISHING THE LEVEL OF FUNDING

1. INDUSTRY GROUPS CONSIDER THE TOTAL LEVEL OF FUNDING AND THE LEVEL OF COMPULSORY LEVY THAT THEY BELIEVE TO BE APPROPRIATE

2. NAFI R&D COMMITTEE DEVELOPS A COMBINED SUBMISSION TO THE MINISTER FOR RESOURCES RECOMMENDING THE LEVEL OF LEVY FOR EACH SECTOR

3. THE LEVY IS COMPULSORILY APPLIED TO ALL PRODUCERS IN THE GIVEN SECTOR, INCLUDING IMPORTERS

4. THE COMMONWEALTH PROVIDES $1 FOR EVERY $2 CONTRIBUTED BY DOMESTIC PRODUCERS

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FOREST AND WOOD PRODUCTS RESEARCH AND DEVELOPMENT CORPORATION

APPOINTMENT OF THE BOARD OF DIRECTORS

1. MINISTER APPOINTS PRESIDING MEMBER OF SELECTION COMMITTEE

2. NAFI NOMINATES UP TO 6 SELECTION COMMITTEE MEMBERS. THE INAUGURAL SELECTION COMMITTEE IS:

Ms Megan Cornelius (Presiding Member)
Mr Warren Hyne
Mr David Bills
Mr Norman Huon
Mr Thorry Gunnersen
Dr Hans Drielsma
Mr John Tompkins

3. SELECTION COMMITTEE ADVERTISES FOR APPLICATIONS FOR BOARD MEMBERSHIP (NAFI OFFICE BEARERS ARE NOT ELIGIBLE)

4. BOARD MEMBERS ARE SELECTED ON THE BASIS OF THEIR PERSONAL EXPERTISE IN KEY FIELDS

5. THE BOARD IS COMPRISED OF:

- A CHAIRPERSON SELECTED BY THE MINISTER
- A GOVERNMENT DIRECTOR SELECTED BY THE MINISTER
- UP TO 6 DIRECTORS SELECTED BY THE SELECTION COMMITTEE
- THE CORPORATION'S EXECUTIVE DIRECTOR SELECTED BY THE BOARD OF THE CORPORATION

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FOREST AND WOOD PRODUCTS RESEARCH AND DEVELOPMENT CORPORATION

ACCOUNTABILITY OF THE CORPORATION

1. THE CORPORATION IS REQUIRED TO PREPARE 5 YEAR RESEARCH AND DEVELOPMENT PLANS IN CONSULTATION WITH INDUSTRY

2. THE CORPORATION IS REQUIRED TO PREPARE ANNUAL OPERATING PLANS CONSISTENT WITH ITS 5 YEAR PLANS

3. THE CORPORATION WILL BE REQUIRED TO SUBMIT ANNUAL REPORTS TO PARLIAMENT AND INDUSTRY

4. THE CHAIRPERSON OF THE CORPORATION WILL BE REQUIRED TO REPORT DIRECTLY TO THE EXECUTIVE OF NAFI ON AN ANNUAL BASIS

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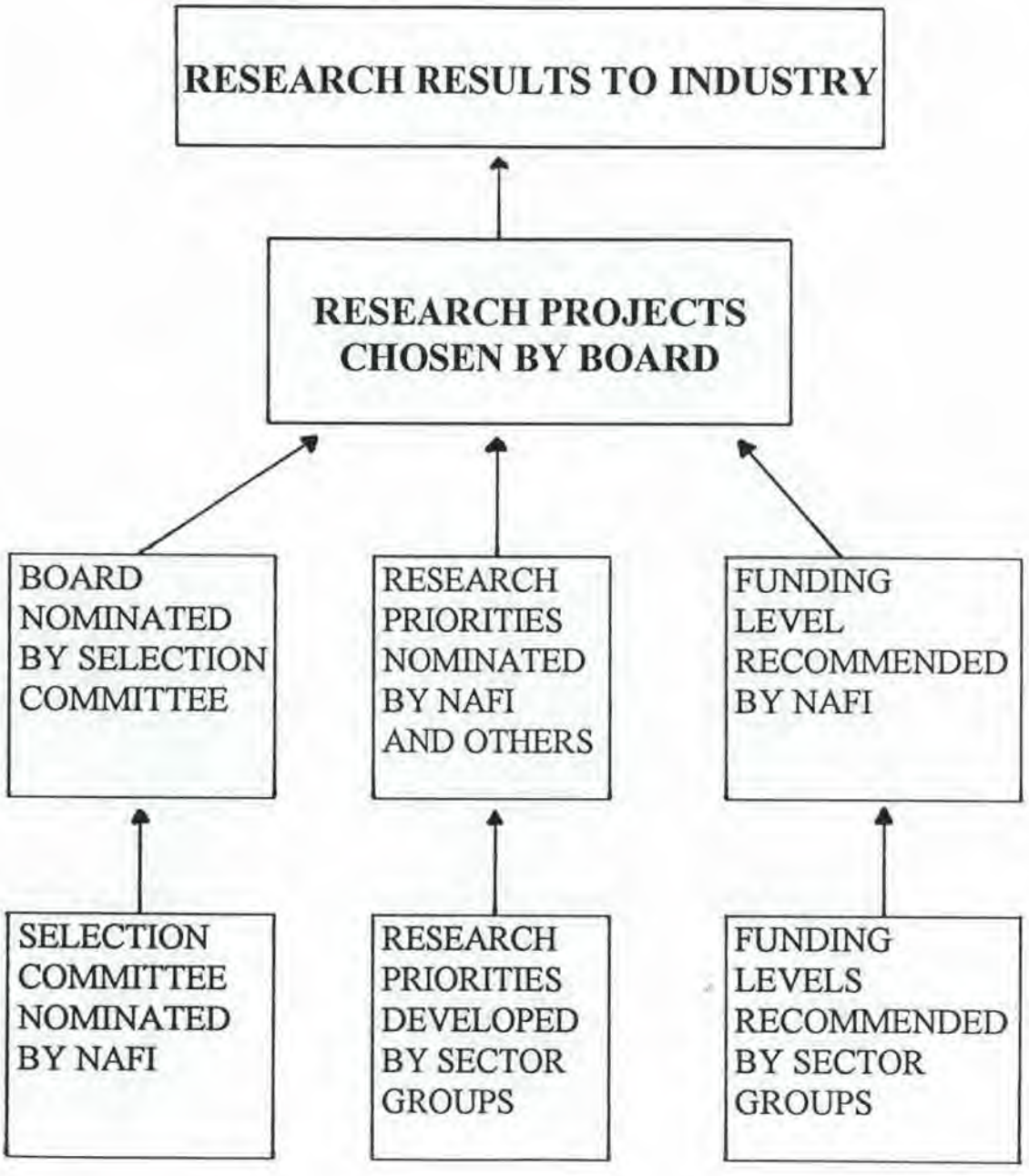
FOREST AND WOOD PRODUCTS RESEARCH AND DEVELOPMENT CORPORATION

SUMMARY



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REPORT OF THE AUSTRALASIAN WOOD PRESERVATION COMMITTEE

24th Forest Products Research Conference

The Australasian Wood Preservation Committee (AWPC) continues to represent the preservation research interests of our region, with current membership drawn from Australia, New Zealand, Papua New Guinea, and Fiji:

Australia

CSIRO Division of Forest Products
State Forests, New South Wales
Queensland Department of Primary Industry, Forest Service
Department of Conservation and Land Management, Western Australia

New Zealand

NZ Forest Research Institute Ltd.

Papua New Guinea

PNG Forest Research Institute

Fiji

Ministry of Forestry

Three meetings were held during the period under review - April 1991 in Rotorua, New Zealand; November 1992 in Sydney; and April 1993 in Brisbane. The AWPC has re-established technical links with the preservation industry (see below for more detail). In addition, Conference might note that membership of the Technical Committee of the Timber Preservers Association of Australia continues to draw on representatives of the AWPC, thus strengthening the integration of research programs and industry needs.

Recent discussion at meetings of the Committee of Research Directors (CORD), Standing Committee on Forestry, has again been concerned with incorporating the AWPC (and the other Forest Products Research Conference Committees) into the Standing Committee Research Working Group (RWG) structure. As Chairman of the AWPC, and a member of CORD, I argued against this proposition on the grounds that:

- the FPRC Committees have a membership drawn from both the industry they represent and the active researchers in the field, while RWGs only represent the research community

- the FPRC Committee meetings framework does not mesh with that laid down by the Standing Committee for the operation of the RWGs.

It was accepted that no further action would be taken on the proposal. However, there should be a mechanism of feedback to Standing Committee from the FPRC Committees in order to better inform the forest services and the RWGs of research progress in forest products areas.

My last report (FPRC 23) addressed the issue of preservation industry in-put to AWPC meetings. Our meeting in Sydney incorporated the Joint Wood Preservation Committee and valuable discussions took place with TPAA and TPANZ members, particularly on the issue of a self-regulatory quality assurance. This is a most important matter facing today's industry, as the consumer becomes more aware of quality and performance in purchase and use of treated timber. The current drive by NAFI to push the preservation industry along the QA path is to be applauded. The revised **AS1604** Australian Standard "Timber - Preservative-treated sawn and round" should provide the foundation for a QA scheme which is now being discussed by treater groups around the country. As Chairman of Standards Australia Committee TM6 I can advise the Conference that the revised **AS1604** should be available by the end of this month (November).

The topic headings set up in 1979 as a framework for AWPC sessions have continued to guide the Committee's activities. The table attached to this report summarises the major agenda items of the three meetings held since my last report to FPRC 23.

It will be seen from the table that much of the work of the AWPC at its meetings was concerned with the above-mentioned **AS1604** standard, related legislation, and quality

control matters. Other items of major importance at the meetings included preservative treatments, biodeterioration, and field testing work.

A major AWPC initiative during the period under review was the commencement of work on developing a suite of protocols. These protocols will serve as guides for the industry to the technical test procedures required in the introduction of new preservatives to the Australasian region. This concept was flagged some years ago by the New Zealand representatives on AWPC, in particular Mick Hedley.

The early ground work for the protocols was laid at the Brisbane meeting in April 1993. I anticipate the first 'public' draft of the protocols being available after our next meeting, to be held at the end of this Conference. I must thank a number of experts and bioassay specialists who have been involved in drawing up the protocols so far. Kevin McCarthy, CSIRO DFP, deserves particular thanks as he has borne the brunt of the work in cajoling individuals, organising input and structure, and writing the early drafts. We plan to send the suite of protocols to a broad representation of the preservation industry for their comments and input before issuing them as firm guidelines.

In concluding this report, I would make the same point as I made at FPRC 23 - the AWPC meetings still meet the requirements under which they were set up, i.e. **"to deal with matters which would otherwise overload the agenda of the Forest Products Research Conference"** *(Tamblyn, in Proceedings of the 15th Forest Products Research Conference, 1971)*. However, AWPC's role has progressed considerably since its inception. It now represents a major forum of exchange of preservation R&D matters and needs in the Australasian region. In addition, the AWPC is a watchdog for the industry and, I suggest, highly relevant to the member organisations it represents.

H. GREAVES
Chairman

Summary of agenda items discussed at AWPC meetings

Topic	Rotorua April 1991 AWPC	Sydney November 1992 AWPC	Sydney November 1992 JWPC	Brisbane* April 1993
Preservatives	2	2	1	
Treatment Processes	2	4		
Remedial Treatments	2	3		
Biodeterioration	5	4	1	
Field Testing	5	7		
Laboratory Testing		2		
Commodities				
Posts				
Poles & Piles	2			
Sleepers	1			
Building Timbers		1		
Panel Products				
Quality Control, Standards, Legislation	1	12	3	
Environmental Plant Hygiene, Safety	1	1	2	
Information	3	1	4	
Miscellaneous	2	3		
Total	**26**	**40**	**11**	

***The AWPC met in Brisbane for two days to discuss the development of protocols for the various AS1604 Hazard Levels which could be used by preservative manufacturers or potential manufacturers wanting to gain ACAC clearance for new preservatives.**

REPORT OF THE JOINT TIMBER SEASONING COMMITTEE

24th FOREST PRODUCTS RESEARCH CONFERENCE FOR THE PERIOD NOVEMBER 1990 TO NOVEMBER 1993

Background

The JTSC was formed by resolution of the 17th Forest Products Research Conference (FPRC) in 1975 following a recommendation from an Institute of Wood Science Seminar on high-temperature drying. The first meeting was on 3 July 1975. It has now met 26 times and reported on its activities to each subsequent FPRC. The next meeting is scheduled to follow this Conference.

The JTSC was established to provide a means of information exchange between organisations involved in research, development and extension in timber seasoning and aspects of the relationship of water and wood. Its membership is by invitation and includes representatives from industry, industry associations and consultants with special interest in the field, as well as research organisations. The membership was originally confined to Australia, but was extended in 1986 to include representation from the New Zealand Forest Research Institute.

Aims

The aims of the JTSC have evolved since its formation. They were last formally stated in 1985 as:

1. Establish and maintain communication links between researchers in the various government organisations, industry association researchers and other industry researchers to facilitate the exchange of information, data and results, with particular attention to perceived needs of industry.

2. Engender and facilitate communication between researchers and industry.

3. Summarise the general state of knowledge in the area of seasoning and relay this information back to the Forest Products Research Conferences.

4. Assist the promotion of adequate training and education in the field of timber seasoning at three levels:

    * Management
    * Technologists
    * Operators

These aims are not static and will continue to evolve to suit the needs of seasoning research, development and practice.

Membership

A list of the current members and their affiliations is attached (Appendix A).

Members who have resigned since the last FPRC are:

Mr D.K. Gough	Mr W.J. Atyeo	Mr A. Jaeger
Mr R. Mills	Mr P. Shedley.	

Dr G.R. Siemon joined and retired between the 23rd and 24th FPRC's.

I wish to record my thanks, and the thanks of the JTSC for their contributions.

JTSC Meetings

The JTSC has held three meetings since the 23rd FPRC. They were generally conducted in two parts:

General business and matters of general concern to the JTSC.

Presentation and discussion of technical reports by members on their activities.

There was some overlap between these.

All three meetings included visits of technical interest to members. The last two also had associated Seminars/Workshops.

A summary of the meetings is:

24th JTSC Meeting

Held at CSIRO, Clayton and Timber Industry Training Centre, Creswick. 22-23 November 1990.

David Gough and Richard Northway retired as Chairman and Secretary and were replaced by Jamie Hartley and Andrew Rozsa respectively.

The meeting recommended trying to establish formal links with the Standing Committee on Forestry of the Australian Forestry Council through the Directors of Research Committee. This was followed up, but was unsuccessful as the JTSC was considered to be "too close to industry".

The proposed revision of AS 1080 Part 1 "Methods of test for timber. Moisture content" which had been almost totally drafted by members of the JTSC was reported to be almost finalised. (We are still waiting - three years later!)

The visit to TITC, Creswick included an inspection of the facilities, particularly air and kiln drying/reconditioning.

25th JTSC Meeting

Held at Department of Conservation and Land Management (CALM), Como, WA on 16-17 September 1991.

The Bibliography from the Australian Furniture Research & Development Institute's "Status of technology in sawmilling, drying and handling of timber" was presented to the meeting.

Discussions led to agreement on the conditions required for "Plasticising" heart-in pine at the commencement of high-temperature drying. These are being incorporated in a revised industry standard as requirements for Pine Australia's Quality Control scheme.

The meeting was followed by a joint JTSC/CALM "Timber Drying Seminar" on 17 September which was well attended and attracted considerable interest.

A subsequent industry tour enabled members to inspect the research facilities of CALM at Harvey and hardwood and commercial pine drying plants in the south-west of WA.

26th JTSC Meeting

Held at Department of Forestry, ANU and NAFI/Forest Industries House, Canberra on 16-17 November 1992.

There was general agreement on the need to make meetings more "workshop" orientated similar to the former ATRI Workshops in order to ensure cross-fertilisation of ideas among members and to be more specific in allocating needed research at meetings.

The ANU meeting was followed by an inspection of the research facilities at the Department of Forestry.

A workshop on "Current research in the drying of softwood", largely presented by members of JTSC and sponsored by Pine Australia/NAFI was held at Forest Industries House on 17 November for industry representatives. General agreement about desirable research priorities in softwood drying was reached in discussion.

The meeting and workshop was followed by an industry tour/inspection of pine drying plants at Canberra and Tumut.

Seasoning Activities

Seasoning research and development has been active and ongoing over the last three years. Cutbacks in some areas and establishments have been more than compensated by expanding activity in others. Too much has been done to be detailed in this report, but an idea of the scope of the work can be gained from the list of subject headings attached (Appendix B).

Particularly relevant has been the increasing industry input to, and support of, programmes of relevance to it - both short term and in the longer term, strategic future. These have also often involved more "fundamental" investigations than the traditional "guided trial-and-error" approaches. Many of these programmes are ongoing. There are also proposals for future programmes.

Training and education activities, other than the Seminar and Workshop referred to previously, have included -

building seasoning education facilities and commissioning the drying kiln at TITC, Creswick

various seasoning and kiln operators' training courses;

co-ordination of an outline for a national common core curriculum in wood drying;

introduction of Wood Technology as a HSC subject.

Future Developments

The current and proposed research and development programmes, and inputs like the research priorities agreed at the Canberra Workshop, indicate continuing activity in wood drying research for both softwoods and hardwoods. The JTSC should continue to provide a valuable forum for communication and coordination.

The need for a more detailed, specialist "workshop" component in meetings may best be solved by meetings of sub-committees of the active workers in the related specialist fields. These would report to the JTSC. This approach worked well with the "Ad-hoc Seasoning Group" sponsored by the Australian Timber Research Institute. A difficulty may be obtaining the necessary travel funds.

The next IUFRO Conference on Wood Drying will be held in New Zealand in August 1994, preceded by a tour of research facilities and wood processing operations in southern Australia. The JTSC is investigating meeting the day before the Conference. This will provide a valuable opportunity for members to meet and exchange information with their overseas peers.

The JTSC currently has no formal links with any representative body. Its only direct reporting is to the FPRC. This situation should be rectified if and when an appropriate body is available.

JAMIE HARTLEY
Chairman

APPENDIX A

Current nominated members of the Joint Timber Seasoning Committee

(After the 26th meeting November 1992)

S. Bolden	Pine Australia ACT
J. Dunstan	Dunstan Drying Consultancy Vic.
G. Hall	Boral Timber NSW
J. Hartley (Chairman)	Jamie Hartley Consultancy NSW
W. Miller	FRI New Zealand
R. Northway	CSIRO Division of Forest Products Vic.
A. Rozsa (Secretary)	CSIRO Division of Forest Products Vic.
D. Wood	Woods and Forests SA
A. McNaught	CSR Softwoods Qld.
G. Palmer	Queensland Forest Service Qld.
R. McKimm	Dept Consv & Nat. Res. (Ret) Vic.
J. Bowler	AFRDI Tas. (Vice B. Ozarska)
R Schaffner	Timber Drying Technology Tas
B. Glossop	CALM WA
R.J. Hyne	Hyne & Son Qld
H. Kippo	Dryades WA
J. Ilic	CSIRO Division of Forest Products Vic.
J. Ferguson	Bunnings WA
P. Evans	ANU ACT

APPENDIX B

Seasoning Activities - November 1990 - November 1993

Facilities	
CSIRO Wood Science and Technology moved to new laboratories at Clayton	C
Portable kiln development	C
High temperature experimental kilns	C, Q
Commissioned manufacture of new high temperature developmental kiln	C
Commercial research batch kiln	W
Acoustic emission equipment to detect degrade formation	NZ, T
Kilns/drying plants/systems	
Kiln evaluation and audits	NZ, Q
Corrosion in hoop pine kilns	Q
Improving existing kilns	NZ
Design of lower cost dryers	NZ
Development and installation of improved pre-driers for WA hardwoods	W
Improved kilns for jarrah and karri	W
Development, sale and installation of CALM solar assisted driers for both softwood and hardwood	W
Installations of various high temperature commercial pine kilns	W+
Dryspec kiln supervisory system	NZ
MContent package	NZ
Softwood Drying	
Hoop pine schedule development -	Q
high quality uses	
equalisation regimes	
wetwood problems	
Very high temperature (200°) drying - slash pine	Q
High temperature drying slash pine - effect of schedule and pre-steaming on distortion and stability	Q
Final steaming	NZ
High temperature drying furniture squares	NZ
Pre-steaming heart-in studs - warp reduction	NZ
Comparing effect of high temperature and conventional temperature drying	NZ
Optimisation of air velocity in high temperature drying	NZ
Effect of stack width in high temperature drying	NZ
Reducing air velocity during high temperature drying	NZ

Drying random widths for re-manufacture	NZ
Accelerated conventional temperature schedule for radiata pine	NZ
Collapse and internal checking in radiata pine	NZ
In-kiln resistance based end point systems	Q

Hardwood drying

Drying for furniture grades - low cost methods (small mills) controlled air drying solar drying	Q
Controlled multi-stage drying thick backsawn hardwood for furniture grades	N
Development of hardwood drying improvements	C
Drying plantation eucalypts for planting on degraded lands	C
Drying under-utilised species for higher quality uses	C
Formation of "collapse study group"	C
Collapse in hardwoods	C
Pre-treatments to alleviate surface and internal checks	C
Batch kiln trials to optimise drying of karri and marri	W
Radio frequency vacuum drying	C
Drying economics - survey of methods and costs	Q
Veneer reconditioning	C

Modelling

Publication of: Oliver, A.R. 1991. A model of the behaviour of wood as it dries (with special reference to eucalypt materials)	T
KILNSCHED program development, improvement and verification	T
Softwood drying model development and progress with interactive kiln controller	C
Modelling solar drying commenced	W

Round and treated timber

Slash pine pole seasoning - air drying and biological attack	Q
Mechanical treatments and modified CCA formulations to reduce checking of CCA treated round timber	A
Slash pine - pre-treatment drying methods heartwood penetration post-treatment drying post-treatment fixation in kiln post-treatment drying schedules	Q
Effect of CCA treatment and low and high temperature re-drying on strength properties of radiata pine	A

Wood properties

Cause of wetwood in hoop pine permeability studies thermogravimetry site relationships	Q
Wood property and processing evaluations of numerous plantation-grown tropical timbers	NZ
Interaction of silviculture and drying degrade	NZ

Miscellaneous

Correlation of acoustic emission and surface elastic strain	T
Stress-strain relations perpendicular to the grain in eucalypts over a range of temperatures	T
Warp in radiata pine - stability in service EMC fluctuations	Q
Kiln schedules for numerous minor species	NZ
Drying a range of species in CALM solar assisted driers	W

Code	Information from:-
A	Australian National University
C	CSIRO DFP
N	New South Wales
NZ	New Zealand
Q	Queensland
T	Tasmania
W	Western Australia

FIRE RESISTANCE RESEARCH COMMITTEE
(Report)

Australia's building regulations have traditionally been conservative, with rigid design prescriptions, and based on non-combustible construction. Nearly five years ago the National Association of Forest Industries (NAFI) set up an Office to work toward building code reform in order to develop potential markets for timber frame construction in all building types. The key to the success of this work has been the developing art of risk assessment and fire safety engineering.

Significant progress has been made over the last four years in creating a climate for change away from the traditional approach to building regulation and the reliance on non-combustible construction.

Town houses, row houses, terrace houses, villa units, duplexes and the like (which may be multi-storey but not have one occupancy above another) have traditionally been required to have their separating walls built in non-combustible construction. These can now be built in timber frame, fire resisting construction.

Two storey apartment buildings have traditionally been required to have all separating walls, loadbearing walls, fire walls and external walls built in non-combustible construction. These also can now be built in timber frame, fire resisting construction.

AUBRCC are currently considering a submission, based on nearly four years research at a cost to the Industry of between $700,000 and $1 million, to allow three storey apartment buildings to be built in timber frame construction. This may be in effect within 12 months.

Since early 1992, NAFI have engaged several Ph.d students to develop computer models for the prediction of the fire resistance of timber frame assemblies. These were to begin with deterministic models and move on to probabilistic models relating to real fires. Simple models predicting time and probability of failure of walls and floors should be produced in the first half of 1994. Limited full scale testing of assemblies at ambient and elevated temperature are expected to occur late 1994. The models will then be extended to include insulation, double framing and end restraint.

There is a move by AUBRCC towards introducing a performance-based BCA in early 1995. In order to provide a means of demonstrating equivalence with the code, a project is being initiated now by AUBRCC, NAFI and other Industry groups and major Research Organisations called the Fire Code Reform Program.

This 5-year project will be based on a risk assessment approach developed initially at the Warren Centre, University of Technology, Sydney, Australia in 1989 under the direction of Dr. Vaughan Beck. This project is the key to accelerating the acceptance of multi-storey timber frame construction in all building types.

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2. Physical wood properties of *Pinus radiata* in irrigated and fertilised stands	J.G. Nyakuengama, M.L. Benson, R. Evans, D. Menz, B.J. Myers & I.E. Craig CSIRO DF & DFP
3. The use of the prism image analysis system for quantifying wood microstructure	L.F. Wilson & C.F. Sandercock University of Melbourne
4. Establishment of a computer-assisted data base on wood gluing for the development of universal type wood adhesives	T. Nikpour & Y. Yazaki CSIRO DFP
5. Determination of moisture content of wood using a microwave oven	S. Manley CSIRO DFP
6. Stress laminated timber bridge (SLTB) deck in ACZA treated Douglas fir for Queensland	J. Keith, J. Best & A. Moffat Western Wood Products, QDT and Queensland Primary Industries
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8. A tropical field trial of preservative treated Donglas fir in Queensland	A.R. Moffat, R.C. DeGroot & J. Keith Queensland Primary industries, US Forest Products and Western Wood Products
9. Wood Collection	B. Gardiner CSIRO DFP
10. Solid wood products from irrigation-grown hardwoods	G. Waugh CSIRO DFP
11. Structural wood adhesives for more efficient use of Australian forest timbers	Y. Yazaki, P.J. Collins, M.J. Reilly, S.D. Terrill & T. Nikpour CSIRO DFP

Internal Checking of Radiata Pine Monitored with ACOUSTIC EMISSION

CHARACTERISTICS

Checks that extend through a single earlywood layer in the radial direction in the interior of boards. They are invisible from the outside until the boards are machined.

FREQUENCY OF OCCURRENCE

[illegible] Form during the [illegible] are likely [illegible] should be [illegible] problem to continue to weed from a [illegible] number of sites.

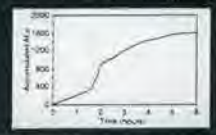
Moulding machined from an internally checked board

WHEN DO THEY FORM

Boards were [illegible] with acoustic emission sensors. Acoustic emissions (AEs) are small pulses of high frequency sound. In this case generated by checking. [illegible] cracking of the wood. AE's were used to [illegible] drying.

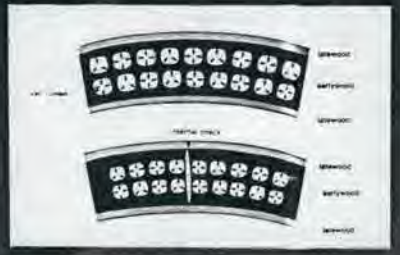
RESULTS

[illegible] only when [illegible] were formed during the first [illegible] of drying, corresponding to [illegible] moisture content of 70%. The maximum rate of checking occurred [illegible] hours after the start of drying, when the [illegible] above the fibre saturation point. [illegible] temperature of 100°C.



THE MECHANISM

Internal checking occurs above the fibre saturation point of 30%mc, and is caused by water stress (tension) in the inter-connecting water columns.



PREVENTION

The following approaches to reducing checking will be tried:

(1) Development of a milder schedule such as 70/60°C [illegible] softened by high temperature.

(2) Identification and separation of boards that are [illegible] to high temperature, while the rest [illegible] high temperature dried.

(3) Development of chemicals that protect the [illegible] water stress.

(4) Long-term breeding programme for trees with stronger cell walls.

R. E. Booker and A.N. Haslett
New Zealand Forest Research Institute

INTERNAL CHECKING OF RADIATA PINE MONITORED WITH ACOUSTIC EMISSION

R.E. Booker

Forest Research Institute, New Zealand

When random width radiata pine boards are high-temperature dried (120/70°C) they occasionally show internal checks. Such checks extend in the radial direction through a single earlywood layer in the interior of the boards. They are invisible until the boards are re-machined.

The drying of boards was monitored with acoustic emission equipment to determine at what stage of drying internal checks form. Approximately 90% of internal checks formed during the first six hours of drying. During this time the moisture content decreased from 146 to 72%. In other words, internal checking, like collapse, occurs well above the fibre saturation point of 30% moisture content.

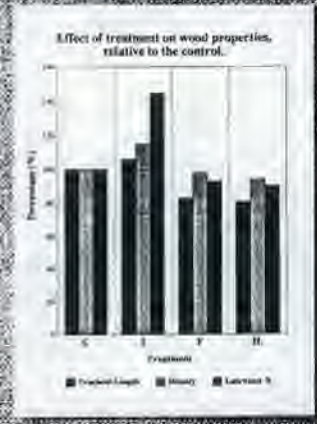
Physical Wood Properties of *Pinus radiata* in Irrigated and Fertilised Stands

Control

Project Objectives

To examine the relationships between
- field growing conditions / waste and nutrient status
- and: (i) wood properties / proportion of early wood and latewood, mean maximum and minimum densities and tracheid length

in radiata pine wood
- in an 11 to 14-year-old plantation near Canberra
- under the following treatments:
  - control (C)
  - irrigation only (I)
  - irrigation plus conventional solid fertiliser (F)
  - irrigation plus conventional liquid fertiliser (F)
  - irrigation plus regular liquid fertiliser (IL).



Control

Irrigation only

Water Stress Integral

- is a measure of stress duration
- based on pre-dawn needle water potential
- reflects both water and nutrient status
- is highly correlated with growth rates
- larger values = greater cumulative stress.

Irrigation only

Irrigation plus regular liquid fertiliser

John G. Nyakuengama¹, Martin L. Benson¹, Robert Evans², David Mertz¹, Brian J. Myers¹, Ian R. Ulrig

1 CSIRO Division of Forestry, PO Box 4008, Canberra ACT 2600
2 CSIRO Division of Forest Products, Private Bag 10, Clayton Victoria 3168

Conclusions

- Physical wood properties are affected by the altered growing conditions that result from silvicultural treatments such as thinning, fertilisation or effluent irrigation.
- Increased availability of water or nutrients resulted in greater wood volume while increased water plus nutrient had the maximum effect.
- Increased availability of water alone produced longer tracheids, higher density and a larger proportion of latewood.
- Increased availability of particular plant or water plus nutrients produced shorter tracheids, lower density and a smaller proportion of latewood.

Irrigation plus regular liquid fertiliser

PHYSICAL WOOD PROPERTIES OF *Pinus radiata* (D. Don) IN IRRIGATED AND FERTILISED STANDS

John G. Nyakuengama[1], Martin L. Benson,[1] Robert X. Evans,[2], David Menz[2], Brian J. Myers[1] and Ian E. Craig[1].

[1]CSIRO Division of Forestry, PO Box 4008, Queen Victoria Terrace, Canberra, ACT, 2600, Australia.
[2]CSIRO Division of Forest Products, Private Bag 10, Clayton, Vic. 3168, Australia.

An experiment in a 10-15 year old stand of *Pinus radiata* (D. Don) near Canberra studied the interaction of water and nitrogen in controlling tree growth. Five treatments were applied, control (C), once-only solid fertiliser (F), irrigation only (I), irrigation plus once-only solid fertiliser (IF) and irrigation plus regular liquid fertiliser (IL). The increase in basal area increment of treated stands relative to the control was IL (260%), IF (204%), I (160%) and F (134%).

Water and nutrient availability affected not only growth but also wood quality. Compared to the C, both IL and F tracheids were shorter (19 and 17%, respectively) however I tracheids were longer (6%). Wood density and latewood proportion were reduced in the IL (6 and 10%, respectively) and also in the F (2 and 7%) but in the I both properties increased (15 and 45%). In irrigated stands, water stress integral (an index of water and nitrogen status) accounted for 85-97% of variation in tracheid length and 62% in density. These properties were highly correlated (r^2 = 89%) suggesting a common controlling mechanism.

Irrigation reduced the effects of drought (false rings, diameter shrinkage and mortality), produced more homogeneous wood and allowed production of more latewood. IL wood was found to contain mild compression wood.

LF Wilson and CF Sandercock Cooperative Research Centre for Hardwood Fibre and Paper Science, Creswick

ABSTRACT

The Prism System

Video or scanned images.

Multiple video screens.

Many measurement options.

Easy data & graphics exchange.

Area	Form factor	x-Cent gravity
Convex area	Roundness	y-Cent gravity
Filled area	Convexity	Orient angle
Perimeter	Solidity	x-Feret
Length	Hole fraction	y-Feret
Breadth	Aspect ratio	x-Location
Width	Elongation	y-Location
Fibre length	Curl	Hole count

Annual Ring Area & Perimeter

Eucalypt annual rings can be difficult for Prism to interpret because they are often incomplete, false or blurred.

Image processing can help but in this case human insight is needed.

Annual Ring Vessel Area

Low power image is used for reference.

Each ring quarter is examined at high power and damaged vessels are edited.

Vessel areas are sorted on x-location (ring boundary distance) and graphed.

Annual Ring Vessel Area Fraction

Custom addition is used to prepare vertical strips of vessels. Prism records length and x-location of each strip.

Excel is used to sort and add lengths at each x-location then plot the length sum of each strip against its x-location.

Annual Ring Fibre Dimensions

Fibre length is easily measured from ~250µ macerated sections.

Fibre cross section dimensions are measured from transverse sections.

Image processing is used because Prism cannot "see" fibre boundaries.

Annual Ring Fibre Dimensions

"Skeletonising" the section inverted binary produces a very close approximation to fibre boundaries.

The skeleton consists of lines of pixels that mark the midlines of features.

The skeleton is always overlayed on the original section to check accuracy.

The use of the Prism Image Analysis System for quantifying wood microstructure

LF Wilson and CF Sandercock
Forestry Section, University of Melbourne
Creswick 3363 Victoria

Prism is an Apple Macintosh based image analysis system. Our system comprises Prism software, a Quadra 950 computer, a Sony colour 3-CCD camera, a 20 and a 14 inch colour monitor, an Olympus BH2 microscope, an Olympus SZ stereo microscope and a Samyang macro zoom lens. The system can acquire colour macro and microscopic images directly or import them from the image processing program Photoshop.

Prism has many grey level image and contrast enhancement options and many neighbour operating filters, including those for contrast enhancement, edge finding, sharpening and smoothing, and noise reduction. Additional filters can be written by the user or requested from the program writer. The user can also write macros to automate error-prone and time consuming manual procedures.

This poster will illustrate the use of Prism to measure annual ring areas and widths; vessel and ray percentage areas; vessel and ray area frequency distribution; and fibre dimensions from eighteen year old *Eucalyptus nitens* trees. Also the advantages of a two monitor system will be shown, where either a low power reference image can be displayed beside a high power image for analysis, or each screen can display different graphics or data management programs.

ESTABLISHMENT OF A COMPUTER-ASSISTED DATABASE ON WOOD GLUEING FOR THE DEVELOPMENT OF UNIVERSAL TYPE WOOD ADHESIVES

T. Nikpour, Y. Yazaki. Division of Forest Products

WOOD SPECIES CHARACTERISTICS

a) Wood Product Classification

b) Wood Species

c) Density

d) Extractives

e) Wood Moisture Content

f) Anatomical Features

COMMERCIAL RESIN CHARACTERISTICS

a) Total Solid Contents

b) Viscosity

c) Gelation Time

d) Alkalinity

e) Resin Shelf-Life and Stability

GLUING PARAMETERS

a) Filler Formula

b) Construction/No. of Plys

c) Veneer Moisture Content

d) Cold Pressing

e) Hot Pressing/Temperature & Duration

f) Open/Closed Assembly Time

g) Assessment Method/Bond Assessment Results

MOLECULAR CHARACTERISTICS OF RESIN

a) NMR Data

b) GPC Data

c) DSC Data

d) etc.

ABSTRACT

Wood gluing requires an integrated knowledge of wood science, adhesives chemistry and gluing technology in order to successfully produce reconstituted wood products.

Australia is in a unique position, in that overseas gluing technology is not always applicable to the Australian situation. CSIRO and Australian industry have been developing several systems applicable for Australian conditions.

OUTPUT

Systematic Recording of Data

Analysis of Data

Sorting and Selecting Records

Searching for Wood Species Record

Data Indexing

Reporting

EXAMPLE OF FINAL OUTPUT

New Species	Specified Product
X	Y

Step 1: Feed wood characteristics of new wood species into data base

Step 2: Optimized molecular characteristics of resin and its gluing parameters

DATA BASE INFORMATION IS BASED ON PRODUCTION OF BELOW RECONSTITUTED WOOD PRODUCTS

a) Plywood

b) Laminated Veneer Lumber

c) Medium Density Fibreboard

d) Finger Jointing

AUTHOR: TOUBA NIKPOUR

ESTABLISHMENT OF A COMPUTER-ASSISTED DATA BASE ON WOOD GLUING FOR THE DEVELOPMENT OF UNIVERSAL TYPE WOOD ADHESIVES

T. Nikpour and Y. Yazaki

Wood gluing requires an integrated knowledge of wood science, adhesives chemistry and gluing technology in order to successfully produce reconstituted wood products.

The Australian reconstituted wood industry is in a unique position, in that overseas technology is not always applicable for manufacturing our reconstituted wood products due to different wood species, and different climatic and mill situations. CSIRO and Australian industry have been developing several systems specifically applicable for the Australian conditions and accumulating empirical technology which has become the basis for current industrial practice.

Based on this empirical technology, the possibility exists for the establishment of a computer-assisted data base. This data-base would consist of the information on wood species and characteristics, conventional resin characteristics, gluing parameters and molecular characteristics of resins.

Since our Wood Adhesive Group was formed at the Division in 1988, data regarding 22 successful gluing examples have been accumulated. These examples cover gluing of high density wood species, fast-curing phenolics and gluing at higher wood moisture contents in the production of plywood, LVL and finger-jointing. Based on these examples, the establishment of a data base containing more than 70 parameters relating to successful wood gluing has been in progress. This data base will play an important role in the development of universal type wood adhesives in the near future.

Determination of Moisture Content of wood using a Microwave Oven

CSIRO
AUSTRALIA

Author - Sharon Manley

Determination of Moisture content of wood using a microwave oven

S. Manley

The accurate determination of the moisture content of wood, especially at high moisture contents above fibre saturation point (f.s.p.), relies on an oven dry sample test. Resistance Moisture meters are inaccurate above f.s.p. and require temperature correction if used at elevated temperatures.

The kiln drying process used for softwoods is very rapid, taking six to eight hours. The initial moisture content variability can be very high and until moisture content reaches 30% resistance probes are inaccurate. There is a need for a fast, reliable method for estimating moisture content under these conditions.

Microwave drying is used to determine moisture content but it can be inaccurate particularly if the sample is over-dried or under-dried.

This investigation determined the accuracy of the microwave dried sample moisture content, the dimensions of the sample, the microwave drying time required and highlighted the need for accuracy of weight measurement.

Samples of Pinus radiata, green and partly dried, of different lengths along the grain were used. They were dried under various heating and cooling cycles in a domestic microwave, to determine the best method. Comparative samples were dried in a conventional oven.

Rapid microwave oven drying of samples to estimate moisture content of kiln drying samples can be used to determine initial moisture content and the progress of drying in the early stages.

STRESS LAMINATED TIMBER BRIDGE (SLTB) DECK IN ACZA TREATED DOUGLAS FIR FOR QUEENSLAND

A three span 21.6m long road bridge over the Yabba Creek No.4 crossing, near Imbil in south-east Queensland, has the conventional girder and plank super structure replaced by a 5m wide stress laminated timber deck. The deck consists of individual lengths of 300 x 50mm (nom.) section, seasoned Ammoniacal Copper Zinc Arsenate (ACZA) preservative treated Douglas Fir (Pseudotsuga menziesii) boards.

The individual laminae are stressed together using 18 high strength coarse threaded VSL stressbar 24mm diameter rods at 1200mm centres (initially 252 kN per rod). The resultant 21.6m x 5m x 0.3m deck behaves as an orthotropic plate structure meeting the design requirements of nominated Queensland Transport H20-S16 bridge design load vehicle.

The timber is treated to AWPA C2-92 standards to a net retention of 0.60 pounds of preservative per cubic foot by the full cell process, and kiln dried after treatment to an average moisture content of 15%. Individual laminae are pre-drilled and precision end-docked, then treated to provide full sapwood and envelop penetration in the heartwood which was incised prior to treatment. The incising pattern was 1" lateral x 1 1/4" longitudinal (diamond) with individual sharpened tapered teeth, 3/4" x 1/8" thick at the base.

Assembling Laminates

Stressing Laminates

Launching SLTB Deck

Copper Napthanate Emulsion between Tallowwood Untreated Truewood Laminates

Completed Bridge

46 tonne Logging Truck Load test

Load Cell monitoring force in Rod

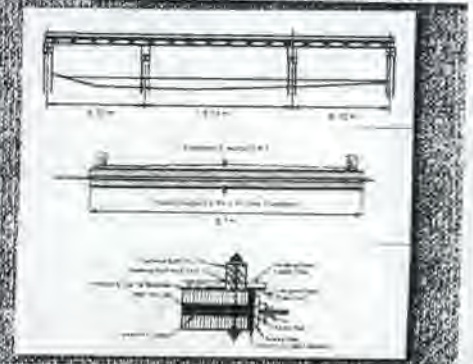
Moisture Protection: Galvanised Steel Scupper Drains & Flashing protect timber from water run-off

Two load cells have been installed to monitor the stress retention in the deck at the mid-span and at one abutment.

Extra detailing of construction of the bridge to minimise water ingress to the wood structure which provides added risk management to the integrity of the structure. The use of a geotextile membrane, saturated and glued with a coal tar base emulsion to the timber deck, together with galvanised steel scupper drains and flashing, ensure surface water is discharged clear of all timber in the deck.

Ongoing monitoring of the bridge by Queensland Transport, Queensland DPI Forest Service, and WWPA will provide further data on the performance of the bridge deck structure.

Large section naturally durable hardwood members for conventional post and beam bridges are becoming increasingly difficult to supply. This stress-laminated bridge technology which is new to Queensland, offers the opportunity to use readily available naturally durable or treated timber boards for the rehabilitation or replacement of Australia's thousands of timber post and beam bridges now in service.



John Keith — Western Wood Products Assoc., Sydney Aust.
John Bess — QDT Bridge Services, S&QB, Technology Div.
Alan Moffat — QDPI Forest Service, Timber Research

By: John Keith — Western Wood Products Assoc., Sydney Aust.
John Best — QDT Bridge Services, S&QB, Technology Div.
Alan Moffat — QDPI Forest Service, Timber Research

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Microdensity Analysis Program

J.L.YANG and G.M.PERKINS

CSIRO
AUSTRALIA

[illegible] density is generally a measure of the [illegible] material per unit volume. It integrates a variety of anatomical features into a single property characteristic. Wood density varies horizontally and vertically primarily due to the variation in anatomical structure of the wood. Basic density is widely accepted as the single most useful descriptor of wood quality, its [illegible] is widely important in determining

[illegible] of the wood products.

Microdensity data, however, can appear difficult to handle or digest due to the large collection of data per specimen. Moreover, microdensity does not appear to have direct meanings as the 'macrodensity' which derives from measuring sizeable wood specimens. A computer program was hence developed to enable meaningful [illegible] representations to be extracted and

microdensity data which could not [illegible] visual observation. These [illegible] would in a readily recognisable format can then be used in a number of analysis. For instance, examining how and to what an extent the variation of density affects drying and strength properties of the wood.

The [illegible] for finding growth rings works by [illegible] interpretation to identify the

Obtain density specimens

X-ray scan specimen

Analyse microdensity data

[illegible] major tangents which were subjectively [illegible] as the ring boundaries. The parameters for locating growth ring boundaries are currently set for Eucalyptus regnans and E. nitens species. For other species which have roughly similar microdensity profiles, this program is expected to also work appropriately either without any change, or with the ring-locating parameters being modified. The major features of this program are:

1. Automatically identifies growth ring boundaries with an accuracy of 70% on average, in some cases reaching over 90%.
2. Enables the user to easily override and modify the growth ring boundaries by using the mouse.
3. Extracts a number of quantities, such as average density and SD of each ring, and calculates a variety of formulae, such as uniformity factor.
4. Allows results to be output to the screen or to ASCII files.
5. Is menu driven and extremely user- friendly with most operations performed by using a mouse input device, and the keyboard is utilised only when absolutely necessary.

Microdensity Analysis Program

J.L. Yang and **G.M. Perkins**

Wood density is basically a measure of the amount of cell-wall material per unit volume. It integrates "a variety of anatomical features into a single physical characteristic" (Polge, 1978). Wood density varies horizontally and vertically primarily due to the variation in anatomical structure of the wood. Whilst density is widely accepted as the single most useful descriptor of wood quality, its uniformity may be equally important in determining wood quality (Harris, 1969; Polge, 1978) and end use of the wood products.

Microdensity data, however, can appear afflictive to handle or digest due to its large amount per specimen. Moreover, microdensity does not appear to have direct meanings as the 'macrodensity' which derives from measuring sizeable wood specimens. A computer program was hence developed to enable meaningful quantities and expressions to be extracted and evolved from microdensity data, which could not practically be obtained otherwise. These quantities, which appear in a readily recognisable format, can then be used in a number of analysis, for instance, examining how and to what an extent the variation of density affects drying and strength properties of the wood.

The algorithm for finding growth rings works by numerical differentiation to identify the centre of major troughs which were subjectively defined as growth ring boundaries. The parameters for locating growth ring boundaries are currently set for *Eucalyptus regnans* and *E. nitens* species. For other species which have roughly similar microdensity profiles, this program is expected to also work appropriately either without any change, or upon its ring-locating parameters being modified. The major features of this program are:

1. Automatically identifies growth ring boundaries with an accuracy of 70% on average, in some cases reaching over 90%.
2. Enables the user to easily override and modify the growth ring boundaries by using the mouse.
3. Extracts a number of quantities, such as average density and SD of each ring, and calculates a variety of formulae, such as uniformity factor (Olson and Arganbright).
4. Allows results to be output to the screen or to ASCII files.
5. Is menu driven and extremely user-friendly with most operations performed by using a mouse input device, and the keyboard is utilised only when absolutely necessary.

References

Harris, J.M. 1969. The use of beta rays in determining wood properties - Part 1. Measurement of wood density and interpretation of results. *N. Z. J. Sci.* 12: 409-418

Olson, J.R. and Arganbright, D.G. 1977. The uniformity factor - a proposed method for expressing variations in specific gravity. *Wood and Fiber* 9(3): 202-210

Polge, H. 1979. Fifteen years of wood radiation densitometry. *Wood Sci. Technol.* 12: 187-196

TROPICAL FIELD TRIALS OF PRESERVATIVE TREATED DOUGLAS FIR IN QUEENSLAND

Tropical field trials with preservative treated Douglas Fir (*Pseudotsuga menziesii*) have been initiated as a cooperative venture involving the Western Wood Products Association, USA; US Forest Products Laboratory; Queensland Dept of Primary Industries - Forestry Service and CSIRO Division of Forest Products with Industry Cooperators in Australia and the USA.

A study plan provides for the treatment and exposure of specimens for both Above Ground and In Ground service hazards. The trial exposures will be installed by 1994.

Above Ground service consists of two types of decay units at a wet tropical location and one termite unit targeting the subterranean termite *Coptotermes acinaciformis* at a dry tropical location.

In Ground service consists of a stake trial exposed at a wet tropical coastal rainforest site.

Exposure specimens will be inspected annually.

Parallel stake specimens will be exposed in Mississippi by the Forest Products Laboratory.

PRESERVATIVES

- Ammoniacal Copper Citrate *
- Ammoniacal Copper Quat type B
- Ammoniacal Copper Zinc Arsenate
- Copper Naphthenate
- Penta in Oil/CCA emulsion
- Tributyltin oxide *
- Creosote
- Copper Unmodified Creosote

* In Ground service trial preservatives only.

Above Ground Service

RETENTION

Treaters produced 20 pieces of 2x4 inch x 8-foot members equivalent to H3 hazard level to the anticipated Australian standard. Preservative chemical analyses on each member will be carried out.

FABRICATION of EXPOSURE UNITS

Each 8-foot member was cut in accordance with the fabrication diagram.

In the field Koppers CN Emulsion was applied to all cut and bored surfaces.

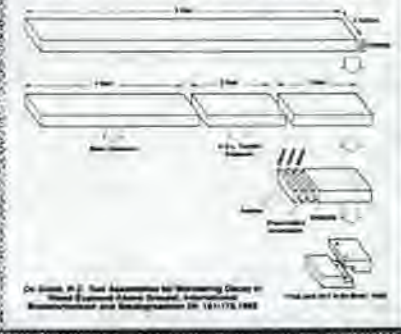
In Ground Service

STAKES 2 x 2 x 20 inches 20 Replications

RETENTIONS 4 levels of active ingredients

Water-borne	Organic-oil borne	CuNap	Creosote
%ai	%ai	%ai	%ai
0.75	0.75	0.75	7.50
1.50	1.25	1.50	15.00
3.00	2.50	3.00	30.00
6.00	5.00	6.00	60.00

ABOVE GROUND EXPOSURE UNITS (Fabrication Diagram)



Alan R Hadlington
Queensland Department of Primary Industries - Forest Service
PO Box 631, 280 Mount Bell
Indooroopilly Q 4068 Australia

Stephen Tin Lum, R. Douglas M. Crawford
US Forest Products Laboratory
One Gifford Pinchot Drive
Madison WI 53705-2398 USA

Jeffrey Morris
Western Wood Products Association
522 SW Fifth Avenue
Portland OR 97204-2122 USA

John Smith
Western Wood Products Association
PO Box 415
Franklin NSW 2077 Australia

DPI
QUEENSLAND DEPARTMENT OF PRIMARY INDUSTRIES
FOREST SERVICE

A TROPICAL FIELD TRIAL OF PRESERVATIVE TREATED DOUGLAS FIR IN QUEENSLAND

A.R. Moffat, R.C. DeGroot and J. Keith
Queensland Forest Service, US Forest Products and
Western Wood Products Association

Field trials with preservative treated Douglas Fir have been initiated as a cooperative venture involving the Western Wood Products Association, Oregon, USA; US Forest Products Laboratory, Wisconsin, USA; Queensland Department of Primary Industries, Forest Service and CSIRO Division of Forest Products, with industry cooperators in USA and Australia.

The study plan provides for the treatment and exposure of specimens for both above ground and in ground service hazards.

Above ground service consists of two types of decay exposure unit and one type of termite exposure unit. The decay units are exposed at the QDPI experimental farm at South Johnstone via Innisfail, north Queensland while the termite exposure is at a drier tropical site, targeting the subterranean termite *Coptotermes acinaciformis*.

In ground service consists of a random block stake trial, installed at a tropical coastal rainforest site.

This poster details the preservatives under test and the exposure unit construction for above ground specimen exposure, along with the preservatives and retentions for the in ground stake trial. Initially all specimens will be inspected annually for 6 years, at which time further inspection frequently will be determined.

Matching stake specimens are exposed at Mississippi in a parallel trial under the care of the US Forest Products Laboratory.

CSIRO
AUSTRALIA

HE DAD S/F T.C MEMORIAL WOOD COLLECTION

Author - ***BRADEN GARDINER***

SUMMARY

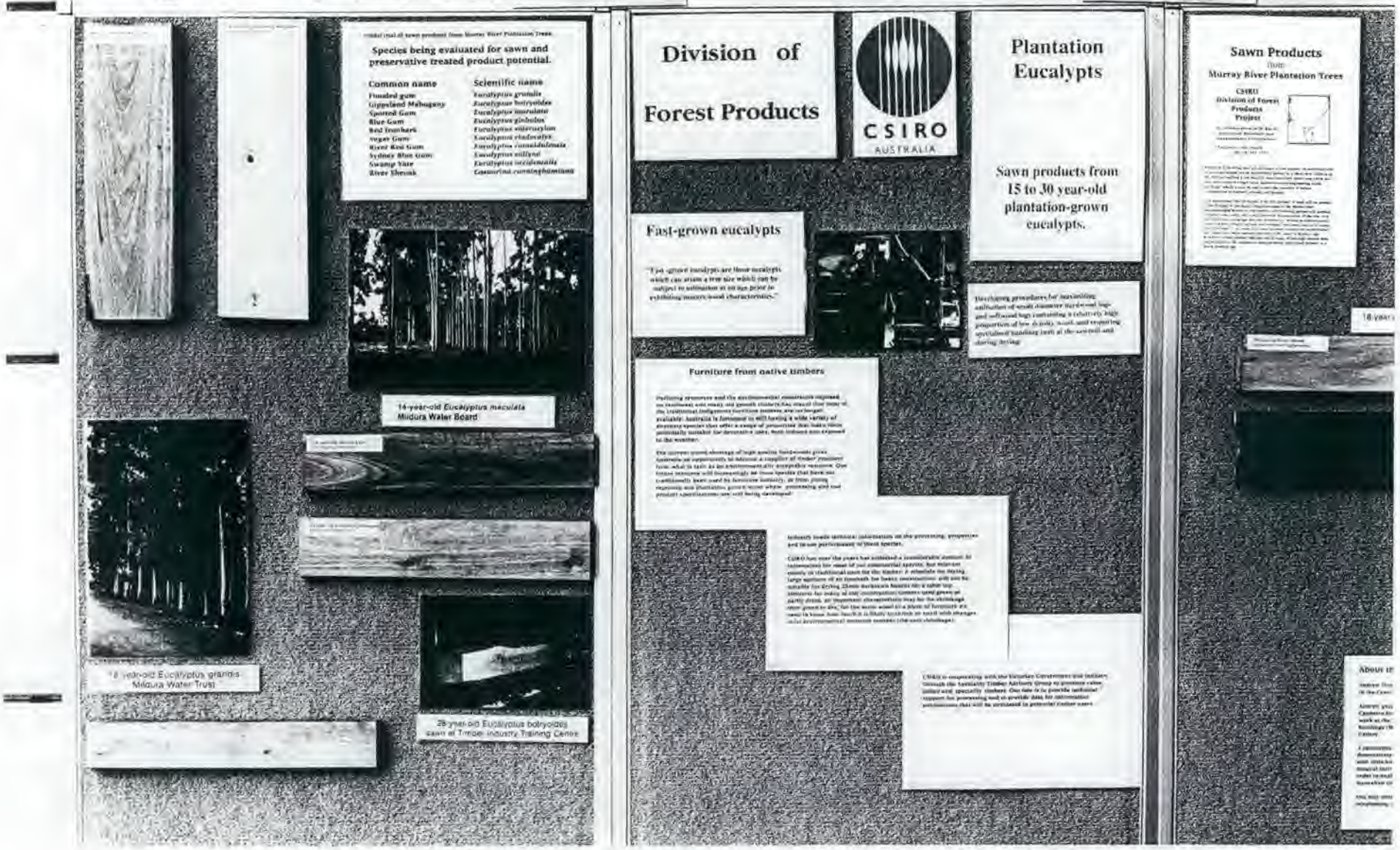
WOOD COLLECTION

Background to CSIRO, Dadswell Memorial Wood Collection is presented along with its usefulness to community and industry. Information on the size of the collection in relation to other collections. The curation of such a collection is important in order to facilitate its use effectively.

Good cataloging of the Wood Collection is an essential requirement for its proper use. This is achieved by using a database program to act as a computer index. The program enables specific information such as botanical name, collection number, tin number, card reference number, slide cut and authority; regarding any specimen to be examined. Currently the computer index is being updated and checked; and a specimen inventory is being conducted.

Currently, the Dadswell collection consists of 47000 samples of which there are: 270 botanical families, 9500 Genera and 13000 different species. Physically the specimens are arranged in alphabetical order by botanical family name, genus and species. Part of the collection consists of samples from Papua New Guinea which are held separately in numeric order and represent the most extensive collection of species from that part of the world.

Braden Gardiner - Wood Science and Technology group.


Species being evaluated for sawn and preservative treated product potential.
Common name
Scientific name
Flooded gum
Eucalyptus grandis
Gippsland Mahogany
Eucalyptus botryoides
Spotted Gum
Eucalyptus maculata
Blue Gum
Eucalyptus globulus
Red Ironbark
Eucalyptus sideroxylon
Sugar Gum
Eucalyptus cladocalyx
River Red Gum
Eucalyptus camaldulensis
Sydney Blue Gum
Eucalyptus saligna
Swamp Yate
Eucalyptus occidentalis
River Sheoak
Casuarina cunninghamiana
14-year-old Eucalyptus maculata
Mildura Water Board
18 year-old Eucalyptus grandis
Mildura Water Trust
28 year-old Eucalyptus botryoides
sawn at Timber Industry Training Centre
Division of
Forest Products
CSIRO
AUSTRALIA
Plantation
Eucalypts
Sawn products from
15 to 30 year-old
plantation-grown
eucalypts.
Fast-grown eucalypts
Furniture from native timbers
Sawn Products
from
Murray River Plantation Trees
CSIRO
Division of Forest
Products
Project

Solid wood products from irrigation-grown hardwoods

Gary Waugh
Division of Forest Products, CSIRO.

Research is showing that a wide range of hardwood species can be successfully grown on a short-length rotation of around 20 years, in the Murray-Darling River basin to meet land care needs and which are also well-suited for high-value appearance and engineering sawn products. However, young plantation-grown hardwoods, in particular eucalypts, can be expected to be difficult to saw. The release of high growth stresses resulting in distortion and sizing inaccuracies in sawn products has defeated any major effort overseas to base any extensive sawmilling industry around eucalypt plantation developments. Research at CSIRO has gone a long way toward developing handling techniques and sawing strategies to minimise growth stress problems during sawing and selected species can be expected to be able to provide sawn products which would meet market expectations for both engineering and appearance products sawn from young eucalypts.

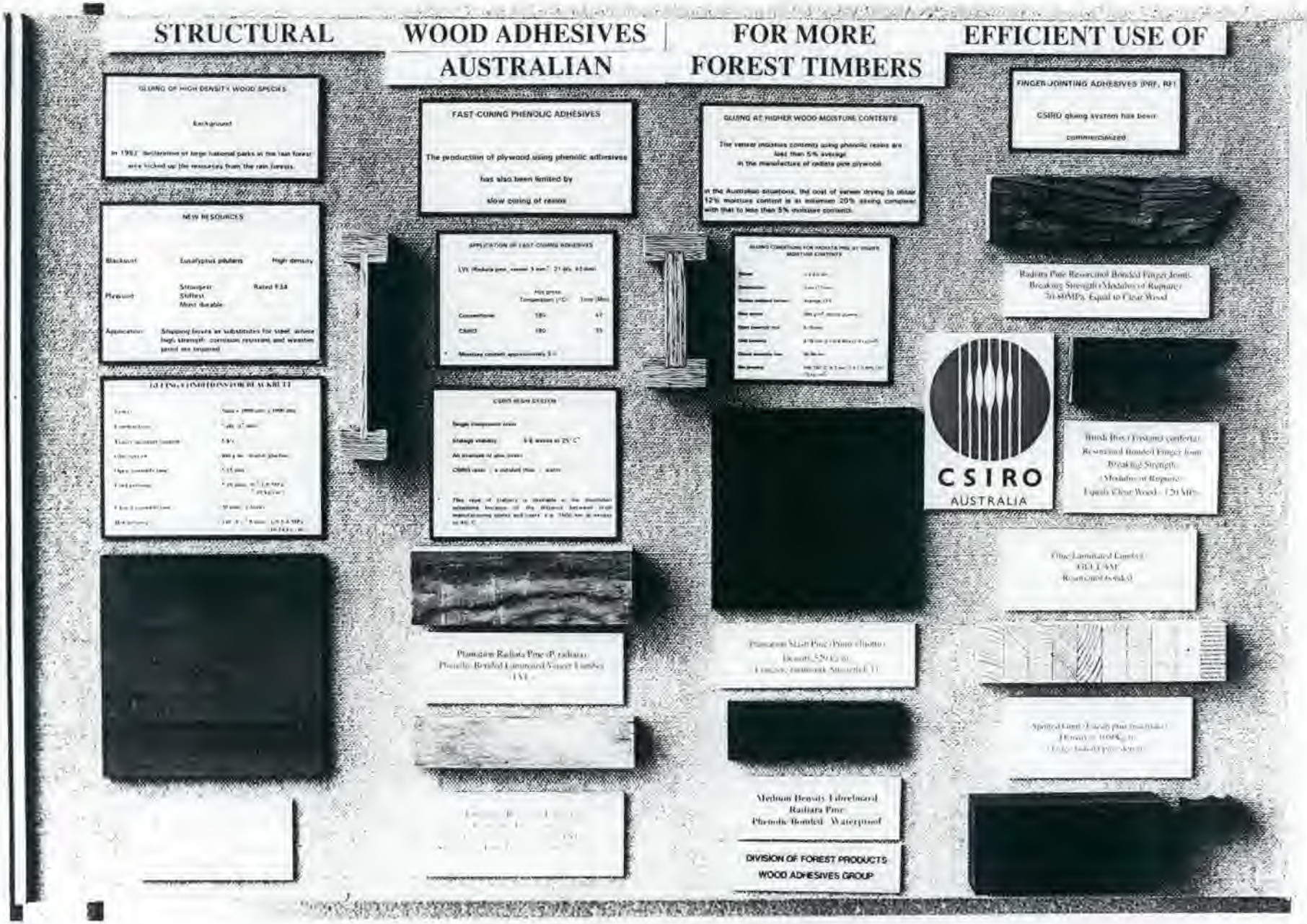
Young trees and fast growth generally leads to low-density wood, resulting in products of lower strength and higher shrinkage than products from mature wood. However, studies are showing that there are species suited for both shorter growing periods and higher-value products. *Eucalyptus maculata* and *E. saligna* are proving to be species that are easy to establish and to manage, with excellent self-pruning characteristics and develop suitable wood characteristics at an early age. These species are expected to achieve growth rates in excess of twenty cubic metres per hectare per year, which is equivalent to our best softwood plantations.

E. maculata in particular has high strength characteristics and fine grain, making it suited for both engineering and appearance products and also specialised uses such as furniture and tool handles, where strength and appearance are both vital attributes. This investigation is also showing that other eucalypt species such as *E. camaldulensis, E. cladocalyx, E. sideroxylon* and *E. botryoides*, while not perhaps achieving the same high growth rates, can also be grown in areas of high water table, or to handle effluent to provide a range of more specialised solid wood products.

In parallel with any consideration for developing this resource for sawn products, CSIRO is investigating the opportunities to improve the durability of the wood through preservative treatment so that it can be utilised for posts and poles. Such an industry can develop earlier on younger wood and at a smaller scale with less capitalisation than is possible for the sawmilling industry.

Growing trees for wood products can provide farmers with a more diversified and more secure income. As alternate forest resources around the world are depleted, imports will decline in availability and export opportunities for wood products will increase. In addition, farmers are not trapped into a single commodity market, as trees grown for poles can be grown on for a further 5-8 years for sawlogs or veneer logs.

STRUCTURAL WOOD ADHESIVES FOR MORE EFFICIENT USE OF AUSTRALIAN FOREST TIMBERS



STRUCTURAL WOOD ADHESIVES FOR MORE EFFICIENT USE OF AUSTRALIAN FOREST TIMBERS

Y. Yazaki, P.J. Collins, M.J. Reilly, S.D. Terrill and T. Nikpour

Australia presently produces more than one million m^3 of reconstituted wood products requiring the use of approximately 60,000 tonnes of adhesives costing the reconstituted wood products manufacturing industry more than $50 million per year.

Since the Wood Adhesives Group was formed at CSIRO, Division of Forest Products in 1988, the Group has been deeply involved in developing more efficient wood adhesive systems in collaboration with a commercial adhesive manufacturing company. Projects are related to the development of structural high durability wood adhesives for gluing of high density wood species such as blackbutt (*Eucalyptus pilularis*), the gluing at higher wood moisture contents and the development of fast-curing phenol-formaldehyde (PF) adhesives for such products as plywood and laminated veneer lumber (LVL). Furthermore, the Group has also collaborated in the development of adhesive systems for finger-jointing and medium density fibreboard (MDF). Adhesive systems relating to fast-curing PFs for plywood, resorcinol-formaldehyde (RF) for finger-jointing and PFs for MDF have been commercialized.

Since these phenolic type adhesives are most suitable for external and structural applications, they offer a viable and more efficient utilization of renewable forest resources.

LIST OF DELEGATES

AHMED, Berhan	CSIRO DFP
ARCHER, Kevin	Chemical Specialities/Laporte
BAIN, Robert	National Association of Forest Industries
BEADLE, Chris	CRC Temperate Hardwood Forestry
BEEL, Martin	Forest Industries Federation (WA)
BEUTEL, Peter	Australian National University
BOLDEN, Stephen	NAFI
BOOKER, James	AFRDI
BOOKER, Rolf	NZ Forest Research Institute
BORZILLO, Robert	Porta Mouldings
BOYLE, Anthony	Sydney Electricity
BREITINGER, Harold	CSIRO DBCE
BULAI, Sairusi	Ministry of Forests, Fiji
CARRUTHERS, Peter	Koppers-Hickson Timber Protection
CARSON, John	NAFI
CAUSE, Myron	Queensland Dept of Primary Industry
CHAFE, Sam	CSIRO DFP
CHAPMAN, Peter	State Forests of NSW
CLARK, Noel	CSIRO DFP
CLINCH, Robert	University of Central Queensland
COBHAM, Peter	University of Melbourne
COLE, Ivan	CSIRO DBCE
COLLINS, Peter	CSIRO DFP
COOKSON, Laurie	CSIRO DFP
COOPER, Graham	Pryda Australia
CREWS, Keith	University of Technology, Sydney
COUTTS, Bob	CSIRO DFP
DEAN, Geoff	North Forest Products
DOWNES, Geoff	CSIRO DFP
DRYSDALE, Jeanette	Koppers-Hickson (NZ)
DUNSTAN, John	Dunstan Drying Consultancy
ELLIS, Brett	Koppers-Hickson Timber Protection
EVANS, Phil	Australian National University
EVANS, Rob	CSIRO DFP
FLETCHER, John	Bunnings Forest Products
FORDHAM, Heather	CSIRO DBCE
FRENCH, John	CSIRO DFP
FUNG, Paul	CSIRO DFP
GARDNER, David	State Forests of NSW
GEORGIOU, Jim	Deakin University
GOODE, Jennifer	Koppers-Hickson Timber Protection
GREAVES, Harry	CSIRO DFP
GREENACRE, Mark	Laporte Timber Preservatives

HAMILTON, Greg	Bunnings Forest Products
HEDLEY, Mick	NZ Forest Research Institute
HEWERTSON, Warren	CSIRO DFP
HIGGINS, Huntly	CSIRO DFP
HILLIS, Ted	CSIRO DFP
HO, Siew	University of Melbourne
HOWICK, Doug	Australian Timberman
HUNTER, Aleck	CSIRO DFP
HYNE, Chris	Hyne and Son Pty Ltd
ILIC, Jugo	CSIRO DFP
INNES, Trevor	Univesity of Tasmania/AFRDI
JOHNSON, Gary	CSIRO DFP
JOHNSTONE, Rex	Consultant
JONES, Darryl	Timber Promotion Council of Vic.
KEATING, Bill	Conference Secretary
KEEGAN, Graham	TRADAC
KEITH, John	Western Wood Products Association
KHO, Peter	University of Melbourne
LADU, Godfrey	Marbut Pty Ltd
LEICESTER, Bob	CSIRO DBCE
LLEWELLYN, Peter	Timber Development Association of SA
LU, Jing Ping	CSIRO DBCE
LYNGCOLN, Kevin	Plywood Association of Australia
MACARTHUR, David	CSIRO DFP
McCARTHY, Kevin	CSIRO DFP
McDOWALL, Mick	Plywood Association of Australia
McEVOY, Chris	Preschem Pty Ltd
McKENZIE, Bill	Consultant
MACKENZIE, Colin	TRADAC
MACKIE, Keith	NZ Forest Research Institute
McNAMARA, Rob	CSIRO DBCE
McNAUGHT, Andy	CSR Softwoods
MAMERS, Heikki	CSIRO DFP
MICHELL, Tony	CSIRO DFP
MILNER, Bob	Monash Timber Engineering Centre
MOTUM, Graham	Sydney Electricity
MUDE, Shefo	University of Melbourne
NDEGWA, Nellie	University of Melbourne
NELSON, Peter	CSIRO DFP
NESTIC, Robert	Monash Timber Engineering Centre
NG, Soo	CSIRO DFP
NGUYEN, Loi	Australian Pulp and Paper Institute
NIKPOUR, Touba	CSIRO DFP
NORTHWAY, Richard	CSIRO DFP
NORTON, Jack	Queensland Department of Primary Industries
NYAKUENGAMA, John	University of Melbourne
OZARSKA, Barbara	CSIRO DFP

PALMER, Graeme	Queensland Dept of Primary Industries
POLLOCK, Angus	Australian Paper
PRICE, Dan	Local Government Electricity Assoc. of NSW
RAWLINS, Bill	CSIRO DFP
RECUPERO, Tina	CSIRO DFP
REILLY, Mary	CSIRO DFP
ROMERO, Javier	University of Melbourne
ROZSA, Andrew	CSIRO DFP
RUDLING, Ken	Southern Timber Treaters
SANDERCOCK, Catherine	University of Melbourne
SCHMALZL, Karl	CSIRO DFP
SCROGINS, Martin	Stanley Bostitch Pty ltd
SEDGLEY, John	CSR Softwoods
SEGAN, Marshall	The Pine Centre
SIOUMIS, Tony	CSIRO DFP
SMITH, Dick	Koppers-Hickson
STRINGER, Geoff	Hyne and Son Pty Ltd
STROHFELDT, David	Hancock Bros Pty Ltd
SUTHERLAND, John	CSIRO DFP
SWEATMAN, Paul	CSR Softwoods
SYME, David	State Forests of NSW
SYME, Michael	CSIRO DBCE
TAN, Jimin	Australian National University
TERRILL, Stewart	CSIRO DFP
THOMSON, Roger	Pryda Australia
THORNTON, John	CSIRO DFP
TIGHE, Maureen	CSIRO DFP
TURNBULL, Peter	Precise Prefabs Pty Ltd
TURNER, Ian	Queensland University of Technology
VINDEN, Peter	University of Melbourne
WALLIS, Adrian	CSIRO DFP
WARD, Chris	Tasmanian Timber Engineering
WAUGH, Gary	CSIRO DFP
WILLIAMS, Max	CSIRO DFP
WILLIAMS, Tom	CSR Softwoods
WILSON, Lawrie	University of Melbourne
WOODARD, Alastair	Monash Timber Engineering Centre
YANG, Jenny	CSIRO DBCE
YANG, Jun Li	CSIRO DFP
YAZAKI, Yoshi	CSIRO DFP
YOUNG, Fran	CSIRO DBCE

A DECADE OF AUSTRALIAN RESEARCH INTO THE FIRE PERFORMANCE PROPERTIES OF FOREST PRODUCTS

W.D. Gardner
Research Division
State Forests Of New South Wales
P.O. Box 100, Beecroft, NSW, 2119

ABSTRACT

Australian research over the last decade has studied the heat release, flame spread, charring and fire resistance properties of forest products. The research results demonstrate that the AS1530.3 Spread of Flame Index is not apporopriate for regulating the use of forest products in Australian buildings and that the charring equations in AS1720.4 need to be revised, particularly for protected timber. The fire resistance data have been used to support a submission to achieve allowances in the BCA for three storey timber framed Class 2 buildings.

INTRODUCTION

Australian research over the last decade on the fire performance of forest products has had the following three objectives:

1. Assess the suitability of Australian Standard (AS) 1530.3 - Simultaneous determination of ignitability, flame propagation, heat release and smoke release as a test method prescribed in the Building Code of Australia (BCA) to regulate materials according to their tendency to spread flame

2. Develop data on the performance of forest products by fire test methods that may be used in the future to regulate materials according to their ability to spread flame and contribute to fire growth and/or will provide data for computer modelling of flame spread and fire growth.

3. Develop data on the fire resistance of forest products and structural elements containing forest products that can be used to demonstrate compliance with both prescriptive and performance based building codes.

The purpose of this paper is to review the Australian fire performance research over the last decade. The research is reviewed according to the objectives outlined above.

1. Assessment of the suitability of AS1530.3 as a test method for the regulation of building materials

AS1530.3 is the method prescribed in the BCA to regulate materials according to their tendencies to spread flame and release smoke. The test was first standardised as Section 3 of AS-A30 - Early fire hazard test of materials in 1958. This test did not include a procedure for measuring smoke release. The test was developed from observations of flame spread over combustible linings in a series of room-fire tests (Ferris, 1955). Smoke release measurement was added to a 1970 revision of the standard.

The allowable uses for combustible materials in buildings are determined by their AS1530.3 Spread of Flame and Smoke Developed Indices. Therefore, to achieve the joint objectives of a) ensuring adequate levels of occupant safety and b) allowing the widest range of materials to be used without jeopardising life safety, it is imperative that AS1530.3

is a suitable test method to determine the tendencies for materials to spread flame and release smoke. Concern about the ability of AS1530.3 to assess the tendency for some forest products to spread flame and contribute to fire growth was reported by Gardner (1986). Ramsay (1986) also expressed concern about the anomalous behaviour of some lining materials containing plastics when tested to AS1530.3.

A study has been undertaken to assess the suitability of AS1530.3 as a test method to regulate forest product wall lining materials according to their tendencies to spread flame and contribute to fire growth.

The nine materials listed in Table 1 were tested as wall linings in an experimental room-fire facility constructed in accordance with the Proposed Method for Room Fire Tests of Wall and Ceiling Materials and Assemblies published in the 1982 ASTM Annual Book of Standards, Part 18. The ceiling was lined with gypsum plasterboard and the floor was non-combustible. A gas fired burner was used at an output of 40 kW for the first 5 minutes, 160 kW for the second 5 minutes and the burner was extinguished for the final 5 minutes of the test. The tests were run for 15 minutes or until flashover was achieved, whichever occurred first.

Flashover was taken to be the indicator of a materials ability to spread flame and contribute to fire growth. Flashover was that time at which flames extended beyond the doorway of the room-fire facility. The time to flashover for the room when it was lined with the materials is given in Table 1. The AS1530.3 Spread of Flame Index of the materials is also given in Table 1.

Table 1 Time to flashover of an experimental room fire-facility with forest product wall linings and the AS1530.3 Spread of Flame Index for those materials (from Gardner and Thomson, 1988).

Material	Time to flashover (minutes)	AS1530.3 Spread of Flame Index
Sawn boards		
Radiata pine (fire retardant coated)	No flashover	0
Cypress pine	7.3	9
Blackbutt	7.2	7
Douglas fir	6.5	9
Victorian ash	6.3	8
Radiata pine	6.1	9
Western red cedar	5.9	10
Panel products		
Particleboard	5.6	0
Lauan plywood	4.5	8

When time to flashover of the experimental room is taken as the criterion for assessing flame spread and contribution to fire growth of the lining materials it is obvious that the AS1530.3 Spread of Flame Index did not correctly predict the tendency of three materials to spread flame and contribute to fire growth. Particleboard with a zero Spread of Flame Index should have performed similarly to the zero Spread of Flame Index fire retardant coated radiata pine - i.e. flashover should not have occurred. Instead, the particleboard

lined room flashed over more rapidly than all other rooms except the one lined with lauan plywood. Western red cedar with a Spread of Flame Index of 10 should have flashed the room over more quickly than when it was lined with any of the other materials. However particleboard (Spread of Flame Index of zero) and lauan plywood (Spread of Flame Index of 8) flashed the room over more quickly than Western red cedar. The room was flashed over most quickly when it was lined with lauan plywood, which with a Spread of Flame Index of 8 was expected to perform similarly to Victorian ash and to take longer to flash the room over than when it was lined with Douglas fir, radiata pine and Western red cedar.

A statistical correlation could not be established between the AS1530.3 Spread of Flame Index of the materials and the time to flashover when the room was lined with them. However, Gardner and Thomson (1988) established a correlation between the time to flashover and the AS1530.3 Time to ignition of the materials.

Time to flashover = 1.094 Time to Ignition (AS1530.3) - 0.038
(R^2 = 0.75, $P<0.05$)

Gardner and Thomson (1988) recommended that the Time to Ignition determined by testing to AS1530.3 was a more appropriate means of regulating materials according to their tendencies to spread flame than the AS1530.3 Spread of Flame Index.

The results of this study demonstrate that the AS1530.3 Spread of Flame Index is not a reliable predictor of materials' ability to spread flame and contribute to fire growth. The use of the Spread of Flame Index in the BCA as a means of regulating materials according to their tendencies to spread flame and contribute to fire growth ensures three outcomes:

1. The expected life safety for building occupants may not always be realised.

2. Because of their unrealistically low Spread of Flame Index, the use of some materials that will spread flame at an unexpectedly rapid rate and hence contribute to unacceptably high rates of fire growth will be allowed in some occupancies and parts of buildings.

3. Because of their unrealistically high Spread of Flame Index, the use of some materials that would not spread flame at an unacceptably rapid rate or contribute to unacceptably high rates of fire growth would be excluded from use in some occupancies or parts of buildings.

This research has demonstrated that the AS1530.3 Spread of Flame Index is not a suitable means of regulating materials in the BCA according to their tendency to spread flame and contribute to fire growth.

2. Development of data by fire test methods that may be used for regulation in the future and/or will provide data for computer modelling of flame spread and fire growth.

It is probable in the future that additional or alternative test methods to AS1530.3 will be prescribed for the regulation of building materials in the BCA. AS1530.3 was developed from studies of flame spread up combustible walls but the test is used to regulate ceiling linings, flooring systems and furniture in addition to wall linings. It is noted by Ramsay (1986) that the method should be limited in scope to wall linings. Therefore, it follows that additional test methods to AS1530.3 need to be prescribed in the BCA for all applications except wall linings unless AS1530.3 can be validated for those uses. The results produced by Gardner and Thomson (1988) also demonstrate that the AS1530.3 Spread of Flame

Index is not a reliable indicator of the tendencies of combustible wall linings to spread flame and contribute to fire growth and they recommend it should be replaced as a means of regulating materials in the BCA.

A range of forest products have been tested to ASTM E84 - Surface burning characteristics of materials (Gardner & Thomson, 1988). ASTM E84 is the method specified in the North American building codes for regulating materials according to their tendancies to spread flame. The materials were tested to ASTM E84 because this method may provide an alternative to the AS1530.3 Spread of Flame Index as a means of regulating materials according to their ability to spread flame. Some of the materials tested to ASTM E84 were also tested as wall linings in the experimental room-fire facility (Gardner and Thomson, 1988).

The building codes of the future are likely to be more performance based and they will require test methods that provide meaningful input data for computer programs that will model flame spread and fire growth. Test procedures based on heat release calorimetric methods are the most likely candidates for regulating materials in building codes in the future.

a) ASTM E84 testing of forest products

Eighteen materials were tested to AS1530.3 and ASTM E84. The AS1530.3 Spread of Flame Index and ASTM E84 Flame Spread Index for the materials are given in Table 2.

Table 2. AS1530.3 Spread of Flame Index and ASTM E84 Flame Spread Index for forest products (from Gardner & Thomson, 1988)

Material	AS1530.3 Spread of Flame Index	ASTM E 84 Flame Spread Index
Sawn boards		
Blackbutt	7	48
Brush box	7	45
Cypress pine	9	51
Douglas fir	9	69
Jarrah	6	26
Radiata pine (fire retardant coated)	0	6
Victorian ash	8	51
Radiata pine	9	77
Western red cedar	10	69
Panel products		
Blackbutt plywood	5	46
Hardboard, exterior	7	86
Hardboard, standard	7	113
Hoop pine plywood	8	168
Hoop pine plywood (fire retardant treated)	0	4
Hoop pine plywood (fire retardant treated with untreated face veneers)	0	26
Lauan plywood	8	170
Particleboard	0	104
Victorian ash plywood	8	91

From Table 2 it is apparent that there is little correlation between the AS1530.3 Spread of Flame Index and the ASTM E 84 Flame Spread Index for the materials. This lack of correlation is of concern because both tests methods are used to regulate materials according to their tendencies to spread flame. It was therefore expected that materials would be ranked similarly by both test methods. The AS1530.3 Spread of Flame Index and ASTM E84 Flame Spread Index are compared for the materials tested in Table 3.

Table 3. Comparison of AS1530 Spread of Flame Index and ASTM E84 Flame Spread Index for materials tested.

AS 1530.3 Spread of Flame Index	ASTM E84 Flame Spread Index
0	4, 6, 26, 104
5	46
6	26
7	45, 48, 86, 113
8	51, 91, 168, 170
9	51, 69, 77
10	69

A correlation was established between the ASTM E84 Flame Spread Index and the AS1530.3 Time to Ignition.

$$\text{Log}_e \text{ Flame Spread Index (ASTM E84)} = -0.720 \text{ Time to Ignition (AS1530.3)} + 8.379 \quad (R^2 = 0.83,\ P<0.001)$$

Nine of the materials in Table 2 were also tested as wall linings in an experimental room-fire facility (Gardner and Thomson, 1988). A correlation was established between the ASTM E84 Flame Spread Index of the materials and the time to flashover for the room.

$$\text{Log}_e \text{ Time to flashover} = -0.003 \text{ Flame Spread Index (ASTM E84)} + 2.065 \quad (R^2 = 0.91,\ P<0.001)$$

This correlation demonstrates that the ASTM E84 Flame Spread Index of the materials was a good predictor of the ability of wall linings to spread flame and contribute to fire growth. For this reason Gardner and Thomson (1988) recommended that ASTM E84 be considered as an alternative test procedure to AS1530.3 in the BCA.

b) Heat release calorimetry testing of forest products

There have been three studies that have produced data on forest products by heat release calorimetric test methods (Dunn, 1988; Lush, 1990; Gardner and Thomson, 1991) that could be used for regulation of building materials or providing input data for computer models.

Dunn (1988) tested forest products using an ignitability test apparatus with a truncated cone electric heater. The specimens were tested horizontally and a 140 mm diameter surface of the specimens were exposed to radiant heat fluxes of 20, 30, 40 and 50 kWm^{-2} for 20 minutes. A gas flame igniter was used. Lush (1990) tested forest products using a cone calorimeter. The specimens, 100 x 100 mm, were tested horizontally and exposed to radiant heat fluxes of 25, 40, 50 and 75 kWm^{-2} for 20 minutes. An electric spark ignition system was used. Gardner and Thomson (1991) reported the results of testing to ASTM E

906 - Standard test method for heat and visible smoke release rates for materials and products. Test specimens, 150 x 150 mm, were injected into an environmental chamber through which a constant flow of air passed. The specimens were tested in the vertical orientation with piloted ignition and exposed to radiant heat fluxes of 20, 40 and 60 kWm^{-2} for 10 minutes.

The maximum rates of heat release reported for each heat flux exposure by Dunn (1988), Lush (1990) and Gardner and Thomson (1991) are given in Tables 4, 5, and 6 respectively.

Table 4 Maximum rate of heat release at heat flux exposures of 20, 30, 40 and 50 kWm^{-2} (from Dunn, 1988).

Materials	Maximum rate of heat release (kWm^{-2}).			
	20 kWm^{-2}	30 kWm^{-2}	40 kWm^{-2}	50 kWm^{-2}
Blackbutt plywood	271	216	240	231
Hardboard, exterior	243	305	353	387
Hardboard, standard	288	332	456	500
Hoop pine plywood	266	308	337	451
Hoop pine plywood (fire retardant treated)	43	43	47	NT[1]
Hoop pine plywood (fire retardant treated with untreated face veneers)	167	222	203	222
Particleboard	243	304	346	302
Victorian ash plywood	304	287	330	NT

Note: 1 - NT = not tested

Table 5. Maximum rate of heat release at heat flux exposures of 25, 40, 50 and 75 kWm^{-2} (from Lush, 1990).

Materials	Maximum rate of heat release (kWm^{-2}).			
	25 kWm^{-2}	40 kWm^{-2}	50 kWm^{-2}	75 kWm^{-2}
Sawn boards				
Blackbutt	183	254	250	423
Victorian ash	198	253	298	428
Panel products				
Blackbutt plywood	254	258	293	326
Hardboard, exterior	281	333	351	418
Hardboard, standard	322	322	381	439
Hoop pine plywood	223	269	313	356
Hoop pine plywood (fire retardant treated)	45	30	67	77
Hoop pine plywood (fire retardant treated with untreated face veneers)	182	214	250	279
Victorian ash plywood	194	240	278	425

Table 6 Maximum rate of heat release at heat flux exposures of 20, 40 and 60 kWm^{-2} (from Gardner and Thomson, 1991)

Materials	Maximum rate of heat release (kWm^{-2}).		
	20 kWm^{-2}	40 kWm^{-2}	60 kWm^{-2}
Sawn boards			
Blackbutt	107	133	200
Brush box	89	133	164
Cypress pine	82	110	154
Douglas fir	55	116	178
Jarrah	56	97	134
Radiata pine	87	134	173
Radiata pine (fire retardant coated)	30	22	61
Victorian ash	100	139	203
Western red cedar	61	122	114
Panel products			
Blackbutt plywood	94	200	223
Hardboard, exterior	275	305	310
Hardboard, standard	302	335	347
Hoop pine plywood	125	210	220
Hoop pine plywood (fire retardant treated)	5	11	44
Hoop pine plywood (fire retardant treated with untreated face veneers)	68	121	113
Particleboard	119	188	242
Victorian ash plywood	127	200	228

The maximum rate of heat release was shown by all studies to increase with increasing heat flux. The effects on the maximum rate of heat release of increasing the heat flux from 20 kWm^{-2} to 40 kWm^{-2} and from 40 kWm^{-2} to 60 kWm^{-2} when forest products were tested to ASTM E906 were shown by Gardner and Thomson (1991) to be:

$$MRHR\ 40 = 0.93\ MRHR\ 20 + 59 \quad (R^2 = 0.87,\ P < 0.001)$$

$$MRHR\ 60 = 0.75\ MRHR\ 40 + 81 \quad (R^2 = 0.80,\ P < 0.001)$$

where MRHR 20, MRHR 40, MRHR 60 are the maximum rates of heat release at 20, 40 and 60 kWm^{-2}, respectively.

3. Development of fire resistance data

Data have been developed for a) the charring of Australian timber species, b) the fire resistance of loaded timber beams and c) the fire resistance of timber framed walls and floor/ceilings.

a) Charring of Australian timber species

Specimens of glued-laminated beams, 1400 x 270 x 150 mm, of eight timber species were exposed to the standard heating conditions specified in AS1530.4 - Fire resistance tests of elements of building construction (Gardner and Syme, 1991). Beams of two softwood species - cypress pine and radiata pine and six hardwood species - blackbutt, blue gum, brush box, jarrah, spotted gum and Victorian ash were tested. The density of the beams ranged from 526kgm^{-3} to 968kgm^{-3}. The beams were exposed to the standard heating conditions for one hour and two hours. Beams protected with 13 mm of gypsum plasterboard were also exposed to the standard heating conditions for two hours. Thermocouples were embedded in each beam to record the position of the char/solid wood interface during the test exposures.

Predictive equations were developed for the depth of char for both unprotected beams and for beams protected with 13 mm gypsum plasterboard exposed to the standard heating conditions for up to two hours.

For unprotected beams

$$C = \frac{413\,t}{D} + 1.6$$

($R^2 = 0.95$, $n = 72$, $p < 0.001$)

For beams protected with 13 mm gypsum plasterboard.

$$C = \frac{234\,t}{D} - 5.8$$

($R^2 = 0.96$, $n = 42$, $p < 0.0001$)

where: c = char depth in mm
t = furnace exposure period in minutes
D = air-dried density of the timber in kgm^{-3}

An equation to determine the notional charring rate is included in AS1720.4 - Fire - resistance of structural timber members. The equation is:

$$c = 0.4 + \left(\frac{280}{D}\right)^2$$

where c = notional charring rate in mm/min
D = timber density at a moisture content of 12% in kgm^{-3}

AS1720.4 also provides an equation for calculating the fire resistant period of a protected timber member. The equation is:

$$Tp = ti + tm$$

where Tp = fire resistance period of a timber member protected with fire resistant insulation, in minutes.

ti = fire resistance period appropriate to the protective insulating system in minutes.

tm = fire resistance period of the structural timber member. For protected timber, the notional charring rate shall be multiplied by 1.1

The predicted char depths determined for both unprotected and protected timber members using the AS1720.4 calculations and those developed by Gardner and Syme (1991) need to be compared. The predicted char depths after two hours exposure to the standard heating conditions specified in AS1530.4 for timber members with densities of 550, 750 and 950 kgm^{-3} are protected with 13 mm gypsum plasterboard given in Table 7. A fire resistance period of 20 minutes was allowed for the gypsum plasterboard.

Table 7. Predicted char depths of unprotected and protected timber members using equations from AS1720.4 and Gardner and Syme (1991).

Density, kgm^{-3}	Char depth, mm			
	Unprotected		Protected	
	AS1720.4	G & S[1]	AS1720.4	G & S
550	79.1	91.7	72.5	45.3
750	64.7	67.7	59.3	31.6
950	58.4	53.8	53.6	23.8

Note 1 - G & S = char depth calculated from Gardner and Syme (1991)

From Table 7 it can be seen that there are differences in the predicted depths of charring depending whether the AS1720.4 calculations or those of Gardner and Syme (1991) are used. The AS1720.4 predictions of char depth for unprotected timber members of 550 and 750 kgm^{-3} density are less than those predicted from Gardner and Syme (1991). There are large differences between the predicted char depths for protected timber members using the calculation of AS1720.4 and Gardner and Syme (1991). The calculations in AS1720.4 are based on the assumption that the charring rate of the protected timber members will be greater after the temperature at the interface between the timber and the protecting material exceeds the charring temperature of timber. This research has shown that this assumption is incorrect when gypsum plasterboard is the protecting material.

The accuracy of the two prediction equations can be determined by reference to the reported depth of charring on loaded beams of radiata pine and brush box tested to AS1530.4 (Dayeh and Syme, 1993). The radiata pine beam had a density of 524 kgm^{-3} and failed in 67 minutes. The brush box beam had a density of 823 kgm^{-3} and failed in 59 minutes. The maximum depth of char reported for the sides and base of the beams after test are compared in Table 8 to the predicted char depths for the test exposure periods using the AS1720.4 equations and that of Gardner and Syme (1991).

Table 8. Comparison of actual and predicted char depths for loaded timber beams.

Species	Char depth, mm			
	AS1720.4	G & S[1]	Side[2]	Base[2]
Brush box	30.4	31.2	30.1	33.0
Radiata pine	45.9	54.4	51.8	56.3

Notes: 1 - G & S = char depth calculated from Gardner and Syme (1991).
2 - Char depth data from Dayeh and Syme (1993).

From Table 8 it can be seen that the char depths calculated from Gardner and Syme (1991) are slightly greater than the char depths from the side of the specimens reported by Dayeh and Syme (1993). The char depths calculated from Gardner and Syme (1991) are also closer to the char depths for the base of the specimens reported by Dayeh and Syme (1993) than those calculated from AS1720.4.

The AS1720.4 equations for the depth of char on unprotected timber members are underestimating the depth of char formed on low density timber species. The AS1720.4 equations are also overestimating the depth of char formed on protected timber members. As the AS1720.4 equations for determining depth of char have been shown to be less accurate than those of Gardner and Syme (1991), it is recommended that the current AS1720.4 equations for determining the depth of char on both unprotected and protected timber members be replaced by those of Gardner and Syme (1991).

b) Fire resistance testing of loaded timber beams

Dayeh and Syme (1993) reported the results of testing loaded beams of radiata pine and brush box to AS1530.4. The beams were nominally 4100 x 420 x 150 mm. The beams were exposed to the standard heating conditions of AS1530.4. The radiata pine beam failed after 67 minutes and the brush box beam failed after 59 minutes. The measured char depths on the beams after the furnace exposure were similar to those predicted by the equations of Gardner and Syme (1991) (see Table 8).

c) Fire resistance of protected timber structural elements

A decade ago the building codes in Australia would not allow even single storey Class 2 buildings (multi-family and commercial residential buildings) to be built entirely with protected timber framed fire resisting walls and floor/ceilings. The reluctance by the regulators to allow wider uses for fire resisting combustible construction was partly due to the lack of appropriate test data that demonstrated that timber framed structural elements would perform adequately.

The development of appropriate test data was considered to be essential to support porposals for obtaining more allowable uses in the BCA for timber framed fire resisting construction. A range of non-loadbearing and loadbearing internal and external timber framed walls have been tested to AS1530.4 (NAFI, 1993). A range of timber framed floor/ceiling assemblies have also been tested (TRADAC, 1993). A number of opinions on the fire resistance of other wall and floor/ceiling assemblies have been prepared from the test data.

The BCA was recently amended to allow two storey Class 2 buildings to be constructed entirely in timber framed fire resisting construction. The test data that have been developed helped create the climate in which such changes could be made. The forest products industry have submitted an application to have the allowances in the BCA further increased to allow for construction of three storey Class 2 buildings in timber framed fire resisting construction.

CONCLUSIONS

The fire performance properties of forest products are a major factor in determining their allowable uses in buildings. Australian research over the last decade has provided fire performance data on forest products that will be used to achieve the goals of a) having appropriate fire test methods prescribed in the BCA and b) ensuring the BCA allows the greatest possible range of safe uses for forest products in Australian buildings.

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A PRELIMINARY ABOVE-GROUND WOOD DECAY INDEX MAP OF AUSTRALIA

John Carter*, Myron Cause+ and Alan Moffat+
Queensland Department of Primary Industries
P.O. Box 631 Indooroopilly QLD 4068

* Drought Research
+ Timber Research

ABSTRACT

A computerised digital map of an above-ground wood decay index for Australia is presented. At this stage, the map uses long-term climate data, and is based on Scheffer's Index formula, as used in the United States. A calculated above-ground wood decay index can be obtained for any location by simply inputting point data for latitude and longitude.

The development of this map represents an important step forward in the quest for better information in designing for durability for weather-exposed wooden structures. Further work is required to secure project support and funding to calibrate an above-ground wood decay index to established actual timber field trial decay scores. The technology used to produce this map will readily facilitate developing a unique Australian Index, if this will produce better predictive results for the performance of timber structures.

1. INTRODUCTION

It is well known that timber structures supported above-ground and exposed to the weather may be subject to decay during service. The decay hazard shows evidence of being climate related e.g. timber exposed in a warm, wet location such as the Tropics is more prone to decay than if exposed in dry or cold climates. DeGroot and Esenther (1982) identified wood moisture content as the key environmental factor that must be either controlled or reckoned with in the design of biologically durable wood structures. They also noted that temperature has an important influence, as it affects the rate at which decay progresses, once it has become established.

Scheffer (1971) developed a formula to estimate the potential of a climate to promote decay of above-ground wood construction in the United States.

$$\text{Scheffer's Climate Index} = \frac{\sum_{\text{Jan}}^{\text{Dec}} \left[(T-2)\,(D-3) \right]}{16.7}$$

where T is the mean monthly temperature (°C); D is the mean number of days in the month with 0.25mm or more of precipitation; and Σ Jan/Dec is the summation of products for the respective months January through December. The sum of the products is arbitrarily divided by 16.7 to make the index for the United States fall largely within the range of 0 - 100. The index was then subdivided and mapped into three hazard areas, with 0-35 considered least favourable for decay; 35 - 65 intermediate; and more than 65 most conducive to decay. It appears that the index was calibrated with some limited timber exposure test results (Scheffer et al. 1963) set out in three locations at Oregon, Wisconsin, and Mississippi.

Later studies on actual decay in houses suggested that the upper limit of the intermediate decay index range be increased to 70 (DeGroot and Esenther 1982). When Setliff (1986) mapped the wood decay hazard in Canada based on Scheffer's climate index formula, he used the three hazard levels low $\langle$ 35; moderate 35-70; and high $\rangle$ 70. Setliff noted that while the decay index map is an attempt to quantify the decay hazards for different climates, actual field experiments are needed in Canada to better establish the accuracy of the decay index. More recently, Scheffer (1991) himself used a U.S.A. map with the intermediate decay index range set at 35-70.

Timber Research of the Queensland Department of Primary Industries Forest Service has made a substantial investment in establishing a long term above-ground timber natural durability trial in Eastern Australia (Cause 1993). This trial is quite extensive, with several thousand test pieces set out in weather exposed racks at eleven sites from Mt Isa to Melbourne. At this time, the test pieces have only been exposed for six years, but the trial appears to be well placed to provide reliable field data to calibrate an Australian above-ground wood decay index map.

This paper presents a digital map of an above-ground wood decay index in Australia. At this stage, the map uses long-term climate data,and is based on Scheffer's Index formula, as used in the United States. Further work will be required to correlate the decay index map to actual wood exposure trial results.

2. METHOD

The Drought Research Group of the Queensland Department of Primary Industries routinely produce and update computerised maps of rainfall and other applications of relevance to Agriculture. For this wood decay index work, a 5km digital elevation model for Australia was used to produce an ascii file of latitude, longitude and altitude. This file was then used as input to the Esoclim software package (Hutchinson 1989), to produce files of average monthly values for the variables *Raindays*, *Minimum temperature* and *Maximum temperature*. The Esoclim software evaluates equations which have been previously fitted to long term point data to enable estimation of climate at any point by simply supplying latitude, longitude, and elevation of that point.The files produced by Esoclim were transformed into binary raster images of Australia, each containing approximately 300 000 pixels.

Custom software was then developed to merge these climate input variables and calculate Scheffer's Index as a final binary image. The binary images of climate and Scheffer's Index were then produced as colour slides and colour postscript maps.

To make the final decay index map more useful, further software was developed to enable enquiry of data from any pixel in the output image. This means a calculated above-ground wood decay index can now be obtained for any location by inputting point data for latitude and longitude. Using this facility, point data was extracted for 22 sites, comprising 11 sites where the QDPI Forest Service above-ground durability trial is located, and a further 11 example sites around Australia.

3. RESULTS AND DISCUSSION

3.1 Mapping with Scheffer's Index

Table 1 presents the point data output of Scheffer's Index for 22 sites in Australia.

Note that in the Australian context, with high decay hazard in the tropical north, the U.S.A. formula (arbitrarily dividing by 16.7) results in index values in the range 0-200. We have calculated that to arbitrarily scale the index to encompass values of 0-100 in Australia, the divisor would need to be 33.2, and Table 1 presents both options for comparison.

AUSTRALIAN LOCATIONS	**SCHEFFERS' INDEX** using traditional U.S.A. formula, producing **0-200 FOR AUSTRALIA**	**SCHEFFER'S INDEX** Modified by Carter,Cause,Moffat **0-100 FOR AUSTRALIA**
Mount Isa, Qld	32	16
Canberra, A.C.T.	44	22
Toowoomba, Qld	66	33
Rockhampton, Qld	77	38
Melbourne (Frankston), Vic	81	40
Sydney (PennantHills), NSW	82	41
Townsville, Qld	87	44
Dalby, Qld	49	25
Hay Point, Qld	114	57
Beerburrum, Qld	116	58
Sth Johnstone, Qld	193	97
Onslow, W.A.	8	4
Alice Springs, N.T.	24	12
Roma, Qld	34	17
Dubbo, N.S.W.	36	18
Albury, N.S.W.	46	23
Perth, W.A.	59	29
Adelaide, S.A.	62	31
Hobart, Tas	64	32
Bundaberg, Qld	95	48
Darwin, N.T.	132	66
Cairns, Qld	175	88

Table 1 - Scheffer's Index for 22 Australian sites scaled 0-200 and 0-100 for comparison.

At this time, we see no reason to restrict the index to the range 0-100, and the maps subsequently presented in this paper use the traditional U.S.A. formula (Australian 0-200 index range).

Figure 1 presents a visual overview of the mapping processes involved, commencing with the digital elevation model and incorporating the binary raster images of temperature and rainfall to produce the final index map.

Figure 2 presents the above-ground wood decay index map of Australia, using three index classes. A further digital map using Scheffer's USA formula was produced with five index classes, but for reproduction reasons it is not presented in this (black and white) paper. This map retained the same two lower index classes as Figure 2, but further subdivided the 〉70 class into 71-105; 106-140; and 〉140.

3.2 Further Work (Map Calibration)

Much further work needs to be done. In particular, it will be important to secure project support and funding to calibrate an above-ground wood decay index to actual field exposure trials. We believe the established QDPI above-ground timber durability trial will be of great importance in achieving this. Calibration may also be assisted with installation of some additional timber test sites.

Initial calibration of an index map against field trial data will need to use actual mean monthly temperatures and raindays for the wood exposure testing period (in the case of the QDPI trial currently 1987-1992) as opposed to long term averages. This is because of decade length fluctuations in rainfall, and to a lesser extent temperature. Figure 3 illustrates these cycles with a ten year moving average for Queensland rainfall plotted against the long-term rainfall mean, showing the present 'below average' conditions.

4. CONCLUSION

The development of this computerised digital above-ground wood decay index map, and its associated ability to output a calculated index for nominated latitude and longitude point data, represents an important step forward in the quest for better information in designing for durability for weather-exposed wooden structures.

Now that the technology has been demonstrated with these interim maps, we anticipate the possibility of also developing a unique Australian index (rather than the USA Scheffer's formula), if such an index can achieve better calibration with actual timber field trial decay scores.

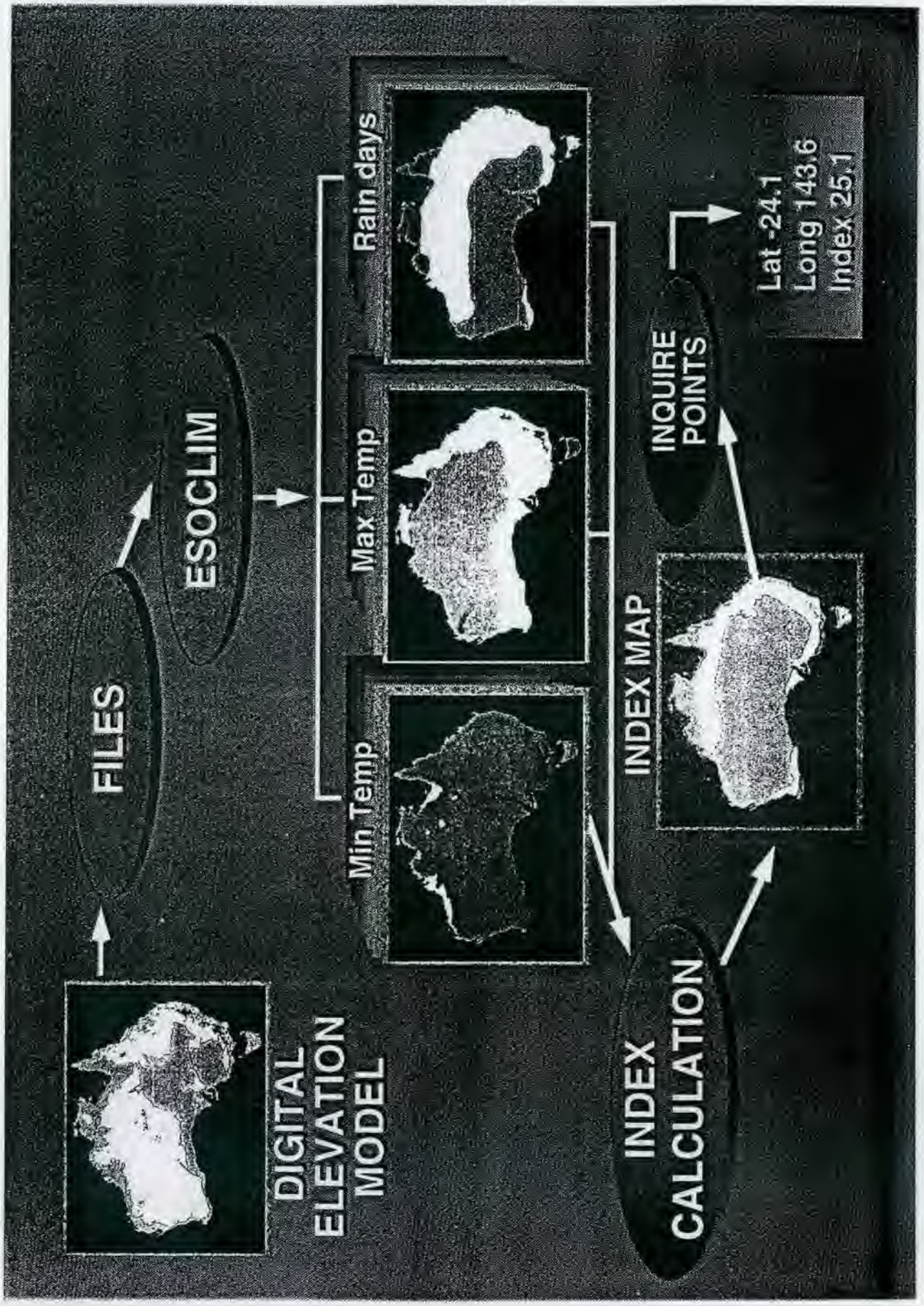
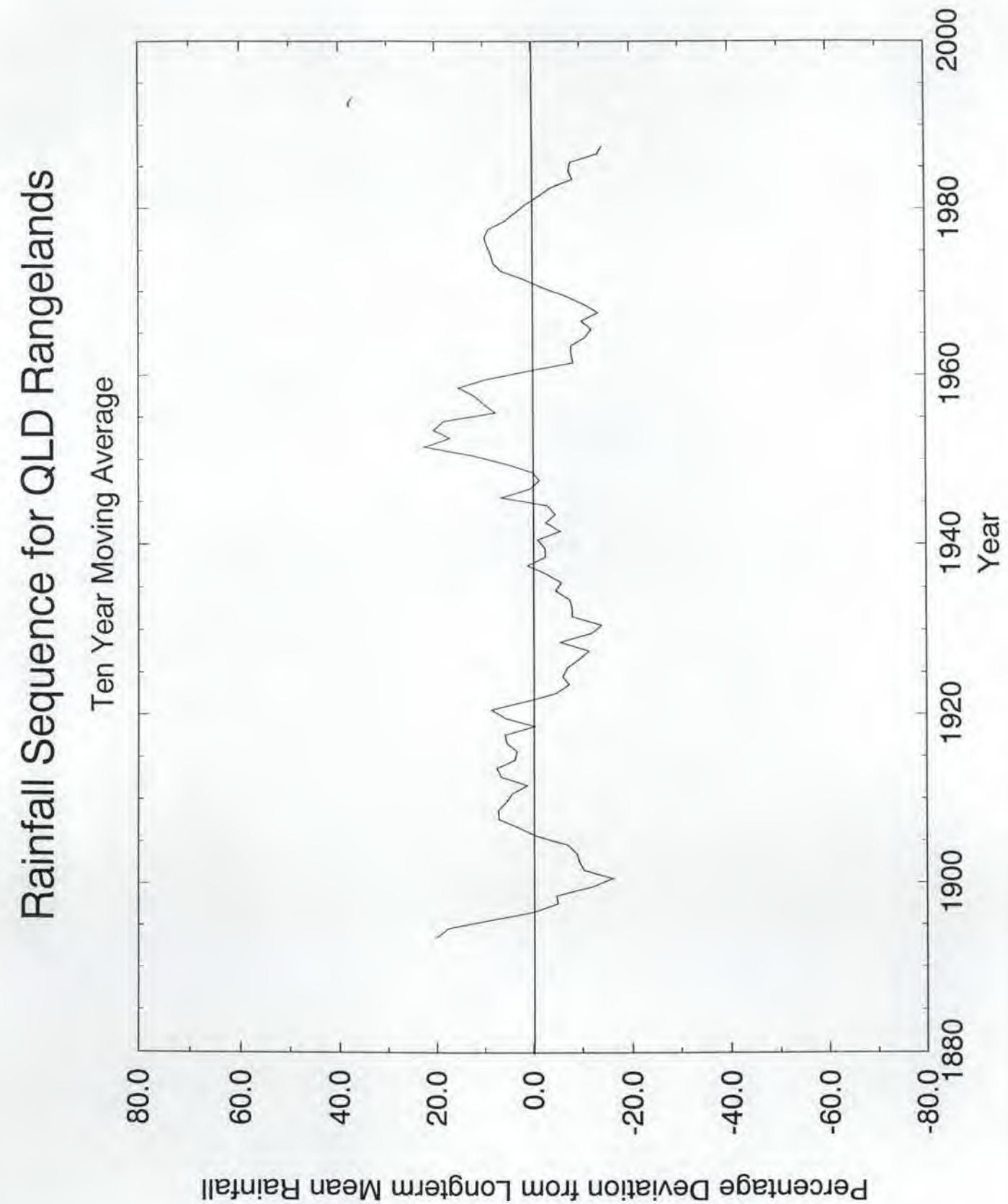


Figure 1- Overview of mapping processes involved

Figure 2 - Above-ground wood decay index map of Australia

Figure 3 - Rainfall fluctuations over time, showing deviation from long-term mean



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NOVEL PRESSURE PROCESSES FOR TIMBER TREATMENT AND CURRENT RESEARCH IN WOOD PRESERVATION AT THE UNIVERSITY OF MELBOURNE

Peter Cobham
and
Peter Vinden
School of Forestry
The University of Melbourne
Creswick VIC 3363

ABSTRACT

The development of pressure treatment processes for impregnating wood is reviewed from 1848 to the present day. The review forms part of research program being carried out by the University of Melbourne to improve heartwood penetration in radiata pine (*Pinus radiata D. Don*). Research focusses on the fundamental mechanisms leading to poor permeability and evaluates both pretreatment methods and novel pressure treatment techniques for improving heartwood treatment. A pilot scale treatment plant has been designed and built at the University of Melbourne to simulate commercial treatment processes and practices. All treatments involve the use of water-borne preservatives.

INTRODUCTION

Since the invention of the full cell process by Bethell in 1848 there have been few major changes or dramatic improvements to pressure treatment processes. The demand for alternative processing technologies has come from :

- environmental concerns - the need for totally self contained processes with no environmental contamination from spillage or waste generation.
- new market opportunities for high performance wood products to include surface hardness, colouring, dimensional stabilisation, fire proofing etc.
- the need for faster or more economic processing.
- better performance - eg. heartwood treatment.

New Zealand and Australia are fortunate in that the prime pine species grown are relatively easy to treat. Over the 150 years since industrial wood preservation began with the Bethell process many alternatives have been developed. Only three have stood the test of

time. These are the Bethell (full cell), Lowry and Rueping (empty cell) processes.In essence these are 3 generic processes from which most other processes have been developed.

One major problem associated with the water-borne treatment of pine species is the difficulty of achieving consistently high standards of heartwood penetration required by treatment specifications. Pretreatment or conditioning of the heartwood prior to treatment probably has as great an effect on the success of the treatment as the process being utilised. This paper reviews all known pressure treatment processes and re-evaluates their potential in the light of the availability of modern equipment and the availability of new techniques and technologies.

TIMBER TREATMENT PROCESSES

Table 1 lists treatment process developments in chronological order. Milestones in pre-treatment methodologies are also given . For the purpose of this review there is a focus on pressure treatments techniques.The permeability of wood to pressure impregnation is determined by the anatomical structure of the different wood species. This in turn influences the suitability of alternative process options. There are fundamental differences between hardwoods and softwoods. The presence of large diameter vessels running longitudinally in hardwoods provides a ready penetration pathway for liquids provided there are no tyloses. Penetration in softwoods generally occurs radially through ray tissue. There are no vessels in softwoods. Relative permeability between softwoods is generally determined by the size and anatomical structure of the ray tissue and the size of cross-field pits, ie. the openings between trachieds and ray tissue. Pine species are characterised by having very permeable ray tissue and large cross-field pits between trachieds and ray-tissue. The ray-tissue in other softwood species may be lignified and have smaller cross-field pits. Preservative penetration pathways become very much more convoluted, with greater resistance to penetration.The process of heartwood formation can lead to pit aspiration and the deposition of extraneous materials around pit membranes and the rays. The drying of wood - a prerequisite for many treatment processes also leads to pit aspiration which can reduce the permeability of wood to pressure impregnation. Many of the preconditioning techniques used for improving the permeability of wood will have a direct impact on these components

A new approach for penetrating refractory wood species involves the use of supercritical fluids as the solvent carrier. Supercritical fluids have properties which resemble liquids and gases, but their primary advantages are low surface tension, high volatility for easy recovery, the ability to dissolve biocides and penetrate through materials which are impermeable to conventional liquid treatments. The most commonly considered supercritical fluid is carbon dioxide which is in the supercritical region above 1076 psi.. These pressures are considerably above those traditionally used in timber treatment so there is concern about

TABLE 1 A CHRONOLOGICAL HISTORY OF PRESSURE TREATMENT TECHNIQUES DEVELOPED FOR TIMBER TREATMENT (1831- PRESENT)

DATE.	PROCESS.	CHEMICAL	REFERENCE
1831	**Breant** A full cell treatment	Creosote	(Wilkinson. J.G., 1979)
1838	**Bethell** A full cell treatment	Creosote	(Bethell. J., 1838)
1838	**Boucherie** Sap-displacement	CuSO4	(Hunt. G.M. & Garrat. G.A., 1953)
1879	**Boulton** Preconditioning and treatment in a single process.	Creosote	(Boulton. S., 1879)
1879	**Wellhouse** Wood initially impregnated with Zinc chloride and gelatine.A secondary impregnation with tannin solution caused a reaction between the gelatine and tannin forming a "leathery substance" which prevented the Zinc chloride from leaching from the wood.	Zinc chloride	(Hunt. G.M. & Garrat. G.A., 1953)
1880's	**Allardyce** A full cell process where the timber is initially treated with Zinc chloride at 75 to 100 psi. followed by Creosote at 100 to 150 psi.	Zinc chloride	(Hunt. G.M. & Garrat. G.A., 1953) Cr
1885	**Card** Two stage full cell process, the first impregnation with creosote followed by higher pressure with Zinc chloride.	Creosote/ Zinc chloride	(Card. JAB., 1885)
1902	**Wasserman (empty cell)** Commercialised by -Max Reuping.	Creosote	(Reuping.M.,1902;Wasserman., 1902)

DATE.	PROCESS.	CHEMICAL	REFERENCE
1902/3	**Heise** The cylinder is flooded with sufficient preservative to treat the wood then air pressure is applied to penetrate.	Creosote	(Van Groenou. H.B.,Rischen.H.W.L & Van Den Berge. J., 1951)
1905	**Creoaire treatment** This process used air pressure after draining the cylinder to improve the penetration of creosote.	Creosote	(Hunt. G.M. & Garrat. G.A., 1953)
1906	**Lowry (empty cell)**	Creosote	(Lowry. C.B., 1906)
1910	**Haltenburg & Berdenich (incising)**		(Haltenburg. & Berdenich., 1910)
1938	**Poulain** Process for improving the protection at groundline, a Rueping process followed by draining the cylinder to 2 metres above bottom of pole, then apply air pressure for further impregnation.	Creosote	(Van Groenou. H.B., et al., 1951)
1939	**Kuntz** A method for applying higher concentrations to the base of the pole compared to the rest of the pole.	Creosote	(Van Groenou. H.B., et al., 1951)
1939	**Nowak** Impregnation of substances such as paraffin oil, montan wax and bitumen in trichloroethylene.	Various	(Van Groenou. H.B., et al., 1951)
1950	**Gewecke pressure and suction method** Sap-displacement	CCA	(Wilkinson.J.G.,1979)
1952	**Hendrikson** The OPM. process	CCA	(Walchli. O., 1970)

DATE.	PROCESS.	CHEMICAL	REFERENCE
1960	**Ultra high pressure** 1000 psi.Australia. For the treatment of difficult to treat Eucalypt species.	CCA	(Dale. F.A., 1960)
1962	**Besher (Cellon Process)**		(Arganbright, 1973)
1972	**Hurst. H.G.,Pinner. A.L.& Kyte. C.T.,** LOSP Double vacuum method LOSP		(Hurst, H.G,et. al.,1972)
1969	**A.P.M. Process** A method for treating wood by alternating pressure from 0 to 1400 kpa for a number of cycles, the wood having been preconditioned by steaming.	CCA	(Vinden. P. & McQuire. A.J., 1978)
1969	**Hudson** Slurry seal process (sap displacement)	CCA	(Hudson. M.S., 1967)
1974	**McQuire** Q process (steam, store, and Bethell treat)	CCA	(McQuire. A.J., 1974)
1981	**Kelso** MSU.process	CCA	(Kelso. W.C. Jr., 1981)
1982(?)	Wet vacuum method as used in South Africa.	CCA	(du Toit. C., 1993)
1983	**McIntrye & Eadkin** Method for reducing sludge formation in CCA treating by the modified Bethell method using cooling of the preservative.	CCA	(McIntyre. C. & Eakin. D., 1984)
1983	**Pulsation.** A process for improving penetration in hard to treat species.	Various	(Hosli. J.P. & Filion. M. , 1983)

DATE.	PROCESS.	CHEMICAL	REFERENCE	
1988	**Vinden,P., R.J.Burton and Vaioleti,** Vapour phase treatment of wood with trimethyl borate	Tri-methyl Borate	(Vinden et al 1988)	
1990	**Vinden, Bergervoet, Nasheri, Cobham, Maynard & Brown** Lite Process-Treatment method using CCA which gives extremely low uptake, with rapid redrying in kilns.	CCA/Boron	(Vinden. P.,et al 1990)	
1990	**Nasheri & Vinden,** Sequential vacuum treatment	LOSP	(Nasheri. K., et al 1990)	
1992	**Cobham** A combination of processes to give environmental and productivity advantages in treatment.	CCA/Boron	(Cobham. P.R.S., 1992)	Flexitreat.

the effect of this pressure on wood. Smith et al (1993) report no significant difference between modulus of rupture or modulus of elasticity between samples treated with supercritical fluid at elevated pressures, temperatures or exposure period or between treated and untreated control samples. No evidence was seen of crushing or deformation of specimens treated at these higher pressures. Other new treatment technologies include high pressure liquid injection, new vapour phase technology and the addition of sonic waves to traditional treatments (Barnes. H.M., 1993).

Treatment standards both in New Zealand and Australia require a degree of heartwood penetration depending on the end purpose of the treated timber (Anon., 1980; Anon., 1984; Anon., 1986; Leightley & Kennedy, 1983). Many plants find the penetration depths required difficult to achieve on a consistent basis and are often unable to explain why various pieces treat and others do not. A simple visual examination is not able to predict treatability.

A pilot scale plant has been designed and built at the University to simulate all the normally used pressure treatment methods. The plant has been designed in such a way that times to reach vacuum and pressure can be controlled to reflect a full commercial treatment facility. Copper, chrome and arsenic (CCA) preservative has been selected to reflect commercial application, but also provide easy analysis of presevative penetration. The Bethell process has been used as the standard from which other processes are compared. The initial vacuum level and time were held constant.The working pressure was also held constant at 1400 kpa. Pressure treatment times were varied for 1, 60, and 180 minutes.The effect of pretreatment conditioning methodologies were also investigated. Predrying methods included no-drying, steaming, air, conventional and high temperature drying.

Internal wood pressure was monitored during treatment using micro-transducers implanted in the wood. Absorption measurements and spot testing of penetration were used in conjunction with video scanning imagery to determine the cross-sectional area treated with preservative to provided an assessment of the most promising techniques for improving heartwood treatment.

Differences between the hydraulic pressure and internal pressure in heartwood samples have tended to vary dramatically. Figures 1,2 and 3 show the pressure / time response curves for one end matched sample pre-conditioned by air drying, conventional temperature drying and high temperature drying. Figure 4 illustrates the almost instantaneous translation of treatment vessel pressures into internal pressures in radiata pine sapwood. Some leakage has been experienced with micro-transducers when used under vacuum. No such leakage has been recorded for hydraulic pressure.

Preliminary results of the effects of treatment time and drying method on the treatability of radiata pine heartwood are summarised in table 2.

TABLE 2. EFFECT OF DRYING TEMPERATURE AND TIME AT PRESSURE ON HEARTWOOD PENETRATION.

TIME ON PRESSURE

DRYING METHOD	1 minute			60 minute			180 minute		
	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV
Air dried*	38	24.0	63	65	27.7	43	74	25.0	33
Conventional**	56	31.0	55	69	21.9	32	88	18.1	21
Hjgh temp.***	66	30.4	46	88	17.4	20	96	5.4	6

SD Standard deviation
CV Coefficient of variation
* Ambient
** 70/60° C drybulb/wet bulb.
*** 120/70° C drybulb/wet bulb.

The results indicate a substantial improvement in heartwood penetration with increasing drying temperature and increasing time on pressure. The coefficient of variation was also markedly reducedwith increasing drying temperature and increasing time on pressure. Many of the heartwood samples had very high resin contents. Work is in hand to determine the effect of resin content and distribution on heartwood treatability.

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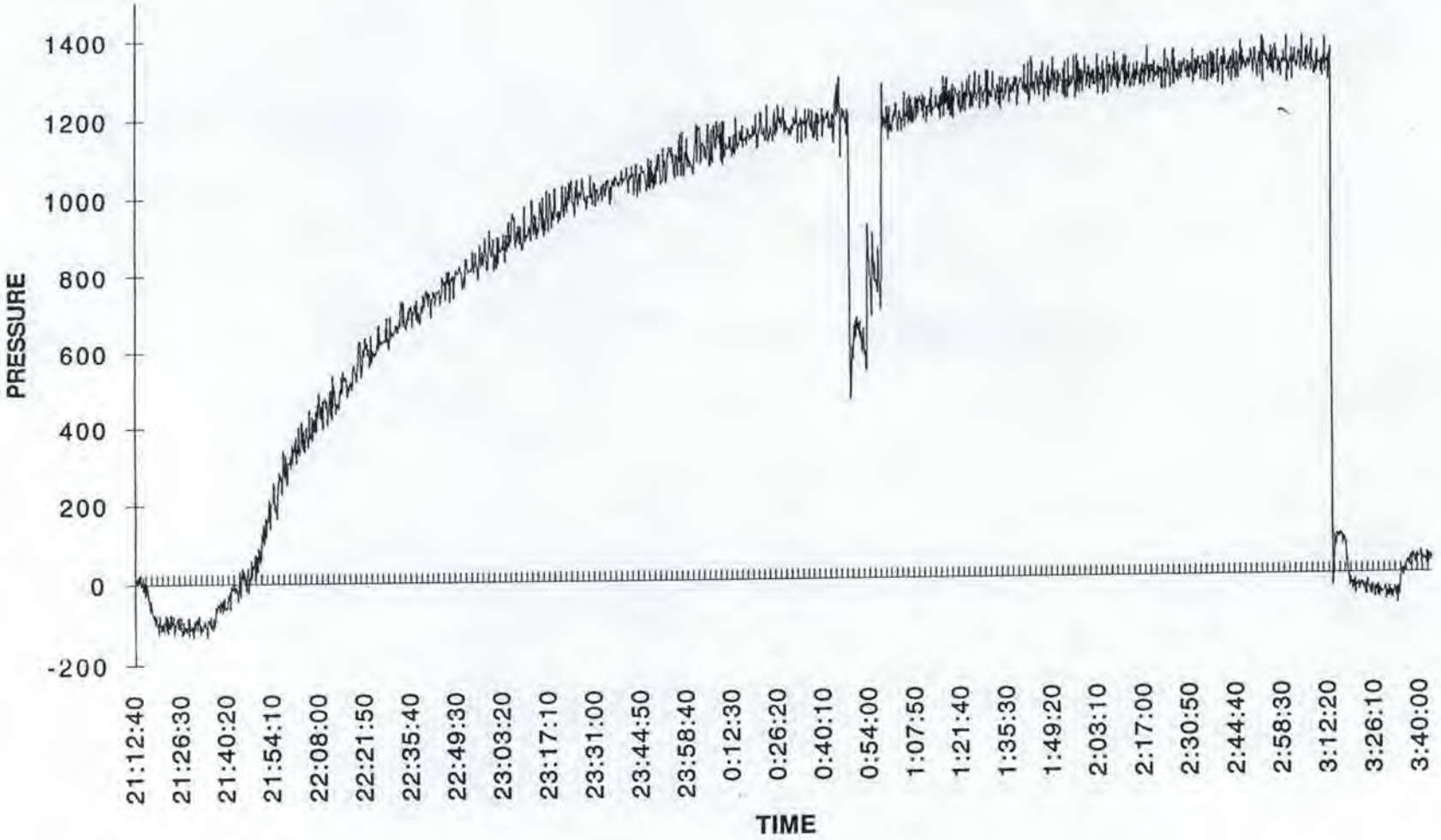
FIGURE 1. SAMPLE 5 AIR DRIED - BETHELL TREATED.

FIGURE 2. SAMPLE FIVE CONVENTIONAL TEMPERATURE DRIED - BETHELL TREATED.



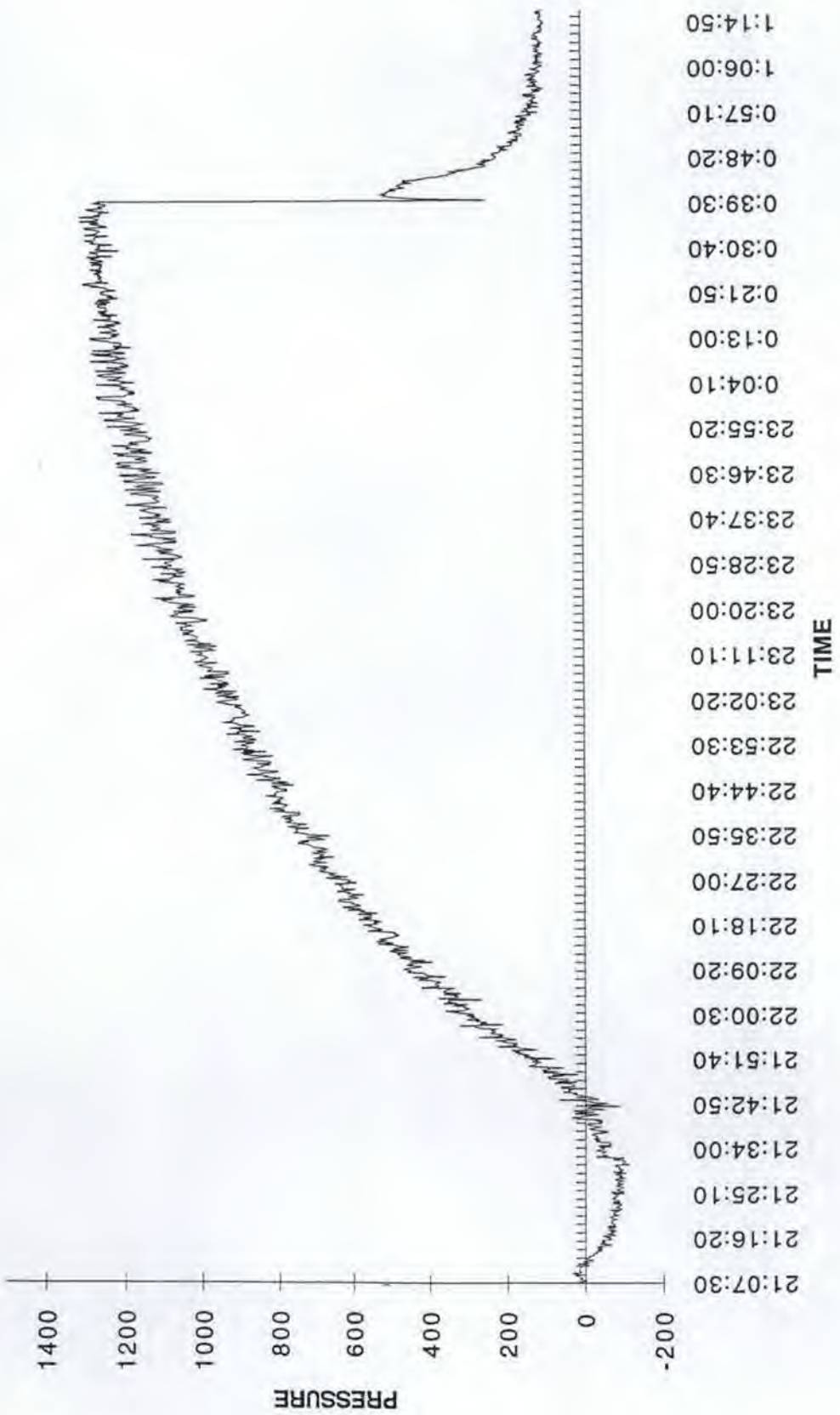


FIGURE 3. SAMPLE 5 HIGH TEMPERATURE DRIED - BETHELL TREATED.

WOOD FIBRE FOR THE SURFACE OF RACE TRACKS

Maureen A. Tighe and Gary C. Johnson
CSIRO Division of Forest Products
Private Bag 10, Rosebank MDC, Clayton, Vic. 3169

ABSTRACT

One of the more innovative uses of timber is as a wood fibre for the surface of training tracks for race horses. Since 1982, eight tracks with a wood fibre surface have been installed in Victoria. The fibre is produced from wood chips of various species. Studies were undertaken on the various physical characteristics of the wood fibre to ensure both suitability and longevity of the track's surface. Microbial aspects were examined in order to retard the biological breakdown of the fibre. The typical track with a wood fibre surface is regarded as an invaluable training facility providing trainers with an all-weather, fast-work surface that is safer and more durable than the alternatives.

INTRODUCTION

A variety of materials are used on the surface of training tracks for race horses. These include:

- sand
- sand coated with a polymer oil binder (Equitrack®)
- dirt
- sand/rubber
- hardwood sawdust
- wood fibre/sand and, more recently
- wood fibre.

Researchers have compared the incidence of injuries to race horses trained on different surfaces (Fredricson *et al.* 1982). Because of the better cushioning effect of the wood fibre compared with the other types of surfaces, a wood fibre surface results in fewer injuries. If properly laid and maintained, a wood fibre surface has the following advantages over other types of surfaces:

- more consistent than sand,
- lower cost than Equitrack,
- lower cost and less watering than USA-style dirt track,
- less prone to degradation than sawdust or wood shavings,
- not affected by UV rays as are the synthetic binders, and
- more environmentally acceptable than oil/sand or bitumen/sand.

In Victoria, there are eight training tracks with a wood fibre surface for race horses. A typical track has the following features:

- Construction costs of $500,000 which includes $150,000 for 4000 cubic metres of fibre plus $350,000 for the base.

- Deterioration of the wood fibre surface requires a replenishing of material every two years at a cost of about $40,000 for 1000 cubic metres.

- Complete surface replacement is required every 3-4 years at a cost of ~$150,000.

- The track is maintained by daily watering.

- In summer, up to 150,000 litres of water/day need to be applied to the track.

- Following watering, the track is levelled and rolled.

In general, the typical wood fibre track is regarded as an invaluable training facility providing trainers with an all-weather, fast-work surface.

CONSTRUCTION OF WOOD FIBRE TRACKS

The base is either crushed rock road base with agricultural drains or a geofabric layer on a blue metal foundation. The geofabric layer is a pervious polyester membrane resistant to rot, soil chemicals and UV. The wood fibre is generated by processing woodchips. The wood chips are fed into a tub grinder and, by using an appropriate sized screen, fibre of the required size is produced. In the early 1980's the fibre consisted of hardwood such as messmate. Other species have been used such as red gum, jarrah and mixed eucalypt species. Quality control of the timber processed to produce the fibre is vital. The material must be the more durable heartwood not sapwood. At the stage of construction, 200 mm depth of fibre is applied. Settling, wear and material loss over a three year period tend to reduce this layer to a depth of 100-150 mm. Proper drainage is

necessary for the performance of wood fibre surfaces. Watering is done using water tankers and is a very labour intensive exercise, and costly.

PHYSICAL ASPECTS

Attempts have been made to define the physical characteristics of a desirable fibre for the surface of race tracks. Eight samples of fibre were examined by several track managers who were asked to rank them in order of suitability. These eight samples were then put through a series of screens using a mechanical separator (Fig. 1) to give five fibre fractions. The separation was originally designed to give a quantitative evaluation of pulpwood chip quality based on chip size.

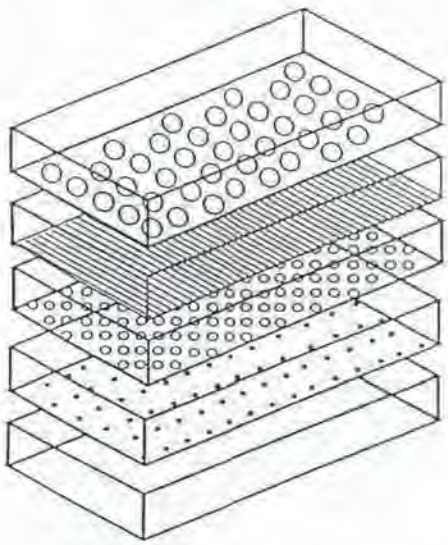


Fig.1. Schematic diagram of fibre screening apparatus showing one slotted screen.

The size of the openings in the screens usually used for wood chips would not have been appropriate for the wood fibre. Table 1 lists the type of screen and the material type retained on the screen.

TABLE 1. FIBRE FRACTIONS PRODUCED BY MECHANICAL SCREENING APPARATUS

Screen	Fraction retained on screen
25 mm round hole screen	Overlarge material
6 mm slotted	Overthick material
7 mm round	Acceptable fibre
3 mm round	Pin fibre
Bottom pan	Fines

Figure 2 shows a typical sample of the five fractions.

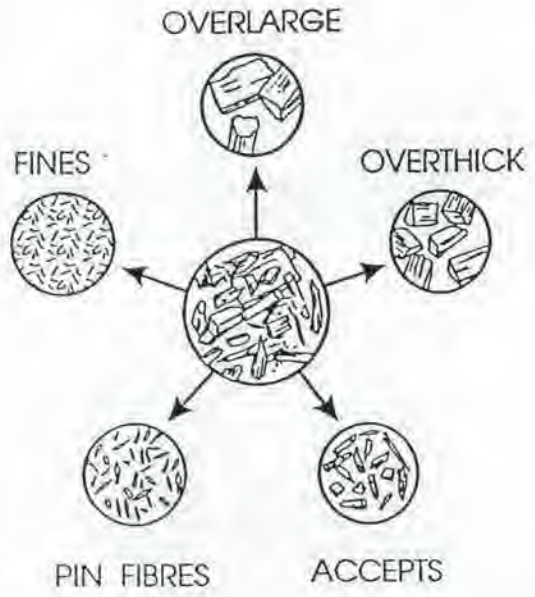


Fig.2. The five fibre fractions produced by mechanical screening

The percentage of each particle size retained by each screen is shown in Table 2. Samples C, E, G and F were chosen by the track managers as being the preferred type of fibre.

TABLE 2. PERCENTAGE OF THE FIVE FRACTIONS OF THE EIGHT SAMPLES OF WOOD FIBRE TESTED

Screen	C	E	G	F	A	B	D	H
25 mm round	-	-	-	-	0.7	-	1.2	-
6 mm slotted	3.5	8.2	2.5	3.1	7.3	0.5	9.3	1.8
7 mm round	47.5	53.0	46.7	40.5	74.7	14.4	31.8	19.8
3 mm round	36.0	28.9	36.7	44.8	15.9	56.9	41.7	52.7
Bottom pan	12.9	9.9	14.1	13.2	1.4	28.1	15.9	25.6

From Table 2 it would seem that the samples of fibre preferred by the majority of track managers contained an average of 47% of the fraction retained by the 7 mm sieve, 37% retained by the 3 mm round sieve and 12% of fines. This mixture of sizes provides a knitted mat that provides a good running surface. Comparing the four preferred types with

the remaining four the following differences in composition can be seen. Sample A had an appreciably higher content of the material retained on the 7 mm round screen and much lower percentages of the 3 mm round and the fines producing a slippery surface that does not settle. Samples B and H contained a very high percentage of the two finer fractions which produces a track that settles too much and becomes quite hard. Sample D contained too much of the oversize and over length pieces which are considered a risk to the horses. The fraction retained on the 7 mm screen was lower than desired and the two finer types too high.

MICROBIAL ASPECTS

Wood fibre will decay when exposed to decay fungi in an environment containing appropriate amounts of water, oxygen and nitrogen. For example, within the range observed at race tracks, the higher the level of nitrogen, the greater the rate of decay. The wood fibre should be protected from sources of nitrogen such as fertilisers, grass cuttings and poor quality water such as treated sewage effluent. Wood decay will occur when the carbon to nitrogen ratio drops to 80:1 or lower (Crawford, 1983). Two tracks with a wood fibre surface failed spectacularly over a very short time. The first was at the Shatin Race Course in Hong Kong and the second at Southport in Queensland. If one compared the two tracks, the following similarities were noted:

- Climate - Both tracks are in areas with hot, humid conditions.
- Rainfall - Both tracks experience high intensity of rainfall.
- Type of water used for watering track - Both used treated sewage effluent.
- Both tracks were in good condition for nine to ten months. The top 50 to 60 mm decayed rapidly resulting in total breakdown within the next two months.

A measure of the C:N ratio of the failed Southport wood fibre was compared with similar fresh fibre that was stockpiled and a sample of wood fibre from the Epsom track in metropolitan Melbourne which is watered with a brackish bore water.

Results of carbon: nitrogen analyses were as follows:

New wood fibre	327 : 1
Epsom (Victoria) track	203 : 1
Southport (Queensland) track	7.6 : 1

Obviously, nitrogen was being added to the Southport track. It was concluded that, in both cases of premature wood fibre failure, that the use of treated sewage effluent was the most likely source of extra nitrogen.

A laboratory scale test of three different sources of water on three different fibre substrates was undertaken for the Victorian Racing Club. The sources of water were: (a) treated sewage effluent from the Melbourne Water sewage works at Carrum; (b) treated sewage effluent from the Mornington Peninsula Water Board, and (c) bore water as used at the Epsom Training Centre.

The three types of wood fibre were: (a) coarse red gum fibre, (b) fine red gum fibre, and (c) mixed eucalypt species fibre. Table 3 shows the effect of watering with treated sewage effluent or bore water on wood fibre after six months.

TABLE 3. EFFECT OF TREATED SEWAGE EFFLUENT AND BORE WATER ON WOOD FIBRE CONDITION AFTER SIX MONTHS

Water source	Fibre type		
	Coarse red gum	Fine red gum	Mixed eucalypt spp.
Melbourne Water	++	+++	++++
Mornington Peninsula	+	++	+++
Epsom	-	-	-

+ = Softening and microbial attack.
- = No microbial attack.

As the cost of total replacement or even replenishing is a large expense, prolonging the life of all eight tracks with a wood fibre surface by just one month would save the industry $10,000.

Treating wood fibre with preservatives has not been effective to date (Wong, 1990). The disadvantages of the preservatives that have been used *in situ* are:

(a) lack of efficacy,
(b) run off problems,
(c) odour problems, and
(d) high cost.

In general trainers prefer the wood fibre surface for training of horses because of the low incidence of injuries incurred compared to other types of surfaces. If tracks with a wood fibre surface are to be cost effective then it is important to maintain good work practices and to ensure that the tracks are only watered with water of minimal nitrogen content.

ACKNOWLEDGEMENTS

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THE APPLICATION OF MODERN PROCESS CONTROL THEORY TO IMPROVE THE TIMBER DRYING PROCESS

J.P.S Viljoen
University of Stellenbosch
Private Bag X5018, 7599
Stellenbosch, South Africa

Abstract

At the present stage the timber drying process is controlled with empirically developed schedules. The drying process can be optimized using principles developed to control manufacturing processes in other industries. In this paper the application of mathematical models and feedback control principles to timber drying is discussed.

Introduction

The timber drying process can still be significantly improved using knowledge developed in other areas of manufacturing processes. A recent example of this is the very sucessful in-production-line green moisture content meter developed from declassified military research material in Canada. In some manufacturing processes advanced technology has been developed to meet high specifications on the final product.

In the timber industry the demands on the efficiency of the drying process have been significantly lower compared to some other industries. This issue will however not be dealt with in this paper. Only a small section of technology that has been developed in the field of process control has been implemented in the timber drying process. The possibilities of using this technology to improve the drying process has not yet been fully recognised.

Why is mathematical modelling necessary

In any manufacturing process the primary concern should be to have control over the quality of the final product. In the case of timber drying the criteria for optimal drying can be stated as follows:

Drying from green moisture content to the specified final moisture content

i) in minimum time
ii) using minimum energy
iii) minimum degrade to the final product.

Drying according to the above criteria should also result in maximum savings for the company. In order to satisfy the conditions for optimal drying it is essential to understand the drying process at a quantitative level, since a qualitative understanding cannot produce satisfactory answers in terms of degrade and resultant costs . For this reason, empirical studies will produce suboptimal results, although a contribution to the knowledge base of timber drying will be made by this approach.

In order to optimize the drying process, means of measuring moisture gradients, stresses and resulting probability of degrade (checking, distortion etc.) has to be available. If these properties can be measured in an industrial set-up, a control system can be designed to control degrade during normal kiln drying using feedback of these measurements. In this process the conditions (dry and wet-bulb temperatures, air speed) will be altered continuously in order to keep the probability or risk of degrade within specified limits (see Fig. 1). The above mentioned measurements however cannot be made accurately in an industrial set-up yet. The only way of reproducing this information is by mathematical modelling.

In order to describe a physical process mathematically it must first be understood as comprehensively as possible. Describing the drying process involves describing firstly the mechanism of moisture

movement and subsequently the mechanism of degrade as a result of the moisture movement. A model of moisture movement has already been developed at CSIRO (Sutherland et. al. 1992). The model attempts to describe the physical processes involved in timber drying mathematically as rigorously as possible. Currently the model is being improved by using the most recent formulations of the different processes involved in moisture movement.

The use of simulation models in timber drying research

Simulation models or predictive models as they are often referred to attempt to simulate the behaviour of a physical process in a software environment. Valuable insight can be obtained from simulation studies which can lead to improved industrial practices and in the case of timber drying improved schedules can be developed in this way. The simulation model also has the function of an education tool because it provides a knowledge based interface with the user.

In the case of timber drying a simulation model can be used to study (or observe) the behaviour of timber under a variety of conditions. Because only a limited number of measurements can be made in experiments, the simulation model has the potential to provide more information , if the model is accurate, than actually drying timber in an experimental set-up.

Open loop simulations can be used to produce close to optimal schedules using a model. This process is illustrated in Fig. 2. Since feedback measurements are not used , it will be however difficult to establish how optimal these schedules would be. This topic has been extensively covered by Northway(1990).

Development of a knowledge based software environment

Knowledge based computer systems are software environments designed to aid in solving problems that require expertise to some degree . A knowledge based system of timber drying would contain a mathematical model and comprehensive data about wood properties for different species related to moisture movement and stress development. Examples of such data are diffusion coefficient, capillary coefficient, permeabilities of gas and liquid , modulus of elasticity etc. Only in this situation can the effect of variable wood properties be accurately observed .

Industrial implementation of developed models

Various mathematical models of moisture movement and degrade have been developed over recent years. The choice of a suitable model for industrial implementation is however quite complex if an optimal solution is sought. It has often been found that the most elegant and rigorous models turn out to be failures when implemented industrially (Pavlik 1978). The statement has also been made that "a model which is too detailed and exact not only causes avoidable expenditure in hardware , software and calculation time, but that too much exactness in detail, paradoxically can also reduce the overall exactness of the simulation (predicted) result " (Karplus 1966).

It might be necessary to make appropriate simplifications in order to combat problems of stability or simulation errors that may arise in industrial implementation. A high degree of insight in the process and model is however necessary to find the "right" model concept and depth (Pavlik 1978).
In the case of drying models the predicted moisture gradients should be verified experimentally, as well as the predicted (simulated) average moisture content. This has not been done by any researcher known to the author in the area of timber drying with the exception of Lessard (1980). An extensive study of moisture gradients that occur in high temperature drying of Radiata Pine has been made by Northway (1989),which can be used to verify the moisture gradients predicted by the model.

Implementation issues:

i) Knowledge based models

One way of implementing a developed model is to integrate it with available plant measurements (dry and wet-bulb temperatures, air speed, average moisture content) in a data acquisition software environment.
The model output can be interpreted as observed internal states within the dried timber that cannot be measured with sensing devices. In this capacity the model will function as a supervisor to provide the operator with information about moisture gradients, resultant stresses and risk of checking. The operator can then decide what action to take.

Because the model is knowledge based, the accuracy of the output of the model (moisture gradients, stresses) will be dependent on how well the wood properties are represented for a particular stack. This is a general drawback of knowledge based models , since it normally requires a large number of wood properties.

If the modern control system approach is to be followed, the setpoints of the kiln (dry and wet-bulb temperatures) should be changed automatically according to some parameter of risk of degrade, that is if the object is to control the quality of dried timber. To achieve this a closed loop feedback configuration must be used (Fig. 1), so that the model output is used to change the setpoints instead of using a schedule. This process will be very complicated if a knowledge based model is used, since these models are extremely non-linear and not necessarily stable in this configuration. Using the model in an open loop configuration might produce better results. This situation still has to be investigated in an industrial set-up. The condition for the model to be representative of the timber currently being dried are that the wood properties of the stack must be known or able to be estimated within reasonable accuracy.

ii) Robust engineering models

The engineering approach would be to use state - space models, which do not depend on specific wood properties but these properties are estimated on-line using system identification techniques.
Powerful such techniques and state observers have been developed in the field of modern control systems theory that can be applied to most industrial processes. Following this approach it is possible to estimate a number of internal states in timber (eg. moisture distribution) using limited measurements (average moisture content, dry and wet-bulb temperatures). The measurements from harsh conditions can also be used, since the system has excellent techniques to deal with process noise. Prior knowledge about initial states (green moisture content, temperature) is also not necessary A stress actuator control system using this approach has been successfully implemented in a replicated industrial kiln at the University of Stellenbosch, South Africa. It was also demonstrated using this system that the drying time can be reduced significantly (30- 50%) without increased risk of degrade if the drying is controlled by allowable stress setpoints instead of schedules.

Conclusions

The highest priority at this stage, according to the author, is to develop a knowledge based software environment in which a mathematical model of drying will be a vital ingredient. This environment can be invaluable to assist a range of users (research workers, engineers, industry people) in problem solving. Final implemented systems should be designed assisted by this knowledge based computer aided shell. It might be necessary to employ several model reduction techniques to find a suitable model for implementation.

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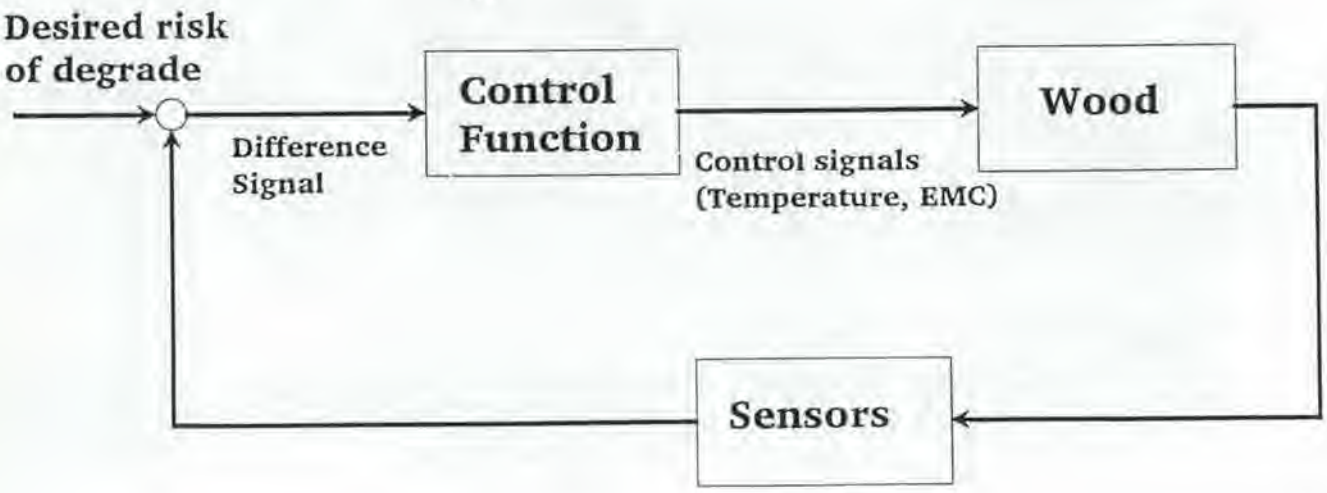

Figure 1. Degrade control system

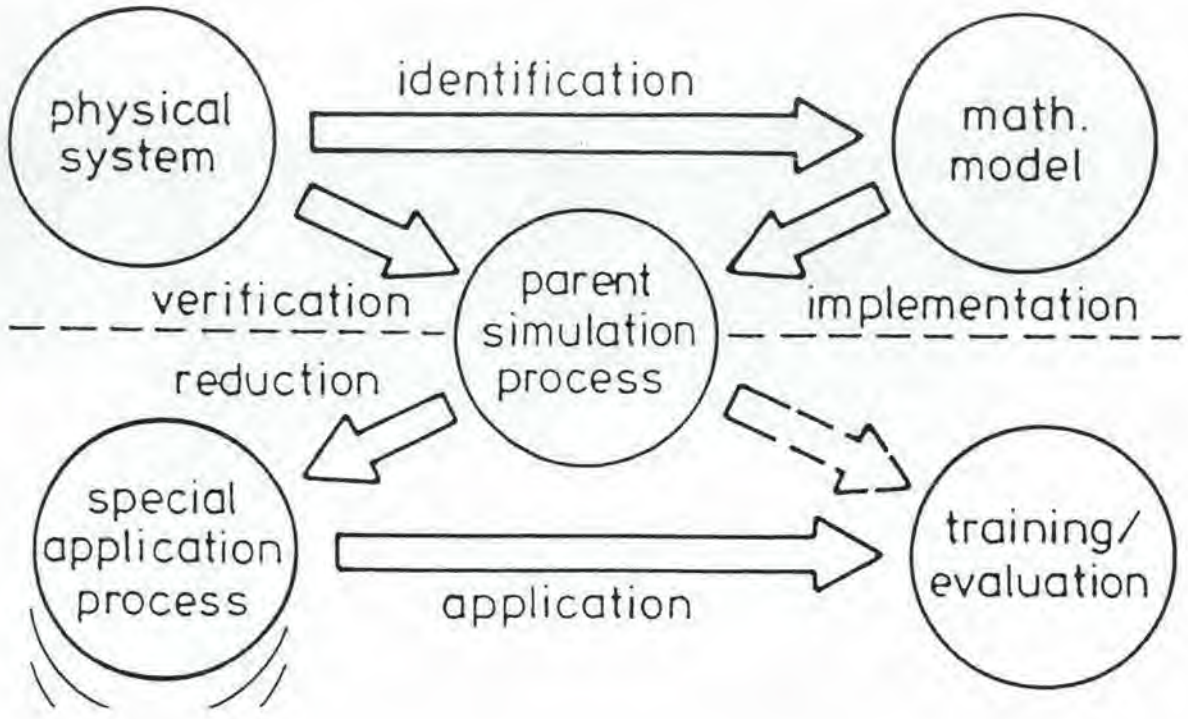

Figure 2. Schematic survey of the simulation development process

(Hoogstraten, J.A., van de Moesdijk, G.A.J.
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THE WOOD PROPERTIES OF PROGENY NZ55 WITH SUPERIOR TMP ENERGY AND OPTICAL CHARACTERISTICS DIFFER SIGNIFICANTLY FROM STANDARD RADIATA PINE.

J.G. Nyakuengama and P.D. Evans
Department of Forestry, Australian National University
Canberra, ACT 0200.

ABSTRACT

Significant differences were found between the physical (wood density, cross-sectional dimensions, cell wall thickness, the thickness of latewood-earlywood middle lamella) and chemical properties (lignin and extractive contents) of the corewood of a genetically improved radiata pine (NZ55) and a standard radiata pine (NZ1060). In addition NZ55, unlike NZ1060, contained a form of "mild" compression wood. These differences in wood properties may in part explain the superior thermomechanical pulping energy and light scattering coefficient characteristics of NZ55 compared to the standard radiata pine (Corson *et al.* 1989).

KEYWORDS

NZ55 radiata pine, thermomechanical pulping, TMP energy saving, paper brightness, basic and X-ray densitometric densities, fibre cross sectional dimensions, lignin and extractive contents, mild compression wood.

INTRODUCTION

Thermomechanical pulping (TMP) produces paper that is used in the manufacture of a number of products, including newsprint and paper nappies. During TMP pre-steamed wood chips are mechanically defibrated into individual fibres inside an electric refiner. Consequently, compared with other forms of pulping TMP consumes a lot of electrical energy and a large international effort has been devoted to reducing the energy consumed during TMP.

Hartler (1990) contends that energy consumed during mechanical pulping depends primarily on wood properties and less importantly on product specification. Literature supports this view suggesting that high density wood with high latewood percentage, i.e., the Southern pines, requires more energy to defibrate than low density wood with low latewood percentage, i.e., spruce (Koch 1972). Latewood fibres of high density wood have poorer lateral conformability (Higgins *et al.* 1973) and may consume a considerable amount of energy to bring about collapse during mechanical pulping (McMillin 1969). Other information on the effect of wood properties on energy consumption during TMP is less readily available. Blechsmeschmidt (1986) found a negative relationship between the ease of fibre separation during mechanical pulping and middle lamella thickness. Timell (1986) reviewed the work of Schafer *et al.* (1937) and concluded that the ease of fibre separation in compression wood

during mechanical pulping was facilitated by the presence of large numbers of inter-cellular spaces. Lastly, pre-treatment of wood prior to TMP, eg. roll-crushing the wood (Puri and Higgins 1984) or digesting it with lignolytic fungi such as white rot *Phanrochaeta chysosporium* (Leatham *et al.* 1990), reduces energy consumption.

Corson *et al.* (1989) found that a fast growing, genetically improved progeny of radiata pine *(Pinus radiata* D. Don), NZ55, had superior TMP properties compared to standard New Zealand radiata pine, NZ1060. In particular, the corewood of NZ55 required 20 % less energy to refine to 100 CSF, had a higher light scattering coefficient and comparable tensile strength to NZ1060. NZ55 also produced paper of equal tensile strength but lower tear strength to that of standard pine (Corson *et al.* 1989). These findings emphasise the importance of wood properties in determining the ease of pulping and eventually the quality of the product. However, the underlining reasons for the superiority of NZ55 during pulping were unknown.

The purpose of this work was to determine the differences (if any) in the physical and chemical properties of the NZ55 and NZ1060 wood used in Corson *et al.* (1989) original study. The general hypothesis of this study is that there are physical and chemical differences between the wood of NZ55 and NZ1060 and that these differences may account for the superior mechanical pulping properties of the former.

MATERIALS AND METHODS

Wood samples

The standard New Zealand radiata pine, NZ1060, wood used in this study was harvested from compartment 1060 of the Kaingaroa State Forest, New Zealand. Wood material of the genetically improved radiata pine, NZ55, came from a compartment adjacent to the compartment 1060, in the Kaingaroa State Forest, New Zealand. The New Zealand standard and genetically improved radiata pines were referred to by Corson *et al.* (1989) as the reference or standard radiata pine and the superior pine, respectively. Single discs (35-55 mm thick) containing 34 growth rings each were collected randomly from the boles of three NZ1060 trees and four discs with 9, 11, 13 and 15 growth rings each, respectively, were similarly collected from NZ55. The wood discs were air-dried and mailed to the Australian National University (ANU) where they were stored under refrigeration (4 °C) during the analysis of their properties.

Fibre length

Fibre[1] length was determined following a modified hydrogen peroxide method of Ladell (1959). Growth rings on each wood disc were sequentially numbered from the pith and slivers 50 mm (tangential) x 30 mm (longitudinal) were cut. Individual growth rings were then dissected from the slivers with a chisel and placed in separate 250 mL conical flasks containing 150 mL of 10 % sodium hydroxide (Analar) and allowed to digest for 4 h in a water bath at 90 °C. Following digestion, the macerated wood was transferred into test tubes containing

[1]Fibre means tracheid.

50 mL of a 1:1 mixture of 30 % hydrogen peroxide (Analar) and glacial acetic acid (Analar). The mixture was left to digest for 3 h in a boiling water bath following which the test tubes were cooled to room temperature and hand shaken to completely macerate the fibres. The fibres were washed in distilled water to a litmus paper pH of 6-7. 150 mL solution containing the macerated fibres were then transferred into sealable plastic vials (Falcon, 116 mm in length and 28 mm in diameter). Sealed vials were then mailed to the Australian Newsprint Mill in Boyer, Tasmania, where fibre length and proportion of fibres in various fibre length classes were measured on a fibre analyser (Kajaani F200).

Gravimetric and X-ray densitometric densities

Gravimetric (basic) density for each wood disc in every odd numbered growth ring from the third to the fifteenth growth ring was determined using an Archimedean method (ASTM 1986).

X-ray densitometric parameters (maximum, minimum and mean density) of the standard radiata pine NZ1060 and the superior radiata pine NZ55 were determined according to a method essentially similar to that of Rudman *et al.* (1969).

Latewood Proportions

The latewood proportions of NZ1060 and NZ55 were determined according to a modified method of Harris (1969). The horizontal distance representing the width of the growth ring (W) was measured on the paper densitometric charts obtained by the above method. Mid density points on the latewood peak of each growth ring were defined as half the vertical distance between maximum and minimum densities on the densitometric trace. The horizontal distance (D) between the mid density points on the latewood peak of each growth ring was also measured. The latewood proportion of the growth ring was then calculated as the ratio of the distance between the mid density points on the latewood peak of each growth ring to the width of the growth ring (D/W). Mean latewood proportions of each tree disc was calculated as the average of the latewood proportions of the third and thereafter every odd numbered growth ring up to growth ring number fifteen. Finally, the mean latewood proportion of the families (NZ1060 and NZ55) was then obtained by averaging the mean latewood proportions of the discs in the families.

Proportions of latewood in arbitrary density classes of 300, 350, 400 up to 650 kg m^{-3} were determined in NZ1060 and NZ55 by firstly drawing horizontal lines corresponding to the densities on the densitometric charts. Mid density points for the density classes were defined by points where the horizontal lines crossed the densitometric trace. The distance between the mid density points of each latewood peak of each growth ring (D_i) and the total horizontal distance of the densitometric trace (R) were measured for each density class. The proportion of latewood in the i^{th} density class of each family member was then calculated as follows;

Proportion latewood for the i^{th} density class = $[(\sum D_i)/R]$

Where, R = Total radial distance from the pith to the latewood of the last ring

$(\sum D_i)$ = The sum of distances between the mid density points of each latewood peak

of each growth ring for the i^{th} density class.

The mean proportion of latewood in the i^{th} density class for the progeny was then obtained.

Electron microscopy

Strips 30 mm (longitudinal) x 40 mm (tangential) were cut from each wood disc, cleaned on an electric sander and growth rings numbered sequentially from the pith. The third and thereafter every odd numbered growth ring up to the fifteenth growth ring were then dissected from the strips and extracted overnight in 99.8 % ethanol (Analar) using a Soxhlet apparatus. The extracted specimens were softened by submerging them in distilled water for 2 days. Specimen blocks 10 mm (longitudinal) x 10 mm (tangential) x 15 mm (radial) were cut from the softened wood using a single edged razor blade (Blu-strike E2010). The blocks were then clamped, transverse face upwards, onto the stage of a binocular light microscope (Nikon 75798). A clean transverse surface was prepared using a single edged razor blade (Magnuson Injector) while viewing the specimens at a magnification of x 40-60. The specimens were then air-dried for 2 days over silica gel and glued onto aluminium stubs with nail polish before being further air-dried as before and gold coated in a gold sputter coater (Polaron E 5000) for 4 min under an electric tension of 1.2 kV and a coating current of 20 mA.

Scanning electron microscope (SEM) images of radially aligned cross sections of each growth ring were obtained using a Cambridge Stereo-Scan SEM 360 operating at an accelerating current of 20 kV and recorded on heat sensitive paper (Mitsubishi thermal paper K61S) using a video-graphic printer (SONY TY UP811).

All fibre dimensions of distance and area were made from the video-graphic images using the Jandel scientific digitiser as follows. Each video-graphic SEM image was laid, face upwards, on top of a digitising tablet (Hipad plus, Houston Instruments). Radial fibre and lumen diameters of any cell within the SEM video-graphic images were measured by tracing the radial distance between the opposite ends of the cell walls and the lumen with a digital pen, respectively. About 150 frames of SEM video-graphic images of transverse sections were photographed at a magnification of x 800 for earlywood and a similar number for latewood in each growth ring. Approximately 2 fibres per frame of SEM video-graphic image were measured for radial fibre diameter and paired lumen diameters. 50 measurements of radial fibre diameter and paired lumen diameters were taken from randomly selected latewood. This procedure was repeated for earlywood. Cell wall thickness was calculated as the difference between fibre and lumen diameter divided by two. Another parameter also calculated was Runkel ratio [twice cell wall thickness divided by lumen diameter]. Additionally, 50 latewood and earlywood fibres SEM images photographed at a magnification of x 800 were randomly selected in each of four growth rings (numbers 3, 7, 11 and 15) of each wood disc. The total area and corresponding lumen area of the fibre images were measured by tracing the borders of the whole fibre and the lumen with a digital pen, respectively. Fibre wall area was obtained by subtracting the lumen area from total fibre area.

SEM images of transverse sections were taken at a magnification of x 1 500 at the

latewood and earlywood boundary between growth rings 3 and 4, 7 and 8, 11 and 12 and 13 and 14 for each wood disc. Latewood and earlywood boundaries 50 measurements were taken at random on the SEM images by tracing the line representing the thickness of the middle lamella with the digital pen of the Jandel scientific digitiser.

Chemical analysis

Strips 30 mm (longitudinal) x 40 mm (tangential) were cut from each wood disc whose growth rings had been previously numbered sequentially from the pith. Pairs of consecutive growth rings from the first up to the fifteenth growth ring were dissected with a chisel and reduced to match-size slivers which were then ground in a Wiley mill to pass 20-40 mesh screen. The resulting wood flour was stored in sealed plastic vials under refrigeration at 4 °C and used for all subsequent chemical analysis (ethanol-extractive and lignin contents).

Ethanol-extractive content of duplicate wood flour samples was determined according to a modified method of Browning (1967). 1 g of wood flour was placed in a tared, oven-dried Whatmann cellulose extraction thimble (30 mm internal diameter and 100 mm depth). The extraction thimble and its contents were then oven-dried at 105 °C (± 2 °C) for 24 h, weighed on an analytical balance (Mettler, Type B) and extracted in a Soxhlet apparatus with 250 mL of 99.8 % ethanol (Analar) for 4 h. After extraction, the wood flour was slowly washed with 1 L of hot-water (80 to 90 °C) and the thimbles and their contents were then removed from the Soxhlet apparatus, dried over-night at 105 °C (± 2 °C) and weighed as before. The mean ethanol-extractive content of the duplicate samples was then calculated as a percentage of the original oven-dry weight.

The Klason (acid insoluble) lignin content of duplicate wood flour samples was determined according to a method essentially similar to the Standard Method T222-om-83, designation: D1106-84, ASTM 1987, except in this study 99.8 % ethanol (Analar) was used to extract the wood flour.

Statistical analysis

To test the specific hypothesis that there are no significant statistical differences between the physical and chemical properties of NZ1060 and NZ55, data obtained on these wood properties were subjected to a split-plot design (Payne and Arnold 1989) analysis of variance (ANOVA) run on GENSTAT 5 (Lane *et al.* 1987) using a VAX/VMU computer. In this study statistical differences in a wood property between NZ1060 and NZ55 are given at the 90, 95, 99 and 99.5 % confidence levels.

RESULTS

The average arithmetic fibre length was similar in NZ55 and NZ1060 but length weighted and weight weighted fibre length were greater in the former (Table 1).

Table 1. Mean results of fibre length

Progeny	Arithmetic mean	Weight weighted	Length weighted
NZ1060	2.061(0.197)*	2.836(0.136)	2.573(0.137)
NZ55	2.138(0.197)	3.444(0.136)	3.101(0.137)

* standard deviation in parentheses.

Both NZ1060 and NZ55 showed radial increases in fibre length similar to those observed in radiata pine in previous studies (Bamber and Burley 1986). Radial profiles of length weighted and weight weighted fibre length were similar to each other, but differed from the radial profile of arithmetic mean fibre length.

There were highly significant ($p<0.005$) within tree differences in fibre length. The length and weight weighted fibre lengths of NZ55 were significantly ($p<0.05$) greater than those of NZ1060 (Table 2). In contrast, there was no significant difference ($p>0.10$) in average fibre length and proportions of fibres greater than 2 mm between the two progenies. Results here also indicate a significant difference in the distribution of fibre lengths between NZ1060 and NZ55 since the latter had a significantly greater proportion of fibres in excess of 4 mm ($p<0.005$). These results confirm that NZ55 has more long fibres than NZ1060 (Table 2).

Table 2. Mean results of fibre length percentage distribution

Progeny	> 2 mm	> 4 mm
NZ1060	69.4(11.08)	7.10(3.36)
NZ55	71.4(11.08)	24.18(3.36)

Minimum, mean and maximum densities (Fig. 1) and basic density in NZ1060 and NZ55 tend to increase with increasing ring number from the pith in patterns similar to those previously observed for radiata pine and loblolly pine (Harris 1969, 1981).

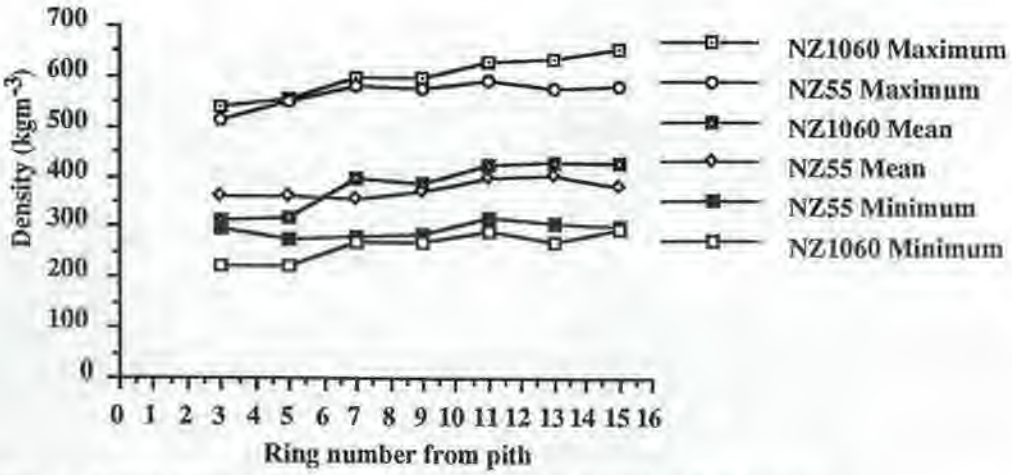


Fig. 1. X-ray density patterns in NZ55 and NZ1060 radiata pines.

Results of basic, mean, minimum and maximum densities shown in Table 3 indicate that NZ1060 has similar basic and mean densities, lower minimum density and a higher maximum density than NZ55. No significant ($p>0.10$) difference was found in the basic and mean densities of NZ1060 and NZ55, but NZ1060 had a slightly higher ($p<0.10$) maximum density and a significantly ($p<0.01$) lower minimum density than NZ55. All components of density exhibited a significant ($p<0.001$) and mainly linear variation with ring number, confirming the trend observed in Fig. 1 that density depends on ring number from the pith. The ANOVA suggested that ring by progeny interaction was weak, but was a significant ($p<0.10$) source of variation for mean density.

Table 3. Mean results of densities

Progeny	Basic density (kg m^{-3})	Mean density (kg m^{-3})	Minimum density (kg m^{-3})	Maximum density (kg m^{-3})
NZ1060	352.2(5.43)	385.9(6.68)	264.3(7.19)	601.0(12.25)
NZ55	334.2(5.43)	372.0(6.68)	293.9(7.19)	563.7(12.25)

The radial pattern for latewood proportion in both NZ1060 and NZ55 was similar to that observed previously (Nicholls and Eldridge 1980) for radiata pine. Results in Table 4 suggested that the average latewood proportion was slightly higher in NZ1060 than in NZ55.

Table 4. Mean results of latewood proportion

Progeny	Latewood proportion
NZ1060	0.2641(0.026)
NZ55	0.2244(0.026)

There was no significant ($p>0.10$) between progeny variation in latewood proportion. In contrast, there was a highly significant ($p<0.005$) within progeny variation in this wood property. More importantly, there was a marked difference between NZ1060 and NZ55 in the

radial variation of latewood proportion as indicated by a significant ($p<0.05$) progeny by ring number interaction.

The distribution of latewood by density classes in NZ1060 and NZ55 is shown in Fig. 2. NZ55 had a higher proportion of earlywood in low density classes and a lower proportion of latewood in high density classes ($\geq$ 400 kg m^{-3}) than NZ1060. No comparable literature is available.

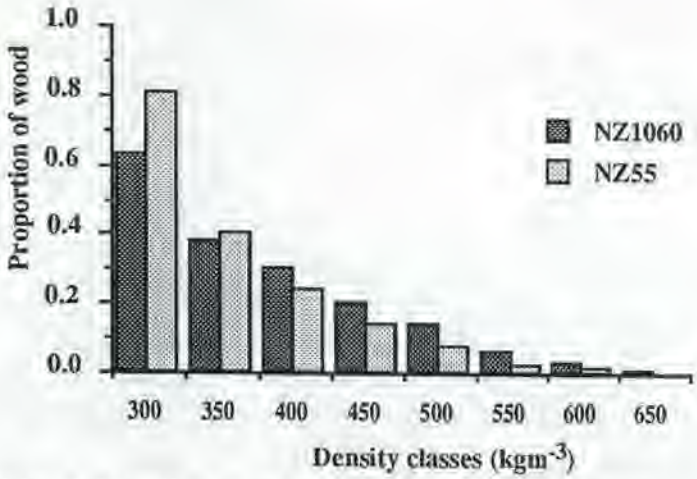


Fig. 2. Distribution of wood across density classes.

NZ55 fibres were generally larger than those of NZ1060, as indicated by the higher average fibre and lumen diameters in earlywood and latewood (Table 5). Latewood fibre walls were thicker than earlywood fibre walls in both NZ55 and NZ1060, but NZ55 tended to have thicker earlywood fibre walls and thinner latewood fibre walls than NZ1060. The within tree variation of fibre wall thickness and diameter in both pines was similar to that observed by Cown (1975).

Table 5. Mean results of radial fibre and lumen diameters and fibre wall thickness

Progeny	Earlywood fibre diameter (μm)	Earlywood lumen diameter (μm)	Latewood fibre diameter (μm)	Latewood lumen diameter (μm)	Earlywood fibre wall thickness (μm)	Latewood fibre wall thickness (μm)
NZ1060	36.82(2.49)	31.29(2.61)	21.45(0.57)	13.98(0.53)	2.765(0.101)	3.740(0.90)
NZ55	41.22(2.49)	35.64(2.61)	22.45(0.57)	15.25(0.53)	2.791(0.101)	3.574(0.90)

No significant ($p>0.10$) between progeny variation in fibre and lumen diameters and cell wall thickness occurred. The results show that the variation in earlywood fibre dimensions between trees was more pronounced than between progenies. However, latewood fibre and lumen diameters and latewood and earlywood cell wall thickness varied significantly ($p\leq0.05$) and linearly with ring number from the pith. There was also a significant ring by progeny interaction for latewood fibre diameter ($p<0.05$) and latewood lumen diameter, indicating that NZ1060 and NZ55 differ in latewood fibre dimensions within certain growth ring numbers from the pith. These results may also explain the difference in maximum density between

NZ1060 and NZ55. ANOVA results also clearly indicated a very strong dependence of latewood fibre dimensions on ring number ($p<0.005$), unlike earlywood fibre dimensions ($p>0.10$). Results also suggest a highly significant linear ($p<0.005$) interactions between growth ring number by progeny in latewood fibre diameter ($p<0.05$) and lumen diameter ($p<0.01$). This indicates that NZ1060 and NZ55 differed radially across the stem in radial latewood dimensions and not significantly in radial earlywood dimensions.

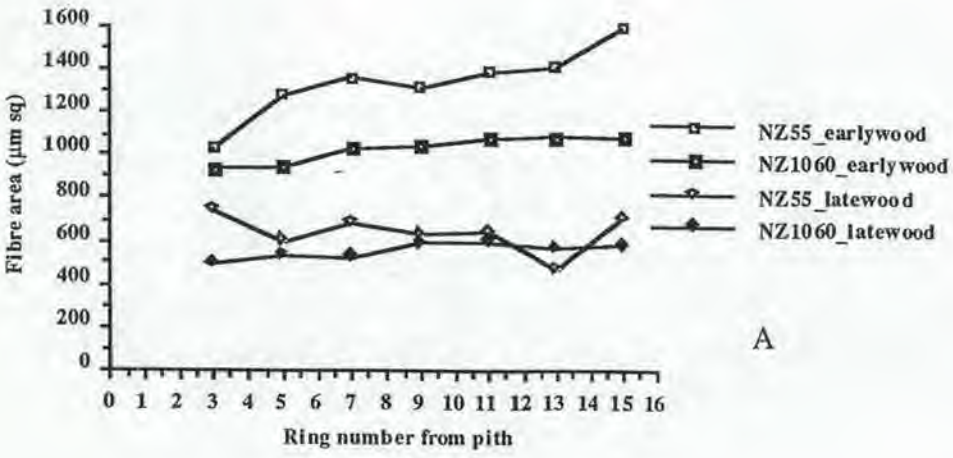
Runkel ratio was slightly higher both in latewood than in earlywood and in NZ1060 compared to NZ55 (Table 6). The Runkel ratio also varied more with ring number in latewood than earlywood and increased with increasing ring number from pith. These results suggest that lateral fibre collapse, especially in latewood, would decrease with ring number from pith due to increasing fibre density. Consequently, fibre flexibility and conformability within the paper made from such wood would be less than paper from earlywood in accord with the findings of Higgins *et al.* (1973).

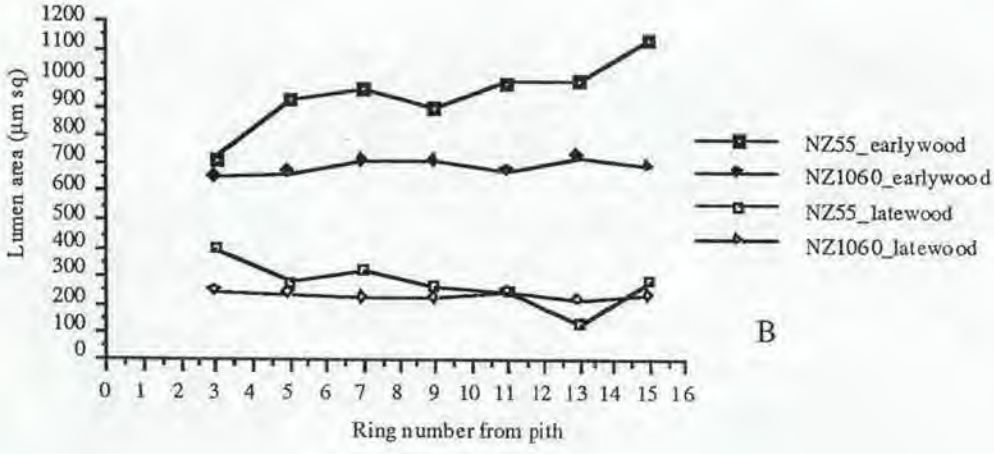
Table 6. Means for the Runkel ratios of NZ1060 and NZ55

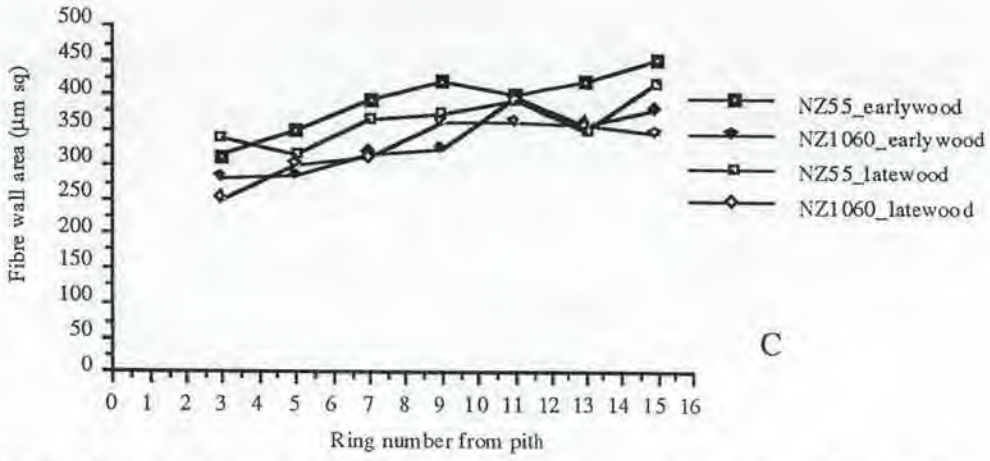
Progeny	Earlywood Runkel ratio	Latewood Runkel ratio
NZ1060	0.190(0.018)	0.619(0.031)
NZ55	0.171(0.018)	0.548(0.031)

The Runkel did not vary significantly ($p>0.10$) between NZ1060 and NZ55 but there was significant ($p<0.10$) variation in the radial fibre dimension ratio between the progenies. Runkel ratio in the radial direction in latewood appeared to be significantly ($p<0.005$) influenced by ring number from the pith whereas earlywood fibre ratios ($p<0.10$) were not, confirming that latewood dimensions varied significantly from pith to bark whereas those of earlywood fibre dimensions remained relatively constant. The ANOVA also indicated a weak ($p<0.10$) quadratic contrast between the latewood radial Runkel ratios for the two progenies. Again, these results support earlier suggestions that the latewood fibres of NZ1060 are denser than those NZ55.

Radial profiles of fibre area, lumen area and fibre wall area of the two radiata pines are shown in Figs. 3a-c. Earlywood fibre, lumen and fibre wall areas increased with ring number in both NZ1060 and NZ55. Latewood lumen area appeared to be the most stable of the three areas, especially in NZ1060 (Fig. 3b). The radial pattern of fibre wall area (Fig. 3c) was broadly similar to that observed previously by Cown (1975).







Figs. 3a-c. Radial variation of fibre area (A), lumen area (B) and fibre wall area (C).

Latewood fibres were on average smaller than earlywood fibres and therefore had lower fibre, lumen and fibre wall areas (Table 7). NZ55 fibres had larger mean fibre, lumen and fibre wall areas than NZ1060 fibres. Fibre, lumen and fibre wall areas of NZ55 were slightly larger than those of NZ1060.

Table 7. Mean fibre, lumen and wall area for earlywood and latewood in NZ1060 and NZ55

Progeny	Earlywood fibre area (µm sq)	Latewood fibre area (µm sq)	Earlywood lumen area (µm sq)	Latewood lumen area (µm sq)	Earlywood wall area (µm sq)	Latewood wall area (µm sq)
NZ1060	1026(76.1)	557(76.1)	692(51.9)	229(51.9)	334.3(17.9)	327.8(17.9)
NZ55	1340(76.1)	640(76.1)	946(51.9)	274(51.9)	393.3(17.9)	366.0(17.9)

There were differences in lumen area and fibre wall area between NZ1060 and NZ55. There was also significant ($p<0.005$) within tree variation in fibre, lumen and fibre wall area and a strong interaction ($p<0.05$) of these features with ring number in earlywood and latewood. It appeared that fibre, lumen and fibre wall areas in earlywood and latewood were very strongly and linearly influenced ($p<0.005$) by ring number. This finding supported pervious observations (Figs. 3a-c). The significant ($p<0.005$) wood type by progeny interaction indicated a highly significant difference between NZ1060 and NZ55 in their earlywood and latewood fibre and lumen areas. This accords with the general conclusion that earlywood fibres of NZ55 are thicker than those of NZ1060 (Table 5). This may be due to the presence of "mild" compression wood in NZ55, or may be a genetically inherited feature of NZ55. NZ55 had a larger proportion of long fibres than NZ1060 which had a higher fibre area than the shorter fibres of NZ1060. This underscores the observation made by Cown (1975) firstly, that there is a strong positive correlation ($r = 0.86$) between fibre area and length and secondly, that physiological factors affecting fibre length may also affect fibre cross sectional dimensions.

The within tree variation in middle lamella thickness at the earlywood-latewood boundary in NZ1060 and NZ55 are shown in Fig. 4. The middle lamella thickness in NZ1060 remained constant with ring number from the pith whereas in NZ55 middle lamella thickness increased with distance from the pith and reached a maximum by ring number 11.

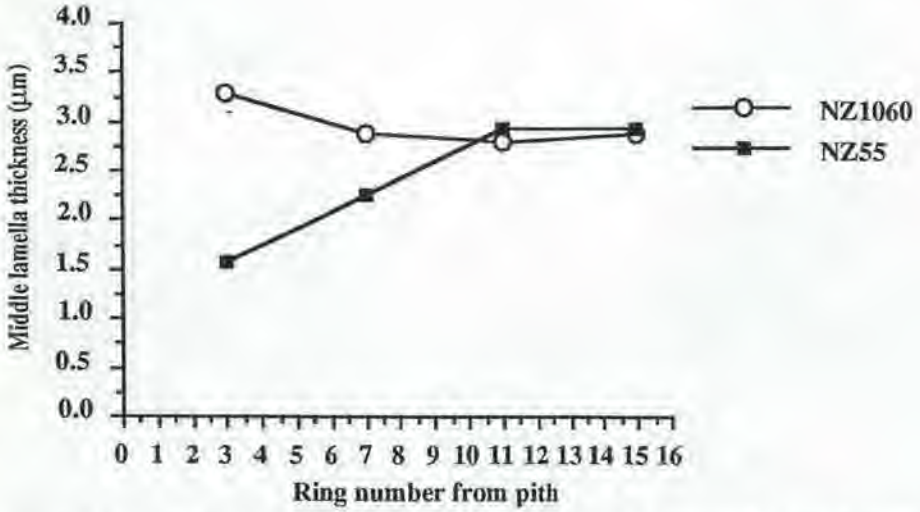


Fig. 4. Middle lamella thickness at the earlywood-latewood boundary in NZ55 and NZ1060.

Split-plot analysis of variance on the middle lamella thickness at the earlywood-latewood border showed that NZ1060 and NZ55 differed significantly ($p<0.05$) in accord with Table 8. At the tree level, the linear contrast of ring number was a significant source of variation ($p<0.05$). Results suggested that the thickness of the middle lamella of the earlywood-latewood border is also heavily influenced ($p<0.005$) by ring by family interactions.

Table 8. Mean results of middle lamella thickness at the latewood-earlywood border

Progeny	Middle lamella thickness (µm)
NZ1060	2.964(0.103)
NZ55	2.428(0.103)

In line with previous observations for radiata pine (Uprichard 1971, Uprichard and Lloyd 1980) the ethanol-extractive content in NZ1060 and NZ55 decreased with increasing ring number from the pith (Fig. 5). However, the radial patterns of the two progenies differed. Initially (growth rings 1-3) the extractive content of NZ55 decreased more markedly than in NZ1060 and thereafter it remained constant.

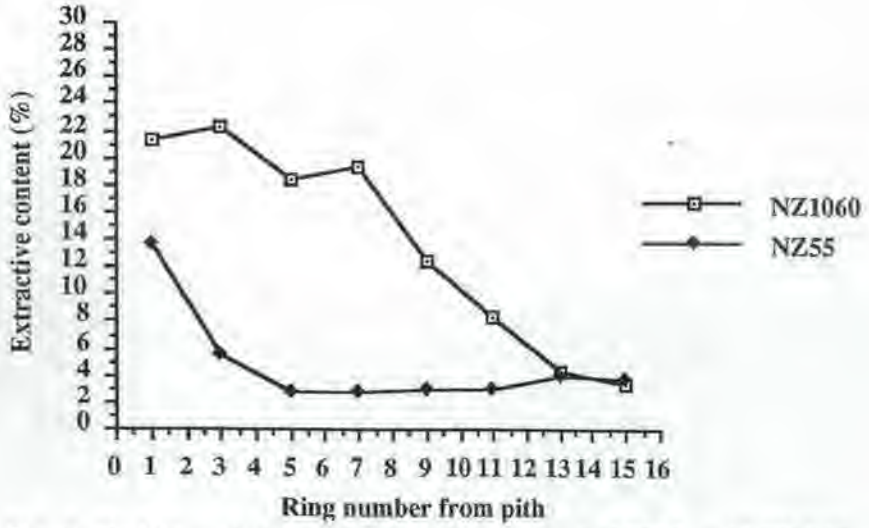


Fig. 5. Radial variation of ethanol-extractive in NZ55 and NZ1060.

The ethanol-extractive content of NZ1060 was clearly higher than NZ55 (Table 9). This may be because the NZ1060 material was significantly older (34 years) than the NZ55 (12 years) material. The ethanol-extractive content of NZ55 is comparable to the alcohol-benzene extractive content of 4.5 % obtained for a 20 year old radiata pine (Smelstorius 1971). In contrast, the ethanol-extractive content of NZ1060 is very high compared to values reported in the literature of 0.6-4.0 % (Wong and Wilkes 1988) but is lower than the acetone-extractive content (17 %) recorded in the heartwood of a 45 years old radiata pine (Lloyd 1978).

Table 9. Mean results of ethanol-extractive content

Progeny	Ethanol-extractive(%)
NZ1060	13.73(1.11)
NZ55	4.5(1.11)

Statistical analyses supported the conclusion that NZ1060 had significantly ($p<0.005$) more extractives than NZ55. The analyses also indicated that ethanol-extractive content decreased significantly both linearly ($p<0.005$) and quadratically ($p<0.005$) with ring number from the pith. There was also a highly significant ($p<0.005$) ring by family interaction for this property.

The Klason lignin contents of both NZ1060 and NZ55 showed a centrifugal decrease (Fig. 6) in accord with previous observations for radiata pine (Harwood 1971). In contrast, Uprichard (1971) did not find no such a relationship.

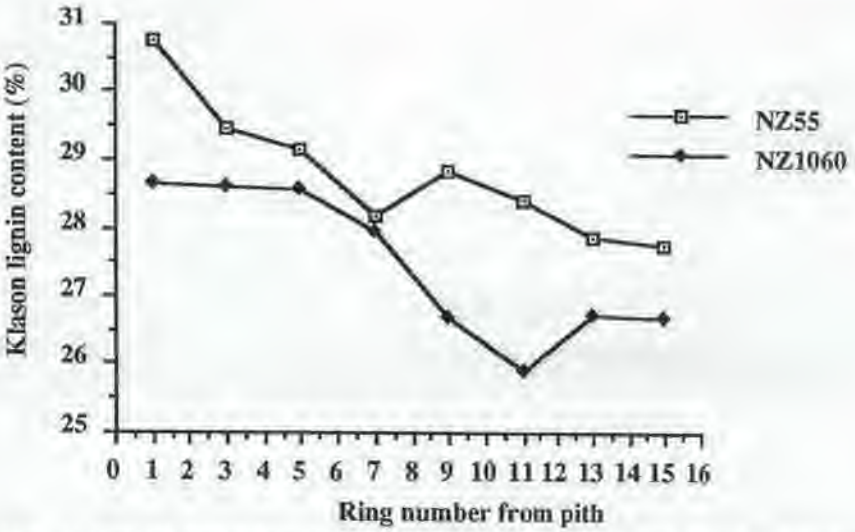


Fig. 6. Radial variation of lignin content in NZ55 and NZ1060 radiata pines.

The lignin content of NZ1060 was significantly ($p<0.005$) lower than in NZ55 (Table 10) and is comparable to the figure of 27.6 % found by Watson *et al.* (1952) for radiata pine pre-extracted with ethanol-benzene. Both progenies exhibited a marked linear ($p<0.005$) decrease in lignin content from the pith. The lignin content of NZ1060 is also similar to that of radiata pine (27.4 %) found by Smelstorius (1971), but the lignin content of NZ55 is lower than the figure of 30.1 % found in the severe compression wood of 27 coniferous species (Timell 1982).

Table 10. Mean results of Klason lignin content

Progeny	Klason lignin (%)
NZ1060	27.46(0.21)
NZ55	28.18(0.21)

Mild compression wood

During the SEM studies it was noted that the wood of NZ55, unlike NZ1060, was characterised by large earlywood cells which are rounded in cross section and have numerous intercellular spaces (Figs. 7a-c). Comparison of this observation with those available in the literature (Low 1964, Jane 1970) suggested that these cells were somewhat similar to those of compression wood. However, the tracheids were of normal length (Table 1), lacked helical or spiral thickening (Fig. 7b) and the stems of NZ55 were not eccentric, or dark in colour. These latter characteristics are found in severe compression wood and it may well be that the wood sampled from NZ55 here contained a mild form of compression wood. Furthermore, the earlywood-latewood border in NZ55 was poorly defined in the annual rings closest to the pith especially in tree number 4 and the fibre length of NZ55 was found to be normal (Table 1). Normally severe compression wood has distinct growth rings and shorter fibres and may show no clear earlywood and latewood formation.

This study also found that the Klason lignin content of NZ55 was higher than that of NZ1060 but lower than that found in severe compression wood. This further suggests that

NZ55 contained "mild" compression wood. The occurrence of "mild" rather than severe compression wood in NZ55, but not in NZ1060, may explain why NZ55 had a higher minimum density than NZ1060, i.e., NZ55 has thicker earlywood fibres and more cell wall substance than NZ1060. No quantitative measurement was carried out of the occurrence of "mild" compression wood.

Figs. 7a-d: Scanning electron photomicrographs of transverse sections showing the presence of "mild" compression wood in NZ55.

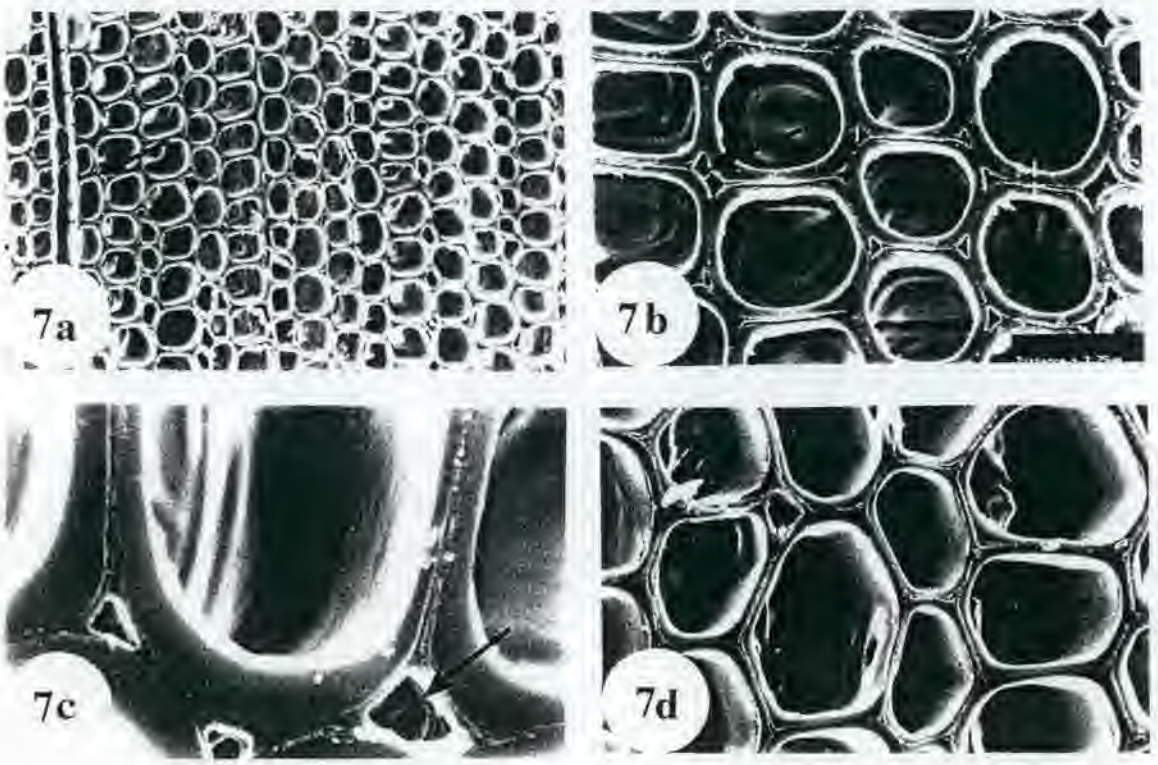


Fig. 7a. Intercellular spaces in NZ55, growth ring number 11 from the pith (x 200);
Fig. 7b. Intercellular spaces in NZ55, growth ring number 11 from the pith (x 800);
Fig. 7c. Intercellular spaces in NZ55, growth ring number 11 from the pith (x 3 000);
Fig. 7d. Normal wood in NZ1060, growth ring number 11 from the pith (x 800);

Arrows point to intercellular spaces. Note the rounded outline and thicker walls of "mild" compression wood fibres in NZ55 (Figs. 7a-c) compared to normal wood (NZ1060, Fig. 7d) and the absence of helical thickening in the secondary wall of NZ55 (Fig. 7c).

DISCUSSION

Possible effects of the differences in wood properties of NZ1060 and NZ55 on the energy consumed during TMP

There was no statistically significant difference in the basic and mean densities of the corewood of NZ1060 and NZ55, but the radial variation in density in the two progenies (Fig. 1) suggested that the average slabwood density of NZ1060 may be higher than that of NZ55. However, it can be concluded that wood density alone was not responsible for the differences in energy consumed by NZ 1060 and NZ55 during TMP. This conclusion accords with that of Corson *et al.* (1989). Maximum density depends on fibre dimensions, especially latewood radial fibre wall thickness, fibre density and Runkel ratio. This study found that the maximum density of the corewood of NZ1060 was slightly higher than that of NZ55. The corewood of NZ1060 also had significantly higher latewood fibre density and Runkel ratios and thus a lower fibre flexibility ratio. More importantly, NZ1060 and NZ55 differed markedly in the within tree distribution of latewood proportion, latewood fibre dimensions of fibre and lumen diameters and areas as well as fibre wall area. Consequently, from the pith to bark NZ1060 and NZ55 differ significantly in their radial profiles of maximum density and ratios of maximum density to minimum density. Results suggest that the maximum density (Fig. 1) and radial latewood fibre wall thickness of NZ1060 may exceed those of NZ55 in the slabwood (growth rings $\geq$ 15). Since wood species with a large proportion of thick walled fibres and high ratios of maximum to minimum density, for example the Southern pines, consume higher amounts of energy than species with a low proportion of latewood, for example spruce (Koch 1972), differences in the radial variation of the proportion of latewood, ratios of maximum to minimum density, latewood fibre wall thickness and maximum density of NZ1060 and NZ55 may partially explain why the latter consumed less energy during TMP. This suggestion accords with the views of McMillin (1969) and Higgins *et al.* (1973) that the ease of fibre collapse and thus the amount of energy consumed during TMP, is inversely related to the proportion of latewood and the wall thickness of latewood fibres and their density.

A previous study found that the ease of fibre separation or amount of energy consumed during mechanical pulping was inversely proportional to the thickness of the middle lamella (Blechsmeschmidt 1986). This study found that the middle lamella at the earlywood-latewood border was significantly thicker in NZ1060 than in NZ55. This border may be important during refining since it is a weak interface. The thicker middle lamella at the earlywood-latewood border in NZ1060 may reinforce this region and thus may require more energy to separate it than the thinner middle lamella in NZ55. The within tree variation in middle lamella thickness at the earlywood-latewood border (Fig. 4) was not similar to the variation in the Klason lignin content (Fig. 6) possibly suggesting that the lignin of the S_2 layer in NZ55 may be higher than normal.

The most surprising finding of this study which may have a bearing on refining energy consumed during TMP is that NZ55, unlike NZ1060, contained a mild form of compression wood (Figs. 7a-c). Schafer *et al.* (1937) found that the ease of fibre separation as measured by energy consumed during mechanical pulping decreased with increasing severity of compression

wood. The presence of "mild" compression wood in NZ55 may lower the amount of energy required to separate fibres during TMP in accord with previous suggestions (Schafer *et al.* 1937). The underlying reasons for this saving are unknown. Timell (1986) suggested that the large number of intercellular spaces in compression wood could reduce the inter-fibre bonding potential of the fibres (Fig. 7b). Thus, fibres in NZ55 may defibrate and lift out more easily than those of the standard radiata pine during refining. Alternatively, the occurrence of "mild" compression wood and the higher lignin content of NZ55 may indicate differences in the distribution of lignin in the cell wall of NZ55 and NZ1060 and this may influence energy consumed during refining. The literature suggests that the heat capacity of fibres is inversely proportional to their lignin content (Kokta *et al.* 1989). As a result of differences in lignin content the fibres of NZ1060 and NZ55 could have different energy relationships during thermo-softening and subsequent refining stage. Further work is required to study the distribution of cell wall lignin and its quantitative genetics characteristics in standard radiata pine and NZ55 and how this may influence energy consumption during TMP.

This study found that NZ1060 had a higher extractive content than NZ55 mainly because the NZ1060 material was older and therefore had more heartwood than NZ55. Alternatively, the NZ55 may have had a lower extractive content than NZ1060 because the former grows faster than NZ1060. Generally faster grown trees tend to produce wood with a lower extractive content (Klauditz 1948). Extractive content is thought to be under low genetic control (Yanchuk *et al.* 1988) and heartwood formation is thought to be significantly heritable (Nicholls and Brown 1974), but results here also indicate significant tree variability in this property. Consequently, selection within NZ1060 and NZ55 may reduce extractive content. It is suggested that the original genetic selection for NZ55 could have selected for this wood characteristic inadvertently. Further work is required to define the genetic parameters governing extractive content in standard radiata pine and NZ55.

Extractives, especially pinosylvin, may adversely affect the glass transition temperature of lignin (Bletchsmidt *et al.* 1986) and possibly the amount of energy consumed during refining. Complete analysis of extractives was not carried out here and consequently results only allow speculation that the higher extractive content of NZ1060 could have resulted in higher energy consumption during TMP. Knowledge of the chemical composition of the extractives in NZ1060 and NZ55 would have been useful in explaining energy relationships during TMP. Further studies should be carried out to examine the composition of the extractives in NZ1060 and NZ55 and their possible effects on the glass transition temperature of lignin.

Possible effects of the differences in wood properties of NZ1060 and NZ55 on the quality of TMP paper

Literature suggest that paper brightness is related to specific area of fibres available for light scattering and that light scattering coefficient is inversely correlated with basic density and fibre density (Corson *et al.* 1991). Thick fibres have poor lateral conformability (Higgins *et al.* 1973) and consequently the area available for light scattering, which is governed by the number of fibres per unit volume of paper, decreases with increasing wood density. The present study

found no significant differences in mean density of NZ1060 and NZ55. Therefore, the superior light scattering properties of NZ55 compared to NZ1060 (Corson *et al.* 1989) probably cannot simply be accounted for by differences in mean density. However, the lower maximum density and lower proportion of wood in high density classes may positively influence the light scattering coefficient of paper made from NZ55. Light scattering coefficient is affected only slightly by large changes in fibre density (Kibblewhite 1982) and there is a loose inverse relationship between light scattering coefficient and density (Corson *et al.* 1991). It thus appears that other wood properties influence light scattering to a greater extent than density.

Fragments or fines have a high specific area available for light scattering due to their large surface area to volume ratio. Consequently, the brightness of paper is positively related to the amount of fines and particularly to the 200 fines fraction (coarse fines) (Corson *et al.* 1991). Pillow *et al.* (1936) found that compression wood fragments more than normal wood and it may be that the presence of "mild" compression wood in NZ55 may positively influence the production of fines and hence produce superior light scattering coefficients in paper made from the wood of NZ55. This suggestion seems to be substantiated by the finding (Corson *et al.* 1989) that the 200 fine fraction content (33.6 %) in the pulp made from the corewood of NZ55 was higher than in NZ1060 (31.2 %). Both were refined to the same degree of freeness. One of the characteristics of severe compression wood is abnormally thick cell walls consisting of a highly lignified S_2 layer. This study found that the earlywood fibres of NZ55 were thicker, had a higher minimum density and a larger fibre wall area than those of NZ1060. Marton *et al.* (1979) found that the light scattering coefficient depends on the cellulosic S_2 layer. The thicker earlywood fibres of NZ55 may as well have a larger S_2 layer and more microfibrils than the earlywood of NZ1060. This may also explain why NZ55 has a higher light scattering coefficient than NZ1060 (Corson *et al.* 1989).

Extractives are undesirable since they darken paper thereby adversely affecting its colour. This study found that NZ55 had a lower extractive content than NZ1060 and as a result paper made from NZ1060 is likely to be darker than paper made from NZ55. Furthermore, in accord with literature (Assarsson *et al.* 1982) the lower extractive content in NZ55 could translate to less clogging of filters, less resinous foam formation during pressing and hence reduced interference with fibre surface properties and inter-fibre bonding than in NZ1060. It is speculated that the potential for bio-mechanical pulping NZ1060 with fungi may be lower than that of NZ55 because NZ1060 has a higher extractive content, some of which may well be fungicidal. Some fungal colonisation was observed in the wood of some trees of NZ55 (Fig. 7c) unlike NZ1060. Again further research is needed on the bio-mechanical pulping potential of NZ1060 and NZ55.

Tear strength of paper is positively correlated with wood density and fibre density (Dinwoodie 1965). However, Corson (1984) and Corson *et al.* (1989, 1991) are of the opinion that the effects of wood density on tear strength are of secondary importance. They suggest that within a wood type, which is determined by the age of the tree, the effect of density on tear is important. Increases in fibre length result in substantial increases in tear strength (Sferraza 1987, Corson *et al.* 1991). The current study found that NZ55 had a higher proportion of fibres

longer than 3 mm and an average arithmetic average fibre length equal to NZ1060. This result does not accord with the observation that paper made from NZ55 had an inferior tear strength to paper made from NZ1060 (Corson *et al.* 1989). There are indications that the proportion of latewood and maximum density, which can possibly influence tear strength, are greater in NZ1060 than in NZ55 and may account for the finding that paper produced from NZ1060 had a higher tear strength than NZ55 (Corson *et al.* 1989). Alternatively, the presence of "mild" compression wood in NZ55 might slightly lower the tear strength of its TMP paper compared to NZ1060 in accord with the findings of Schafer *et al.* (1937) and Dadswell *et al.* (1958) that paper produced from compression wood has inferior strength properties.

Tensile strength of paper is not significantly influenced by wood density but is influenced by fibre length (Dinwoodie 1965). Tensile strength increases with the proportion of long fibres and fines fraction which is important for the consolidation of fibres (Corson *et al.* 1991). The fibre length results of this study suggest that the tensile strength of paper made from NZ55 could be higher than that of NZ1060 since the former has longer fibres (≥3 mm) and is likely to provide a higher fines fraction due to the presence of "mild" compression wood.

CONCLUSION

There were significant differences in the wood properties of NZ1060 and NZ55 and these differences probably influence the amount of electrical energy consumed during thermomechanical pulping and the strength properties and light scattering coefficient of paper produced from the pulp. This study found statistically significant differences in a number of wood properties (principally fibre length, minimum and maximum densities, the thickness of middle lamella at the latewood-earlywood border and extractive and lignin contents) between NZ1060 and NZ55. In addition, NZ55 unlike NZ1060, contained "mild" compression wood which is possibly genetically inherited.

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ASSESSMENT OF THE STRUCTURAL PROPERTIES OF MECHANICALLY STRESS GRADED AUSTRALIAN PINE

Stephen A. Bolden(1), Paul F. Walsh(3), Denis J. Grant(2), Robert H. Leicester(3), Fran Young(3), Craig Seath(3)

(1) Pine Australia, PO E89 Queen Victoria Terrace, Canberra, ACT. 2600
(2) Wood Technology Australia, 56 Atchison Street, Crows Nest, NSW 2065 (formerly FCRD, NSW Forestry Commission)
(3) CSIRO Division of Building, Construction and Engineering, PO Box 56, Highett, Vic 3190

ABSTRACT

This paper describes a major in-grade test program, undertaken by Pine Australia during the past two years. Roughly 8500 specimens were tested to evaluate the primary structural properties of mechanically stress-graded Australian pine. Detailed results of the program are not reported herein; however in general, the results showed that Australian pine is underrated by current Australian Standards.

INTRODUCTION

Background

In-grade testing is defined as the testing of structural timber within the stress grades and in the sizes it is to be used commercially.

In the past, Australian timber grading and engineering codes were established from structural design properties derived essentially from testing small clear, defect free pieces of wood. Bending strength values were assigned as a proportion of the small clear strength values and the other design properties as a ratio of the bending value. Over the past twenty years, the problems associated with the use of this type of system for the derivation of design properties have become evident. The design properties were not always matched by the true properties of structural size stress-graded timber; also, since the real properties were unknown, no improvements in timber utilisation could be planned. Some improvements were introduced with the advent of the mechanical stress grading system because it was calibrated to actual material bending strengths.

Recently improved technology has allowed accurate evaluation of the full range of structural properties of timber grades; in addition, there has also been a recent trend towards the use of reliability based design procedures. Consequently, an irreversible shift towards in-grade technology for the measurement and derivation of timber design properties is taking place in Australia and worldwide. It is of interest to note that in North America the intensive in-grade test program over the past decade has involved testing some 200 000 specimens at a cost of roughly $15 m.

In 1988, in a collaborative research project with the Commonwealth Scientific and Industrial Research Organisation (CSIRO), NSW Forestry Commission Research Division (FCRD) and the Radiata Pine Research Institute Inc. (RPRI which is now the research wing of Pine Australia) completed a detailed study of the in-grade properties of F5, F8 and F11 90 x 35 mm and 140 x 35 mm mechanically stress graded (MSG) pine from member mills subscribing to its quality control scheme (Leicester *et al.*, 1988). This study was used to measure the true bending strength, modulus of elasticity and tension strength properties of the radiata pine population.

The implications of these new in-grade design properties were discussed in detail with Pine Australia members during 1991 and 1992. The outcome was a firm commitment by the Australian plantation pine industry to undertake a more comprehensive in-grade evaluation comprising a wide range of sizes, grades and properties of mechanically stress graded Australian pine.

The perceived benefits to the industry of a comprehensive in-grade evaluation are greater structural reliability and optimised utilisation of an important timber resource. Timber has a high potential strength and stiffness: the challenge is to reliably utilise that potential.

Objective

The specific objective of this study then was to measure the actual in-grade properties of commercially available grades and sizes of seasoned mechanically stress graded Australian Pine. For the purposes of this study, the term 'Australian Pine' was taken to be plantation grown pine that is predominantly radiata, slash and Caribbean pine; the population assessed comprises structural pine produced under the Pine Australia quality control scheme and the Queensland Timber Board (Pine Division) quality control scheme.

As well as providing end-users with new reliable in-grade design properties under the current grading system, it was envisaged that the data obtained would provide the basis for developing a more efficient and responsible utilisation of the plantation resource. The data obtained would provide a basis for modifying our engineering and framing codes to better fit with the natural properties of plantation pine and hence lead to a more efficient utilisation of that resource.

Description of Research Project

With this in mind Pine Australia has set about measuring the structural design properties of material encompassed by the range of sizes 70 x 35 up to 290 x 45 and by the grades F5 up to F11 and better.

The project involved the sampling and measurement of the structural properties of a significant quantity of commercially graded Australian pine. The plan was to test over seven thousand full size timber specimens sampled from across the country.

The research and laboratory studies for this project were undertaken by the CSIRO Division of Building, Construction and Engineering and the Forestry Commission of NSW, Research Division. The Australian Pine industry through RPRI was responsible for the sampling and supply of the timber as well as the predominant portion of the funding.

The assessment was made to be in accordance with the provisions of AS 4063 'Timber – Stress-graded – In-grade Strength and Stiffness Evaluation'.

SAMPLING

The timber tested was seasoned and dressed and consisted of three populations:

- Radiata pine (Mainland, the largest group)
- Queensland pine of mixed Caribbean and slash pine
- Tasmanian radiata pine (a small sample only).

Samples were taken from a wide range of locations throughout Australia and involved the active cooperation of the many individual mills which are listed in Table 1. Table 2 provides a list of sample sizes tested within each size/grade. Table 3 gives the targeted machine settings for sorting timber during the mill grading operations. Four threshold values of local modulus of elasticity were used; these corresponded to the F4, F5, F8 and F11 stress grades. Note that the timber designated F11 contains all timber at F11 and higher grades, and the timber designated as F5 contains both F5 and F7 grade materials.

During sampling, information was recorded on various matters such as log size, cutting patterns, type of grading machine used etc., that could be useful for classifying the timber resource covered by the study.

The sampling of the Radiata pine from the mainland mills was undertaken by RPRI in accordance with a strict protocol approved by CSIRO. The initial sampling runs at the mills were supervised by RPRI, FCRD or CSIRO technical staff.

During sampling care was taken to ensure that material was selected according to the grade threshold as specified above. Furthermore, care was taken to ensure that there was no

culling of material on the basis of visual appearance, other than that specified in the Australian Standard AS 1748. All material shipped from the mills to the laboratories was packaged and plastic wrapped so as to minimise the likelihood of damage or change of moisture content.

The sizes and grades were selected to cover the range of material expected to be available commercially and to allow reliable interpolation of other sizes and grades.

The timber was graded and supplied in the following lengths:

4.8 m for depths 70 and 90 mm;

5.4 m for depths 140 mm; and

6.0 m for depths 290 mm.

These particular lengths were chosen as they were considered to be typical of those available in commercial sizes.

The mechanical stress grade settings for the 290 mm depth were based on those currently available for the next lower size. Although not currently in common use, this size was expected to be more readily available in the immediate future and hence was included in the study.

Sampling was undertaken from mills which were chosen to be representative of production throughout Australia. Due to resource availability problems, some mills were not equally represented in the larger sizes. However, this represents the commercial availability of this material.

At all times considerable effort was taken to ensure that the sample of MSG radiata pine was representative of that supplied to the market in Australia.

TESTING

Testing for the in-grade evaluation was essentially carried out in accordance with AS 4063 – 1992 'Timber – Stress-graded – In-grade Strength and Stiffness Evaluation'. The primary design properties measured in the study included bending modulus of elasticity, modulus of rupture, tension strength, compression strength and shear strength. Secondary properties measured included compression strength perpendicular to grain and modulus of rigidity (torsion). Most of the testing was carried out by CSIRO at Highett.

Detailed mechanical grading information was also recorded for each stick sampled. This grade check was carried out by the Forestry Commission of NSW at West Pennant Hills.

RESULTS AND DISCUSSION

Table 4 lists the indicative relative strength and stiffness of in-grade evaluated Australian pine relative to AS 1720.1.

The results in Table 4 clearly shows that on average, Australian pine as currently graded, is potentially well above the material property requirements as stated in the timber design code AS 1720.1. In addition the fact that the ratios throughout Table 4 are not constant indicates that mechanically stress graded Australian pine does not fit efficiently within the current system of stress grades and the associated concomitant design properties.

Detailed results of the study will be published in a future report. Currently an 'Implementation Committee' of Pine Australia is examining the marketing implications and future potential for mechanically stress graded pine; both domestic and engineered construction are under consideration. The in-grade study has not only provided a measure of the effectiveness of currently marketed stress grades; it has also revealed for the first time the true structural properties of Australia's dominant timber resource and hence prepared the way for the development of new utilisation strategies which have a potential to effect dramatic increases in utilisation efficiency.

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TABLE 1. PARTICIPATING MILLS IN IN-GRADE STUDY

Mill No.	Company	Location	No. of Samples Supplied
3	Forwood	Nangwarry, SA	876
4	Forwood	Mt. Gambier, SA	222
5	CSR Softwoods	Mt. Gambier, SA	751
7	CSR Softwoods	Dartmoor, VIC	27
9	Australian Forest Industries	Myrtleford, VIC	399
12	Timber Industries	Bathurst, NSW	419
16	Brown & Dureau	Morwell, VIC	524
20	Brown & Dureau	Canberra, ACT	406
22	French's Enterprises	Scottsdale, TAS	159
25	Timber Industries	Tumbarumba, NSW	496
28	CSR Softwoods	Wingfield, SA	27
41	CSR Softwoods	Tumut, NSW	900
45	Wespine	Manjimup, WA	620
	CSR Softwoods	Caboolture, QLD	793
	Hyne & Son	Tuan, QLD	785
Total number of samples			7404

TABLE 2. NUMBER OF SPECIMENS PER TEST PER SIZE/GRADE

Population	Grade	Size	Test				Total
			Bending	Tension	Shear	Compression	
Radiata	F5	70 x 35	151	155	80	80	466
Radiata*	F5	90 x 35	153*	142*	80	84	459
Radiata*	F5	140 x 35	144*	141*	84	84	453
Radiata	F5	290 x 35	149	149	76	76	450
Radiata	F5	70 x 45	150	152	81	81	464
Radiata	F5	90 x 45	152	156	80	79	467
Radiata	F5	140 x 45	154	157	81	80	472
Radiata	F5	290 x 45	152	150	79	80	461
Radiata Tasmania	F5	90 x 35	150				150
Queensland pine	F5	90 x 35	154	154	75	75	458
Queensland pine	F5	190 x 45	147	148	75	76	446
Radiata	F8	70 x 35	152	155	80	80	467
Radiata*	F8	90 x 35	151*	145*	78	83	457
Radiata*	F8	140 x 35	152*	153*	81	81	467
Radiata	F8	290 x 35	147	150	80	80	457
Radiata	F8	140 x 45	148	156	82	79	465
Radiata	F11	70 x 35	156	154	81	81	472
Radiata*	F11	90 x 35	154*	143*	79	82	458
Radiata*	F11	140 x 35	114*	117*	96	96	423
Radiata	F11	290 x 35	129	130	69	69	397
Radiata	F11	140 x 45	156	150	78	81	465
Queensland pine	F11	90 x 35	154	157	77	78	466
Queensland pine	F11	190 x 45	153	151	80	80	464
Total			3422	3265	1752	1765	10204

TABLE 3. GRADE THRESHOLDS

Species	Size (mm)	Mechanical stress grade thresholds (GPa)			
		F4 Threshold	F5 Threshold	F8 Threshold	F11 Threshold
Radiata pine	70 x 35	4.83	6.10	8.59	11.59
Radiata pine	90 x 35	4.14	5.52	8.27	11.59
Radiata pine	140 x 35	4.14	5.52	8.27	11.59
Radiata pine	290 x 35	4.14	5.52	8.27	11.59
Radiata pine	70 x 45	4.20	5.52	8.02	11.03
Radiata pine	90 x 45	4.41	5.19	7.67	11.02
Radiata pine	140 x 45	4.20	5.52	8.02	11.03
Radiata pine	290 x 45	4.20	5.52	8.02	11.03
Queensland pine	90 x 35	4.29	5.04	7.48	10.54
Queensland pine	190 x 45	4.31	5.05	7.36	10.40

TABLE 4. IN-GRADE STRENGTH AND STIFFNESS OF AUSTRALIAN PINE RELATIVE TO AS 1720.1 F-GRADE VALUES

Industry grade	Bending	Tension	Shear	Compression	Stiffness
F5	1.10	1.1	3.00	2.12	1.52
F8	1.21	1.26	2.78	1.62	1.39
F11	1.38	1.49	2.57	1.56	1.46

AN INVESTIGATION OF FACTORS INFLUENCING NAIL DEVIATION AND NAILING INDUCED SPLITTING IN AUSTRALIAN GROWN SLASH PINE

G R Stringer B.Eng. (Hons), A.I.W.Sc.
Hyne & Son Pty Limited
160 Kent St, Maryborough
Queensland, 4650, Australia

ABSTRACT

Timber wall framing manufacturers in Australia are concerned about nail deviation and splitting induced by nailing. Hyne & Son have addressed these concerns by researching practical factors which can help reduce these phenomenon. Test methods for deviation and splitting were developed. The use of blunt point nails can reduce deviation by 50% and splitting by 80%. Modifying punching depths, end distances and edge distances can reduce splitting while modifying nail diameter and steel strength can reduce nail deviation. The withdrawal resistance of blunt point nails was investigated and found not to be significantly different from diamond point nails. It is concluded that blunt point nails can provide a practical means of improving the quality of timber connections in framing as well as reducing the risk of injuries due to nail deviation and poor safety practices. It is recommended that all wall frame manufacturers consider the increased use of blunt point nails. Nail manufacturers are also encouraged to increase their range of blunt point nail products and consider modification to the standard diamond point.

INTRODUCTION

Nailing is the most common method of connecting timber and a typical house frame in Australia can contain in excess of 2000 nails. Installation of these nails is traditionally by hand hammering. However air driven guns are being increasingly used. A recent survey (Hyne and Stringer 1993) of wall framing manufacturers revealed that deviation of nails and splitting of timber due to nail installation are two matters which need to be addressed if the quality of pine house frames is to be further improved. Prompted by these suggestions from timber users, Hyne & Son recognised the opportunity to develop specific recommendations for the nailing of its slash pine framing products. This report details the research on this matter, undertaken by Hyne & Son's Research Division.

NAIL DEVIATION

Nail deviation occurs when a nail does not follow the intended path through the timber. It is a phenomenon that occurs in most species and has been particularly observed in the common softwood framing timbers used in Australia, i.e. Radiata Pine, Slash Pine and Douglas Fir. It can be quite unexpected and can result in weak connections, splitting and even personal injuries. A preliminary investigation of the phenomenon identified three types of nail deviation. These are:

(i) **Reflection** which occurs when a nail strikes a relatively strong feature within the wood, like a knot or the harder part of the growth ring, i.e. the latewood. Refer to Figure 1.

(ii) **Ring Tracking** which occurs when a nail tends to track along the soft part of the growth ring, i.e. the earlywood. Refer to Figure 2.

(iii) **Radial Tracking** which occurs when a nail tends to track along the rays or a radial feature of the timber. Refer to Figure 3.

FIGURE 1 NAIL REFLECTION

FIGURE 2 RING TRACKING

FIGURE 3 RAY TRACKING

Nail reflection is generally the most serious of these, as it is extremely difficult to predict and can cause nails to deviate in excess of 60° from the intended installation path. Ring and radial tracking does not generally appear to cause the same degree of nail bending and deviation, however there can be extensive splitting associated with these types of nail deviation. It seems that ray tracking is the most common type and rarely causes problems for timber users as the deviation is generally quite small. Nail reflection and ring tracking seem to occur less frequently with severe deviation occurring on average about once or twice per thousand nails. The main factors suspected of influencing the degree of deviation which occurs are given in Table 1.

Modification to wood features, gun type, driving practices and/or the extra cost of special shank nails would not seem to offer the most practical means of reducing deviation. Therefore a number of tests were carried out to better quantify the beneficial effects of increased nail strength or using blunt pointed nails. A special test method was developed by Hyne & Son to assess these factors. Figure 4 shows the way in which nail deviation was assessed.

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TABLE 1 FACTORS INFLUENCING NAIL DEVIATION

Factors	Suspected Influence
Nail Strength	Stronger nails deviate less, because more force is required to cause bending.
Nail Point	A diamond point nail which parts the timber fibres is more likely to deviate than a blunt point nail which punches through the timber.
Nail Shank	The screw action of helically shanked nails reduces the tendency for deviation.
Driving Angle	Ray or radial tracking is more likely to occur when nails are driven close to or parallel with each one of these features.
Gun Type	Nail guns, which have good drive pin/nail head and point alignment and provide adequate lateral restraint to the nail during driving, are less likely to cause deviation.
Wood Features	The increased presence of knots or large density variations between earlywood and latewood is likely to cause increased deviation.

The testing involved the selection of 11 pieces of 70 x 35 seasoned slash pine studs (2.4m in length) which had wood features considered most likely to cause deviation, i.e. relatively thick latewood bands with similar sized earlywood bands. These pieces were marked on edge at 90mm intervals along the full length and a distance of 165mm from each end. A total of 24 nails were installed in each piece and the intended installation path was from the centre of one edge to the centre of the opposite edge. Four different nail types were used and every fourth nail along the piece was the same nail type, i.e. 6 nails per stud, times 11 studs, equals 66 nails of each type. The nail types chosen were based on the most common nail currently used in softwood wall framing, i.e. 3.06 x 75mm plain shank diamond point. The magnitude of any nail deviation was measured in accordance with Figure 4, i.e. the difference between the entry and exit locations. The selection of the timber and the design of the test were both aimed at exaggerating any nail deviation that occurred. The test was also designed to induce nail reflection and ring tracking rather than the less important radial tracking. The same nailing gun was used for every test and all nails were driven as near to perpendicular as is possible with a hand held nailing gun. Details of the plain shanked nails used and a summary of results from the tests are shown in Table 2.

TABLE 2 NAIL DETAILS AND SUMMARY OF DEVIATION TEST RESULTS

Test Code	A	B	C	D
Nail Details - diameter (mm) length (mm) point Steel strength	3.33 90 Diamond Medium	3.06 75 Diamond Medium	3.06 75 Blunt Medium	3.06 75 Blunt Lower
Number Tested	66	66	66	65
Nail Deviation Range (mm) Side Exit of Nail (No.)	18 to -26 4	18 to -20 10	17 to -6 1	16 to -13 0
Mean Nail Deviation (mm) Standard Deviation (mm) Absolute Mean Nail Deviation (mm)	0.3 8.4 6.1	2.8 9.0 7.7	3.7 4.3 4.5	-0.6 5.2 4.0

Note: The blunt point nails used in these and other tests reported herein are actually chisel point nails where the angle of the blunt point to the nail axis is greater than 50 degrees. Standard diamond points generally make an angle of less than 25 degrees.

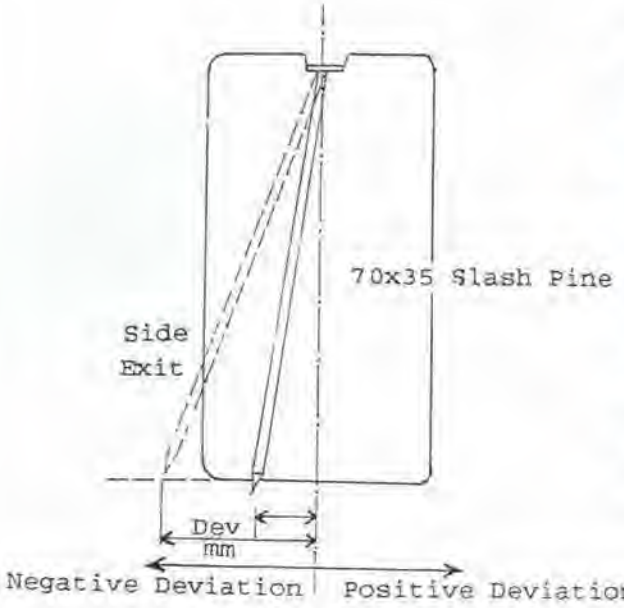
In general the exit hole side of each piece showed that blunt point nails deviated less than diamond point nails. The exit hole from blunt point nails exhibited considerably more "blow out" than the cleaner diamond point exit.

The number of side exits gives an indication of the severity of nail deviation. Test D nails showed no side exits while tests A, B and C showed 4, 10 and 1 side exits respectively. The differences between the mean nail deviation values suggest that driving angle due to human or gun factors varied between the different nail types.

A comparison of the standard deviation of each nail type minimises these human or gun influences and gives a statistical indication as to the influences of using nails with different strengths (i.e. diameters or steel strength) or points.

The effect on nail deviation of using stronger nails was evaluated by comparing tests A and B (nail diameter) and tests C and D (steel strength). Although the 3.33mm diameter showed slightly less deviation than the 3.06mm diameter nail, it was not a statistically significant difference. The difference between deviation of the nails with varying steel strengths (C & D) was significant at the 0.1 level with the stronger nail showing less deviation.

The effect of nail point was determined by comparing tests B and C. The blunt point nail showed considerably less deviation and the difference between blunt and diamond point nails was significant at the 0.001 level, i.e. there is less than a 0.1% probability that the results occurred by chance. An example of the effect of blunt pointed nails is shown in figures 5 and 6 which are 100mm apart in the same test specimen. The diamond point (figure 6) reflected off the latewood and exited from the side while the blunt point (figure 5) has punched through the same latewood band.



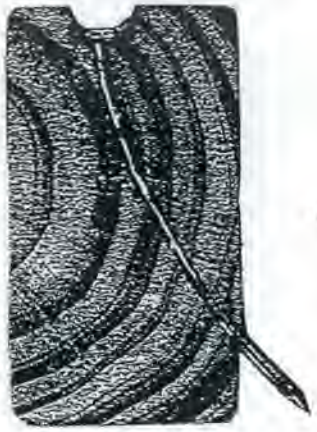


FIGURE 4 NAIL DEVIATION MEASUREMENT **FIGURE 5 BLUNT POINT** **FIGURE 6 DIAMOND POINT**

In general the results indicate that nail deviation can be reduced by about 50% if blunt point nails are used in preference to diamond point nails.

The reason that blunt point nails deviate less seems to be that they tend to punch through the wood fibres, breaking them as they go, whereas the diamond point tends to part the fibres leaving them largely intact. The sharper point and the angle on the side of the diamond point nail seem to act as steering devices which deflect the nail towards a path of least resistance, be it towards a soft earlywood band or away from a harder feature like a knot or a dense latewood band.

NAILING INDUCED SPLITTING

Splitting of timber as a result of nailing is most commonly encountered when nailing near the end of timber members. The joint in a house frame where splitting seems to be most likely is the end of a plate to a stud connection. This joint is the focus of this study. A number of factors are suspected of influencing the occurrence and/or magnitude of splitting in timber. These are summarised in Table 3.

TABLE 3 FACTORS INFLUENCING NAILING INDUCED SPLITTING

Factors	Suspected Influence
Nail Diameter	Larger diameters increase splitting
Nail Length	Longer nails are more likely to cause splitting
Nail Point	Blunt nails cause less splitting (This is well established for high splitting species like Cypress.)
Nail Punching	Larger punching depths cause more splitting
Nail Installation	Hand nailing causes more splitting than machine nailing?
Nail Orientation	Nailing fully perpendicular or parallel to the grain is more likely to cause splitting
Wood Density	Denser woods or nailing near knots can result in increased splitting
End & Edge Distances	Smaller distances result in more splitting
Distances between nails both across and along the grain	Smaller distance results in more splitting
Angle of Nailing	Skew and Toe nailing result in more splitting than full through nailing
Joint Tightness	Joints which are held firmly during nailing are less likely to result in splitting

The factors suggested in Table 3 are based on anecdotal reports from timber users and field observation of nailed joints.

Nail point, nail punching, edge distances and end distances were the factors considered worthy of investigation as minor modifications of these factors can be relatively easily achieved.

A test method using a total of 180, 70 x 35mm slash pine framing specimens, 300mm long was chosen. In test series I a total of four nails were driven into each of 90 specimens while in test series II three nails were driven into the remaining 90 matched specimens. Nails were driven into ends and the width and length of any resulting split was measured. These measurements were then combined to give a split severity score developed specifically for this investigation to reflect user perceptions of splitting. The score system adopted is shown in Table 4.

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TABLE 4 SPLIT SEVERITY SCORE

Score	Split Width (mm) (On End)	Split Length (mm) (Average of Top & Bottom Lengths)
0	0	0
1	Just visible, < 0.1	Less than or equal to 25
2	Just Visible, < 0.1	Greater than 25
3	0.1 to 1.0	Less than or equal to 25
4	0.1 to 1.0	26 to 50
5	0.1 to 1.0	51 to 75
6	0.1 to 1.0	Greater than 75
7	1.0 to 2.0	Less than or equal to 50
8	1.0 to 2.0	Greater than 50
9	Greater than 2.0	Less than or equal to 75
10	Greater than 2.0	Greater than 75

Details of the differing nail points, nail punching, edge distances and end distances used in the testing are shown in Table 5. A summary of the measurements from the tests is also included in Table 5. The mean density of the slash pine used in the tests was 619 kg/m³ with a standard deviation of approximately 90 kg/m³. All nails were plain shank 3.06mm dia x 75mm and were machine driven. Except where indicated nails were punched by the drive pin of the nailing gun to a depth of approximately 4mm.

TABLE 5 SPLITTING TEST DETAILS AND SUMMARY OF RESULTS

Test Series	I				II		
Test Code	E	F	G	H	I	J	K
Nail Point Nail Punching (Y/N)	Blunt Y	Blunt Y	Diamond Y	Diamond Y	Diamond Y	Diamond Y	Diamond N
Number Tested	90	90	90	90	90	90	90
Edge Distance (mm) - Nominal - Actual Mean - Actual Std. Dev.	 20 - -	 20 - -	 20 - -	 20 - -	 35 32.6 1.7	 20 21.8 3.4	 20 - -
End Distance (mm) - Nominal - Actual Mean - Standard Deviation	 15 16.7 1.6	 25 25.2 2.0	 15 17.0 1.5	 25 25.5 2.0	 15 - -	 15 15.5 1.5	 15 16.0 2.2
Splitting Occurrence -Number -Percentage %	 14 16	 7 8	 67 74	 46 51	 71 79	 79 88	 65 72
Splitting Severity -Mean Score -Standard Deviation	 0.56 1.72	 0.41 1.75	 3.97 3.14	 2.54 2.93	 3.24 2.39	 3.79 2.52	 2.67 2.64

Note (1) "-" indicates that no measurements of this quantity were taken.

(2) The splitting severity results are not normally distributed and the standard deviation is included to give an indication of the variation in splitting.

Comparing the results of individual nails gives an indication of the effect of varying nail point, end distance, punching and edge distance.

(i) **Nail Point.** A comparison of tests E and F with G and H suggests that the use of blunt point nails in preference to diamond point nails will reduce the occurrence and severity of splitting by 80% and 85% respectively.

(ii) **End Distance.** The effect of increasing end distances from about 17mm to 26mm can be assessed by comparing tests G and H. In diamond point nails a reduction in the occurrence and severity of splitting by about 30% was achieved.

(iii) **Punching.** A comparison of the results between test J and K indicates that where nails are not punched below the surface of the timber, the occurrence and severity of splitting can be reduced by about 20% and 30% respectively.

(iv) **Edge Distance.** Comparing tests I and J shows that increasing the edge distance from 22 to 33mm, results in a reduction in the occurrence and severity of splitting by 10% and 15% respectively.

In general it appears that any factor which either reduces or resists the perpendicular to grain tensile stresses in the wood will result in reduced splitting. A blunt point nail and no punching reduces the forces trying to split the timber, whereas increasing edge and end distances provides increased resistance to these forces.

WITHDRAWAL RESISTANCE

The results of the deviation and splitting tests suggest there are significant advantages in using blunt point nails in preference to diamond point nails. Some anecdotal reports of the use of blunt point nails suggest that the withdrawal resistance of blunt point nails is less than that of diamond points. Although nails in a finished house frame are not designed to resist withdrawal forces (AS1720.1 does not provide allowable withdrawal loads for nails into end grain), plate to stud joints are required to resist withdrawal forces which may be applied during manufacture, transport and erection. It was considered necessary to investigate the relative withdrawal resistance of available blunt point nails as compared to the typically used diamond point nails.

Testing in accordance with the requirements of AS1649-1974 "Determination of Basic Working Loads for Metal Fasteners for Timber" was carried out. Slash pine 70 x 35 framing was selected and manufactured into a "T" connection where the leg was 350mm long and the horizontal member was 450mm long. The pieces were connected using two nails. The 4 different nail types tested were all 3.06mm in diameter, coated with anti-withdrawal fluid and were machine driven at a distance of approximately 20mm from the edges of the piece and into the end grain of the "T" leg. The point was then pulled apart using Hyne & Son's tension testing machine at the Maryborough Structural Testing laboratory. A load cell calibrated against an independently tested proving ring, was used to determine the maximum withdrawal force resisted by the "T" joints. The mean density of all samples was 615 kg/m^3 with a standard deviation of 110 kg/m^3. The mean moisture content of all samples was 11.8% with a standard deviation of 3.2%. Details of the nails tested and

the results are shown in Table 6. The characteristic withdrawal resistance per 1mm penetration, suitable for limit state design purposes, was determined using an expression suggested by CSIRO. (Leicester 1991) This characteristic resistance is based on the weakest test result, the co-efficient of variation of the results and the sample size.

TABLE 6 NAIL DETAILS AND WITHDRAWAL TEST RESULTS

Test Code	L	M	N	O
Nail Point	Blunt	Blunt	Diamond	Blunt
Nail Shank	Ring	Plain	Plain	Plain
Antirust Treatment	None	Cadnium	None	None
Nail Length (mm)	83	75	75	75
Number Tested	15	15	15	15
Failure Mode				
Withdrawal of Shank (No.)	5	13	13	14
Pull through of Head (No.)	10	2	2	1
Wood Density (kg/m^3)				
- mean	619	614	612	615
- s.d.	124	116	99	109
Wood MC % - mean	12.2	12.3	11.4	11.4
- s.d.	3.4	3.8	2.9	2.8
Penetration Depth (mm)				
- mean	52.1	43.5	46.2	44.4
- s.d.	1.5	2.9	0.9	2.2
Joint Resistance (N)				
- mean	3665	2737	2977	2800
- s.d.	1152	1201	848	1075
- max	6725	5475	4650	4250
- min	2300	725	1850	875
Withdrawal Resistance (N/mm)				
- mean	35.0	31.5	32.2	32.4
- s.d.	12.1	14.5	9.1	10.6
- char.	21.0	8.5	18.6	9.8

An analysis of the results showed a significant but weak positive relationship between joint strength and wood density for nail types L and M.

An analysis of the mean withdrawal resistance per 1mm of penetration showed no significant difference between the nail types.

An analysis of the mean joint resistance also showed that standard blunt and diamond point nails were not significantly different. The 83mm ring shank blunt point nail was significantly different from the 75mm plain shank diamond point nail at the 0.05 level. This appears to be due to the increased penetration depth rather than the ring shank.

From a practical point of view the tests would suggest that the use of machine driven blunt point nails in wall frames would not be significantly different from diamond points with regard to separation of plate to stud connections, due to manufacture, transport or erection forces. The higher variations in joint resistance could mean that on occasion a blunt point nailed joint may be weaker than the weakest diamond point nailed joint. The effect of these occasional weak joints could be overcome by either reducing the forces on the joint, (i.e. more care in handling) or by using a blunt point nail which has increased resistance (i.e. longer and/or special shank nails). A possible reason for the increased variation associated with plain shank blunt point nails is that the wood fibres adjacent to the nail shank may apply more variable normal forces to the nail due to the increased disturbance of fibre as a result of the punching action.

DISCUSSION

The main reason that most machine driven nails have a diamond point can be traced to hand nailing practices where a sharp point is required to easily start and then hold the nail, so that hands can be kept free during the manual driving process. Machine driving techniques do not require nails to have diamond points as the nail driving operation is automated. It also seems that the angle on the diamond point traditionally used in Australia is quite low by world standards, i.e. the point is sharper. This is most probably due to the relatively hard eucalypt species which were once the main construction timber in Australia. In Europe and North America blunter diamond points with a 30 degree angle to the nail axis are commonly used. In these areas softwoods similar to Australian softwood species are the most common construction timbers. Blunt point nails are also more commonly used in these countries.

CONCLUSION

1. The use of blunt point nails in preference to diamond point nails is the most practical way to reduce both nail deviation and nailing induced splitting in typical house frame joints.

2. Smaller nail diameters and high steel strength nails seem to be only slightly beneficial in reducing nail deviation.

3. Maximising end distances, side distances and reducing the depth of nail punching will result in less splitting.

4. Separation of plate/stud connections during manufacture, transport and erection will not be significantly increased if blunt point nails are used in preference to diamond point nails.

In general, the increased use of machine driven blunt point nails will result in an improvement in the quality of softwood wall framing due to less splitting and deviation. The use of blunt point nails should also result in fewer personal injuries where safe nailing practices are not used.

RECOMMENDATIONS

1. Manufactures of pre-nailed wall framing who are concerned about improving the quality of their framing products and workplace safety should seriously consider the increased use of blunt point nails.

2. Nail manufacturers should increase the range of blunt point nail products currently offered to Australian timber users. They should also investigate the modification of the current relatively sharp diamond points so that they achieve some of the advantages of blunt point nails.

POST SCRIPT

Trials within a number of Hyne & Son's own wall framing plants have shown that the benefits identified in the above research can be achieved in practice. Not only were the benefits obtained in the common softwood framing species but also in the denser hardwoods where predrilling of top plate ends was found to be unnecessary when blunt point nails were used.

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Table 5. Separation of means, by Duncan's multiple range test (DMRT), of timber species and treatments after 184 weeks' exposure in the AFS

Species and treatment	Means[2,3,4]	DMRT
E. maculata, mature	6.6	
E. wandoo, mature	6.4	
E. wandoo, regrowth	6.4	
E. resinifera, mature	6.2	
E. microcorys, mature	6.0	
E. maculata, regrowth	5.6	
E. microcorys, regrowth	5.0	
E. camaldulensis, mature	5.0	
E. patens, regrowth	4.8	
E. patens, mature	4.6	
E. muelleriana, mature	4.4	
E. calophylla, regrowth	4.2	
E. marginata, regrowth	4.2	
E. diversicolor, regrowth	4.2	
P. radiata sapwood, 8-10 kg/m^3 CCA	4.2	
E. diversicolor, mature	3.8	
A. fraserana, mature	3.8	
E. calophylla, mature	3.8	
A. fraserana, regrowth	2.8	
E. marginata, *Fistulina*-affected	2.8	
E. marginata, mature	2.6	
E. resinifera, regrowth	2.2	

[1]All specimens are heartwood unless otherwise indicated.

[2]Means joined by the same line are not significantly different at the 5% level.

[3]Species and treatments with mean ratings of less than 2 were excluded from the analysis.

[4]Mean of five replicates.

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