BROWN.

23rd FOREST PRODUCTS RESEARCH CONFERENCE

19–22 NOVEMBER 1990

HELD AT

CSIRO
DIVISION OF FORESTRY & FOREST PRODUCTS
Clayton, Victoria, Australia

VOLUME 1

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LIST OF DELEGATES

ATYEO, Bill	SA Woods & Forests Dept
BALODIS, Bill	CSIRO DFFP
BARNACLE, John	CSIRO DFFP
BEEL, Martin	WA Forest Products Assoc.
BIER, Hank	NZ Forest Research Institute
BOLDEN, Stephen	Radiata Pine Assoc.
BREITINGER, Harold	CSIRO DBCE
BROWN, Alan	CSIRO DFFP
CARSON, John	National Assoc Forest Industries (took offered)
CHIN, Charles	CSIRO DFFP
CLARK, Noel	CSIRO DFFP
COLLEY, Dick	Forestry Commission of NSW
COLLINS, Peter	CSIRO DFFP
COOKSON, Laurie	CSIRO DFFP
COSTOLLOE, John	SECV
COUTTS, Bob	CSIRO DFFP
COWN, Geoff	NZ Ministry of Forests
CREFFIELD, Jim	CSIRO DFFP
DEAN, Geoff	Invited Speaker (APPM)
DUNNINGHAM, Elizabeth	NZ Forest Research Institute
ELLYARD, Peter	Commission for the Future
FARRINGTON, Alan	APPITA
FERGUSON, Ian	Melbourne University
FRENCH, John	CSIRO DFFP
FRICK, Tony	Royal Melb Inst Technology
FUNG, Paul	CSIRO DFFP
GARDNER, David	Forestry Commission of NSW
GARTSIDE, Geoff	CSIRO DFFP
GLOSSOP, Brett	WA Conservation and Land Management
GOODE, Jenny	Invited Author (Koppers/CSIRO)
GOUGH, David	Qld Dept Forestry
GRANT, Denis	Forestry Commission of NSW
GREAVES, Harry	CSIRO DFFP
HALL, Scott	CSIRO DFFP
HARDING, Kevin	Qld Dept Forestry
HARTLEY, Jamie	Forestry Commission of NSW
HEWERTSON, Warren	CSIRO DFFP
HIGGINS, Huntly	Research Fellow, CSIRO DFFP
HILLIS, Ted	Research Fellow, CSIRO DFFP
HOWICK, Doug	CSIRO DFFP
ILIC, Jugo	CSIRO DFFP
IRVINE, Geoff	CSIRO DFFP
JOE, Bill	Forestry Commission of NSW

JOHNSON, Gary	CSIRO DFFP
KEATING, Bill	Conference Secretary
LEICESTER, Bob	CSIRO DBCE
LHUEDE, Ted	CSIRO DBCE
LLEWELLYN, Peter	SA Timber Development Assoc
LYNGCOLN, Kevin	Plywood Assoc of Australia
MacKENZIE, Colin	TRADAC
MAMERS, Heikki	CSIRO DFFP
MAULDIN, Joe	USDA Forest Service
McARTHUR, David	CSIRO DFFP
McCARTHY, Kevin	CSIRO DFFP
McDOWALL, Mick	Invited Speaker (c/o PAA)
McKENZIE, Alex	CSIRO DFFP
McLAUGHLAN, Jack	NZ Forest Research Institute
McNAUGHT, Andy	Qld Dept Forestry
MICHELL, Tony	CSIRO DFFP
MILLER, Wayne	NZ Forest Research Institute
MILLS, Robert	Aust Furniture Res & Dev Institute
MILNER, Bob	Monash University
~~MOFFAT, Alan~~ CAUSE, Myron	Qld Dept Forestry
NELSON, Peter	CSIRO DFFP
NIKPOUR, Touba	CSIRO DFFP
NORTHWAY, Richard	CSIRO DFFP
OZARSKA, Barbara	Aust Furniture Res & Dev Institute
PRESTWICH, David	Aust Hardwood Quality Council
RAWLINS, Bill	CSIRO DFFP
REILLY, Mary	CSIRO DFFP
ROZSA, Andrew	CSIRO DFFP
RUDLING, Ken	Southern Timber Treaters Group
SCHMALZL, Karl	CSIRO DFFP
SIEMON, Graeme	WA Forests Dept
SIOUMIS, Tony	CSIRO DFFP
STROHFELDT, David	Invited Speaker (Hancock Bros)
TERCELLI, Fabian	CSIRO DFFP
TERRILL, Stuart	CSIRO DFFP
THORNTON, John	CSIRO DFFP
TIGHE, Maureen	CSIRO DFFP
TSUNODA, Kunio	Kyoto University
VICKERS, Lloyd	CSIRO DFFP
VINDEN, Peter	NZ Forest Research Institute
WADE, John	Forestry Commission of NSW
WALLIS, Adrian	CSIRO DFFP
WATKINS, John	Invited Speaker (Koppers/CSIRO)
WAUGH, Gary	CSIRO DFFP
WEARNE, Ross	CSIRO DFFP
WILLIAMS, Max	CSIRO DFFP
YAZAKI, Yoshi	CSIRO DFFP
YURITTA, John	CSIRO DFFP

23RD FOREST PRODUCTS RESEARCH CONFERENCE

19-22 November 1990
CSIRO Division of Forestry and Forest Products.
Bayview Ave. Clayton. Victoria

VOLUME 1

* KEYNOTE ADDRESS: Dr Peter Ellyard. Director.
Commission for the Future
(10.30 a.m.. 19 November)

SESSION 1 Biodegradation and Chemical Treatments (1.30 p.m. 19 November)

1/L Environmental Issues in Wood Preservation - J. Norton. Chemistry and Wood Preservation Section. Queensland Forest Service.

* 1/1 Emulsions - the Key to the Future - John Watkins. Jenny Goode. Koppers-Hicksons/CSIRO Division of Forestry and Forest Products.

1/2 The Effect of Impregnated and Surface Coated Fire Retardants on the Fire Performance of Forest Products - W.D. Gardner. Forestry Commission of N.S.W.

1/3 Chemical Modification of Wood Surfaces for Protection Against Weathering - Karl J. Schmalzl. Anthony J. Michell. Lloyd J. Vickers. CSIRO Division of Forestry and Forest Products and Philip D. Evans. Department of Forestry. A.N.U.

1/4 Preservation Research in Western Australia - G.R. Siemon. G.K. Brennan. Department of Conservation and Land Management of Western Australia.

1/5 Decay. Detection and Remedial Treatment in Wooden Poles - K. McCarthy and H. Greaves. CSIRO Division of Forestry and Forest Products.

SESSION 2 Structural Application (9 a.m. 20 November)

2/L Where to From Here - The Needs of Industry - C.E. Mackenzie. Timber Research and Development Advisory Council of Queensland.

2/1 Developments in New Zealand Timber Engineering Research - Hank Bier. Forest Research Institute. Rotorua. New Zealand.

2/2 A Review of Bolted Timber Connections - E.P. Lhuede. CSIRO Division of Building. Construction and Engineering.

2/3 Mechanical Stress Grading of Timber in Australia - D.J. Grant. Forestry Commission of N.S.W.

2/4 Durability - A Structural Approach - R.H. Leicester, CSIRO Division of Building, Construction & Engineering and J.E. Barnacle, CSIRO Division of Forestry & Forest Products.

2/5 Finger Jointing of Hardwoods - H.R. Milner, Monash Timber Engineering Centre, Monash University.

SESSION 3 Primary Conversion, Drying and Utilisation (2 p.m. 20 November)

* 3/L Industry Requirements for Future Research - I.S. Ferguson, University of Melbourne.

* 3/1 The Role of Computer-based Models in Wood Drying - Richard Northway, CSIRO Division of Forestry & Forest Products.

3/2 Stockpiling and Sawing Regrowth Eucalypts - G.K. Brennan, Department of Conservation and Land Management, W.A.

3/3 Seasoning Regrowth Eucalypts - B.R. Glossop, Department of Conservation and Land Management, W.A.

3/4 Sawn Products from Regrowth *Eucalyptus regnans* - Gary Waugh and Andrew Rozsa, CSIRO Division of Forestry & Forest Products.

3/5 Drying Developments in Australia - Jamie Hartley, Forestry Commission of N.S.W. and David K. Gough, Queensland Forest Service.

SESSION 4 Reconstituted Wood Products (9 a.m. 21 November)

4/L VALWOOD® for Value-Adding in Regrowth Eucalypts - G.R. Siemon, Department of Conservation and Land Management, W.A.

* 4/1 Laminated Veneer Lumber, In-Grading Testing - R.H. Leicester, CSIRO Division of Building, Construction and Engineering and B. Hutchings, Consultant.

4/2 Molecular Designing of Wood Adhesives - Y. Yazaki and P.J. Collins, CSIRO Division of Forestry & Forest Products.

4/3 The Design and Construction of Stressed Skin Panelised Floor Systems - C.G. McDowall, Queensland University of Technology.

4/4 Bridgewood®, Application of Very Thick Plywood - David Strohfeldt, Hancock Bros. Pty. Ltd.

4/5 Development of CSIRO Activated Wood Pellet Carbon for Gold Extraction - P.Y.H. Fung, CSIRO Division of Forestry & Forest Products.

SESSION 5 Growth for End-Use (1 p.m. 21 November)

* 5/L Introductory Address - A. Brown. CSIRO Forestry & Forest Products. Canberra.

5/1 Impact of Silvicultural Decisions on Radiata Pine Log Quality for Sawmilling - D.J. Cown and O. Cox. Forest Research Institute. Rotorua. New Zealand.

* 5/2 Breeding Eucalypts for Manufacture of Pulp and Paper - G.H. Dean, J. French and K.N. Madden. APPM Research. Burnie. Tasmania.

5/3 Growth Rate Effects on Some Juvenile Wood Properties of *Pinus caribaea* var. *hondurensis* Stems Subject to Heavy Thinning - K.J. Harding. Queensland Forest Service.

5/4 Variation in Wood Density of *Pinus radiata* in New South Wales - R. Colley and F.R. Humphreys. Forestry Commission of N.S.W.

* 5/5 Thinning Regrowth Ash and its Effect on Wood and Fibre Yields - C.M. Kerruish. CSIRO Division of Forestry & Forest Products.

SESSION 6 Optimal Use of Fibre Resources (9 a.m. 22 November)

6/L Recycling - Prospects and Practices - A.W. Mackenzie. CSIRO Division of Forestry & Forest Products.

6/1 The Commonwealth Guidelines for New Bleached Eucalypt Kraft Pulp Mills - P.J. Nelson. CSIRO Division of Forestry & Forest Products.

* 6/2 Alternative Fibre Sources - G. Gartside. CSIRO Division of Forestry & Forest Products.

6/3 Rediscovering the East Gippsland Forest - H. Hamers and V. Balodis. CSIRO Division of Forestry & Forest Products.

6/4 Process Alternatives for Chemical Pulping and Bleaching - A.F.A. Wallis. CSIRO Division of Forestry & Forest Products.

6/5 High-Yield Mechanical Pulp - What's In It For Us? - M.D. Williams. CSIRO Forestry & Forest Products.

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

ENVIRONMENTAL ISSUES IN WOOD PRESERVATION

by

J. Norton

Chemistry and Wood Preservation Section
Queensland Forest Service
Department of Primary Industries

INTRODUCTION

The environment is a very topical issue and contamination of the environment by chemicals in any concentration is generally seen as a major threat. The public at large is in a state of 'chemophobia', and chemicals in many situations are considered guilty with little chance of being proved innocent. This fear has led to ridiculous situations.

For example, in California last year, "Proposition #65" was made law, where by it is illegal for any organization to put into water, any detectable amount of chemicals known to cause cancer or re-productive toxicity in laboratory animals. (1)

Taken to the extreme, this means that a cafe may not put a peanut butter sandwich down the sewerage system because the natural toxin aflatoxin can be detected in minute amounts.

This is not to say that chemicals are harmless. In adequate quantities even salt is poisonous, yet most households place this chemical on the dining table every time

a meal is eaten. Chemicals play a vital part in our quality of life but their use must be reasonable and judicious.

The preservation of timber is regularly condemned because 'poisonous' chemicals are used. Wood preservative chemicals are chosen for the specific purpose of preventing biological attack and when used properly and safely, these same 'poisonous' chemicals can actually help to protect the environment. Treatment of timber with preservatives results in a longer service life than might otherwise be possible in construction and other commercial applications.

Timber preservation is an activity that decreases the demand for the exploitation of the timber resources of this planet.

Because it uses toxic compounds, the timber treatment industry must not only operate in a safe manner, but must also be seen to operate in an environmentally responsible way. Any environmental contamination from industry sources is likely to cause a far more adverse response than is warranted.

ISSUES ASSOCIATED WITH WOOD PRESERVATIVE CHEMICALS

Copper chrome arsenic (CCA) formulations are the most commonly used timber preservatives in this country, followed by boron-based systems.

The chemistry of CCA formulations causes fixation of the chemicals in the wood and a great deal of work has been carried out to describe and quantify the fixation processes involved. (2) Chemical reactions between CCA components and the wood convert a water soluble preservative system to one which is insoluble.

There has been a move, especially in the Scandinavian countries, to restrict the use of CCA preservatives to ground contact uses (3). The reasons for such actions are unclear. Researchers can not agree on methods for evaluating leaching or movement of biocides from treated timber and having obtained a result, can only postulate the

levels of risk. (4) The main methods for coming to terms with the level of risk are to adopt official limit values established by industrial hygienists for indoor air, and to apply an arbitrary safety factor.

A lot of effort is being put into the development of wood preservatives with low mammalian toxicity. A great danger however, lies in being forced to use new preservative systems that have not been fully tested, because tried and proven formulations have fallen victim to the "if in doubt ..... BAN" syndrome that is presently in vogue. Banning chemicals such as CCA, because of their arsenic and chromium content, may create more problems than currently exist.

A great deal of the arsenic used in the manufacture of CCA formulations is a by-product of essential metal refining industries. Anderson et al point out that if CCAs are removed from use because of the arsenic content, the metal refining industries would continue to produce arsenic and would encounter a serious waste disposal problem.(5) In this instance, the wood preservation industry is actually decreasing the disposal problems associated with arsenic by-products by locking the chemical into timber. Banning CCAs could lead to an environmental problem where as their continued proper use would not.

Haste in banning CCAs would also escalate the cost of housing, as the building industry would need to increase its use of non-renewable resources.

The draft Australian Standard on wood preservation has identified Hazard areas to which timber is to be treated, and specifies the preservative, the preservative penetration and preservative retention that may be used. The trend both nationally and internationally is to target end use areas with particular preservatives.

In Queensland for example, boron compounds have been used since the Second World War to treat interior timbers, whereas CCA formulations are generally used to treat timber exposed to the weather. Boron-base wood preservatives have been internationally rediscovered and in Queensland, the technology is generally in place.

ISSUES AFFECTING THE TREATMENT PLANT

The way in which timber treatment plants carry out their operations is likely to have a greater affect on the future of the treatment industry than the chemical or formulation in use. Connell et al (6) point out that the UK Government's Health and Safety Executive (1988) differentiates between risk and hazard. The authors state that:

> "... poor control can create a substantial risk, even from a substance with low hazard and that with proper precautions the risk of being harmed by the most hazardous substances can be adequately controlled."

Irresponsible plant operation resulting in environmental contamination could cause at best, the end of a perfectly good chemical and at worst, the shut down of a viable timber treatment industry.

The main reference for timber treatment plant operations in this country is the Australian Standard AS 2843. Part 1 (7) of this Standard deals with timber treatment plant design, and Part 2 (8) deals with plant operation.

Part 1 of the Standard refers to "controlling" environmental contamination and not its prevention. In Queensland, the task of preventing contamination has fallen to the Department of Environment and Heritage (DOEH) which is moving towards a condition of 'zero discharge' for timber treatment plants, with all plants being required to comply with the requirements of AS 2843.1.

DOEH have also imposed extra conditions on the design of timber treatment plants. All new timber treatment plants will be required to comply with the requirements of AS 2843 plus other specified conditions (9) and existing plants will be required to comply by the end of 1992. A summary of these extra requirements is set out in Table 1.

Table 1: Time table for compliance with requirements extra to AS 2843

Diversion of storm water from around the site	31/12/90
Construction of a Sediment basin for run-off from inside the boundary fence	31/12/90
Collection of storm water run off from the working area (covered) to site storage for re-use	30/6/91
Storage tanks for working area run-off storage	30/6/91
Roof the treatment facility	31/12/90
Roof the drip area	31/12/91
Concrete the working area	30/6/91
Concrete the drip area (48 hr storage)	30/6/92
Provide a dedicated vehicle or crane (to operate on the concreted area only)	31/12/92
Bunding to contain 120% of the chemicals on site	31/12/92
Sump alarm & cut off device	30/6/91
Anti-blowback device	30/6/91
Mist traps	30/6/91
Pressure vessel interlocks	30/6/91
Mix/storage tank fail-safe shut off devices	30/6/91

A number of other constraints have been applied as well, but these do not apply to timber treatment plant design.

DOEH have been as reasonable as possible in the implementation of these extra design constraints. The timber treatment industry has been given the opportunity to pass comment on the requirements, and all existing treatment plants are given the opportunity to vary from the deadline dates. All constraints however, must be complied with by the end of 1992.

Vacuum pressure impregnation plants were first installed in Queensland in the mid 1960s when CCA preservatives were first introduced. The first CCA plants had very little in the way of environmental features included in their design, with the result

that the older plants are likely to be severely contaminated. Plants that have shut down, or intend to shut down, will be faced with high decontamination expenses that must include the disposal of contaminated soil.

Borax treatment vats have been used in Queensland since 1949, when the *Timber Users Protection Act* was enacted. At that time, the purpose of the Act was to protect timber from attack by the *Lyctus* beetle. Although there are no requirements yet, it is considered that borax vats will also be affected by new environmental constraints, so that these will be the next to be made environmentally safe.

ISSUES ASSOCIATED WITH TREATED TIMBER

There are two aspects to this topic. The first is the disposal of waste material prior to installation. In the factory, planer shavings are produced and at the building site, off- cuts may become a disposal problem.

Hardwood timbers are often dressed after preservative treatment, and because of their relatively small proportion of treated sapwood to untreated heartwood, the quantity of treated shavings from hardwoods is not generally considered to be a problem.

Softwoods may be dressed to shape before preservative treatment when Light Organic Solvent preservatives are used, but preservative treatment of timber in its final shape and form with water-borne systems will cause dimensional movement that may destroy machined joints.

When planer shavings from CCA treated timber are used as boiler fuel, the remaining ash is high in unfixed preservative components, and cleaning ash from boiler grates and its consequent disposal can create a severe health risk. In the last twelve months, there have been two instances in Queensland involving boiler ash that was obviously contaminated with CCA preservative.

When timber containing boron-based preservatives is burnt, a glass-like substance called 'clinker' is produced. Where excessive clinker is produced, it has to be smashed from the firebox.

Whilst boron-based preservatives are considered to be safer than CCA, they are phytotoxic and can cause problems in agriculture if spillage occurs.

Waste timber from building sites is not generally regarded as an environmental problem. The offcuts are usually burnt on the site but increasingly, disposal involves dumping at a domestic tip. Individual home owners are unlikely to generate enough volumes of treated wood to create a problem through conventional garbage disposal. CCA-treated timber is obviously different from untreated timber and most home owners realize that the timber contains chemicals and as such should not be burnt in heating or cooking fires.

A potentially more severe problem is the disposal of treated timber once it has reached the end of its commercial life. Large volume products such as treated power poles and sleepers are usually reused. CCA-treated landscaping timbers may also be largely reused but preservative-treated sawn products are likely to be dumped and estimating the quantities involved is very difficult. The problem in this case is the potential leaching of preservative components that may occur

Ruddick (1990) poses the question:

> "Which is more acceptable, a treated product that can last 50 years but which has no easy method of disposal at the end of its life, or one which lasts only 20 years, but which can be incinerated without production of harmful products?".(10)

ISSUES ASSOCIATED WITH CHEMICAL WASTES.

As soon as CCA solutions come into contact with timber, chemical changes start to take place, causing the preservative components to become fixed into the wood.

When these fixation reactions take place outside the timber, a phenomenon called 'sludging' takes place.

A number of causes of sludge production have been identified (11), but the most common cause is the treatment of timber at too high a moisture content. The Bethell-based processes are generally used. They result in fluids rich in wood sugars being 'kicked back' into the treating liquid. These compounds cause the reduction of chromium and the production of sludge. The problem is also quite severe when empty- cell processes are used to treat *Pinus* timbers at high moisture contents.

In Queensland, the problem has been most severe with the preservative treatment of eucalypt power poles. Vacuum times in the order of seven hours are not uncommon, and the long contact time between the preservative solution and the timber causes sludging. In these cases, the problem is exacerbated by the use of preservative solutions that contain in the vicinity of 10% m/v CCA salt.

For the purposes of dealing with sludge, two types have been identified.(12) The first is the waste material associated with debris that occurs around a timber treatment plant. This usually involves contaminated soil, sawdust and other rubbish from around the treatment yard. The second type of sludge is a chemical sludge, and refers to the solid chemical precipitate that occurs in the treatment solution.

The composition of chemical sludge varies with the source, but it may be typically 5% copper, 10% chromium and 15% arsenic. Sludge costs the timber treatment plant owner money, through loss of the chemical from the treating system and cost of disposal.

The earliest methods of sludge disposal involved burial. In some cases this was with approval whilst in others it was most probably carried out 'in the dead of night'. A later method involved blending the sludge with concrete and disposal of the resulting block in land fill.(13)

Concreted sludge cannot be used for structural purposes because of its poor compressive strength. The cementation technique used in Queensland involves a concrete pipe as a mould into which the blended sludge is poured. The pipe is fitted with a plug of clean concrete at both ends as well as a lifting eye.

Once sealed, these concrete-filled pipes may be used as land fill; however, this practice has stopped as they must now be disposed of in a toxic waste site. The only waste site in Queensland is situated just outside Brisbane, but only waste from the metropolitan Brisbane area is accepted. The biggest problem with this is that most of the CCA treatment plants in the state are outside metropolitan Brisbane.

A recent development involves the recycling of chemical sludge. This task is being carried out by the preservative salt suppliers, and whilst the details of the techniques have not been released, it probably involves the use of chromic acid to solubilize the sludge followed by adjustment of the resultant solution to achieve the proper chemical balance.

It has been reported that the value of the chemicals recovered exceeds the costs involved in carrying out the process.

ISSUES OF CONTROL OVER THE INDUSTRY

In Queensland, the *Timber Utilization and Marketing Act (1987)* and in New South Wales the *Timber Marketing Act (1986)*, deal with the sale of preservative-treated timber. No other States of Australia have similar legislation and neither piece of legislation involves any control over environmental issues.

Environmental aspects are dealt with by other State legislation and most tend to follow the example set by the USA and Canada. Three instruments are used for the control of pollution:

- Regulation;
- Guidelines; and
- Codes of Practice.

Regulations are subordinate legislation and are enforceable. They apply to a given operation and usually specify limits of toxic substances that may be found at a defined location. In the absence of such limits, zero discharge or contamination is allowed. By complying with regulations, an organization is exempt from prosecution under the applicable Act.

Regulations are usually preceded by Guidelines. Like regulations, guidelines may include some specific limits on toxic substances; however, they differ in that operators are given a period of time in which to achieve compliance with the specification. Usually, guidelines are upgraded to regulations when enough time has elapsed for compliance to have been achieved. Queensland is very definitely proceeding in this way.

Codes of Practice are used when it is difficult to regulate for a desired condition. They may involve matters such as 'good housekeeping', but may in some instances be imposed by regulation.

Estimates of expenditure required to upgrade existing vacuum pressure plants are in the order of half a million dollars, and unless some form of taxation relief is obtained, it is quite likely that a number of the smaller operations will shut down because of the capital expenditures involved. There is little doubt, however, that environmental considerations will have a major impact on timber treatment plant operations and that because of the level of political interest in the environment, plants will have no choice but to comply with regulations.

Preservative manufacturers will continue to look for environmentally friendlier chemicals, but they need the help of the treating industry. Industrial accidents through poor operation that cause spillage and environmental contamination will bring a rapid response from an outraged public and their reactions will be emotively intensified by the media. The whole industry would suffer if the banning of a perfectly good chemical system was followed by its replacement with an incompletely researched substitute.

It is suggested that the future of the timber preservation industry depends largely on the timber treater. A clean and safe operation will firstly ensure that the chance of accidents is minimized and secondly contribute to the effective utilization of a very useful product.

1. Whelan M. E. Keynote Address, American Wood Preservers' Association, 1989.

2. Dahlgren S. E., The Course of Fixation of Cu-Cr-As Wood Preservatives, Proceedings of the British Wood Preservers' Association Annual Convention, 1972, p.109.

3. Moldrup B., Radical Changes in the Requirements for More Safe Pressure Impregnation in the Nordic Countries in 1988, Proceedings from the wood preservation symposium, The Challenge - Safety and Environment, Cannes, France 1990, 211-222.

4. Pichard A., Evaluation of the Biocide Diffusion from Treated Wood in Indoor Air. Bibliographic Study, Proceedings from the wood preservation symposium, The Challenge - Safety and Environment, Cannes, France 1990, 151-167.

5. Anderson D. G., Connell M., Waldie P., Environmental Issues in Europe: A review of current EEC Regulations Affecting the Pretreatment Preservation of Wood, Proceedings of the B.W.P.A. Annual Convention, 1987.

6. Connell M., Cornfield J. A., Williams G.R., A New Preservative - A Double Edged Sword, Proceedings from the wood preservation symposium, The Challenge - Safety and Environment, Cannes, France 1990, 329-350.

7. Australian Standard 2843 - 1985 Part 1 SAA Timber Preservation Safety Code - Plant Design, Standards Association of Australia 1985, 1-16.

8. Australian Standard 2843 - 1985 Part 2 SAA Timber Preservation Safety Code - Plant Operation, Standards Association of Australia 1985, 1-24.

9. Environmental Guidelines - Interim, CCA plants in Queensland, Department of Environment and Heritage, 1990, pp/1-2.

10. Ruddick J. N. R., Wood Preservation and the Environment: A Canadian Perspective, Proceedings from the wood preservation symposium, The Challenge - Safety and Environment, Cannes, France 1990, 223-240.

11. Norton J., Timber Treatment Plant Operator's Course, Queensland Timber Industry Training Council, 1987.

12. Norton J., Butler B., The Management of CCA Wastes, Timber Preservation Division of the Queensland Timber Board, Advisory publication. 1990 1-6.

13. Norton J., Butler B., The Management of CCA Wastes, Timber Preservation Division of the Queensland Timber Board, Advisory publication. 1990 1-6.

14. Baker M, Timber Treaters and the Law, A paper delivered to the Timber Treaters' Environmental Conference, ANA Hotel, Gold Coast, Queensland, May 1990, pp.1-30.

THE EFFECT OF IMPREGNATED AND SURFACE COATED FIRE RETARDANTS ON THE FIRE PERFORMANCE OF FOREST PRODUCTS

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P.O. Box 100, Beecroft. N.S.W. 2119. Australia.

INTRODUCTION

Fire retardants are applied to forest products in Australia to achieve compliance with specifications in building codes related to flame spread and contribution to fire growth. There are two main methods of applying fire retardants - either by impregnation using vacuum/pressure treatment schedules or by surface coating.

Forest products are impregnated with waterborne fire retardants during their processing or manufacture and surface coatings are normally applied to forest products after they have been fixed in a building. To avoid discolouration and surface checking that can result from fire retardant treatment by vacuum/pressure impregnation, fire retardant treated plywood is sometimes overlaid with an untreated timber face veneer.

The effect of fire retardant treatment by (a) impregnation and (b) coating on the tendencies for two forest products to ignite, propagate flame, release heat and release smoke as determined by testing to several standard small scale test methods will be examined. The effect on its fire performance of overlaying fire retardant treated plywood with an untreated timber face veneer will also be examined, as will the effect of a fire retardant coating on the tendencies for a forest product to release smoke, propagate flame and contribute to fire growth during a room fire test when used as wall lining in a full-scale experimental room.

MATERIALS

Hoop pine plywood

Hoop pine (*Araucaria cunninghamii*) plywood, 12 mm thick, was tested.

Radiata pine boards

Radiata pine (*Pinus radiata*) boards were machined to a double V-joint, tongue and groove 135 x 77 mm profile.

Fire retardant impregnated hoop pine plywood

Hoop pine veneers were impregnated with mono ammonium phosphate to a dry salt retention of 80 kg/m ^{3} and manufactured into 12 mm thick plywood.

Fire retardant impregnated hoop pine plywood with untreated face and back veneers

The fire retardant impregnated hoop pine was overlaid on the face and back with 0.6 mm untreated veneers of hoop pine.

Fire retardant coated radiata pine boards

The radiata pine boards were coated with Albert-DS-Clear, manufactured by American Vamag Company, Inc. Albert-DS-Clear is a clear, intumescent fire retardant coating. The retardant was applied in two coats, each at the rate of 5 m^2/l to give a final application rate of 2.5 m^2/l. The retardant coating was overcoated at 7.5 m^2/l with Overcoater 66-H, which was also manufactured by American Vamag Company, Inc.

TEST METHODS

AS 1530.3 - Simultaneous determination of ignitability, flame propagation, heat release and smoke release

A 600 x 450 mm panel of the test material is exposed to increasing regimes of impressed radiation and the pyrolysis products emitted are ignited by a pilot flame. During the test procedure four Reaction to Fire Parameters are measured from which four Early Fire Hazard Indices are determined.

Reaction to fire parameters

Time to Ignition - the time from the start of the test to the ignition of the test material.

Heat Release Integral - the integral of the radiant flux, measured by a prescribed radiometer, from the burning test material over a two minute interval following ignition.

Flame Propagation Time - the time taken for the radiant heat emitted following ignition of the test material to increase by 1.4 kWm^{-2}.

Optical Density of Smoke - the optical density across a light path in a flue above the test apparatus is monitored.

Early fire hazard indexes

Four Early Fire Hazard Indexes are determined from the above Reaction to Fire Parameters.

Ignitability Index - materials are rated from zero to 20, with those that do not ignite having an index of zero.

Heat Evolved Index - materials are rated from zero to 10, with increasing indexes indicating increasing quantities of radiant heat evolution.

Spread of Flame Index - materials are rated from zero to 10. Increasing indexes indicate shorter times to produce the specified radiant heat increase after ignition.

Smoke Developed Index - determined from the peak optical density of smoke averaged over one minute during the test. Materials are rated from zero to 10, with increasing indexes indicating greater smoke production.

ASTM E 84 - Surface burning characteristics of building materials

The test material, nominally 20.25 in. (514 mm) wide and 24 ft. (7320 mm) in length, is placed as a lining in the top of a tunnel 17.75 in. (451 mm) wide, 12 in. (305 mm) deep and 25 ft. (7620 mm) long. This test is known as the 25 ft. tunnel test.

A standard flame is applied to the test material at one end of the tunnel. The distance travelled by the flame over the surface of the material and the rate at which the flame travels are used to calculate a Flame Spread Index. Red oak flooring has arbitrarily been assigned a Flame Spread Index of 100 and inorganic reinforced cement-board a Flame Spread Index of zero. A material with a higher Flame Spread Index will spread flame further and/or faster down its surface in the test tunnel than a material with a lower one.

The smoke produced during the test is photometrically monitored. Materials are assigned a Smoke Developed Value relative to red oak flooring and inorganic reinforced cement-board, which are assigned Smoke Developed Values of 100 and zero respectively.

The performance of materials in the test is determined by considering the following performance parameters:

(1) Maximum distance the flame spreads over the surface of the test material.

(2) Time taken for the maximum flame spread distance to be reached.

(3) Reduction in light transmission across a standard light path.

These performance parameters are used to derive two performance indicators:

(1) Flame Spread Index; and

(2) Smoke Developed Value.

ASTM E 906 - Heat and visible smoke release rates for materials and products

Test specimens, 150 x 150 mm, are injected into an environmental chamber through which a constant flow of air is passed. The materials described in this paper were tested in a vertical orientation with piloted ignition of the gas phase and were exposed to radiant heat fluxes of 20, 40 and 60 kW/m^2 for ten minutes.

During the test, the temperature difference between the air entering and leaving the environmental chamber is recorded. From these data, the following properties are calculated -

Maximum Heat Release Rate - the maximum heat release rate per unit area of specimen.

Cumulative Heat Released - the total heat released by the specimen during the test.

Maximum Smoke Release Rate - the maximum rate of smoke released per unit area of specimen.

Cumulative Smoke Released - the total smoke released by the specimen during the test.

Room fire tests

The test room is 2400 x 3600 mm with a 2400 mm high ceiling and was constructed in accordance with the Proposed Method for Fire Test of Wall and Ceiling Materials and Assemblies, published in the 1982 ASTM Annual Book of Standards, Part 18. It was lined with gypsum plasterboard. The test material was fixed to three walls with construction adhesive and nails and the ceiling and one wall were lined with gypsum plasterboard during the tests.

The ignition source in the test room is a 310 x 310 mm propane gas burner situated in the corner of the room. During tests, the burner is operated at 40 kW output for the first five minutes and this is then increased to 160 kW for the second five minutes. If flashover of the room is not achieved within ten minutes, the burner is extinguished and the performance of the room monitored for another five minutes. (Flashover was deemed to have occurred when flames left the room via the door.)

The temperature at several locations in the room and the radiant heat flux on the floor are recorded during tests. The combustion products are collected in a hood outside the room and removed through a duct by an extraction system. The concentrations of oxygen, carbon monoxide and carbon dioxide are recorded in the duct during tests. The light transmittance across the duct is also recorded.

DETERMINATION OF FIRE PERFORMANCE

The fire performance was determined from data derived from the above standard fire test methods as detailed below.

Tendency to ignite - from the Time to Ignition determined by testing to AS 1530.3.

Tendency to propagate flame - from the Flame Propagation Time determined by testing to AS 1530.3 and the Flame Spread Index determined by testing to ASTM E 84.

Tendency to release heat - from the Heat Release Integral determined by testing to AS 1530.3 and the Maximum Heat Release Rate and Cumulative Heat Released determined by testing to ASTM E 906.

Tendency to release smoke - from the Mean Optical Density of the smoke determined by testing to AS 1530.3, the Smoke Developed Value determined by testing to ASTM E 84 and the Maximum Smoke Release Rate and Cumulative Smoke Released determined by testing to ASTM E 906.

Contribution to fire growth and smoke release in a test room - the contribution of a forest product wall lining to fire growth in a room fire test was indicated by the temperatures recorded during a room fire test by a thermocouple placed 100 mm below the ceiling in the centre of the experimental room and the time required for the test room to reach flashover. The tendency to release smoke was indicated by the reduction in the percentage light transmission across a light path in the extraction duct from the test facility.

RESULTS

The ignitability, flame propagation, heat release and smoke release of the forest products and their fire retarded (impregnated or coated) forms determined from the standard small scale tests are detailed in the following tables.

Ignitability

The Time to Ignition for the materials when tested to AS 1530.3 are given in Table 1.

Table 1. AS 1530.3 - Time to Ignition (from Gardner and Thomson, 1988)

Material	Time to ignition (mins.)
Hoop pine	4.7
FRI hoop pine (1)	No ignition
UFV/FRI hoop pine (2)	5.5
Radiata pine	5.6
FRC radiata pine (3)	15.4

Notes: (1) Fire retardant impregnated hoop pine plywood
(2) Fire retardant impregnated hoop pine plywood with untreated hoop pine face and back veneers
(3) Fire retardant coated radiata pine

Flame propagation

The Flame Propagation Times determined by testing to AS 1530.3 and the Flame Spread Indexes determined by testing to ASTM E 84 are given in Table 2.

Table 2. AS 1530.3 - Flame Propagation Times (FPT) and ASTM E 84 - Flame Spread Indexes (FSI) (from Gardner and Thomson, 1988)

Material	AS 1530.3 FPT(secs.)	ASTM E 84 FSI
Hoop pine	37	168
FRI hoop pine	not applicable	4
UFV/FRI hoop pine	greater than 203	26
Radiata pine	23	85
FRC radiata pine	greater than 203	6

Note: (1) Not applicable because specimens did not ignite

Heat release

The Heat Release Integrals determined by testing to AS 1530.3 are given in Table 3. The Maximum Heat Release Rates and Cumulative Heat Released determined by testing to ASTM E 906 with heat flux exposures of 20, 40 and 60 kW/m^2 are given in Table 4.

Table 3. AS 1530.3 - Heat Release Integrals (HEI) (from Gardner and Thomson, 1988)

Material	AS 1530.3 HEI (kJ/m^2)
Hoop pine	222
FRI hoop pine	0
UFV/FRI hoop pine	61
Radiata pine	232
FRC radiata pine	24

Table 4. ASTM E 906 - Maximum Heat Release Rates (MHRR) and Cumulative Heat Released (CHR) for specimens exposed to heat fluxes of 20, 40 and 60 kW/m^2 (from Gardner and Thomson, 1990)

	MHRR (kW/m^2)			CHR (MJ/m^2)		
	20	40	60	20	40	60
Hoop pine	125	210	220	38	73	79
FRI hoop pine	0	11	44	0	2	6
UFV/FRI hoop pine	68	121	113	0.2	3	7
Radiata pine	87	134	173	29	58	71
FRC radiata pine	30	22	61	9	4	35

Smoke release

The Mean Optical Densities determined by testing to AS 1530.3 and the Smoke Developed Values determined by testing to ASTM E 84 are given in Table 5. The Maximum Smoke Release Rates and the Cumulative Smoke Released determined by testing to ASTM E 906 for specimens exposed to heat fluxes of 20, 40 and 60 kW/m^2 are given in Table 6.

Table 5. AS 1530.3 - Mean Optical Densities (OD) and ASTM E 84 - Smoke Developed Values (SDV)

	1530.3 OD(m^{-1})	ASTM E 84 (SDV)
Hoop pine	0.014	416
FRI hoop pine	0.255	691
UFV/FRI hoop pine	0.099	787
Radiata pine	0.039	122
FRC radiata pine	0.177	90

Table 6. Maximum Smoke Release Rates (MSRR) and Cumulative Smoke Released (CSR) determined by testing to ASTM E 906 for specimens exposed to heat fluxes of 20, 40, and 60 kW/m^2.

	MSRR (SMOKE/min, m^2)			CSR (SMOKE/m^2)		
	20	40	60	20	40	60
Hoop pine	4	23	60	14	33	52
FRI hoop pine	1	14	18	6	57	102
UFV/FRI hoop pine	2	14	13	3	54	62
Radiata pine	1	12	27	1	26	85
FRC radiata pine	7	2	7	2	1	8

Contribution to fire growth in room fire test

The temperature profiles recorded 100 mm below the ceiling in the centre of the experimental room during a room fire test when the walls were lined with (a) radiata pine boards and (b) fire retardant coated radiata pine boards are given in Figure 1. The temperature profile recorded at the same position during a test when the room was lined with gypsum plasterboard is included for reference.

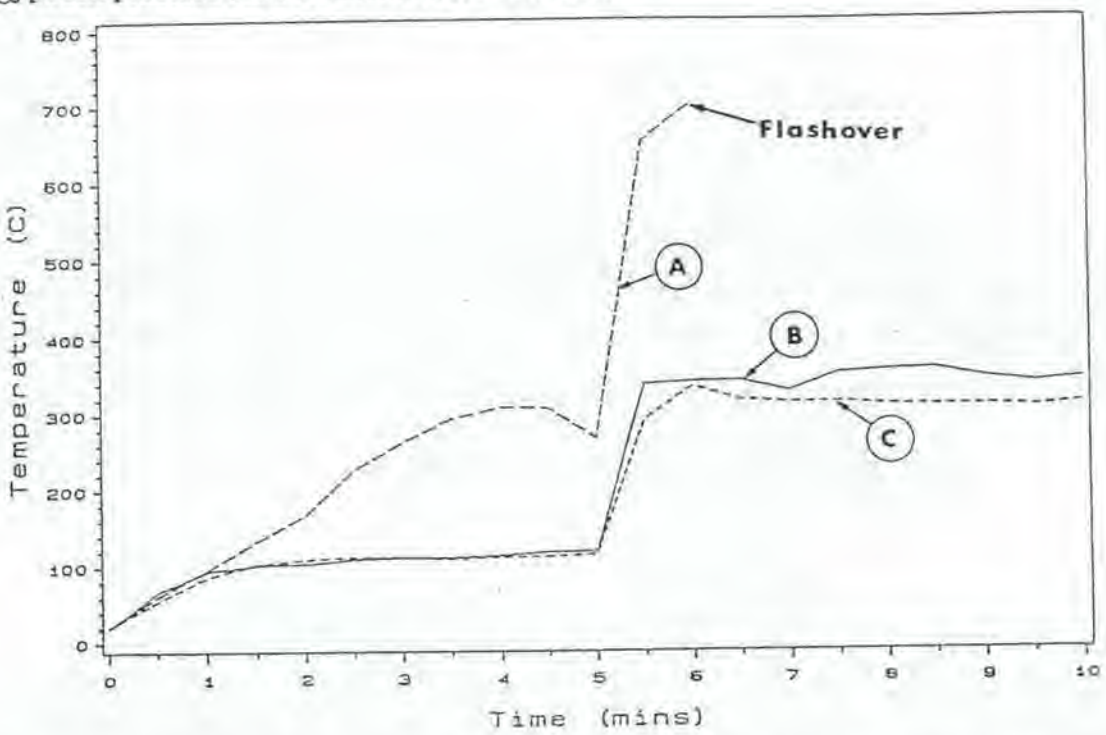

Figure 1. Upper air temperature profiles during room fire test at the centre of an experimental room lined with (A) radiata pine boards, (B) FRC radiata pine boards and (C) gypsum plasterboard.

Contribution to smoke production in room fire test

The percentage light transmission recorded across the extraction duct during room fire tests when the walls were lined with (A) radiata pine boards and (B) fire retardant coated radiata pine boards is shown in Figure 2.

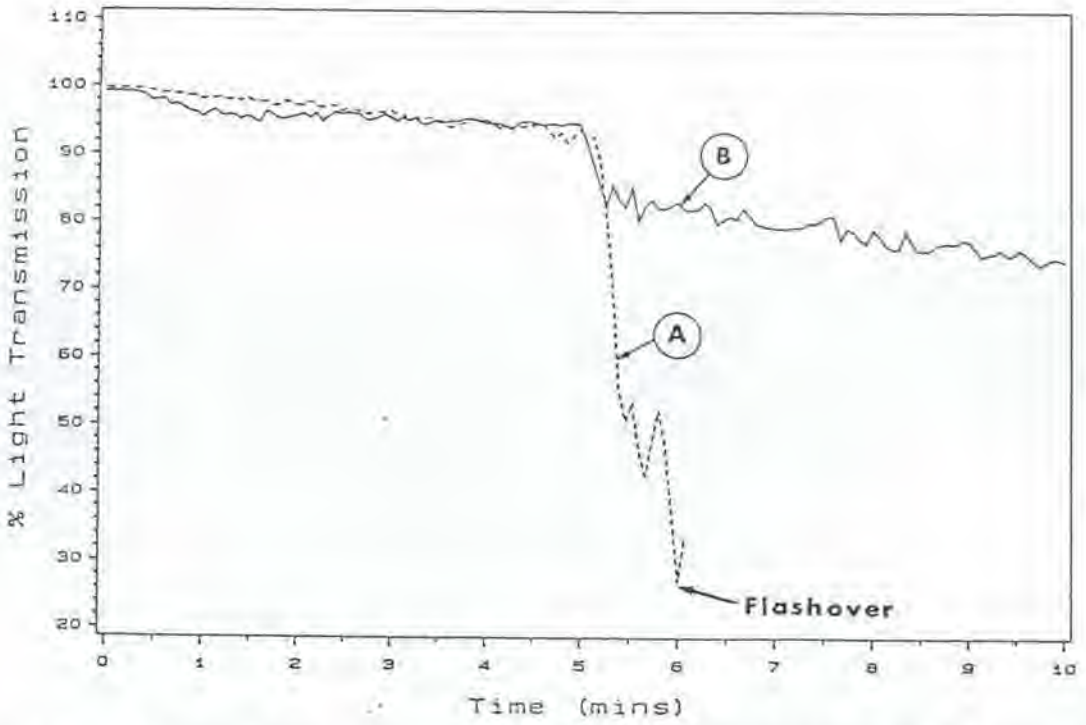

Figure 2. Percentage light transmission across the extraction duct during room fire tests with walls lined with (A) radiata pine boards and (B) fire retardant coated radiata pine boards.

DISCUSSION

The impregnated fire retardant and the fire retardant coating both affected the fire performance of the forest products to which they were applied.

These effects were achieved by different mechanisms for the two types of fire retardants. The impregnated fire retardant changed the manner in which the hoop pine plywood behaved when exposed to heat in several ways including reducing the temperature at which it began to pyrolise resulting in combustion products that were difficult to ignite and the formation of greater quantities of char rather than combustible volatiles during its thermal degradation (Levan, 1984). The fire retardant coating intumesced when heated and formed an insulating foamed layer on the surface of the radiata pine boards.

Both fire retardant applications reduced the tendencies for the forest products to ignite, propagate flame and release heat.

Effect of fire retardants on ignitability

The fire retardant impregnated hoop pine plywood did not ignite when tested to AS 1530.3 whereas fire retardant coating the radiata pine delayed its ignition by 9.8 minutes (see Table 1).

Overlaying the fire retardant impregnated hoop pine plywood with an untreated face veneer allowed the plywood to ignite when tested to AS 1530.3 (see Table 1).

Effect of fire retardants on flame propagation

When assessed by AS 1530.3 Flame Propagation Time and ASTM E 84 Flame Spread Index (see Table 2) both fire retardant applications reduced the tendency for forest products to propagate flame across their surfaces. Even though both the fire retardant impregnated hoop pine plywood with untreated face veneer and the fire retardant coated radiata pine boards ignited during the AS 1530.3 test procedure, the fire retardants prevented the forest product substrates releasing sufficient heat to register an increase of 1.4 kW/m^2 by the prescribed radiometer during the 203 second post-ignition period of the test. The ASTM E 84 Flame Spread Index is a direct measure of a material's ability to propagate flame across its surface and the AS 1530.3 Flame Propagation Time is an indirect measure of flame propagation times up a wall and is based on correlations from room fire tests established by Ferris (1955). Ramsay (1986) considers the AS 1530.3 Flame Propagation Time provides information on rate of heat release rather than flame propagation time.

Effect of fire retardants on heat release

The ASTM E 906 Maximum Heat Release Rates for the forest products were reduced by both fire retardant impregnation and coating (see Table 4). Overlaying the fire retardant impregnated hoop pine plywood with an untreated face veneer increased the ASTM E 906 Maximum Heat Release Rate but the overlaid material still achieved a much lower value than that recorded for the untreated plywood for all heat flux exposures.

Both fire retardant applications reduced the ASTM E 906 Cumulative Heat Released by the forest products (see Table 4). These data indicate that the face veneer on the fire retardant impregnated hoop pine plywood with untreated face veneer was the principal factor contributing to heat release. They also indicate that the protection provided by the intumescent coating was insufficient to prevent significant contribution to the Cumulative Heat Released by the fire retardant coated radiata pine when exposed to the maximum heat flux of 60 kW/m^2.

Effect of fire retardants on smoke release

Fire retardants affected both the rate at which smoke was released and the total smoke released during a test.

The AS 1530.3 Mean Optical Density is determined from the maximum value of the average reduction in percentage transmission of light across the prescribed light path and is therefore a measure of the maximum increase in the rate of smoke released during any one minute period of the test. The ASTM E 906 Maximum Smoke Release Rate is a measure of the maximum smoke release rate over the whole test period. Both the ASTM E 84 Smoke Developed Value and ASTM E 906 Cumulative Smoke Released are indicators of the total smoke produced during a test.

The ASTM E 906 Maximum Smoke Release Rate data indicate that both the fire retardant impregnated and coated forest products generally released smoke at a lower rate than the non-fire retarded forms (see Table 6).

From the AS 1530.3 Mean Optical Density data (see Table 5) the maximum increase in the rate of smoke release during any one minute period was greater for both the fire retardant impregnated and coated forest products than the non-fire retarded forms. However, this may have been due in part to the different times the fire retarded forest products were exposed to the AS 1530.3 heating regimes. The AS 1530.3 test is terminated between 120 and 203 records after specimens ignite, depending upon the time taken for the radiometer to register an increase of 1.4 kW/m^2 following ignition. Thus, the hoop pine plywood was exposed to the AS 1530.3 test conditions for 6.7 minutes while the fire retardant impregnated hoop pine plywood was exposed to the test conditions for twenty minutes. The radiata pine boards and fire retardant coated radiata pine boards were exposed to the AS 1530.3 test conditions for 7.6 and 18.8 minutes respectively.

The fire retardant impregnated hoop pine plywood was assessed to produce more smoke than the non-fire retarded hoop pine plywood by both ASTM E 84 Smoke Developed Values (see Table 5) and the ASTM E 906 Cumulative Smoke Release data for the 40 and 60 kW/m^2 heat flux exposures (see Table 6). The ASTM E 84 Smoke Developed Values and ASTM E 906 Cumulative Smoke Released data for heat flux exposures of 40 and 60 kW/m^2 indicate that total smoke production during the test period from radiata pine is reduced by the application of a fire retardant coating.

Effect of fire retardant coating on contribution to fire growth during a room fire test

The contribution to fire growth of the radiata pine boards used to line the walls of the experimental room can be assessed from the upper air temperatures recorded in the room during tests (see Fig. 1). When the burner was operating at 40 kW output (first five minutes) maximum upper air temperatures of approximately 300°C were recorded in the centre of the room when the walls were lined with radiata pine boards. This maximum temperature was reduced to approximately 120°C during the same phase of the test when the walls were lined with fire retardant coated radiata pine boards. When the burner output was increased to 160 kW upper air temperatures of approximately 700°C were recorded in the centre of room with walls lined with radiata pine boards when flashover occurred at 6.1 minutes. When the room was lined with fire retardant coated radiata pine boards the room did not flashover during the ten minute test period and maximum upper air temperatures of approximately 350°C were recorded in the centre of the room.

The lower temperatures recorded during the test when the walls were lined with fire retardant coated radiata pine were due to the effectiveness of the fire retardant coating in reducing flame propagation across the surface of the walls. This is illustrated in Figures

3 and 4. The upper part of the wall lining is burning and the flames are propagating rapidly across the surface when the experimental room with walls lined with radiata pine boards reaches flashover (see Fig. 3) . By contrast, only the lining boards in the corner adjacent to the burner had been affected during the test when the experimental room was lined with fire retardant coated radiata pine boards (see Fig. 4). Intumescence of the fire retardant coating can also be seen in Figure 4.

The upper air temperatures in the centre of the experimental room when the walls were lined with fire retardant coated radiata pine boards were similar to those recorded for a room fire test when the walls were lined with gypsum plasterboard (see Fig. 1).

Effect of fire retardant coating on smoke release during a room fire test

The smoke released during the first five minutes of the room fire test (burner output 40 kW), as demonstrated by the reduction in the percentage light transmission across a light path in the extraction duct, was very similar for the tests when the walls were lined with radiata pine boards or fire retardant coated radiata pine boards (see Figure 2). When the burner output in the test room was increased to 160 kW after five minutes, the smoke released from the room lined with radiata pine boards increased until flashover of the room occurred. At flashover, light transmission across the light path in the extraction duct was reduced to approximately 30%.

Figure 3. Experimental room with walls lined with radiata pine at flashover.

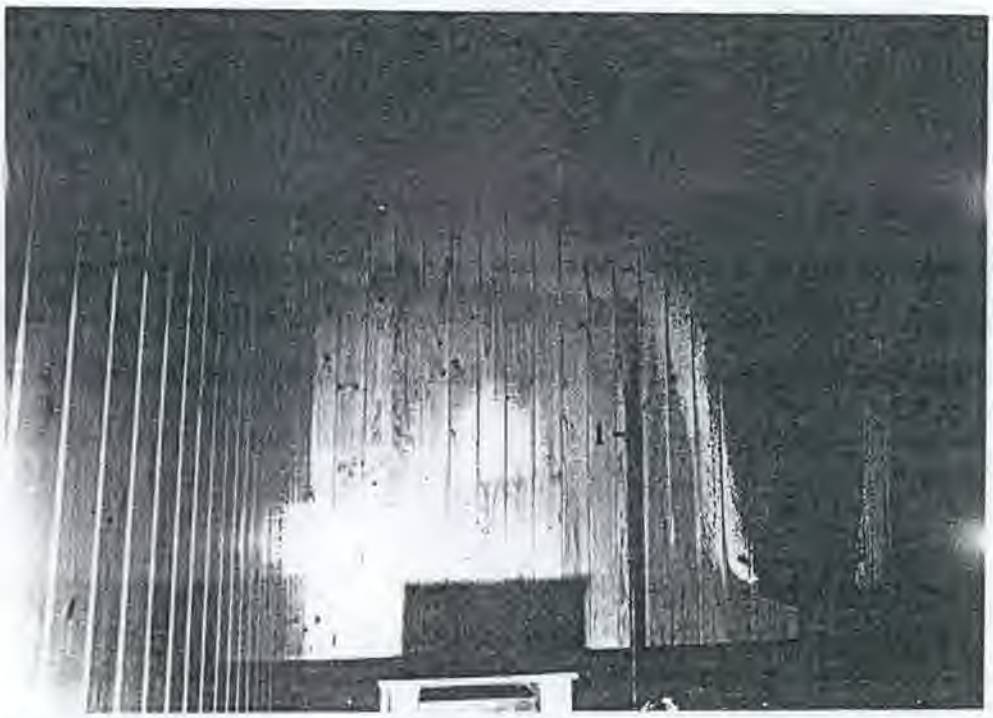

Figure 4. Experimental room with walls lined with fire retardant coated radiata pine boards after room fire test.

The light transmission was only reduced to approximately 75% during the ten minute test period when the walls of the room were lined with fire retardant coated radiata pine. This lower smoke release was due to the greatly reduced surface area of the wall lining involved in fire when the walls were lined with fire retardant coated radiata pine boards (see Figs. 3 and 4).

CONCLUSIONS

Impregnating hoop pine plywood with a fire retardant and applying an intumescent fire retardant coating to radiata pine boards reduced their tendencies to ignite, propagate flame and release heat when assessed by small scale test methods. The fire retardants affected the tendencies for the forest products to release smoke in a manner that sometimes varied according to the test method and parameter used to assess smoke release.

Coating radiata pine boards that were used to line the walls of an experimental room, with an intumescent fire retardant reduced their tendencies to ignite, propagate flame, contribute to fire growth and smoke release during a room fire test.

REFERENCES

Ferris, J.E. (1955). Fire hazards of combustible wallboards. Commonwealth Experimental Building Station. Special Report No. 18. 51 pp.

Gardner, W.D. and Thomson, C.P. (1988). Flame spread properties of forest products. Comparison and validation of prescribed Australian and North American flame spread test methods. Fire and Materials (12), 71-85.

Gardner, W.D. and Thomson, C.R. (1990). Ignitability and heat release properties of forest products. Fire and Materials. In press.

Ramsay, G.C. (1986). Fire test - old technology for new problems. Fire Journal 11(12), 19-23.

CHEMICAL MODIFICATION OF WOOD SURFACES FOR PROTECTION AGAINST WEATHERING

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ABSTRACT

The weather-protective effect of a number of novel wood surface treatments was compared with that of the recognized wood surface stabilizing agent chromic acid. The new treatments were generally superior to chromic acid in preventing zero-span tensile strength loss of thin *Pinus radiata* veneers during weathering. Chromic acid was the most effective substance tested in terms of preventing weight loss. The novel treatments K-1 to K-4 appear to bind or complex with cellulose whereas chromic acid is primarily a lignin complexing agent. FTIR internal reflectance spectroscopy has been used to monitor chemical changes occurring on veneer surfaces during weathering.

INTRODUCTION

Wood undergoes extensive surface degradation when exposed to the weather which imposes restrictions on the use of timber in outdoor situations. *Pinus radiata* wood is very susceptible and suitable chemical stabilization of this substrate could have considerable commercial impact in Australia. Photodegradation of lignin in wood is surprisingly rapid. Even beneath clear finishes where ultraviolet light may be blocked, degradation of lignin can be initiated by transmission of light in the visible spectrum (Derbyshire, Miller 1981). Other breakdown pathways involve the hydrolytic degradation of wood after uptake of water through the end grain or imperfections in finishes (Evans, Banks 1988). Surface colonization of weathered wood by destructive microorganisms also occurs during the final stages of surface deterioration.

Earlier workers concluded that the photodegradation of wood surfaces beneath clear finishes caused loss of adhesion and contributed to failure of the film (Miniutti, 1967). Furthermore finishes applied to pre-weathered wood surfaces were rapidly degraded (Ashton 1967). The application of chemical pre-treatments to stabilize wood surfaces should therefore extend the life of clear finishes in particular.

The application of aqueous chromic acid as a pre-treatment retarded the deterioration of oil-based or latex-based stains and clear finishes on western red cedar and Douglas fir during 30 months exposure in a natural weathering trial (Williams, Feist 1988). The application of aqueous chromic acid to wood reduces cell wall checking caused by irradiation with ultraviolet light (Chang et al. 1982) and surface erosion of wood caused by artificial accelerated weathering (Feist 1977). Disadvantages to the potential commercial use of chromic acid include health concerns about hexavalent chromium and the discolouration of treated wood. Work is underway to fully elaborate the protective mechanism of chromic acid (Schmalzl, Vickers 1990), in order to develop superior environmentally acceptable treatments. Photostable lignin complexes are believed to be involved in the protective process (Evans, Michell, Schmalzl, in press).

One of the traditional obstacles to the development of new surface pre-treatments for wood has been the lack of rapid statistically reliable assessment techniques to assess their efficacy. Loss of weight and zero-span tensile strength of thin wood veneers during natural weathering have recently been demonstrated to be useful criteria for the convenient assessment of protective chemicals. During weathering, untreated veneers rapidly lose weight and zero-span tensile strength (Evans 1988). Iron III and chromium VI reference compounds have been assessed using this methodology. Weight losses of 5.5% in chromic acid treated thin *Pinus radiata* veneers after 35 days natural weathering are dramatically lower than the weight losses of 26.7% observed in untreated weathered controls (Evans, Schmalzl 1989). It has been suggested that while both zero-span tensile strength and weight loss of treated wood veneers during weathering are caused by radical induced oxidative processes, the former results from depolymerization of cellulose whereas the latter results from degradation and loss of lignin (Evans, Schmalzl 1989). The strength and weight loss criteria may therefore be used as a quantitative means of assessing the ability of chemical treatments to protect respectively, the cellulose, or the lignin components of the wood during weathering. In this study several new protective treatments are compared with iron III and chromium VI reference compounds for their ability to retard zero-span tensile strength loss and weight loss during weathering.

Fourier transform infra red (FTIR) internal reflectance spectroscopy can be used to monitor chemical changes taking place on wood surfaces during weathering (Michell 1988), (Evans, Michell, Schmalzl, in press). In particular, clear evidence for modification, stabilization or destruction of the lignin aromatic system can be obtained. In this paper untreated and chromic acid treated veneers are examined by FTIR internal reflectance spectroscopy before and after weathering. The significance and mechanistic interpretation of observed changes are discussed.

MATERIALS AND METHODS

Preparation of Wood Veneers

Boards measuring 200 cm (longitudinal) x 7 cm (tangential) x 20 cm (radial) were cut from a 45 year old radiata pine (*Pinus radiata* D.Don) tree (49.6 cm in diameter under bark at 3.7 metres) in Victoria, Australia in 1977. After air drying for one year and subsequent storage under cover, straight grained sapwood (2.5 - 3 growth rings per cm), free of all visible defects was converted into blocks, 100 mm (longitudinal) x 50 mm (tangential) x 20 mm (radial). Veneers approximately 100 μm thick were cut using a microtome (Spencer lens) from the radial face of the blocks after these had been vacuum impregnated with distilled water. Veneers were batched serially (in order to minimize the tangential variability of wood), into batches of 10 replicates, placed in a conditioning room at 21 $\pm$ 1°C and 65 $\pm$ 5% relative humidity for 5 days and the weight of each batch of 10 veneers recorded. The thickness of each individual veneer was measured with a digital micrometer (Lorentzen and Wettre type 222). Odd numbered batches of veneers were assigned to exterior weathering while even numbered batches acted as unweathered controls.

Chemical Treatments

Veneers from the odd numbered batches were fixed to nylon mesh using plastic paper clips. The upper surface of the fixed veneers was spray treated with a Badger 350 Air-Brush using 0.32 or 0.96 M solutions of the trial chemicals in an appropriate carrier solvent. Several passes of the Air-Brush were necessary to deliver an application volume of 0.008 mL per cm^2. Reference compounds used were chromium trioxide (CrO_3 anhydrous; BDH, minimum purity 99%), ferric chloride ($FeCl_3$ anhydrous; Fluka, purity > 99%), and ferric nitrate ($Fe(NO_3)_3 . 9H_2O$; Fluka, purity > 99%). Substances K-1, K-2, K-3 and K-4 were chosen for assessment because of their ability to complex lignin model compounds in preliminary screening tests.

Weathering and Weight and Zero-span* Tensile Strength Determinations

After treatment, veneers were placed in a conditioning room (as above) for 20 days and the weight of each batch recorded. For each treatment 5 or 10 batches of veneers were placed against glass backing plates (2 batches per plate) and clamped lightly at their ends with the treated surface facing upwards. These plates were exposed outdoors in a randomized complete block design facing equatorially and at an angle of 45° to the horizontal for 35 days in Canberra, Australia during the spring of 1987 or the autumn of 1988.

After weathering, veneers were conditioned as above for 20 days and the weight of each batch recorded. Percentage weight losses during weathering are expressed relative to the initial treated weight.

Strength tests were carried out with a Pulmac paper tester at zero-span using a clamping pressure of 550 kPa. Strength was calculated as ultimate load (kg) at failure divided by the cross sectional dimensions (mm^2) of each veneer.

Spectroscopic Analysis of Veneers

Two veneers each of the following; treated unweathered, treated weathered, untreated weathered, and untreated unweathered controls, were fixed with a torque wrench against the faces of a KRS-5 prism in a RIIC TR25 frustrated multiple internal reflectance (FMIR) unit. The sections were backed by films of polytetrafluoroethylene instead of the pressure sensitive tape used previously (Michell 1988), because of problems with adhesive contaminating the crystal through the larger voids in the weathered wood structure. The spectra were obtained by using a Mattson Alpha Centauri Fourier Transform Infrared Spectrophotometer equipped with a water cooled source, with a computer controlled iris and a DTGS detector. They were at a resolution of 4 cm^{-1} and were the averages of 128 scans. Background spectra were obtained with the FMIR unit in the spectrophotometer without having a sample against the crystal.

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* In zero-span tensile testing all the fibres are gripped and failure occurs via fibre fracture. Thus zero-span tensile strength is a measure of individual cellulosic fibre strength, whereas in conventional tensile strength tests interfibre bonding forces are also important. Only zero-span tensile strengths were measured in this study.

RESULTS AND DISCUSSION

Large weight losses occurred in untreated radiata pine veneers after exposure to the weather for 35 days in the spring of 1987 (26.7%, Table 1) and the autumn of 1988 (23.9%, Table 2). Weight losses are similar to those observed previously (Evans 1988, 1989). Variations in different weathering trials probably arise from seasonal changes in the weather and may be dependent on the number of sunshine hours (Evans, Michell, Schmalzl, in press). Weight losses in chromium trioxide, ferric chloride, ferric nitrate and K-1 treated veneers exposed to the weather for 35 days in the spring of 1987 were 5.5, 30.3, 24.0 and 18.8% respectively (Table 1). Weight losses in chromium trioxide, K-1, K-2, K-3 and K-4 treated veneers exposed in autumn 1988 were 7.7, 18.1, 27.8, 17.0 and 30.9% respectively (Table 2).

TABLE 1. EFFECT OF CHEMICAL TREATMENT ON THE WEIGHT LOSS OF THIN WOOD VENEERS AFTER NATURAL WEATHERING IN THE SPRING OF 1987

Treatment and Concentration	Average Post-treatment batch weight (g)	Average Post-weathering batch weight (g)	% Weight Loss after weathering
Chromic Acid (0.96 M)	0.73	0.69	**5.5
Ferric Chloride (0.96 M)	0.66	0.46	**30.3
Ferric Nitrate (0.96 M)	0.75	0.57	**24.0
K-1 (0.96 M)	0.69	0.56	**18.8
Untreated	0.60	0.44	26.7

Each weight value in the Table is the mean of 10 batches.

** indicates significant difference ($p < 0.01$) for individual treatments compared to untreated weathered veneers.

TABLE 2. EFFECT OF CHEMICAL TREATMENT ON THE WEIGHT LOSS OF THIN WOOD VENEERS AFTER NATURAL WEATHERING IN THE AUTUMN OF 1988

Treatment and concentration	Average Post-treatment batch weight (g)	Average Post-weathering batch weight (g)	% Weight loss after weathering
Chromic Acid (0.32 M)	0.91	0.84	7.7
K-1 (0.32 M)	0.94	0.77	18.1
K-2 (0.96 M)	0.97	0.70	27.8
K-3 (0.96 M)	0.94	0.78	17.0
K-4 (0.96 M)	1.10	0.76	30.9
Untreated	0.88	0.67	23.9

The weight values in the Table for chromic acid, K-1 and untreated are the mean of 10 batches. The remainder are the mean of 5 batches.

Weight losses of chromic acid treated veneers during both weathering trials were significantly lower than weight losses of untreated controls or veneers treated with any of the new protective agents. The lower rate of chromic acid (0.32 M) tested in 1988 was still very effective. It has been suggested that photostable lignin complexes are responsible for the ability of chromic acid to prevent weight loss during weathering (Evans, Michell, Schmalzl, in press). If this theory is valid then the conclusion to be drawn from the present work is that neither the ferric salt treatments, nor K-1 to K-4 are able to form photostable lignin complexes as effectively as chromic acid. This conclusion has been confirmed both by model reaction studies (Schmalzl, Vickers 1990) and FTIR spectroscopy (Evans, Michell, Schmalzl, in press). Nevertheless, both K-1 and K-2 did retard weight loss when compared with untreated controls suggesting that photodegradation of lignin had been arrested to some extent.

Very large zero-span tensile strength losses occurred in untreated veneers during weathering; 65.7% in the spring of 1987 (Table 3) and 38.6% in the autumn of 1988 (Table 4). The greater tensile strength losses in spring 1987 were probably partly due to a greater number of sunshine hours during this exposure period. Veneers were thinner in the 1987 experiment which would also have contributed to their greater tensile strength loss. Tensile strength losses in chromium trioxide, ferric chloride, ferric nitrate and K-1 treated veneers exposed to the weather for 35 days in the spring of 1987 were 65.0, 83.9, 77.2 and 43.5% respectively (Table 3). Tensile strength losses in chromium trioxide, K-1, K-2, K-3 and K-4 treated veneers exposed in the autumn of 1988 were 29.6, 23.3, 30.3, 26.6 and 25.1% respectively (Table 4).

TABLE 3. EFFECT OF CHEMICAL TREATMENT ON THE ZERO-SPAN TENSILE STRENGTH OF THIN WOOD VENEERS AFTER NATURAL WEATHERING IN THE SPRING OF 1987

Treatment and Concentration	Mean Batch Strength kg/mm^2	% Strength Loss
Chromic Acid (0.96 M)	2.66	65.0
Controls	7.61	
Ferric Chloride (0.96 M)	1.26	**83.9
Controls	7.85	
Ferric Nitrate (0.96 M)	1.73	**77.2
Controls	7.61	
K-1 (0.96 M)	5.21	**43.5
Controls	9.23	
Untreated	3.29	65.7
Controls	9.58	

Each strength value in the Table is the mean of 10 batches.

** Indicates significant difference ($p < 0.01$) for individual treatments compared to untreated weathered veneers.

TABLE 4. EFFECT OF CHEMICAL TREATMENT ON THE ZERO-SPAN TENSILE STRENGTH OF THIN WOOD VENEERS AFTER NATURAL WEATHERING IN THE AUTUMN OF 1988

Treatment and Concentration	Mean Batch Strength kg/mm^2	% Strength Loss
Chromic Acid (0.32 M)	5.77	29.6
Controls	8.20	
K-1 (0.32 M)	5.96	23.3
Controls	7.77	
K-2 (0.96 M)	5.25	30.3
Controls	7.53	
K-3 (0.96 M)	6.01	26.6
Controls	8.19	
K-4 (0.96 M)	5.86	25.1
Controls	7.82	
Untreated	4.78	38.6
Controls	7.79	

The strength values in the Table for chromic acid, K-1 and untreated are the mean of 10 batches. The remainder are the mean of 5 batches.

Treatments K-1 to K-4 significantly retarded the loss of zero-span tensile strength in thin *Pinus radiata* veneers during weathering. Earlier workers have claimed that in general, the most profound effects on wood surface integrity and tensile strength stem from depolymerization of the cellulose constituent (Derbyshire, Miller 1981). It seems likely, therefore, that K-1 to K-4 are able to bind or complex with cellulose. It has not yet been established whether they also retard the depolymerization of cellulose during weathering. The ferric salt treatments were clearly detrimental and an explanation for these effects has been suggested previously (Evans, Schmalzl 1989). The lower rate of chromic acid used in 1988

(0.32 M) reduced strength losses in treated veneers during weathering relative to untreated veneers (29.6% compared with 38.6%, Table 4), and this observation is worthy of further comment. It could well be that there is a fine balance between the protective effect of chromic acid via photostable lignin complexes and possible cellulose degradation by strong acid hydrolysis. In the spring 1987 experiment the higher rate of chromic acid used (0.96 M) did not significantly ameliorate tensile strength losses during weathering when compared with untreated veneers (65.0% compared with 65.7%, Table 3).

FTIR internal reflectance spectroscopy has been used to monitor chemical changes occurring on weathered veneer surfaces. Two regions of the infrared spectra of untreated wood and weathered untreated wood surfaces are shown in Fig. 1. The regions (1800-1200 cm^{-1}) and (950-720 cm^{-1}) have been chosen because bands in these regions can be related to the different wood components (Evans, Michell, Schmalzl, in press).

The spectrum of the weathered untreated wood is very different from that of the unweathered wood (Fig. 1). The most obvious differences are the absences of bands at 1601, 1506, 1263 and 870 cm^{-1} indicating that the major process induced by weathering is delignification. Weakening of bands at 1728, 809 and perhaps, 775 cm^{-1} is also observed indicating hemicellulose degradation.

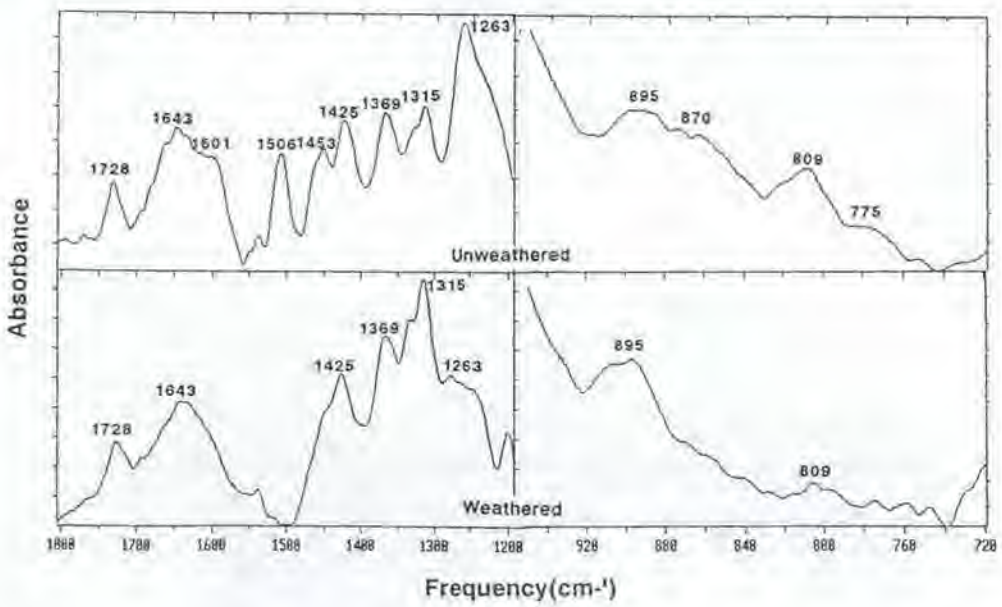

Fig. 1. FTIR spectra of untreated veneers

The spectra of the samples treated with chromium trioxide and subsequently weathered are shown in Fig. 2. The most important feature of the spectrum is how little it has been modified by weathering. The absorption centred around 1590 cm^{-1} is now more intense. In addition the 1506 and 1263 cm^{-1} bands have been substantially reduced in intensity relative to the corresponding bands in the spectrum of the parent wood, but the intensities of the other major bands seem to have been maintained. Further details of the FTIR spectra of chromic acid as well as ferric salt treated *Pinus radiata* veneers have been presented elsewhere (Evans, Michell, Schmalzl, in press).

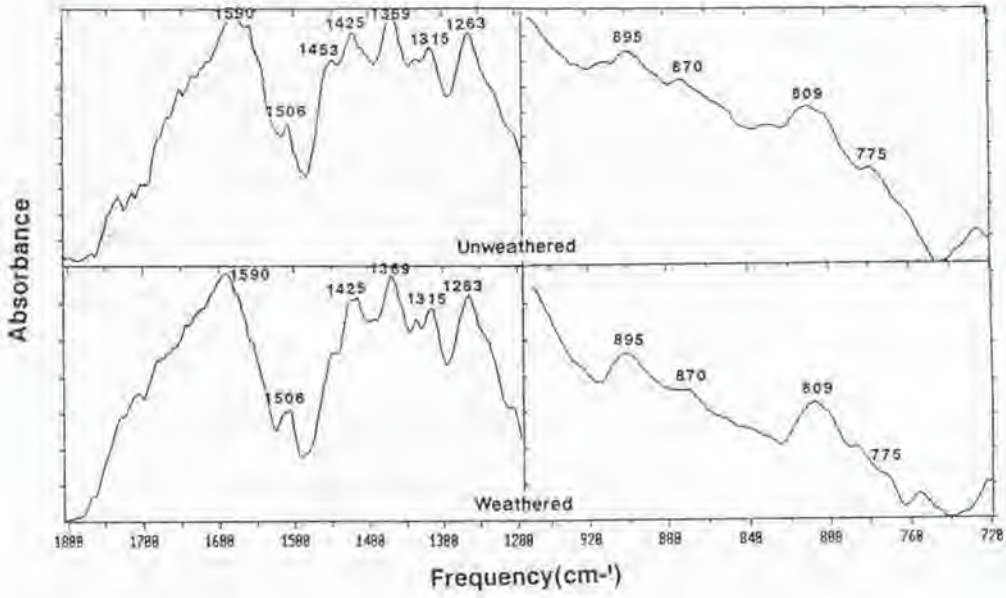

Fig. 2. FTIR spectra of chromic acid treated veneers

These FTIR studies show that when wood surfaces are treated with chromic acid much of the lignin polymer on the wood surface is chemically modified. The appearance of a new band around 1590 cm^{-1} and the reduction in intensity of the 1506 cm^{-1} band after treatment are consistent with some of the lignin polymer subunits being complexed and some subunits remaining unaltered. The chromium modified lignin polymer is very resistant to degradation during weathering. By comparison, lignin is completely lost from untreated weathered veneer surfaces under the same conditions as indicated by the complete absence of the 1506 cm^{-1} band (Fig. 1).

FTIR analysis of K-1 treated veneers shows little or no change of the characteristic lignin bands after treatment indicating that the degree of lignin complexing is much less than with chromic acid.

This study has shown that various members of the K-series treatments can significantly reduce tensile strength loss and in some cases weight loss of thin *Pinus radiata* veneers during weathering. It is generally accepted that the deterioration of wood surfaces underneath coatings substantially contributes to film failure and it is thus reasonable to expect that these treatments will confer benefits when used as wood primers.

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REFERENCES

Ashton, H.E. 1967: Clear finishes for exterior wood, field exposure tests. J. Paint Technol. 39: 212-224.

Chang, S.T.; Hon, D.N.S.; Feist, W.C. 1982: Photodegradation and photoprotection of wood surfaces. Wood Fiber. 14: 104-117.

Derbyshire, H.; Miller, E.R. 1981: The photodegradation of wood during solar irradiation. Part 1. Effects on the structural integrity of thin wood strips. Holz Roh-Werkst. 39: 341-350.

Evans, P.D. 1988: A note on assessing the deterioration of thin wood veneers during weathering. Wood Fiber Sci. 20: 487-492.

Evans, P.D. 1989: Effect of angle of exposure on the weathering of wood surfaces. Polymer Degradation and Stability. 24: 81-87.

Evans, P.D.; Banks, W.B. 1988: Degradation of wood surfaces by water. Changes in mechanical properties of thin wood strips. Holz Roh-Werkst. 46: 427-435.

Evans, P.D.; Michell, A.J.; Schmalzl, K.J. In press: Studies of the degradation and protection of wood surfaces. Wood Science and Technology.

Evans, P.D.; Schmalzl, K.J. 1989: A quantitative weathering study of wood surfaces modified by chromium VI and iron III compounds. Part 1. Loss in zero-span tensile strength and weight of thin wood veneers. Holzforschung. 43: 289-292.

Feist, W.C. 1977: Finishing wood for exterior applications - paints, stains, and pretreatments. In: Goldstein, I.S. (Ed.): Wood Technology, Chemical Aspects. Ser. 43, Chap. 19, pp. 294-300. Washington D.C.: Amer. Chem. Soc.

Michell, A.J. 1988: Note on a technique for obtaining infrared spectra of treated wood surfaces. Wood Fiber Sci. 20: 272-276.

Miniutti, V.P. 1967: Microscopic observations of ultraviolet irradiated and weathered softwood surfaces and clear coatings. U.S. Forest Service Research Paper FPL 74.

Schmalzl, K.J.; Vickers, L.J. 1990: Unpublished results.

Williams, R.S.; Feist, W.C. 1988: Performance of finishes on wood modified with chromium nitrate versus chromic acid. For. Prod. J. 38: 11/12, 32-35.

PRESERVATION RESEARCH IN W.A.

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ABSTRACT

Early CSIRO preservation trials in Western Australia are briefly discussed, including a fence post trial established in 1930. A trial using treated dowelled two-piece sleepers was established in 1984. Current co-operative trials with CSIRO include a durability trial comparing regrowth and mature timber from a range of Western Australian and Eastern States species, and *Lyctus* -susceptability trials, being conducted at CSIRO, Highett. Local trials have included assessment of C.C.A.-treated jarrah fence posts, effect of sapstaining and C.C.A. treatment on pole strength, and recent research in treating fence posts.

INTRODUCTION

In Western Australia, three major companies have been involved with timber preservation through membership of the Timber Producers Association of Australia: Koppers Australia, Bunnings Forest Products Pty Ltd and Timber Treaters (W.A.) Pty Ltd. The Department of Conservation and Land Management liaises with the above companies and with CSIRO Division of Forestry and Forest Products. Preservation research at this stage is comparatively limited, but the need is recognised for greater involvement.

The research into timber preservation in the State includes an early CSIR fence post trial (established in 1930) [(1)] and a CSIRO marine borer trial (established in 1960) [(2)]. Mr John Barnacle and other CSIRO researchers have had regular involvement in rail sleeper research, particularly in the North-west where treated karri (*Eucalyptus diversicolor* F. Muell.) sleepers have been widely used [(3)].

The preservation research by the then Forests Department included a trial of treated dowelled two-piece pine sleepers, which commenced in 1984 in association with Westrail, Koppers Ltd and the W.A. timber industry [(4)].

The Department of Conservation and Land Management (CALM) is involved in the following co-operative research:

- a joint trial with CSIRO Division of Forestry and Forest Products to assess the comparative durability of six regrowth and native Western Australian species and several Eastern States species [(5)]. Dr Gary Johnson and Dr John Thornton are using the accelerated field simulator at Highett.

- joint trials with CSIRO assessing the *Lyctus*-susceptability of regrowth karri [6], and W.A. sheoak (*Allocasuarina fraseriana*) (Miq.) L. Johnson) [7].
- liaison with Alcoa Australia, who are carrying out a durability study of regrowth eucalypts grown on rehabilitated bauxite mine sites.

In addition, research trials have been or are being carried out on the following:

- assessment of C.C.A. treatment of regrowth jarrah (*E. marginata* Donn ex Sm.) posts [8].
- assessment of the effect of sapstaining and C.C.A. treatment on strength properties of radiata pine (*Pinus radiata* D. Don) poles [9].
- assessment of preservatives which have been recently registered in Western Australia, to assist the increasing demand for do-it-yourself treatment by farmers. There is particular interest in Tasmanian blue gum (*E. globulus* Labill. subsp. *globulus*), which is becoming a major plantation species in the state.

Wickepin fence post trial after 57 years of service

(Although this was originally a CSIRO trial, it is included because Department of CALM staff carried out the 1987 assessment).

In 1930 the then CSIR, in conjunction with the then Forests Department, established three fence post trials in Western Australia [1]. The trials were located near Pemberton, Wickepin and Southern Cross, on sites rated as having severe decay hazard, light decay and intermediate termite hazard, and severe termite hazard respectively.

The Pemberton and Southern Cross trials are no longer operational. However, the Wickepin trial is generally in good condition, except for a small section of pine and jarrah posts which were damaged by fire. This trial was assessed in September 1987 [10].

The trial used 75 to 125 mm diameter posts of the following species: wandoo (*E. wandoo* Blakely), jam (*Acacia acuminata* Benth.), brown mallet (*E. astringens* (Maiden) Maiden), jarrah, marri (*E . calophylla* R. Br. ex Lindl.) and radiata pine.

The treatments assessed were: creosote and crude oil (2:1); zinc chloride (3.5 %) and arsenic trioxide (2.0%); sodium fluoride (3.5 %) and arsenic trioxide (2.0 %); arsenic trioxide (2.0 % solution); untreated.

Untreated wandoo and jam have lasted extremely well, considering that the trial was established in 1930. The natural durability of the heartwood of these species has been well proven, but unfortunately supplies for fencing purposes have become limited. Untreated posts of the other four species had failed many years previously, long before the first assessment by Tamblyn in 1951 [11].

Preservative treatment has increased the service life considerably. The data indicated

that the performance ranking of these species (from best to worst), when treated with one of the preservatives tested, was as follows:-

marri, jarrah, pine, brown mallet.

Treated marri performed better than treated jarrah, presumably because of its wider sapwood band giving better penetration and retention of preservative.

Marri treated with zinc chloride and arsenic trioxide, or with sodium fluoride and arsenic trioxide, gave the best individual results, except for the untreated wandoo.

Dowelled two-piece Westrail Sleepers

Two softwood species, radiata pine (*Pinus radiata* D. Don) and maritime pine (*P. pinaster*) and regrowth jarrah were selected for testing two-piece sleepers [4]. The two-piece sleepers were preferred to the one piece sleeper owing to limited availability of large sawlogs and to the laminated sleeper owing to fabrication difficulties and high cost.

The two-piece sleeper is fabricated by inserting four twisted steel dowels horizontally into pre-drilled holes before seasoning and treating with preservative. In an initial trial, fifty per cent of each pine species were then treated with 80 per cent oil/20 per cent creosote, at 1400 kPa (average retention: 180 kg/m^3), at Koppers, Picton Junction. The remaining 50 per cent of each species was treated with 99.5 per cent oil/0.5 per cent termiticide at 7000 kPa (retention: 175-350 kg/m^3), at Bunnings, Pemberton. Pandrol plates were used.

In 1985 these test sleepers were placed on the relatively heavily trafficked railway line between Northam and Goomalling, where they are inspected at regular intervals to ascertain performance levels.

CSIRO durability trials using an accelerated field simulator

The Department of CALM considered that durability of regrowth eucalypts required assessment, and requested CSIRO involvement. Consequently CSIRO and the Department of CALM, with involvement from other State Forest Services, are conducting durability studies of heartwood from a range of regrowth and mature eucalypts. The following species are being assessed at CSIRO in Highett, using an accelerated field simulator [5]: W.A. blackbutt, jarrah, karri, marri, wandoo, red mahogany (*E. resinifera* Sm.), river red gum (*E. camaldulensis* Dehnh.), spotted gum (*E. maculata* Hook.), tallowwood (*E. microcorys* F. Muell.), yellow stringybark (*E. muellerana* Howitt.). In addition, regrowth and mature W.A. sheoak, and radiata pine and maritime pine, are included in the trial.

Mature jarrah attacked by *Fistulina hepatica* (which causes pencilling), and regrowth karri affected by brownwood, have been included, as well as CSIRO standard controls of C.C.A. treated radiata pine and mountain ash (*E. regnans*).

Preliminary results have indicated that regrowth karri affected by brown wood should not be used in ground contact.

Lyctus-susceptibility trial with CSIRO

Joint trials by CSIRO Division of Forestry and Forest Products and the Department of Conservation and Land Management to investigate the susceptibility of regrowth karri and W.A. sheoak sapwood to attack by *Lyctus brunneus* commenced in 1987.

Based on the assumption that high temperature drying could modify starch composition and therefore *Lyctus*-susceptibility, samples of both high-temperature-dried and air-dried karri and W.A. sheoak were subjected to *Lyctus* attack. Two different provenances and ages of regrowth karri have been examined [6] and one provenance of W.A. sheoak [7]. The results indicated that regrowth karri sapwood was susceptible to *Lyctus* attack, although the species was previously considered non-susceptible. Drying temperature had no effect on the results.

As a result of the karri trial, mature karri from 3 sites (northern, central and southern) and regrowth karri (45 to 50 years old), and mature and regrowth jarrah from 3 sites (western, eastern and southern), were stored under intermittent water spray (15 min on: 105 min off) for 0, 1.5, 3, 6 or 12 months before being inoculated, to test the alternative assumption that stockpiling under water spray reduces starch content and therefore *Lyctus* susceptiblity. Results from this series of trials will be reported on their completion.

Alcoa - rehabilitation timber durability trial

Some regrowth eucalypt forests growing on rehabilitated bauxite-mined areas will require thinning within the next decade. Little is known of the in-ground durability of species (some from the eastern states) grown on rehabilitated bauxite pits. This trial aims was designed by Alcoa, in consultation with the Department of CALM, to provide information on the suitability of these timbers for use as fence posts, rails and poles.

The following species are included: marri,Tasmanian blue gum, spotted gum, jarrah, tallowwood, yellow stringybark, W.A. blackbutt , Sydney blue gum (*E. saligna* Sm.) and red mahogany.

The regrowth jarrah and W.A. blackbutt were sampled from native jarrah forest near Dwellingup. All other trees were grown on rehabilitated bauxite-mined areas at Jarrahdale minesite. Age of the samples from the rehabilitation area ranged from 13.5 to 17.5 years, and mean sapwood areas ranged from 30 per cent (Sydney blue gum) to 88 per cent (marri).

Stakes were cut for each of these nine species, with half treated with C.C.A. and half left untreated, and jarrah and radiata pine heartwood used as controls. Graveyard trials are located at Marrinup and Pinjarra.

Stakes have been in the ground for approximately 6 months and will be assessed every 12 months.

C.C.A. treatment of regrowth jarrah posts

Irrespective of the durability of the heartwood, a band of sapwood made durable by preservation is obviously essential to provide strength to small diameter round timber in-service.

A study using regrowth jarrah was designed to determine whether visual assessment of sapwood width provided a satisfactory estimate of penetration of copper-chrome-arsenic (C.C.A.) preservative into the sapwood of posts [8]. The alternative method assessed was using a starch test to identify the sapwood/heartwood boundary.

The sapwood in jarrah is a narrow band compared with that of other eucalypt species, and tends to be uniform in width. In this trial, mean sapwood width (visually assessed) in posts ranging from 130 to 190 mm small end diameter under bark was 16.0 mm, with standard deviation of 3.7 mm.

The two methods of assessing sapwood width gave similar results, and pre-sorting of regrowth jarrah posts before CCA treatment (to identify the individuals with sapwood width likely to result in less than optimum penetration) was considered to be impractical for commercial practice.

Effect of sapstaining and C.C.A. treatment on strength properties of radiata pine poles

In Western Australia the State Energy Commission (SECWA) has an annual requirement of about 20 000 wooden poles each year to maintain and extend the power grid in the State. Jarrah, a naturally durable species, has been most extensively used, with smaller volumes of West Australian blackbutt and wandoo. Availability of these poles have been reduced due to decreases in the area available for timber production.

C.C.A.-treated radiata pine poles were considered by the Department of CALM to be a suitable alternative, provided they received the correct storage treatment, and were not attacked by sapstaining fungi before C.C.A. preservative treatment. Two years previously, poles which showed evidence of sapstain attack had also been attacked by wood-destroying fungi.

At the request of the SECWA, strength tests were carried out on poles in five different treatments [9]. Mean values of modulus of rupture and modulus of elasticity increased in the following ranking:-

i) poles tested untreated.
ii) sapstained poles.
iii) poles sprayed with Koppers NP-1 sapstain control chemical.
iv) sapstained/C.C.A. treated poles.
v) NP-1 sprayed/C.C.A. treated poles.

With modulus of rupture, grouped treatments (i) to (iii) were significantly less than treatments (iv) and (v), while treatment (i) was significantly less than grouped treatments (ii) to (v). Modulus of elasticity was not significantly different in the five treatments.

The results indicated that radiata pine poles, treated to minimise sapstain fungal attack and then pressure treated with C.C.A., have acceptable strength properties and should provide a long service life.

Treatment of fence posts

Farmers throughout the south west of W.A. are planting large areas of Tasmanian blue gum, many as joint ventures with CALM. The major use planned is for pulp wood but there is interest in alternative uses such as fence posts.

Posts were cut from sub-dominant or suppressed 17-year-old trees from a plot in the Harris River dam site in Collie District. Preservatives being assessed are: Busan 300 W.B. Cleansote (emulsified creosote), Boracol 200 RH, and copper-chrome arsenic (C.C.A.).

The sap-displacement method was used on freshly fallen, debarked green posts for the Busan, Boracol and Cleansote, while C.C.A.-treated posts were dried to below fibre saturation point (f.s.p.) before treating to a retention of approximately 23 kg/m^3 of oxide. The sap-displacement method resulted in good penetration in the butt half of the post (below the water level) with traces into the crown half of the post. Busan returned to a solid sludge on the bottom of the drum after 2 to 3 days and would require constant agitation to keep it in solution, making treatment difficult. Boracol and Cleansote produced good results, but costs of the Boracol and Busan would limit their use.

Currently the posts are in-service at a farm at Denmark in the South Coast Region, and six monthly inspections are planned.

A Department of CALM timber inspector has assessed emulsified creosote treatment of jarrah, marri, W.A. blackbutt, and radiata pine. Treatments used were hot and cold soak or cold soaking, using posts which were either green or dried to below f.s.p. These posts have been placed in-service to determine durability properties.

REFERENCES

1. Cummins, J.E. (1932). Preservative treatment of fence posts in Western Australia. Progress Report No. 2. 1st Inspection Report. CSIR Division of Forest Products. Project P4-1. Limited distribution.

2. Cookson, L.J. (1986). Marine borers and timber piling options. Revised and reprinted from CSIRO Division of Chemical and Wood Technology Research Review 1986.

3. Barnacle, J.E. (1990). Rail sleepers of oil-treated eucalypts - more evidence of rail track performance and untapped potential. Paper presented at 8th Rail Track Conference, Sydney, October 1990.

4. Syers, J.D. (1984). Development of two piece sleepers within Westrail. Unpublished Report, Westrail.

5. Johnson, G.C. and Thornton, J.D. (1990). AFS study of the natural durability of heartwood from mature and regrowth trees. CSIRO Division of Forestry and Forest Products. Report. Limited distribution.

6. Creffield, J.W., Brennan, G.K. and Chew, N. (1987). Susceptibility of air-dried and high temperature dried Western Australian sheoak (*Allocasuarina fraseriana*) to attack by the powder post borer (*Lyctus brunneus*). CSIRO Division of Chemical and Wood Technology Progress Report, June 1987.

7. Creffield, J.W., Brennan, G.K. and Chew, N. (1988). Susceptibility of air-dried and high temperature dried regrowth karri (*Eucalyptus diversicolor*) to attack by the powder post borer (*Lyctus brunneus*). CSIRO Division of Forestry and Forest Products Progress Report, November 1988.

8. Brennan, G.K. (1988). Penetration of copper-chrome-arsenic preservative into regrowth jarrah posts. Department of Conservation and Land Management. W.U.R.C. Report No. 6.

9. Donnelly, D.J. and Siemon, G.R. (1989). Effect of sapstaining and C.C.A. treatment on strength properties of radiata pine poles. Department of Conservation and Land Management. W.U.R.C. Technical Report No. 9.

10. Rule, R. (1989). The Wickepin fence post trial after 57 years of service. Department of Conservation and Land Management. W.U.R.C. Report No. 11.

11. Tamblyn, N. (1954). Preservative treatment of fence posts in Western Australia. Eighth inspection - November 1951. CSIRO Division of Forest Products. Sub-project P4-1, Progress Report No. 9. Limited distribution.

DECAY DETECTION AND REMEDIAL TREATMENTS IN WOODEN POLES

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ABSTRACT

Wooden poles represent a huge investment to Australia in the telecommunications and electricity supply industries. There are approximately six million wooden poles throughout Australia all of which may be subject to biodeterioration, notably from decay fungi and termites, at some time during their service lives. These various forms of biodeterioration can be detected using a range of simple or sophisticated pole inspection techniques. A wide variety of instrumental devices have been developed to improve the accuracy and reliability of pole inspection. Furthermore, control can occur via the judicious application of appropriate chemicals. This paper discusses development of detection and control techniques for ground-line defects in wooden poles. In addition, comment is made on the justification and overall benefits to pole using authorities in implementing inspection and maintenance procedures.

1. INTRODUCTION

There are over 7 million poles in service in Australia's power and communications network. The majority are wooden and are regarded as engineered structural components produced to national standards to ensure safe and effective use. In the northern hemisphere, particularly throughout Europe, USA and Canada softwood timbers dominate the pole market. In Australia, however, hardwoods represent around 95% of wooden pole supplies. There are approximately 6 million wooden poles of which 3 million are preservative treated with either creosote or CCA. The remaining 3 million wood poles are untreated naturally durable eucalypt species. Table 1 shows pole statistics for Australian power and telecommunications networks.

Table 1. Pole statistics for Australian power and telecommunications networks as at mid-1990

	Treated hardwood	Untreated hardwood	Treated softwood	Concrete	Concrete and steel	Steel	Total
ACT	4 000	36 000		100	100		40 200
NSW	620 000	1 420 000	1 000*	5 000		3 000	2 049 000
NT				100	100	25 000	25 200
Qld	750 000	375 000	50	18 000	1 200	36 200	1 180 450
SA			200		600 000		600 200
Tas.	190 300	28 400			18 300	400	237 400
Vic.	580 000	360 000	5 000	160 000			1 106 000
WA	93 000	630 000	1 000	3 000		18 000	745 000
Telecom	700 000	110 000	40 000			330 000	1 180 000
Total	2 937 300	2 959 400	48 250	186 200	619 700	412 600	7 153 450

* Untreated cypress pine
Total wooden 5 944 950 - 83% of all poles
50.2% of wood poles are treated
49.8% " " " " untreated.

We have estimated that Australia's wood pole population represents a resource investment of ~$2 billion - assuming an average cost of $350 for each pole. With replacement costs variously stated to be anything from $2000 to $3000+ per pole, the nation's commitment to wooden poles is around $15 billion. It becomes very clear that adequate service lives must be obtained with such an expensive resource. In addition, current insurance requirements are helping to enforce the development of soundly based risk management procedures. Over the years there have been a number of huge litigation cases against pole using authorities. Bushfires, accidents to linesmen including deaths, etc. have resulted from inadequate inspection of wooden poles. Thus, there is an obvious need to research, develop and implement inspection and maintenance procedures.

In our opinion, all wooden poles require some form of inspection and maintenance, a fact well recognised in other parts of the world, particularly in Europe and North America. In these countries both

inspection and maintenance may be undertaken by contractual arrangements with preserving companies who specialize in providing such a service.

2. DETERIORATION IN SERVICE

Wooden poles may be subject to a number of deteriorating factors in service. By far the most important of these are the biological agencies of deterioration, viz. decay and termites.

2.1 Decay Types in Poles

Internal fungal attack (centre rot) is one of the principal causes of pole deterioration and generally occurs without warning or any visible external signs. Basidiomycetes producing brown rot and white rot are responsible for centre rot. The early signs of centre rot normally occur with the establishment of these fungi in the low durability pith region located in the central heartwood of a pole. Under favourable conditions decay extends rapidly outwards from this inner heartwood-pith zone to the relatively more durable outer heartwood region.

To date very little is known about how or when a pole becomes infected with centre rot fungi. However, the most likely explanations are as follows:

1. Decay is already established in the living tree where pathologists refer to it as "heart rot" and the fungi continue to attack the wood when the tree is felled, thus creating a centre rot condition in the poles.

2. Infection of poles by decay fungi occurs via checks and splits while the timber is seasoning in pole yards.

3. After installation, new poles are infected by decay fungi present in the soil, or by spores in the air being carried to the pole surface and rainwater assisting the germination of the spores, thereby promoting fungal hyphae to grow into the wood.

External fungal attack (soft rot) is also a major cause of pole deterioration. It occurs at or around groundline, either in the sapwood of preservative treated poles, or with time, in the outermost layers of desapped untreated poles. In Australia, pole engineers first became aware of soft rot in the sapwood of CCA-treated eucalypt hardwood poles after ten years in service in Queensland (Greaves, 1977a).

The rates of deterioration of wooden poles caused by soft rot and centre rot may vary and are dependent upon conditions suited to the

causal fungi. Both types of decay will reduce service life substantially if not attended to.

2.2 Termite Attack in Poles

Subterranean termites are the most common form of termite attack in wood poles in service. Among the most voracious of these is the giant northern termite, *Mastotermes darwiniensis* found mainly north of the Tropic of Capricorn. Because of its limited distribution to Northern Australia, its reputation is virtually unknown by pole using authorities in the south. It will attack any wood in contact with the ground or accessible from the ground and occurs in very large colonies, each with up to seven million individuals.

Beside the giant northern termite, there are also several species of *Coptotermes* that will attack poles in service. One particular species *Coptotermes acinaciformis*, is widely distributed throughout Australia and is responsible for greater economic loss than all the other Australian species of termites combined (Gay and Calaby, 1970).

Some species of *Nasutitermes* and *Schederinotermes* damage poles in service. *Nasutitermes walkeri* is often encountered attacking poles in the coastal bushland of Sydney and further north where it constructs characteristic arboreal nests in trees.

The drywood and dampwood termites are generally not considered to be important pests of poles. One exception, drywood termites belonging to the genus *Glyptotermes*, have been described fairly frequently attacking transmission poles in New South Wales. Several pole failures associated with the presence of *Glyptotermes* have been recorded (Eldridge and Gardner, 1981).

3. THE SERVICEABILITY OF WOODEN POLES

The quality of wooden poles is ensured through various standards, State Government and regulatory authority Acts. All poles (wooden or otherwise) are required to be maintained during service.

It is unfortunate that for many years few engineers systematically collected service records of their poles. But now, many pole users record the statistics associated with a pole's life, and, where information on failure rates is available, the various causes of the failure may be documented. We have estimated that 1% is the national annual condemnation rate of wood poles - all causes - and well over 75%

of these are a result of decay and termites. However, condemnation criteria may still be inaccurately measured often giving rise to misleading failure rates.

Where data has been collected, it indicates that the wooden pole can provide a service life in excess of thirty years: CCA-treated class 3 poles in Tasmania, 40-50 years; creosote-treated class 2/3 poles in Victoria, 30+ years; CCA- and creosote-treated class 2 poles in New South Wales, 25-35+ years; untreated class 1 poles in NSW, 35+ years (in one region, reputedly 60+ years); and CCA-treated class 2 poles in Queensland, 30 years. Concrete pole specifications have changed considerably over the past few years, as has the nature of the concrete itself. These poles are claimed to provide 50+ years in service, but of course records to derive such data do not yet exist in Australia and therefore the figures can be little more than enthusiastic reliance on the concept of their man-made nature!

The importance of record keeping, reliable inspection procedures, and maintenance strategies are now well recognised by pole using authorities. Risk management programmes aimed at reliably optimising pole service lives are now being devised. Computer assisted evaluations are becoming more widespread and there is far more information being collected per pole - wood or otherwise - than at any other time before.

4. INSPECTION PROCEDURES

It is important that inspection procedures accurately detect the extent of deterioration, and, equally significant, detect the defect in early stages so that preventative measures can be taken to inhibit serious strength losses.

Soft rot can be detected by probing the surface with a knife and visually examining the wood. On the other hand, detection of centre rot has long been a major problem for those responsible for wood pole maintenance. Badly deteriorated poles may be relatively easy to detect, but poles in early stages pose a more difficult yet challenging problem.

In Australia the internal condition of most wood poles is determined by the traditional sounding (hammer) and boring (drilling) inspection methods. In the hands of an experienced operator, a hammer is considered to be simple, rapid, and an effective tool for sounding poles to detect large internal defects. Furthermore, boring the pole allows visual confirmation of a defect by examining shavings extracted, as well

as a measurement of shell thickness. To date these techniques still remain the most widely practised in Australia, and are an integral part of risk management.

Inexperienced applications of sounding and boring techniques may prove to be unsatisfactory, since the inspector may be unable to quantify the defect; the techniques rely solely on the experience and judgement of the pole inspector. Seasoning checks, internal checks, pockets of high moisture content, pole species and knots can affect the sound produced by a hammer making detection of decay extremely difficult. Furthermore, boring a pole, even with multiple holes, can miss pockets of decay which can subsequently affect the overall strength of the pole.

Due to limitations of traditional pole inspection techniques various non-destructive defect detection systems have been developed in an attempt to improve the accuracy and reliability of pole inspection. At CSIRO we have assessed most of the systems available to pole using authorities. The systems developed can be grouped into four categories as follows:

4.1 Electrical Resistance Techniques

The best known and most widely used resistance meter is the Shigometer. Electrical resistance is generated and measured at known depths along a small diameter hole drilled radially to the pith. The presence or absence of decay can be predicted from the radial pattern of resistance observations (Shigo and Shigo, 1974; McGinnes and Shigo, 1975; Shigo and Berry, 1975; Shortle *et al.*, 1978). The Shigometer's ability to produce reproducible results is influenced by a number of factors such as moisture content, pole species, internal checks and collapse splits, all of which make interpretation of results difficult. With experience the difficulty of interpretation can be overcome to a certain extent.

4.2 Residual Strength Measuring Techniques

These techniques are designed to subject the wood fibres to a measured stress, and hence determine the serviceability of the pole. They have been developed and used successfully on softwood poles in the UK and Europe. When a similar instrument was developed by the State Electricity Commission of Victoria and evaluated on hardwood poles, the

spread of results between new poles of the same and similar species were so widespread that it was felt that no further work could be justified.

The residual strength measuring techniques are not as portable as most other systems and moisture content, pole species, preservative impregnation, etc. make calibration difficult. On the other hand, they are able to provide the much needed strength information which is not obtained from methods of decay detection such as the Shigometer or sounding techniques. However, without information on the presence of decay fungi, no effective remedial treatment program can be organised.

4.3 Radiographic Techniques

The use of radiographic equipment to locate internal defects in wood has been in use for over forty years. These techniques have not been adopted by pole using authorities in Australia, mainly because of the increased cost over traditional inspection methods, possible problems of interpreting the film radiographs, and the size of the early equipment. Advances in radiographic equipment and technology, as well as changes in the economics of wood pole utilisation has led to a reassessment of radiographic inspection techniques.

A method recently devised using a radioactive source is Computerised Tomography (CT). CT uses data acquired from radiation transmitted through a section of material and processed by a computer in order to reconstruct an image of that section. The Computer Imaging group at Monash University, Caulfield Campus, Victoria, is using CT for non-destructive testing and evaluation of timber and some recent results obtained are very encouraging. The group has looked at the sensitivity of tomography in detecting decay and other forms of defects in poles. The instrument is sufficiently sensitive in discriminating between decayed and sound timber. They have succeeded in developing a field portable CT unit for scanning poles up to a diameter of 450 mm. It takes 2-3 minutes to scan the pole at the critical zone and another 40 seconds for reconstruction of the image. It is believed to be the first of its kind and patents have been applied for.

Radiographic inspection techniques are relatively quick in skilled hands and even slight defects are readily detected. In addition to providing a permanent record of the extent of decay present at a given time, these techniques, particularly CT, could be used to monitor the progress of decay during subsequent inspections.

4.4 Sonic and Ultrasonic Techniques

The use of sound as a medium to examine the internal condition of poles has played a major role. Today sonic assessment varies in complexity from the traditional sounding techniques to highly sophisticated computer analyses. A large number of these instruments has been used in field testing in Australia. These include Resotest Pole tester, Portable Ultrasonic Rot Locator (PURL), and the De-K-Tector.

The use of ultrasonic and sonic techniques to detect defects in poles has been met with mixed reactions by pole using authorities. The techniques are generally quick to assess the condition of the pole as well as being non-destructive. However, they are affected by a number of conditions which may be present in Australian eucalypts, e.g. internal checks, collapse splits, knots and pockets of high moisture content. These conditions may lead to an incorrect interpretation of the internal condition of the pole using this type of equipment. A correct interpretation of results may be overcome with experience.

Many varied instrumental techniques to detect internal defects have been developed, each with certain limitations, mainly due to the variability both within wood and between pole species. Pole using authorities are moving towards instrumental devices via computer aided assessment. However, this still relies on the ability of the pole inspector to correctly assess and feed in the right information. To date very little research has been performed using such techniques on Australian hardwoods, thus further research is necessary if these techniques are to be useful tools for inspecting poles in Australia. We believe that none of the instruments should be used solely as a means to pass or condemn a pole. Instead we recommend that they be used by inspectors as an aid in conjunction with existing techniques.

5. MAINTENANCE PROCEDURES

In Australia there is no standard approach to groundline maintenance of wooden poles. Most engineers appear to have their own 'pet' approach. Most of these approaches have been reviewed from time to time (e.g. Greaves and McCarthy, 1985) and are applicable - though not necessarily effective in controlling the various types of biodeteriogens in poles. Pole engineers are starting to realise the benefits associated with *in situ* remedial preservation and most authorities have developed

intensive maintenance programs. On the other hand, in some areas throughout Australia there is no attempt to maintain the groundline of wooden poles.

The most effective means of preventing or limiting deterioration at or near the groundline is to apply a sterilizing chemical. For new poles, treated or otherwise, and where no deterioration is present, this should be applied for the first time after 8 to 10 years. Continuing application at about 3-5 year intervals should maintain a sound state of wood.

6.1 Soft rot Control

After extensive research and in-service testing we believe that the most effective means of controlling soft rot is to apply a preservative-containing bandage. In principle, the bandage delivers a known fungitoxic chemical to the surface of the infected wood and the chemical diffuses freely into the pole, sterilizing as it goes. The bandage must be weatherproof, isolated from ground-water, and not a hazard to either the user, the environment, or the general public.

At CSIRO we have developed what we believe to be an ideal format for a pole bandage (Dale *et al.* 1977). It consists of a horizontally-laminated open-celled foam matrix which is impregnated with a diffusing fungitoxicant, backed by a cross-linked polyolefin outer cover. The cover is heat-shrunk into place and provides highly effective upper and lower seals to prevent chemical loss. It is a robust and durable bandage and has already undergone seven years of testing on SEQEB poles in service at Gattan. We can also replenish the chemical, if necessary, without disturbing the general integrity of the bandage or re-excavating the groundline. The development, installation, and testing of the CSIRO Mark IV bandage has been described by Chin *et al.* (1982).

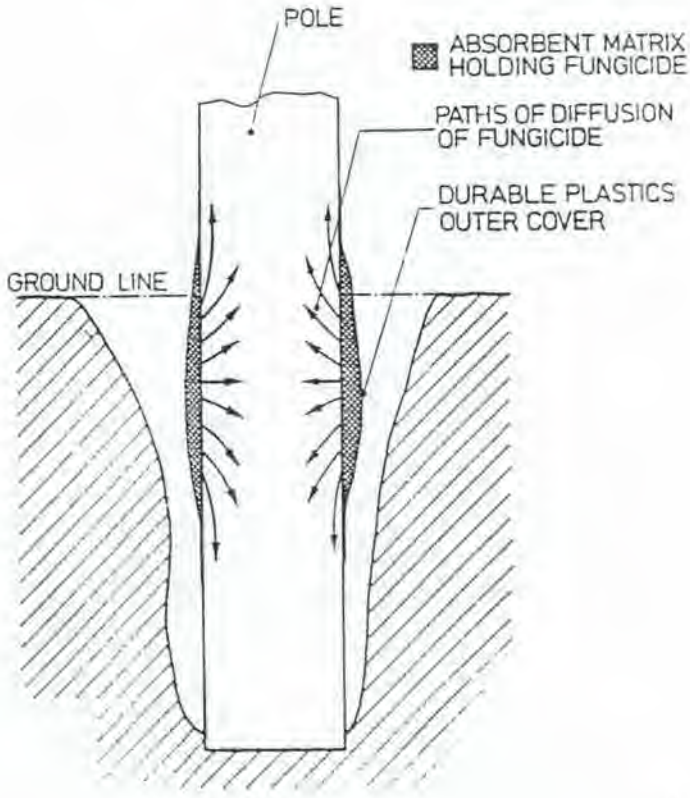

Figure 1. Schematic representation of a bandaged pole

There are a number of effective chemicals which can be used in bandages. These have been arrived at by detailed laboratory work, and as with the CSIRO bandage, by service testing. The following chemicals have been shown to control soft rot *in situ* and can be recommended for groundline use in bandages:

Blue 7 (copper, fluorine, boron). Valchem (Australia) Pty. Ltd., Melbourne;

Busan Pole Preservative Gel (2-thiocyanomethylthio benzothiazole). Buckman Laboratories Pty. Ltd., Sydney.

Other chemicals may be considered, but are not specified here because they may not freely diffuse, they may be difficult to obtain, or else require making up, or have doubtful acceptance for environmental reasons.

The CSIRO bandage has not gained wide acceptance by pole using authorities experiencing soft rot problems. Some authorities in Queensland have used the bandage successfully, however, others particularly in high fire danger areas have been reluctant to adopt the bandage technique. In this situation, chemicals such as creosote gels and copper naphthenate pastes are used. These chemicals merely reside on the outside, at their place of application and provide a water repellent barrier. Since they do not diffuse into the pole, they are incapable of affecting control of fungal infection which is already present.

5.2 Centre Rot/Termite Control

As for soft rot control, chemicals for controlling centre rots must be able to diffuse from the site of application, which is a hole, or holes, bored into the centre of poles from the outside just above groundline. In view of the need to introduce chemicals into the heartwood of poles, the most suitable formulations are those of high viscosity or are specifically thickened to assist in their application. This will prevent loss of chemical via internal checks and splits.

Early work undertaken at CSIRO indicated that three or four holes (depending on pole circumference) bored abaxially from 150 mm above groundline to 450 mm below it, as shown below, provide an appropriate configuration for introduced chemicals to diffuse into the maximum amount of heartwood. Once the chemical has been introduced the holes are then sealed using a screw-in tapered plastic plug. The plug is readily removed for future re-treatments.

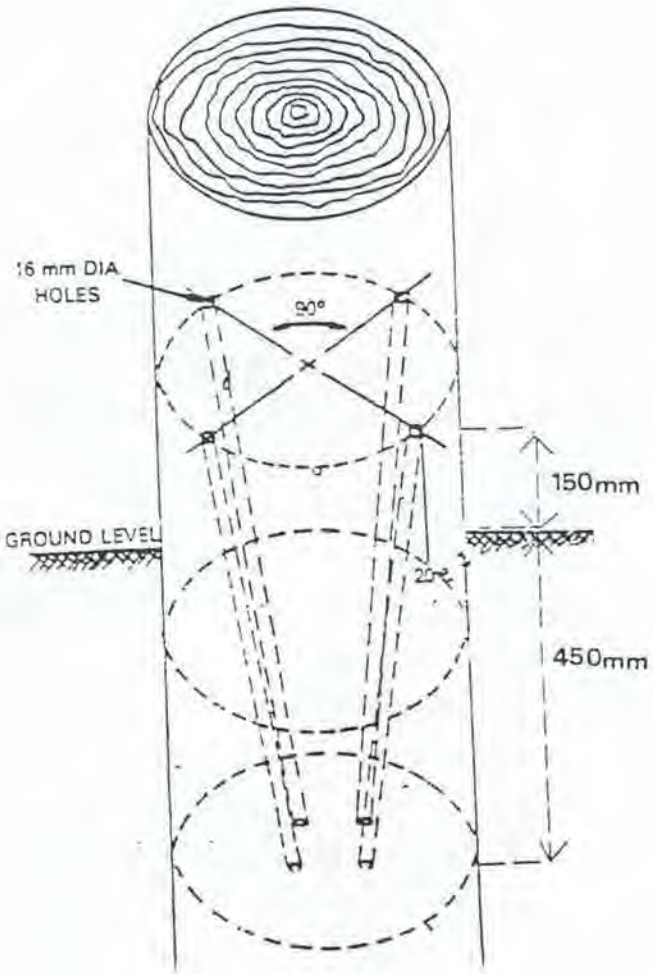

Figure 2. Internal treatment of poles

CSIRO has formulated a diffusion paste for control of centre rot and termites. The formulation, which is environmentally acceptable, contains fluorine and boron as the active ingredients. Boron and fluorine are well known for their diffusibility and toxicity to most common basidiomycetes (Greaves, 1977b,c). In addition, when present in high concentrations within the wood both elements have termiticidal properties (Becker, 1959). The preservative known as Preserval, which

contains boron and fluorine as the active ingredient has performed extremely well in field trials alongside other commercial preservatives. The manufacturers of Preserval are awaiting registration of the product. Once registered it will be commercially available for *in situ* treatment of wooden poles.

A number of effective chemicals which are now commercially available are also suitable for control of centre rot:-

Polesaver rods. Preschem Pty. Ltd., Melbourne
Thickened Blue 7. Valchem (Australia) Pty. Ltd., Melbourne
Busan Pole Preservative Gel. Buckman Laboratories Pty. Ltd., Sydney.

The above formulations have been shown to diffuse sufficiently through the heartwood of eucalypt pole species (Ampong *et al.*, 1985; Greaves *et al.*, 1982; McCarthy and Greaves, 1989). Both Blue 7 and Busan Pole Preservative Gel have been used successfully by electricity supply authorities throughout Australia for the control of centre rot.

We believe chemical fumigants such as chloropicrin, and Vampam, to be unsuitable for Australian hardwood poles. While these types of *in situ* sterilants have been used successfully in the USA in softwood poles (Graham, 1973) the eucalypts of this country tend to develop internal checks and sometimes collapse splits sufficient to allow gaseous-acting chemicals to dissipate too rapidly to have any real and long-term effect.

Pole species, soil type, climatic conditions, remedial treatment used and rate of application, vary considerably from region to region and this makes it difficult to accurately quantify the increased service life to be expected when a pole is subject to regular groundline maintenance. CSIRO and other research bodies throughout Australia have carried out extensive research in this field taking into account the above variables. Valuable information on groundline maintenance has emerged giving pole using authorities on increased level of confidence in remedial treatment usage.

The State Electricity Commission of Victoria has carried out an assessment of their groundline maintenance program and found replacement rates have decreased and cost savings are now being realised (J. Costolloe, *pers. comm.*).

It is now widely accepted throughout Australia that groundline maintenance will significantly extend service lives and the benefit is substantially greater than the initial cost.

7. CONCLUDING REMARKS

Wooden poles - preservative treated, or untreated Regal species - represent a huge investment by the telecommunications and electricity industries. At some stage during their service lives the poles may be subject to some form of biodeterioration; soft rot externally, or centre rot and termite attack internally. Inspection procedures and chemical control techniques exist whereby such biodeterioration can be prevented or restricted.

Not all wooden poles will require chemical maintenance at regular intervals, but since every pole, wooden or otherwise must be regularly inspected, and the economics of inspection generally outweigh the economics of chemicals cost and application, we believe that pole engineers should seriously consider the use of remedial chemicals as a preventative measure.

The use of concrete or steel sleeves, rebutting and staking procedures for condemned poles has become more frequent due to the large cost of pole replacements. An exhaustive study was carried out by the Connell Group for the NSW Department of Energy, who concluded that positive economic benefits could be achieved by reinstatement procedures.

Data available suggests that wooden poles can provide service lives in excess of 30 years. No data yet supports such a claim for concrete poles. Effective inspection and maintenance can guarantee the figures for wood and provide engineers with a soundly-based measure of confidence in wooden poles.

References

1. Ampong, F.F.K., McEvoy, C. and McCarthy, K. (1985). Development of diffusible pastes for control of centre rot in wooden poles. Paper prepared for the National Pole Conference, Rockhampton, Queensland, September 18-20.

2. Becker, G. (1959). Contribution to the knowledge of boron compounds against wood destroying insects and fungi. Holz Roh-Werkst 17, 484-488.

3. Chin, C.W., McEvoy, C. and Greaves, H. (1982). The development and installation of experimental fungitoxic pole bandages. International Journal of Wood Preservation 2(2), 55-61.

4. Dale, F.A., Greaves, H. and Thornton, J.D. (1978). A preservative bandage for the protection of wooden transmission poles. Aust. Patent No. 517086, 1978.

5. Eldridge, R.H. and Gardner, W.D. (1981). *Glyptotermes* in transmission poles. 20th Forest Products Research Conference, November, Topic WP14 pp.10.

6. Gay, F.J. and Calaby, J.H. (1970). Termites of the Australian region. In Krishna, K. and Weesner, F.M. (Eds). Biology of termites, Vol. II. 643 pp. New York and London, Academic Press, pp. 393-448.

7. Graham, R.D. (1973). Preventing and stopping internal decay in Douglas fir poles. Holzforschung 27(5), 168-173.

8. Greaves, H. (1977a). An illustrated comment on the soft rot problem in Australia and Papua New Guinea. Holzforschung 31(5), 71-79.

9. Greaves, H. (1977b). Potential toxicants for controlling soft rot in preservative treated hardwoods. I. Laboratory screening tests using filter papers. Material and Organismen 21(1), 1-15.

10. Greaves, H. (1977c). Potential toxicants for controlling soft rot in preservative treated hardwoods. III. A compost-block test of eight formulations. Mater. Organismen 12(4), 287-299.

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

12. Greaves, H. and McCarthy, K. (1985). Inspection and maintenance procedures for groundline defects in wooden poles. Paper prepared for National Pole Conference, Rockhampton, Queensland, September 18-20.

13. McCarthy, K. and Greaves, H. (1989). Diffusion tests of Preschem Polesaver Rods. CSIRO Division of Forestry and Forest Products Technical Report No. FP135.

14. McGinnes, E.A. and Shigo, A.L. (1975). Electronic technique for detecting discoloration decay, and injury associated ring shake in black walnut. Forest Products Journal 25(5), 30-32.

15. Shigo, A.L. and Berry, P. (1975). A new tool for detecting decay associated with *Fomes annosus* and *Pinus resinosa*. Plant Disease Reporter 59, 739-742.

16. Shigo, A.L. and Shigo, A. (1974). Detection of discoloration and decay in living trees and utility poles. United States Forest Service, North eastern Forest Experiment Station Research Paper NE-294.

17. Shortle, W.C., Shigo, A.L. and Ochrymowych, J. (1975). Patterns of resistance to a pulsed electric current in sound and decayed utility poles. Forest Products Journal 28(1), 48-51.

WHERE TO FROM HERE - THE NEEDS OF INDUSTRY

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ABSTRACT

The future direction of research into structural applications should be geared towards the needs of Industry. These needs will be strongly influenced by security of resource (producer) and market opportunities (consumer). A number of potential research projects, priorities and possible directions have been identified.

Unless industry is made aware of these market opportunities, limited research funds will be available to progress this work. A proposed research network and programme are suggested as one possible way to increase current research activities into structural applications.

INTRODUCTION

Within the context of this paper, Industry is defined as both the producer/manufacturer and the consumer. This in itself has the potential to introduce conflict as both groups have specific research needs that may not necessarily concur.

For the producer, security and tenure of resource, improved sawn recoveries, minimal processing for maximum profit and value adding are the main objectives.

For the consumer (engineer, architect, builder, home owner), value, quality, durability, stability, structural reliability and environmental acceptance are the prime needs.

One of the most significant issues we face is to integrate the research needs of both sectors of industry and to maximise the very limited research dollar currently available.

The following topics briefly describes the author's thoughts on current and future research needs as they relate to structural applications. These topics should not be considered in any way to be 'rigid' or prioritised as many factors beyond industry's control will influence the appropriate direction of research. Not the least of these factors are security of resource and environmental pressures.

SPECIES

Because of changing resource availability and political and environmental pressures, the native forest sector is under threat, particularly relating to traditional sawn unseasoned hardwood applications and markets.

Plantation softwoods, on the other hand, are being seen by some sectors of the "public" as the saviour of our native forests particularly where they can replace traditional hardwood uses and lead to a 'locking up' of native forests. If we could "crystal ball", the same could also be said for plantation hardwoods.

These pressures have led the hardwood sector into placing much greater emphasis on value adding, through seasoning and specialised product development such as mechanically joined beams, and furniture components.

For plantation softwoods, their ability to be easily dried, glued and fabricated has led to significient technical advances in commercial construction utilising large members and long spans. These markets are yet to be fully realised.

Two areas that should be considered for specific further research are: -

Hardwoods

The availability of long length, large section, durable hardwoods is diminishing as the resource moves more towards regrowth. Whilst significant advances have been made with mechanical end jointing and plating for conventional framing, additional research is required to upgrade the reliability of these products to produce large sections (to say 400x100) for heavier engineering applications. A need also exists for durable, high strength members for overhead mains, bridge, wharf and heavy decking applications, and in other weather exposed situations where glued-laminated timber and/or the use of softwoods are not usually suitable.

Softwoods

In 1986, Leightley([1]) presented data that showed by the year 2000 demand for hardwood transmission poles in the eastern States of Australia would outstrip supply, particularly in the 10 to 14 m length class. Further, he indicated that suitable pole stock to fill this gap could be obtained from plantation softwoods.

Pole consumers will be faced with a choice of either using alternative materials (concrete, steel, etc.) or accepting treated softwoods. Many trials and some use of treated softwood poles has already commenced. However, there is still some user bias towards hardwoods as softwoods require different handling and installation techniques and preservative treatment is not preferred or accepted by some pole authorities.

Irrespective, treated softwood poles with their much higher reliability (durability wise) have the potential to compete directly with concrete and could command a price about twice that currently being paid for hardwood poles. Refer Table 1.

This could also apply to hardwood poles if the durability of these poles could also be lifted to be competitive with concrete. This has been demonstrated in the U.S. where 'deep' incising is used to obtain the necessary penetration and loading of preservative in refractory species such as Douglas fir.

TABLE 1. COSTS COMPARISON OF POLES (12.5 m long Medium Class)

Material	Unit Price	Installed Cost
Hardwood (Durability Class 2 treated)	$200	$1350
Softwood (Plantation treated)	$200	$1400
Concrete	$400	$1600 + additional earthing

Note: The difference in cost of Concrete to Softwood is $200.00/pole. This equates to approximately $285/m^3 for round timber.

The ability of softwoods to compete, is dependent upon industry and/or users developing appropriate, reliable, mechanical properties data. I do not believe this data is currently available for treated Australian Grown Plantation Softwoods. To fill this void, an extensive in-grade study along similar lines to that conducted by Boyd[2] in the 1960's is required. This study would provide the necessary data to enable the power authorities to take a true reliability or probabilistic approach to the engineering design of poles.

The study would need to include consideration of the effects of:-

- load configuration and type
- seasoning (including steaming where necessary)
- possibly, the effects of high temperature drying
- species
- species distribution
- material grade (grading rules developed) and
- on-going in-grade assessment

I believe the need for this research is of such public significance that it should be funded along similar lines to the Young Eucalypt Programme as a public interest project. The materials properties data collected would also flow on to benefit all softwood round timber applications including, pole framed housing, piling and perhaps bridge girder applications.

STRESS GRADING, RELIABILITY AND LIMIT STATE DESIGN

The recent wave of in-grade testing hysteria that has emerged from some sectors of industry, scientific and engineering groups needs to be tempered against the specific needs of both producers and end users.

It is estimated that about 90% of sawn timber is currently utilised in "structural" domestic and associated applications. This being the case, other than for a minor manipulation of the current small clear/visual grade system, it must currently be very questionable if widespread in-grade studies can be justified on commercial or economical grounds, particularly for the smaller volume or mixed species.

Little if any evidence exists (earthquake, wind or dead or live load failure) to suggest the current systems of stress grading are deficient for domestic construction, including closely spaced domestic trusses. This may be by default, (private communication - Madsen, B - Queenscliffe 1990) however, to expend around $60,000 per species will not improve the reliability of "domestic" engineering. The money would be far better directed towards studying the 'real' issues of loadsharing, systems development and connection research.

Specific Needs

The cost effectiveness of trying to improve current stress grading systems, structural reliability or implementing limit state design should be viewed critically with respect to specific market needs and current known limitations in the performance of structural timber.

In order of priority these limitations are: -

- reliability of design for durability of members
- reliability of design for durability and strength of connectors
- reliability of serviceability design
- reliability of mechanical properties (strength) for members

Strength Testing

Most current in-grade strength/stiffness testing programmes in Australia[3,4,5] have been conducted on relatively small sizes, typically up to 150x38 mm in cross-section.

It is ironic that other than for trusses, the vast majority of this timber is used in non-critical, loadsharing domestic framing applications whereas the real "in-grade testing" need is to develop reliable mechanical properties for critical, non-loadsharing engineering applications. Invariably these critical applications require large spans, wide spacings and big section sizes, typically in excess of 3.6 m in length and 200x75 mm in cross-section. It can be argued that we can test smaller "in-grade" sections and lengths and modify the data to take account of size and length effects. It could be equally argued that we could similarly modify "small clear" data.

Prior to any future in-grade testing being conducted, the following should be considered: -

- Isolate Specific Needs
  - loadsharing framing
  - loadsharing "domestic" trusses
  - engineered/architectural trusses
  - non-loadsharing critical applications
- Critical Applications include - poles, cross arms, bridge/wharf girders, large bearers, beams and truss members and all laminated fabricated and composite members i.e. glulam, LVL, Scrimber(R) plybox beams etc.
- Species Options
  - low volume vs high volume species
  - mixed species groups
  - hardwood vs softwood
  - seasoned vs unseasoned

In summary, there is no simple, single course of action appropriate for in-grade testing.

Timber Engineering/Structures Code

For 25 years, the current Code (plus predecessors) in conjunction with the visual stress grading system has served industry well. It is conceded the Code may need some minor massage to bring it into line with the purported "reliability" of other structural codes(A) however, the massage should initially be directed towards repairing the more commercially important deficiences, namely: -

- adjustment of "E's" for some seasoned species
- catering for varying F'b/F't ratio's between species and grades and
- developing a user friendly limit state format that accounts for both serviceability and strengh limits.

COMPOSITES AND MANUFACTURED PRODUCTS

As previously stated, the role of manufactured and reconstituted or composite timber products have taken on great importance for the critical non-loadsharing engineering applications currently being utilised in Australia. They are readily available in long lengths, large cross-sections

and for a few products (LVL, some glulam and plywood and perhaps Scrimber(R) when it becomes available) reliable engineering mechanical properties, based on in-grade testing are available.

However, unlike solid durable hardwood timbers, the application for these products is still very limited. None can currently be recommended for applications involving exposure to the weather.

The company or researchers that come up with a long length, large cross-section product that can be exposed to the weather (for 25 years*) with the required reliability for both structural and durability considerations will be on the biggest 'winner' Industry has ever known.

Some current products - glulam, LVL and Scrimber(R) have the potential to reach this goal provided sufficient research effort is directed towards raising the level of basic wood durability and improving weather resistance i.e. preservative treatment + water repellency.

With respect to structural reliability, recent full size testing of a range of commercially available glulam has demonstrated the questionable reliability of these products relative to their published or implied properties. Unfortunately, neither the current Timber Structures Code or building legislation properly addresses the limitations of end jointing, particularly with respect to higher stress grade hardwoods. Refer Table 2. This is one area of structural reliability that needs to be urgently addressed.

JOINTS AND CONNECTIONS

For "heavier" engineering applications, particularly portals and heavy trusses, a need exists for "architecturally" acceptable connectors that have the capability to develop the moment and shear resistance capacity of the 'parent' members.

Examples of these types of connections are already in wide use in Europe[7] and to a much lesser extent in Australia[8] where dowels and steel reinforcing are utilised. To date, the structural long term reliability of these types of connections are yet to be quantified, therefore significant research in this area is also required.

TABLE 2. INDICATIVE TESTS ON FULL SIZE LAMINATED BEAMS

SUPPLIER	TEST NO	SIZE (mm)	SPAN (mm)	MOE (Mpa)	MOR (Mpa)	MOR ÷ 2.4	OUTER TENSION LAMINATE JOINTS	BEAM GRADE AS MARKETED	REMARKS
A SOFTWOOD	1	240x70	3300	16700	60	25	-	F17	
	2			20080	39	16*	FJ		
	3			15020	60	25	FJ		FJ outside max moment
	4			19440	74	31	-		
	5			19440	73	30	-		
	6			18240	38	16*	FJ		
B HARDWOOD	1	190x66	2500	18852	63	26	Scarf	F22	Initial failure both beams @ 47 MPa
	2			23206	94	39	-		
C HARDWOOD	1	270x65	4000	18050	38	16*	FJ	F27	FJ outside middle 1/3 span
	2			17730	34	14*	FJ		Middle 1/3
D HARDWOOD	1	330x85	4000	14560	61	25*	FJ	F27	FJ outside middle 1/3 span
	2			16030	52	22*	-		
E SOFTWOOD	1	310X70	4500	13014	48	20	FJ	F17	
	2			14986	34	14*	FJ		
F SOFTWOOD	1	345x70	4500	11547	25	10	FJ	F8	
	2			10037	22	9.2	FJ		
	3			-	30	12.5	FJ		
	4			11632	28	11.7	FJ		
	5			11204	32	13.3	FJ		Outside middle 1/3 span
	6			11483	-	-	FJ		2 adjacent outer 2 lams
	7			11775	25	10.4	FJ		
	8			10483	22	9.2	FJ		
	9			10365	30	12.5	FJ		
G HARDWOOD (MIXED)	1	300x70 (Approx)	5000	18580	39	16*	FJ	F27	All FJ's this group random but many in bottom tension laminate
	2			18750	49	20*	FJ		
	3			18770	52	22*	FJ		
	4			19220	56	23*	FJ		
	5			19200	70	29	FJ		
H HARDWOOD	1	300x70 (Approx)	5000	12854	36	15*	FJ	F22	All FJ's this group random but many in bottom tension Laminate
	2			13683	40	17*	FJ		
	3			14300	55	23	FJ		
	4			14700	55	23	FJ		
	5			15688	73	30	FJ		
I SOFTWOOD	1	300x70 (Approx)	5000	13460	34	14*	FJ	F17	As above
	2			13870	35	15*	FJ		
	3			14540	38	16*	FJ		
	4			15030	43	18	FJ		
	5			16210	49	20	FJ		
J HARDWOOD	1	300x70 (Approx)	5000	14040	23	9.6*	FJ	F27	As above
	2			15540	31	13*	FJ		
	3			16000	43	18*	FJ		
	4			16500	44	18*	FJ		
	5			16500	54	22*	FJ		

NOTE: FJ = Finger Joint ; * Does not satisfy a simplistic analysis of purported stress grade

One of the great advantages of these types of 'hidden' connections is their potential to not only perform aesthetically and structurally but to be able to offer a Fire Resistance Level (FRL) of at least 1 hour[9]. This has been demonstrated by full scale fire testing.

Another area for connection research relates to the move towards limit state design. Our current Engineering Code provides a single basic working load for connectors based on either a serviceability limit (slip) or a strength limit. When we move to limit state design, the designer will need to know both criteria to enable economic and efficient design.

FIRE AND SOUND

The National Association of Forest Industries (NAFI) Fire Research Office has a programme scheduled to develop fire and sound rated timber framed wall and floor systems that achieve FRL's of 90/90/90, the intent being that these would be suitable for use in constructing Class 2 or 3 buildings of up to 3 storeys.

Assuming this information becomes available and the necessary changes are made to the Building Code of Australia to permit fire rated combustible construction, Industry still faces an extremely competitive market place that will demand the most cost efficient systems available.

To achieve this, the fire/sound requirements need to be married with structural requirements. This will necessitate: -

- developing a conventional structural framing system for 3 storeys (floors and walls)
- extending the system to take full advantage of structural sheathing, particularly for diaphragms, stressed skins and plate stiffening effects.
- developing appropriate earthquake ratings for these systems and
- developing the necessary building practice details including those that account for fire stopping, service penetrations and shrinkage.

It has been reported that some work in this area is currently being undertaken in New Zealand for sheathed 3 storey frames.

Unless complete building systems (fire, sound, structural, economical and practical) are developed, Industry will not have a "marketable" product.

INNOVATIVE BUILDING SYSTEMS

Numerous market surveys [10,11] conducted over the last 10 years in Australia have all indicated the potential available to Industry to develop innovative building systems, particularly for domestic and commercial construction. Just as the domestic framing market is, or was dominated by timber[12], so the "high rise" partition framing market is dominated by steel.

There are currently no restrictions on the "combustibility" of non-loadbearing in-fill partitioning in high rise construction yet, as an Industry, there has not been one system developed for this market. A market estimated to be worth in excess of $10 million p.a.

Similarly, for domestic construction, the potential rewards for limited expenditure on structural systems research can provide new and innovative systems that have the potential to reverse market trends[10].

One particular area that needs an extremely high priority relates to suspended floor systems.

With increasing health and environmental pressures to ban the use of underslab chemical termite treatment, it is paramount that Industry have, as one alternative, cost competitive suspended timber floor systems available by the mid 90's. If we don't develop these systems, we face the potential for a severe reduction in the total domestic timber framing market.

McDowall[13] in his paper presented at this conference, has provided the basic groundwork for the future development and implementation of a stress skin, low profile floor system. The system has the potential to regain part of the market lost to concrete slabs, can be site or factory fabricated[14] and, potentially offers significant economic savings over conventional timber floors.

Many other systems opportunities can be considered. These include: -

- timber portals for domestic construction
- the application of the Truss Frame[8] system in Australia
- further development of treated pine piles and stumps
- further development of the "McDowall"[15] stressed skin "box"
- the application of shearwalls and diaphragms to commercial construction
- prefabricated timber bridges
- feature timber floors over slabs.

The market opportunities have been identified, all that is needed is the commitment by Industry to carry out the research.

CONCLUSION

There is urgent need for research into structural applications for timber. For some specific market orientated projects (fire, sound, AS 1684), Industry have shown they are prepared to fund the necessary research. However, for more basic or fundamental research, neither Industry or the Government have the funds, or appear prepared to commit funds to conduct this research.

Irrespective of the co-ordinated effort NAFI is pursuing, the following have or may be contributing to this: -

- insecurity facing the native timber sector
- current demand exceeds supply for softwoods
- potential markets and profits have not been 'sold' to Industry
- specific Industry sectors do not have medium or long term goals
- Industry is not prepared to be "taxed" to fund research and
- research with respective sectorial goals is not co-ordinated

With the demise of the timber engineering expertise in CSIRO - DFP and DBR, a recent proposal[16] being considered, has the potential to redress the situation. The following is offered as one possible course of action to try and overcome these deficiencies.

1. The development, on a truly National basis, of an Integrated Network of Timber Engineering Excellence. See Figure 1, and
2. The funding and management of this Network being driven by true market forces.

Table 3 lists enough urgent research to keep the network busy for the next ten years.

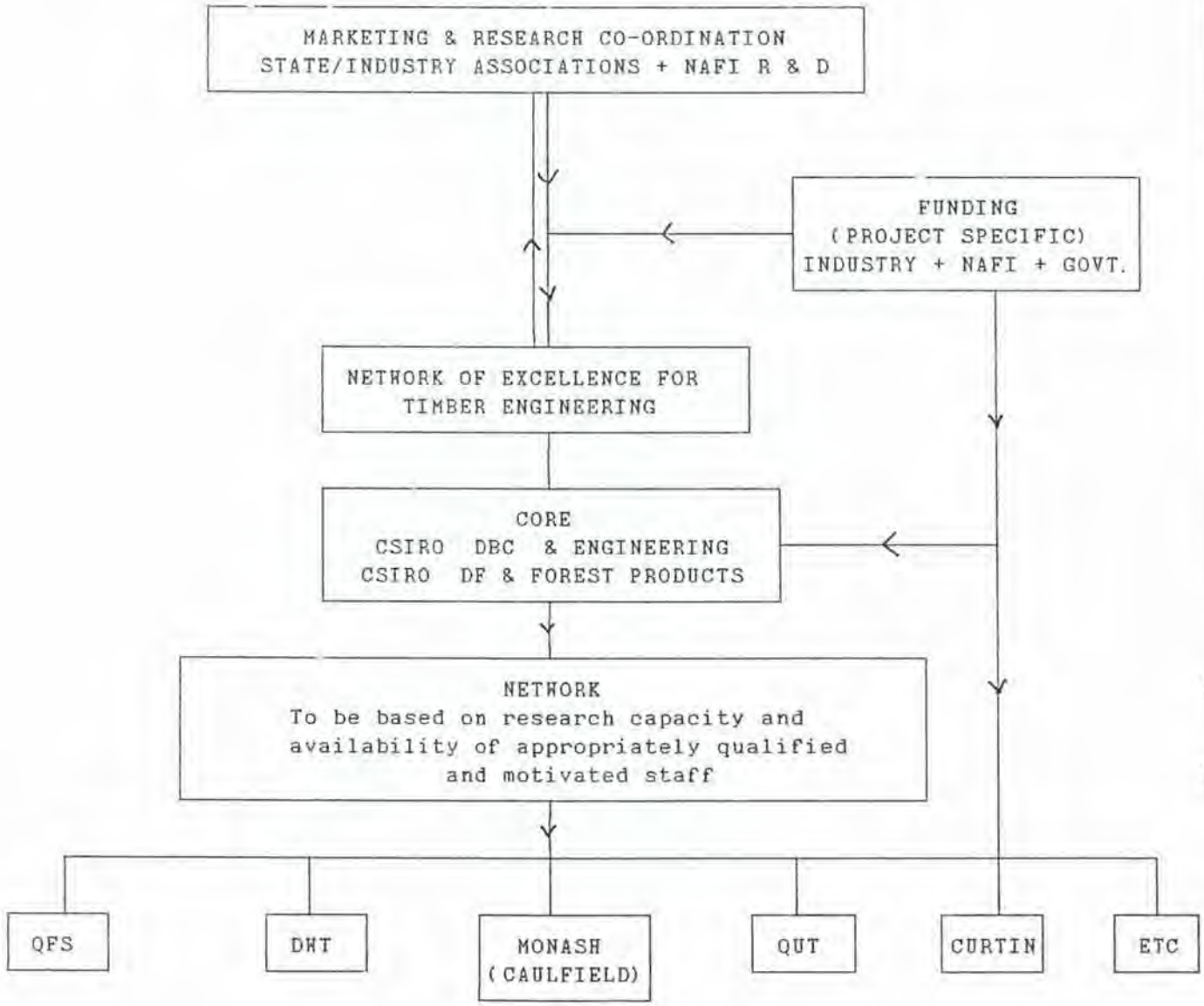

FIGURE 1. A PROPOSED NETWORK OF TIMBER ENGINEERING EXCELLENCE

TABLE 3. A PROPOSED R & D PROGRAMME (1990 - 2010)

PROJECT	RESEARCH GROUP	POSSIBLE FUNDING	ESTIMATED COSTS
DESIGN FOR DURABILITY	CSIRO DBCE CSIRO DFFP QFS	NAFI + GOVERNMENT FOR SPECIFIC PRODUCTS - INDUSTRY	$100,000 - $200,000 p.a. ?
STRUCTURAL RELIABILITY AND IN-GRADE TESTING	CSIRO DBCE, DHT & PERHAPS TERTIARY INST. FOR SOME SPECIFIC PRODUCTS	SAWN TIMBER - SPECIES GROUPS POLES - POLE PRODUCERS USERS, TREATERS AND GOVERNMENT MANUFACTURED PRODUCTS - INDUSTRY	$100,000 PER SPECIES OR PRODUCT
FIRE & SOUND	BRANZ & CSIRO DBCE	NAFI + SHEET MATERIALS MANUFACTURERS	$100,000 - $200,000 p.a.
- STRUCTURAL ASPECTS	TERTIARY INST.	"	$ 40,000 p.a.
JOINTS & CONNECTIONS	TERTIARY INST.	MOMENT JOINTS - GLULAM MANUFACTURERS ASSOC. ETC GENERIC - NAFI	$ 20,000 p.a. $ 20,000 p.a.
STRUCTURAL SYSTEMS	TERTIARY INST.	GENERIC SYSTEMS - NAFI PROPRIETARY - INDUSTRY	$100,000 p.a. ?
MANUFACTURED PRODUCTS	CSIRO DBCE AND TERTIARY INST.	INDUSTRY AND OR INDUSTRY ASSOCIATIONS	?
		TOTAL:	$500,000+ p.a.

REFERENCES

1. Leightley, L.E. 1986. The Potential for the Expanded Use of Treated Softwood Poles. 22nd Forest Products Research Conference - Volume 1. CSIRO Division of Chemical and Wood Technology. Clayton, Victoria, Australia.

2. Boyd, J.D. 1968. The Strength of Australian Pole Timbers - VI Grey Ironbark Poles. CSIRO Division of Forest Products. Technological Paper No. 53. Melbourne, Australia.

3. Nicol, R.L. 1988. The Mechanical Properties of Cypress Pine - Master of Civil Engineering Thesis - New South Wales Institute of Technology, Sydney, Australia.

4. Leicester, R.H; Grant, D.J; Rumball, B.L; Young, F.G. 1988. Structural Engineering Properties of Machine Stress Graded Australian-Grown Radiata Pine. Technical Report TR 88/1 CSIRO Division of Construction & Engineering. Victoria, Australia.

5. Joe, W. 1989. Critical Evaluation of Strength & Stiffness Properties of Selected Hardwoods with Reference to Grading. Civil Engineering Monograph No. CE 89/1 M.E. University of Technology, Sydney, Australia.

6. Leicester, R.H; Pham, L; Holmes, J.D; Bridge, R.Q. 1988. Safety of Limit States Structural Design Codes. Institution of Engineers Australia. Canberra, ACT.

7. Syme, D.R. 1989. Timber Jointing Systems in Europe. Proceedings of the Second Pacific Timber Engineering Conference - Volume II. University of Auckland, N.Z.

8. Gardner, G.P. 1989. A reinforced Glued Laminated Timber System. Proceedings of the Second Pacific Timber Engineering Conference - Volume II. University of Auckland, N.Z.

9. Din Deutsches Institut Fur Normung E.V. 1981. Din 4102 Part 4, Fire Behaviour of Building Materials & Components. Beuth Verlag GMBH, Berlin.

10. ..... 1987. Research Report of a Market Segment Study for Queensland Market Development Plan. TRADAC Queensland 1987.

11. Browning, J.R; Cripps, D.H; Collins, M 1987. Report on Consumer Groups for National Timber Marketing Group. Australian Timber Producers Council Ltd. Canberra, ACT.

12. Greve, D.M. 1990. Domestic Building Materials and Practices in Queensland. January - March 1990. Queensland Forest Service, Brisbane, Australia.

13. McDowall, C.G. 1990. The Design and Construction of Stressed Skin Panelised Floor Systems - 23rd Forest Products Research Conference. CSIRO - Division of Chemical & Wood Technology - Clayton, Victoria, Australia.

14. ..... 1990. Rapid Modular Construction Uses - Prefabricated Stress Skin Walls, Roof and Floor Systems. Timber Facts Magazine, June 1990 - TRADAC, Brisbane, Australia.

15. McDowall, C.G. 1984. Qualitative Assessment of Whole House Structural Response to Lateral Wind Loads. Proceedings First Pacific Timber Engineering Conference Volume II. University of Auckland, N.Z.

16. Leicester, R.H. 1990. Private Communication.

DEVELOPMENTS IN NEW ZEALAND TIMBER ENGINEERING RESEARCH

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Abstract

This paper summarises the research effort in New Zealand which is concentrated at the Forest Research Institute in Rotorua, the NZ Schools of Engineering in Auckland and Christchurch and recently at the School of Architecture in Wellington. Engineering projects at each establishment are outlined, including work on earthquake resistant shear walls, jointing systems for portal frames, creep deformation of sawn timber, and development of composite beams. Materials developments include enhancement of radiata pine by impregnation, a system of finger jointing green wood, systems for grading structural timber and a reappraisal of glued laminated timber strengths using proof tested timber.

Introduction

New Zealand produces nearly two cubic metres of sawn wood per capita, per year, compared with 0.5 for Australia, 0.6 for USSR, 0.9 for USA, 2.6 for Scandinavia and 3.8 for Canada.(1,2). From these figures it is clear that the use of timber for building should be prominent in New Zealand, as it might be in Canada or Scandinavia. Likewise, it should be expected that research in forest products should be significant in New Zealand. The Forest Research Institute in Rotorua (FRI) with a staff of over 350 is one of the larger establishments of its kind in the world. Research functions there are diverse, from soil preparation before planting, through the growing and tending of trees, to properties and uses of highly processed final product. Workers in the field of timber engineering are numerically few at FRI. Research is primarily (though not exclusively) aimed at the materials definition end of the spectrum with components and structural elements being addressed mainly by the Engineering Schools at Universities of Auckland and Canterbury. General building systems (often not timber specific) are also researched at the Building Research Association of New Zealand, who run a nationally accepted appraisal system for new materials. Recently, the Victoria University of Wellington, School of Architecture has joined the research effort.

It must be emphasised that a number of consulting engineering or manufacturing firms have made major contributions to development as well (notably the truss nail plate manufacturers and members of the Structural Engineered Timber Manufacturers Association (SETMA)). Arguably, it is those having to solve workface problems, that appear

to make the most spectacular advances, such as in erection methods for portal buildings, manufacture of "off the shelf" connection hardware, and design solutions for buildings. The New Zealand Timber Design Society has provided a significant vehicle by which all these various contributors can communicate and share results in the timber engineering field: witness two successful conferences in Auckland in 1984 and 1989 and the quarterly NZ Journal ofTimber Construction produced jointly with the Timber Industry Federation.

This paper is restricted mostly to developments involving the academic institutions and is a brief overview of developments in New Zealand. Consult the references for detail.

A factor that has greatly influenced recent directions in research is the call by the New Zealand Government for increased user pays funding. This has meant that some government laboratory research is commercial, company specific, and more focussed in the short term, and long term projects are more difficult to justify. The result is a change in the way the FRI operates, but the policies have only just begun to bite at University level.

The FRI effort in recent times has included the development of design data for a range of clients' products as well as Government funded projects that could provide opportunities for the FRI, or for downstream development by industry. Issues of timber quality and strength are continuing programmes, with projects on stress and proof grading. The Auckland University effort has been primarily in joint systems for glulam, which has identified some consequences for glulam quality whereas Canterbury University has focused on work required to establish light timber frame for multistorey construction, with an emphasis on earthquake resistant design.

New Products

1. Twinaplate I-beams

The Twinaplate I-beam concept of using a corrugated thin steel web with timber flanges was introduced to New Zealand from the United Kingdom as a means of producing long span floor ceiling systems with gypsum plaster board (3). Design data for the Twinaplate beam were derived at the FRI for beams made with radiata pine flanges from tests on both laboratory assembled and production beams (4).

Tests were designed to find: flange pullout strength, safe flange-web shear strength, web strength in compression from point loads, and to verify a complicated design method for deflection as proposed by United Kingdom researchers. FRI also produced design software as an aid to marketing the product. This was well received by many designers. The UK design method was simplified after the test programme by removing an empirically derived F factor that under-estimated deflections at low loads and grossly over-estimated them at high loads (Figure 1). The method now uses conventional engineering principles. Deflection due to shear should be calculated and shear

flow capacity at the flange-web interface should be checked because unlike shear in rectangular sawn members it may be critical.

Beam behaviour is ductile with extensive deformation of the teeth in the wood flanges so that about half of the total deflection to failure occurs within 10 percent of the ultimate load. In the third point bending beam tests there were some remarkable secondary effects near ultimate load (Figure 2) resulting in tensile bending rupture of the "compression" flange.

One crucial factor in the performance of these beams is quality control of the flange material which is finger jointed to give long lengths. This has been addressed by proof testing of the flanges after end jointing and ensures all finger joints and timber are of the required strength.

2. Metal-web trusses

Gang-Nail NZ Ltd has begun production of metal-web trusses in competition with Twinaplate. The same benefits of longer spans with lightweight beams apply.

3. Wood-I beams.

There is no reason why the web material in I beams could not be made of plywood or some other proven wood product. It is in North America and in one off site nailed beams.

4. Triboard

Triboard is a world first for New Zealand. Available in sheets up to 4m x 2.4m and thicknesses from 20mm to 100mm it is used in panel housing systems and for interior partitions, doors, and furnishings. This three layer MDF-strandboard composite was tested at both the FRI and at Auckland University to establish design values for the material (5) and its fasteners (6). Standard tests were used where possible but as with any new material, standard tests such as those in BS5669 (7) or ASTM D1037 (8) do not always apply, especially when trying to establish design values from tests aimed at quality control.

One of the more interesting test problems was to evaluate punching shear for concentrated point loads. Four methods of analysis were tried, and applied to loads found from five tests on each of four panel thicknesses. One method found shear values consistent with rolling shear from (glulam!) shear block tests (Figure 3). Another found tension perpendicular stresses (Figure 4) consistent with internal bond values, which were correlated with density to obtain a fifth percentile and basic working stress.

Material developments

1. Creep and shrinkage

Creep studies on initially green or dry, sawn and nail plate jointed timber beams began at FRI in January 1986, on 46 pieces of

150x50mm and 60 pieces of 250x50mm timber over 2.6 and 4.4m spans respectively. Results for 250x50mm specimens after three years of loading are illustrated in figure 5. Samples for each load/moisture/jointing condition contained 6 to 9 beams. Each sample had the same average stiffness with equal numbers of low, medium and high stiffness pieces. Load levels were 20%, 50% and 100% of basic working stress to model real in-service load behaviour. This is different from most overseas work that has been done at proportions of ultimate strength well above usual design stresses (9). Because of this, it was possible to identify and isolate deformation attributable to shrinkage processes (10).

The shrinkage deformations are quite large relative to the small creep movement at low loads and lead to very large proportional deflections. They could in fact explain some of the large proportional creeps previously reported in the literature. The observed shrinkage deflection (up or down randomly) (Figure 6) was consistent with that calculated from the curvature induced by a difference in longitudinal shrinkage (Figure 7) at the top and bottom edges of beam cross sections using a number of assumed sawing patterns. A method for calculating percentiles of total deflection was derived, allowing for natural variation in E (the modulus of elasticity), creep, and the differential longitudinal shrinkage deflection.

$$\delta = \delta_E (1 + C_2) \pm z \sqrt{a^2 + b^2} \qquad (1)$$

The deflection δ is found from the calculated initial elastic deflection δ_E, creep factor C_2, the standard normal variate z, the standard deviation of creep deflection a, and the standard deviation of shrinkage deflection, b.

$$a = 0.30\ \delta_E (1 + C_2) \qquad (2)$$

$$b = 0.00004\ (L^2/d) \quad \text{for initially green timber, 0 for dry} \qquad (3)$$

where L is the span and d the depth of the beam.

At lower percentile levels, shrinkage deflection of initially green timber is much more significant than creep. Furthermore the coefficient 0.00004 could be as high as 0.00010 depending on the cutting pattern used to saw the timber (10). The method could easily be applied to other species with known longitudinal shrinkage data.

Average creep factor (C_2) for dry beams was 1.0, and for green beams drying under load 1.5. The current code value of 2.0 for green beams would allow for some of the increased variability observed in the test programme.

2. Proof testing of timber for use in tension

Proof testing can be used either to guarantee or to raise the strength of beams or to recover adequate strength material from lower visual quality stock. Experience with some poorly graded and poorly jointed beam laminations has shown that the only certain way of ensuring the strength of higher strength glulam beams or I-beams is to proof test the critical laminations after finger jointing. To guarantee stiffness, stiffness grading is also required (11). The first production tension proof tester was commissioned in a New Zealand plant in 1987 (12). There are now three manufacturers with tension testers, and the FRI Hilleng bending proof loader is being used to test I beam flanges.

Quality control: The value of proof testing as a quality control check was dramatically illustrated when one consignment of timber was supplied for finger jointed flanges for the first ever New Zealand Twinaplate beams. The tension tester failed 66% of the first packet at a modest proof stress or 13.3MPa, mostly in the wood (not at joints). It transpired that the material was from young trees from a very low density stand. It is horrifying to think of what may have happened had this timber been used in the product launch.

In another example one in four pieces of finger jointed glulam stock failed at finger joints, revealing dry powdery joints in product from a plant that had supposedly been making "satisfactory" joints for 20 years. Within a few days the finger jointing operation had identified its problem and was supplying stock with an acceptable failure rate of one or two percent.

Improved recovery: A truss manufacturer is using a tension proof tester to prove the strength of finger jointed truss stock obtained by docking gross defects from lower visual quality timber and jointing the remainder. This ensures that all the truss chords are of sufficient strength and adds value to otherwise waste timber. An added benefit is that trusses are dry and more dimensionally stable after jointing but the building industry is not yet awake to this, tending to prefer lower cost at source rather than minimal site problems.

Better properties: Apart from quality control, a proof tester can also be used to prove selected stock for higher strength glulam. Walford at FRI (11) tested eighty glulam beams (about $18,000 retail!) that had tension edge laminations that were: visually graded, clearjointed, bending proof tested, tension proof tested or LVL. Figure 8, shows the results for strength and stiffness respectively.

Walford concluded that stresses 20% in excess of those currently used for engineering grade could be achieved by proof testing or using LVL tension flanges in beams. Low density or juvenile wood yields beams of stiffness lower than code values. Visual grading cannot ensure beams of the minimum strengths normally assigned to the visual grade. On the other hand, proof testing of tension laminations did not improve the more than adequate strength and stiffness of beams

made from high density timber, but did exclude potential finger joint failure, observed in one visually graded beam.

Hence, to make good glulam:

- choose a high density wood source
- stiffness test to find the stiffest timber
- use the stiffer timber for outer laminations and joint if required for longer beams and
- proof test the jointed outer laminations or
- use continuous LVL outer laminations. (assuming LVL quality control continues to be reliable). If end joints are required in long LVL these should also be proof tested.

3. Glulam basic working stresses

Glulam stresses in New Zealand are derived from early tests on glulam and are given directly in the design code rather than being factored from the sawn timber stress grade, as they are in Australia. This is simpler for the small number of species we use but has given higher stresses than expected under the Australian system. The current code values are under review because of fears induced by some apparently low failure stresses in glulam portal frame joint tests at the University of Auckland (13). These concerns have been reflected in the current revision of the working stress Timber Design Code (NZS3603) (14) by retaining the previous lower load duration factors for glulam, whereas for sawn timber the load duration factors have been increased. A testing programme is being carried out by the FRI and the two engineering schools with the support of industry to evaluate the strength of current production glulam in a range of sizes to include size effects.

4. Machine stress grading issues

Most machine stress graded material is exported and follows the standards and developments required by the major export market, Australia. However the Timber Engineering Laboratory at FRI is continually monitoring developments world wide. The laboratory has established a method of datalogging the output from production grading machines. This can provide very useful data for production analysis for millers and researchers alike. An Ep profile is obtained for each stick of timber. A recent mill visit recorded all data from 55 packets (about 130m^3) of timber on four 720kByte floppy disks. Such data can be used to identify the log grades that give the best machine grade recoveries and to optimize the recovery of shorter lengths of higher machine grades from longer stock.

Much of FRI's work in machine stress grading (MSG) is in restoring the credibility of the process in the minds of producers, domestic customers, and regulatory authorities in New Zealand after a somewhat unsuccessful first introduction of machine stress grading in the early 1970's (15). A proposed Australian Standard for structural verification of timber (16) and changes to the New Zealand building codes should advance the need for a quality assured product. The

main factor limiting MSG usage is the processing required before grading. A percentage of the dried and gauged timber will be rejected and is often in sizes that are then not resaleable on the local market. FRI has developed a program that complies with the Australian QA system which does not require the timber (Douglas fir in this case) to be kiln dried, saving processing cost. Further cost reductions are also possible and are being investigated. FRI will continue to be the primary repository of the NZ expertise in machine stress grading.

5. Enhanced hardness pine

One of the problems for a medium density softwood like radiata pine is a lack of hardness in wearing applications such as floors and bench or table tops. There has been an extensive programme at FRI that has developed patented methods of enhancing radiata pine for these uses. Most involve introduction of some sort of polymer to fill the voids in the wood. To determine the improvement in surface hardness performance a wedge hardness test was used measuring force to 0.25mm and 1mm indentation. This was preferred over the Janke ball hardness test which measures more of the substrate than the surface (17).

Using the techniques developed at the FRI, radiata pine can be surface-hardened by as much as a factor of eight times the unhardened pine. The improvement depends on the type of polymer and its loading or concentration in the wood. Treatment schedules have been developed to allow accurate control of the depth of penetration of the hardening agents thereby improving process economies.

As a by product of the hardening, there are improvements in other mechanical properties such as stiffness, strength and toughness. Figure 9 shows the influence of one hardening system on Modulus of Rupture of radiata pine sapwood samples. Hardened radiata pine has improved water repellancy, dimensional stability and gluing properties. Colouring agents can be introduced to extend the variety of end products available. In addition, on the hardened pine obtained from the FRI process, a surface gloss can be obtained simply by buffing the wood surface, avoiding the need for subsequent surface finishing

Commercial interest has been high and FRI is beginning to work with industry to transfer the research results into a viable commercial process.

Jointing

1. Finger jointed green wood

The FRI has been studying ways of carrying out finger jointing of green wood using a range of adhesive types and gluing methods. One or two methods were most promising in the laboratory and have been patented to allow development for introduction to industry. Radiata pine sapwood in excess of 100 percent moisture content has been glued

successfully in the laboratory and gave strengths and wood failure percentages as good or better than those for joints made with conventional methods on dry controls. It is anticipated that major savings are possible by excluding docked waste from the drying cost, or by the recovery of short lengths of green material containing acceptable defects, jointed for use as framing after extracting clearwood for other uses from the sawn timber stock. If used with dry timber, the method would remove the need for the very tight moisture controls that are currently desirable for successful gluing.

2. Joints for I-beam portals

The Twinaplate beams described above are lightweight and suited to use in "do it yourself" labour intensive construction such as farm or light industrial buildings. Using the simple site-nailed Timbertec joint system, it is possible to fabricate frames for a range of spans and spacings (18). Nailing is possible on only the flanges of the I beams so joint performance and design methodology was assessed by test.

Knee joint test specimens made from 240x67mm Twinaplate beams with 3mm mild steel knee gusset plates were tested in cyclic loading, first with 14 nails per wood-steel interface at 60mm or 30mm spacings, and then (all but one joint) with 28 nails per interface at 30mm spacings (Figure 10). All joints were then tested to destruction (19). The short joints (14 nails at 30mm spacings) lacked stiffness. The long joints were similar in stiffness and strength at both 14 nail, 60mm spacing and 28 nail, 30mm spacings. A design method for frames was derived (18) which allows for the stiffening effect of the steel gussets by inserting nodes in the frame analysis at the ends of the nail groups. Without this adjustment, the observed deflections in the test joints were half of those calculated assuming that Twinaplate stiffness was continuous to the knee node point. The design method can be used for both steel and plywood gusset joints and is likely to be applicable to other wood based I-beam frames.

3. Epoxied connections

Joint design and detailing are essential elements in the successful performance of timber buildings. One of the many challenges in joint design is to be able to hide the necessary hardware where clean details are required for aesthetic reasons. Victoria University School of Architecture in Wellington is studying one solution wherein steel dowels are placed through tight fitting holes in a steel plate that is hidden in a slot in the timber. The dowels are in oversize holes in the wood which are epoxy filled to transfer the load, and capped with wood plugs to hide the ends of the dowels. (Figure 11).

Epoxy has also been used to fit deformed reinforcing steel or threaded rod into oversize holes drilled in the end and side grain of glulam to affect moment connections at column footings and beam column joints (Figure 12). Not only is the joint aesthetically clean, but it

is also corrosion and fire resistant and has excellent strength properties. Work at the University of Canterbury (20) has developed the design basis for these joints which gives the pullout strength as a function of bar diameter, embedment length, hole diameter and the edge distance from the bar to the face parallel to the bar. An embedment depth of only 150 to 200mm was sufficient to yield the steel in 12mm bars, and 300mm in 20mm bars, or to fail the timber in longitudinal tension. In tension perpendicular to the grain, the longer depths caused bar yielding, whereas shorter depths developed splits in the glulam.

4. Portal frame joints

The Auckland University Research Fellowship has contributed greatly to the understanding of nailed-gusset moment-resisting joints. Much of this work has been reported in detail and was referenced by the current fellow, Richard Hunt, at the 1989 Pacific Timber Engineering Conference (13).

The seismic problem or "When the earth moves"

Until events in Newcastle in 1989 Australian engineers did not worry much about earthquake loads. However seismic events are very common on the other side of the Tasman and all structural design in New Zealand must consider the effects of earthquake motions on buildings. As the earth moves, so the inertia of the building mass induces forces. These depend on the ground accelerations, velocities and displacements imposed by the 'quake, and on properties of the structure that determine how it responds, such as its mass, stiffness, natural frequency of vibration, damping, and designed load paths.

Structures must be designed to survive earthquakes in a controlled manner. This can be done either by designing the building to respond elastically to the ground motion, or by ensuring that there is adequate ductility to accommodate the displacements and reduce the forces that are generated. Ductility is the capacity for movement at a given (usually maximum) load. Figure 13 illustrates the two approaches and shows how the imposed ground movement gives higher loads when a structure responds elastically. Stiff, brittle structures attract more load and may fail suddenly at small displacements.

Although elastic design is usually simpler it carries the penalty of higher design loads. To lower the induced earthquake loads requires that the timber structure has ductility. Timber as a material is brittle in tension and has limited ductility in compression so that ductility must be derived from the joint characteristics and careful detailing to avoid brittle failure modes. Some lowering of the design load is possible by allowing for the non-linear stress-strain behaviour of wood structures (Figure 13). However, in timber buildings, a major factor is that masses are

generally much lower than in concrete and steel, so that inertia forces are smaller. Therefore wind loads may often govern and will ensure that there is adequate strength for the building to respond elastically to the smaller design earthquake. Nevertheless because the distribution or magnitude of earthquake motion is unpredictable, the design loads can be exceeded and the mode of failure of a building should be checked since it needs to be relied upon to give safe egress even after the building is no longer serviceable.

In steel and concrete structures this is achieved using a hierarchical "capacity design" procedure, in which the basic principles are to ensure that essential elements such as columns are stronger than secondary elements, (strength capacity) and that joint details have sufficient ductility. In this way, the inevitable failure of minor members in larger earthquakes will not result in the collapse of the whole structure, and large movements can be accommodated without failure. True capacity design requires a limit states approach to enable the calculation of likely maximum strengths of the secondary elements and hence determine the required sizes of the essential parts. A first draft limit states design code for timber was prepared earlier this year by changing the relevant sections of the current working stress design New Zealand code of practice for Timber Design (21,14). This is an essential step towards sensible capacity design in timber.

1. Research in earthquake resistant timber structures.

The Timber Design Society and the National Society for Earthquake Engineering jointly sponsored a study group from 1982 to 1986. (22). In the early meetings of this group it was clear that little was known about how timber buildings actually achieved an enviable earthquake performance. It was also clear that the way the performance of other materials was quantified might not be applicable to timber design. It was recommended that tests be carried out to form a basis for design methods for timber structures. Much of this work has since been addressed at Canterbury University (23) (24) and there is a much better understanding of the principles involved (25).

2.Bracing systems

The results for three main timber bracing mechanisms can be summarised as follows:

Plywood shearwalls and diaphragms. Correct nailing of the sheathing can ensure ductility, relying on the ductile behaviour of the nails under cyclic loading (Figure 14). Foundation connections must be adequate and not eccentric to highly stressed critical members. A tie from the top of the wall to the foundations will induce compression in all chord members eliminating the weaker tension mode. Other elements must have enough strength to mobilize the nail behaviour. There appeared to be enough redundancies in larger walls (9m x 3.6m) (Figure 15) to re-distribute load resistance paths and retain maximum load even after some plywood sheets failed.

Diagonally braced frames. Connections must be detailed to ensure yielding before the onset of brittle tension failure in timber elements.

Moment resisting frames. Portal frame joints are strong and stiff and attract higher design loads. Attempts to improve ductility have not been successful (26).

3. Other observations.

Much of the work at Canterbury University involved modelling the force displacement behaviour for cyclic loading, calibrating the model with cyclic load tests on wall assemblies and then imposing known earthquake motions on the computer models to compare non-linear degrading-stiffness timber wall responses with those of the elasto-plastic response typical of steel or concrete. The main mechanism of load reduction was the progressive increase in flexibility under cyclic loading. This reduction in stiffness (or development of slackness) at low loading increases the natural period of vibration (lower frequency) of the structure, allows larger displacements and gives lower forces in response to the earthquake. Increased flexibility means the structure is be able to cope with the bigger displacements without failure or interference. Hence a strong flexible structure gives the best protection against earthquake motion (27). Stiff structures need to be designed for much higher loads.

Building Code Changes

New Zealand's Building Regulations are changing to a five tier performance based structure. These changes are driven by a desire for de-regulation and innovation. There will be opportunities for timber to enter new markets and there will be threats from other materials. A combination of commercial and technical perception to identify the code changes will lead to greater opportunities for wood based products in engineered structures.

For example Gibraltar (gypsum plaster) board is a common internal lining in New Zealand's timber frame houses. There have been many tests to demonstrate its effectiveness as a fire resistant lining (28) and indeed, it could be the vehicle whereby timber frame can capture a firewall market currently monopolised by concrete. The new Building Regulation requirements are performance based so that walls can be built to a fire rating rather than according to past practice (traditionally concrete).

Likewise the load capacity of a reinforced gypsum plaster board with special patented fasteners developed at the FRI was tested under standard cyclic load tests (29) and performs well as a wind or earthquake sheet brace compared with the rating assigned to plywood bracing walls (30) in the current housing code (31). Data from tests on plywood bracing panels will be needed to enhance their rating for house bracing as there is a greater emphasis in the new regulations on

manufacturers providing hard data to justify claims made in technical trade literature.

A major emphasis at the University of Canterbury has been to investigate wind, earthquake and fire safety issues for multistorey timber frames. This work includes the shearwall and seismic testing described above and is providing a base on which to obtain the maximum advantage of new freedoms that will be available under the changing regulations.

Conclusions

Many aspects of timber engineering are being investigated by New Zealand's research establishments. This paper has dealt briefly with those known to the author. Ultimately, the strength of the timber construction industry relies on the team effort of researchers, designers, developers, manufacturers, and our ability to convince specifiers and users that timber is a safe, reliable, cost effective construction material. All of us should benifit from the developments that have been described.

References

(1) FAO Yearbook of Forest Products, 1987.

(2) Statesman's Yearbook 1989-90. MacMillan.

(3) Golding, K.J. 1989: Twinaplate beams - from concept to customer. Proc. 2nd Pacific Timber Engineering Conf. Vol 2, pp 9-12. Auckland.

(4) Bier, H. Parker, J.R. 1989: Development of design data for steel-web timber flange I-beams from New Zealand pine. Proc. 2nd Pacific Timber Engineering Conf. Vol 1, pp 195-198. Auckland.

(5) Bier, H. 1989: Derivation of design data for Triboard Proc. 2nd Pacific Timber Engineering Conf. Auckland.

(6) Hunt, R.D. & Davy, B.J. 1989: Testing of Triboard joints. Proc. 2nd Pacific Timber Engineering Conf. Vol 1, pp 177-182. Auckland.

(7) BS5669:1979: Specification for wood chipboard and methods of test for particleboard. British Standards Institution.

(8) ASTM D 1037-78: 1984: Standard methods of evaluating the properties of wood-based fibre and particle board materials. ASTM, USA.

(9) Bier, H. & Davy, B.J. 1988; Creep of solid and nail-plate jointed beams of New Zealand radiata pine. Proc. 1988 International Conference on Timber Engineering, Vol 1, pp 510-512. Seattle.

(10) Bier, H. & Davy, B.J. 1989; Design of radiata pine beams for creep deformation and shrinkage effects. Proc. 2nd Pacific Timber Engineering Conf. Vol 1, pp 61-65 Auckland.

(11) Walford, G.B. 1989: Reliable glulam through proof testing and LVL. Proc. 2nd Pacific Timber Engineering Conf. Vol 1, pp 93-98. Auckland.

(12) Bier, H. & Barraclough, R. 1988; A glue laminating plant with radio frequency high speed glue curing, and proof tested lamination stock. Proc. 1988 International Conference on Timber Engineering, Vol 1, pp 510-512. Seattle.

(13) Hunt, R.D. 1990: The testing of moment resisting joints at Auckland University. Proc. IPENZ Annual conference p225-232. Institution of Professional Engineers NZ.

(14) NZS3603:1981: NZ Standard code of practice for timber design. Standards Association of New Zealand.

(15) Parker, J.R. Machine stress grading: What went wrong and how to fix it. NZ Forest Industries Journal. July 1989.

(16) Leicester, R.H. 1989: Pre-public draft TM 3/89-4. Draft Australian Standard. Timber-stress graded-structural verification. (unpublished).

(17) Britton, R.A.J. 1989: Surface hardness of wood and wood composites by wedge tests. NZ Journal of Timber Construction. 5(3) 12-13, Timber Design Society, Wellington.

(18) Bier, H. 1989: The design of portal frames made with Twinaplate I-beams. NZ Journal of Timber Construction. 6(3), Timber Design Society, Wellington.

(19) Bier, H. and Davy, B.J. 1989: Testing of Twinaplate Beam-column portal joints. Parts I, II, III, report for Winstone Industries. WTC1228, Forest Research Institute, Rotorua.

(20) Buchanan, A.H. Moss, P.J. Townsend, P.K. 1990: Reinforcing bars epoxy bonded in glue laminated timber. Proc. International Timber Conference, Tokyo.

(21) Walford, G.B. 1990: Commentary on the changes made to NZS3603 to convert to LSD. Report to NZ Timber Design Society, WTC 1480, Forest Research Institute, Rotorua.

(22) Williams, R. 1986: Seismic design of timber structures - Study group review. NZ Journal of Timber Construction. 2(3) 10-14, Timber Design Society, Wellington.

(23) Dean, J.A. Deam, B.L. Buchanan, A.H. 1989: Earthquake resistance of timber structures. NZ Journal of Timber Construction. 5(2) 12-16, Timber Design Society, Wellington.

(24) Stewart, W.G. Dean, J.A. 1989: A procedure for the seismic design of timber sheathed shearwalls. Proc. 2nd Pacific Timber Engineering Conf, Vol 2, p273-281, Auckland.

(25) Buchanan, A.H. Dean, J.A. 1988: Practical design of timber structures to resist earthquakes. Proc. 1988 International Conference on Timber Engineering, Vol 1, pp 813-822. Seattle.

(26) Boult, B.F. 1987: Moment resisting joints. Proc. IPENZ Annual conference p265-276. Institution of Professional Engineers NZ.

(27) Dean, J.A. Stewart, W.G. Carr, A.J. 1986: The seismic behaviour of plywood sheathed shear walls. NZ Journal of Timber Construction. 2(3) 21-27, Timber Design Society, Wellington.

(28) Fire rated gibralter board systems. Winstone Industries Sept 1987.

(29) Cooney, R.C. Collins, M.J. 1979: (Rev. 1987) A wall bracing test and evaluation procedure. Technical paper P21, Building Research Association of New Zealand, Porirua.

(30) Braceline gypsum plaster board. Winstone Industries 1990.

(31) NZS3604-1981: Code of practice for light timber frame buildings. Standards Association of New Zealand.

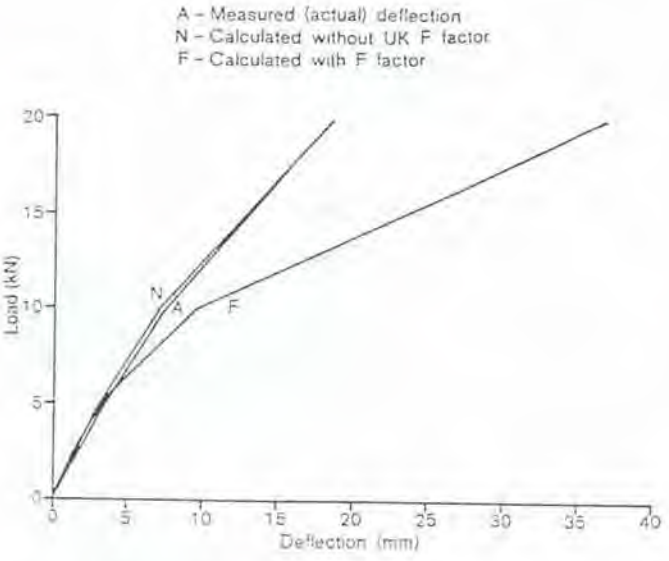


Figure 1: Average deflection of five 92mm x 240mm Twinaplate beams

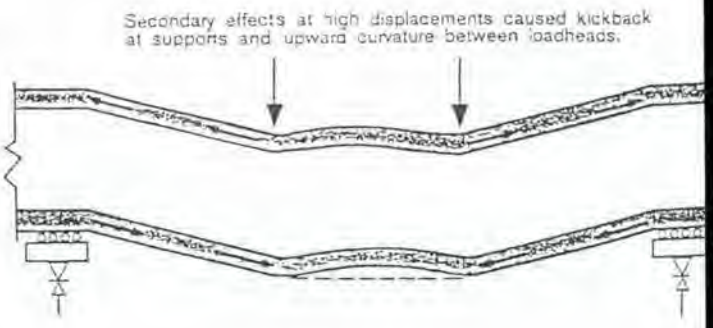


Figure 2: Point loads on Twinaplate beams

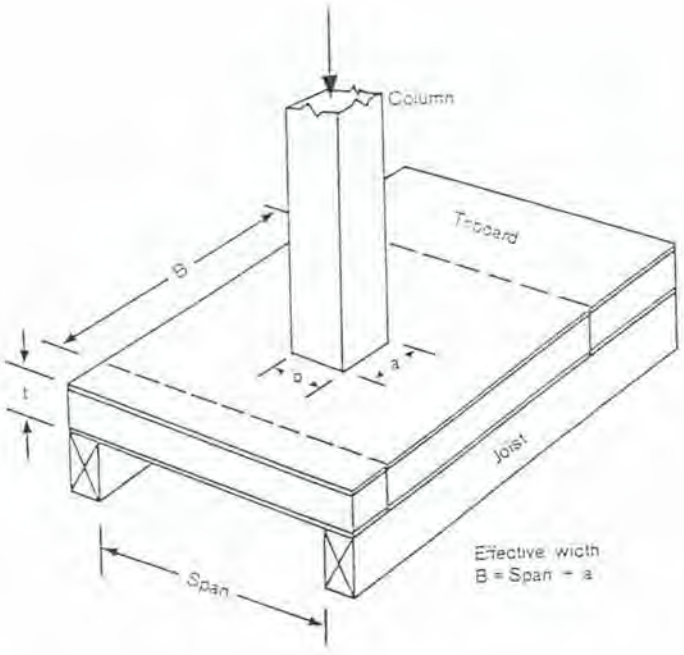


Figure 3: Effective width of Triboard used in rolling shear model for point loads

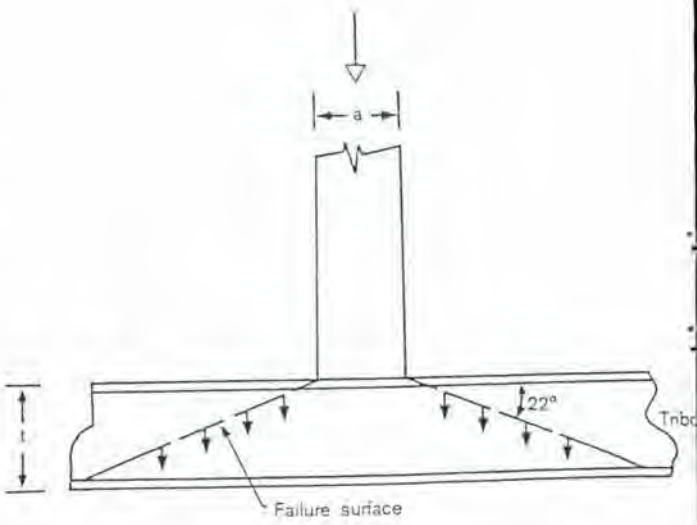


Figure 4: Failure surface in tension perpendicular to face of Triboard in punching shear

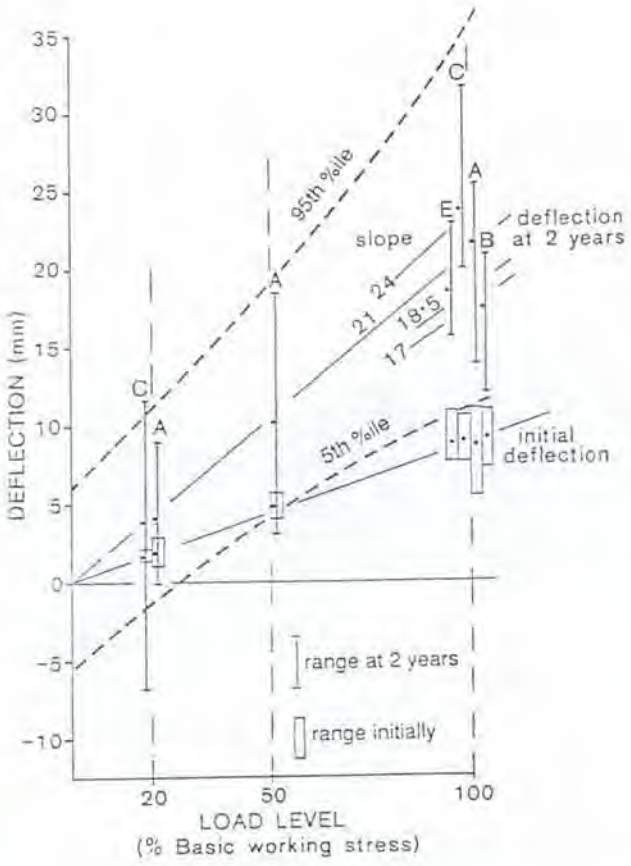


Figure 5: Deflection of 250mm x 50mm timber:

A solid, initially green C jointed, initially green
B solid, initially dry E jointed initially dry

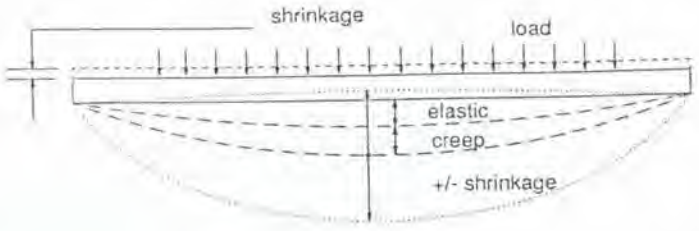


Figure 6: Components of deflection in sawn timber

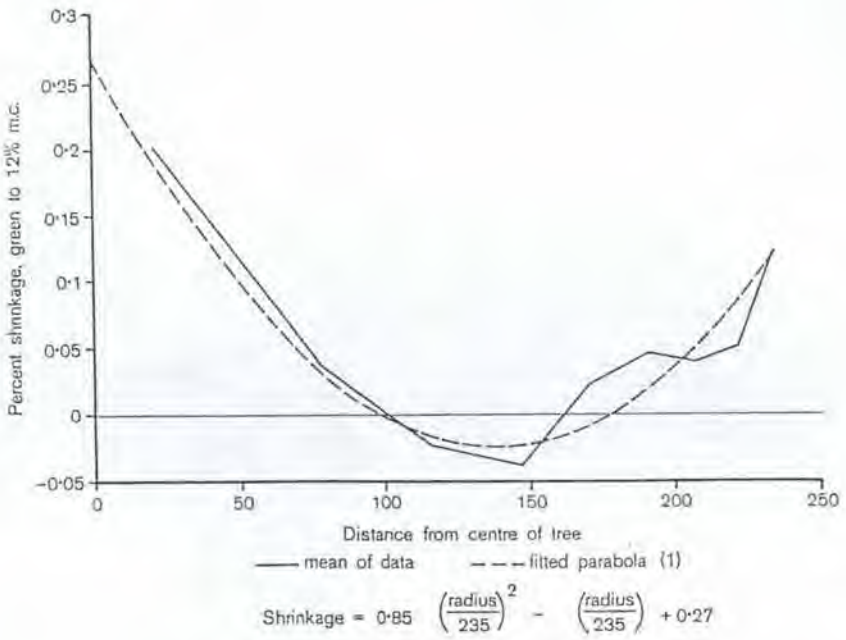
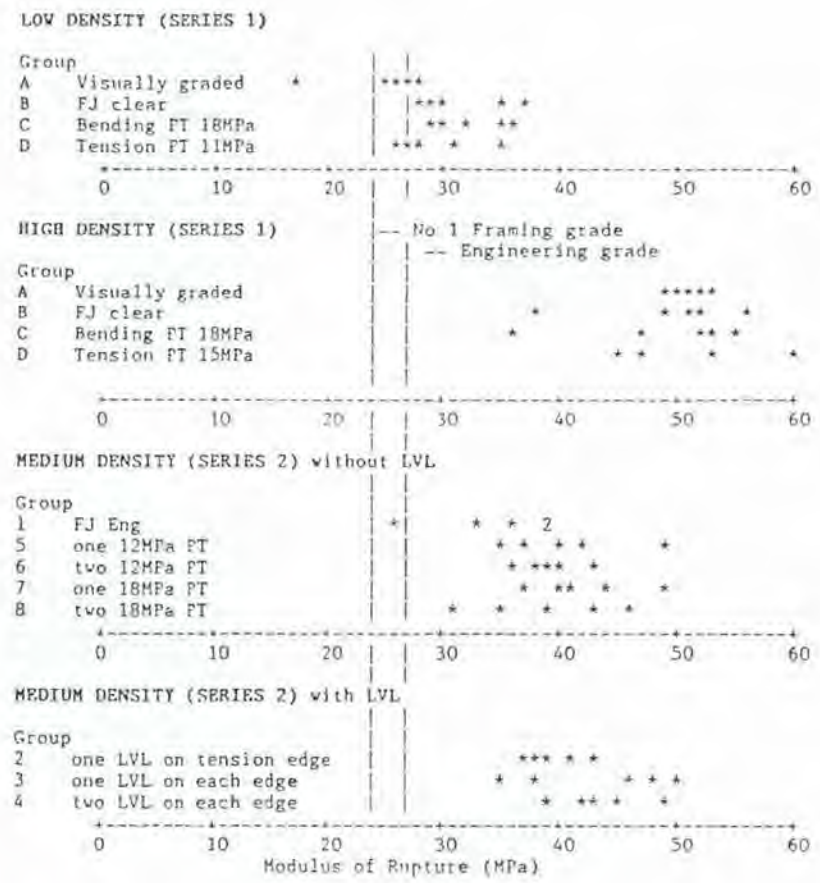
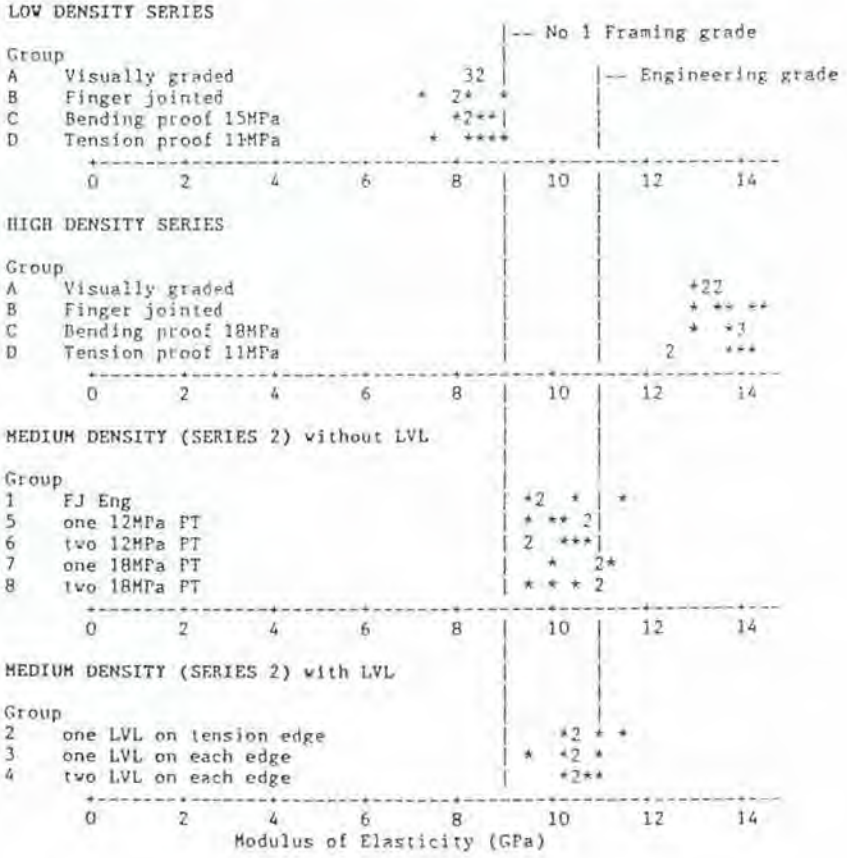


Figure 7: Longitudinal shrinkage across a log
(mean of 10 trees, 4 heights)



(a) - Comparison of failure stresses of glulam beams.



(b) - Comparison of stiffnesses of glulam beams.

Figure 8: Results of bending tests on glulam

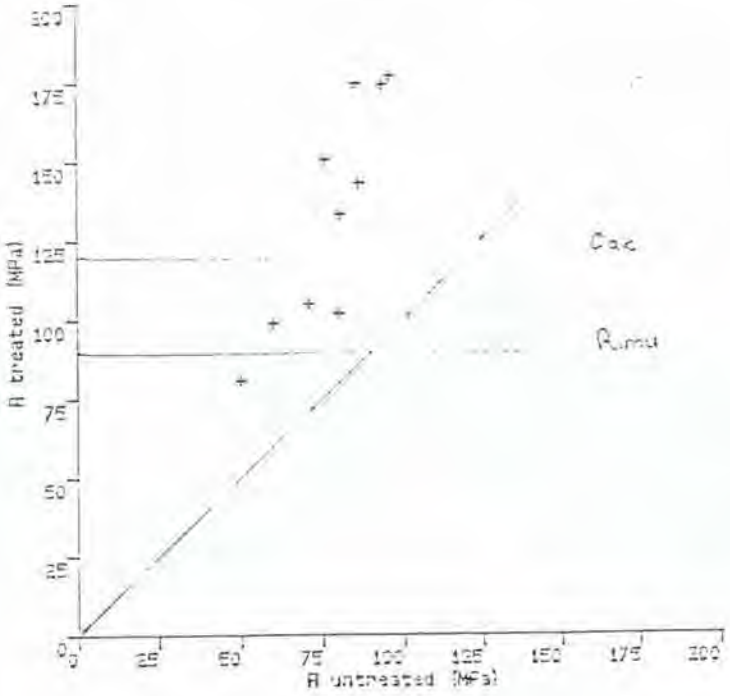


Figure 9: Increased strength of hardened radiata pine

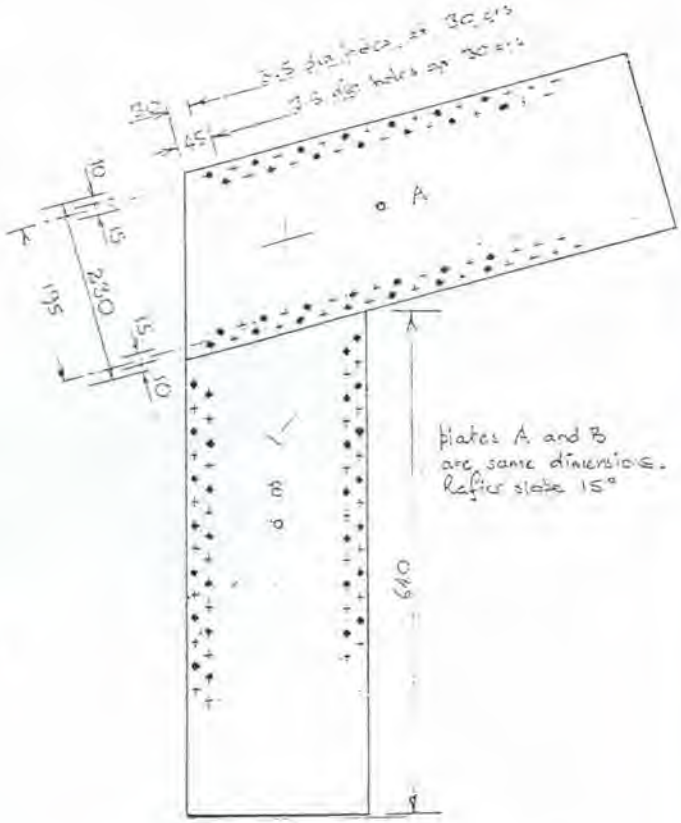


Figure 10: Typical nail pattern in I-beam frame joints

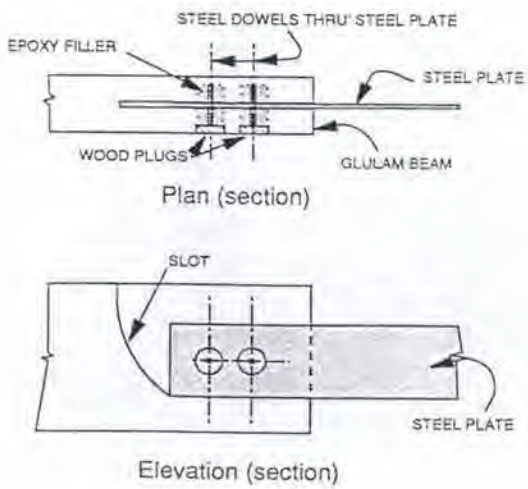


Figure 11: Proposed hidden joint for glulam members

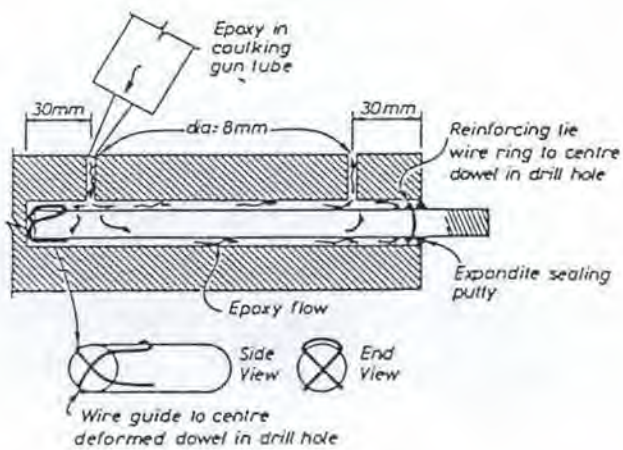


Figure 12: Schematic of epoxied bolt connection

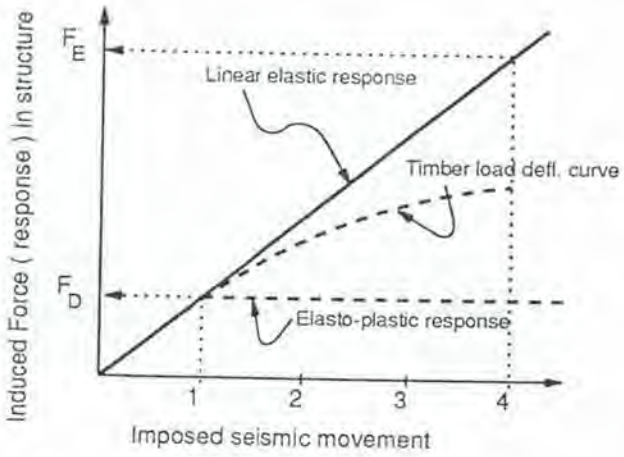


Figure 13: Types of response to earthquake motion

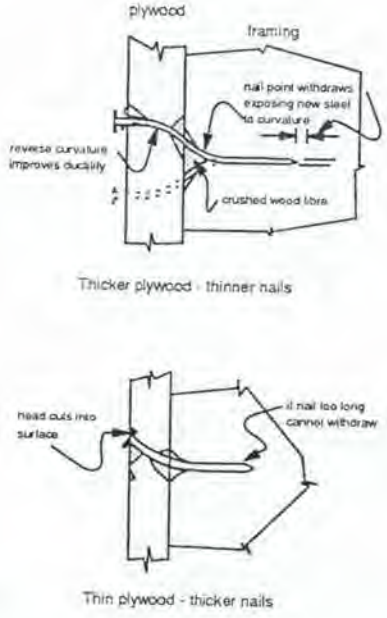


Figure 14: Influence of nail size and panel thickness on ductile behaviour of plywood sheet bracing

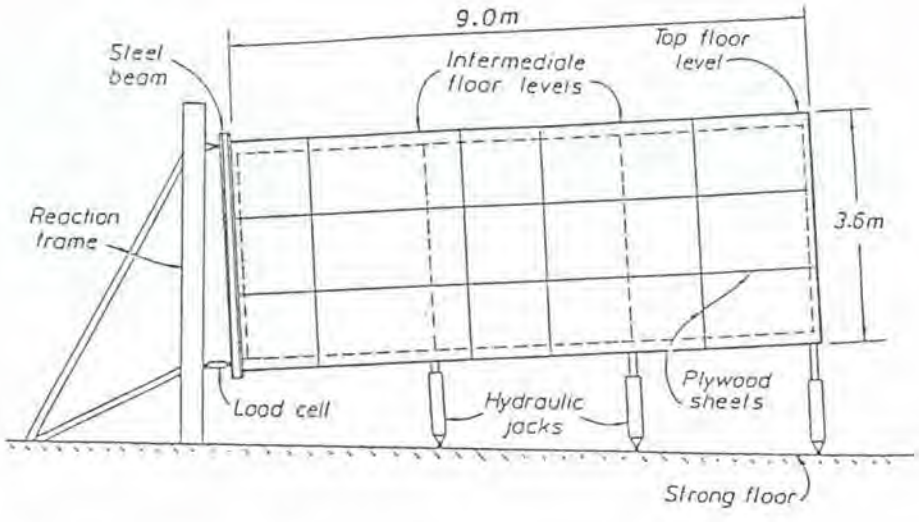


Figure 15: Full scale 3 storey shear wall test setup

EPL003/RMR.1

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A REVIEW OF BOLTED TIMBER CONNECTIONS

by E.P. Lhuede

SUMMARY

The paper reviews the basis on which current design code basic working loads for bolted joints has been derived. Experiments have been carried out on joints loaded perpendicular to the grain, using a tee-section and an end-supported or propped-beam arrangement; the tee-section test provides a useful basis for establishing test load capacities and the propped-beam has been used to measure load capacities of joints made near the end of members.

Capacity of joints loaded perpendicular to the grain with relatively large thickness to bolt diameter ratios were tested and found to exceed Code provisions with an unanticipated failure mode.

The high deformation characteristics of two member joints is discussed and the need to use large dimension washers is reaffirmed.

A review of some current research trends as evidenced from literature is presented.

INTRODUCTION

This paper reviews the results of research on bolted timber connections carried out in CSIRO since 1980. The investigations have concentrated mainly on single bolt connections loaded in tension perpendicular to the grain, with particular reference to joints made near the ends of members; the research has parallelled some similar areas of work carried out in New Zealand (Gerlich[1] ; Harding and Fowkes[2]; Spurr and Philips[3]), in the USA at the Madison laboratories (Patton-Mallory[4]; Soltis and Wilkinson[5]) and in Japan (Hirai[6]). As discussed by Soltis and Wilkinson[5] there is a shortage of information on the effect of tension loads on bolt spacings, end and edge distances, and this is especially the case with perpendicular to the grain loadings; other research in Australia (Mack[7]; MacKenzie[8]; Walker *et al.*[9]) also identified problems with joints loaded perpendicular to the grain and failures in service were reported; it was considered that a requirement existed to improve the design and reliability of bolted joints where load capacity was determined by cross-grain tension stresses.

The main results of the work conducted have been reported (Lhuede[10], [11], [12], [13]) and where appropriate they have been incorporated as changes to the relevant timber design code; the most recent edition of this document is the SAA Timber Structures Code Part 1 - Design Methods, AS 1720.1-1988[14]. Some previously unreported results are also documented in this paper; the

topics discussed include:

(a) The background to the basic loads for bolted joints as listed in AS 1720.1-1988.

(b) Results of tests and analyses of joints loaded perpendicular to the grain where maximum loads are determined by a splitting mode of failure.

(c) Test load capacities of specimens loaded perpendicular to grain with relatively large specimen thickness to bolt diameter ratio.

(d) Load capacity of two and three member joints and further tests of two and three member joints, using a short, end-supported beam, to determine the load capacities of these assemblies.

(e) The use of washers on bolted joints, and some earlier unpublished test data.

(f) A brief review of the literature available.

2 BACKGROUND TO CODE DATA

2.1 Current Basic Working Loads

The basic working loads for bolted connections in AS1720.1-1988 can be traced to the Wood Handbook[15] in which Langlands and Thomas adopted the method of Trayer[16] for determining bolt load capacities for different species. The method was refined in the Timber Engineering Design Handbook by Pearson *et al.* [17] with the inclusion of design charts and the data derived from these charts can be related directly to the procedures of Langlands and Thomas for timber from a given species group. For the earlier version of the SAA Timber Engineering Code, AS1720-1975[18], a set of equations was formulated, which, according to J.J. Mack[19], were the simplest that could be devised to fit the data in the design handbook referred to above.

These equations specify that the Basic working load parallel to (or along) the grain 'Qa' shall be the lesser of

$$t/2 \cdot Fcj \cdot D, \quad \text{or} \quad k_1 Fcj \cdot D^2,$$

and the basic working load perpendicular to the grain 'Qp' shall be the lesson of

$$t/2 \cdot Fpj\, D \quad \text{or} \quad k_2 \cdot Fpj \sqrt{D^3}$$

where t = an effective thickness defined for the joint (mm)

D = bolt diameter (mm)

Fcj = allowable joint bearing stress parallel to grain (MPa)

Fpj = allowable joint bearing stress perpendicular to grain (MPa)

k_1, k_2 are numerical constants for particular species joint groups.

For the two directions of loading Qa, Qp the first equation is for the lower values of t/D where capacity is limited by the bearing stress and applies up to (about) $t/D = 4$ for Qa and up to $t/D = 6$ for Qp. The second equation is independent of timber thickness and load capacity is determined by bending of the bolt and the allowable bearing stress under the bolt.

The code data is applicable to a two member assembly and the half thickness ($t/2$) is included to rationalise the code data for three member joints. Bolted joint design in United States is

also based on the Trayer approach and direct comparisons can be made between local and United States data. The load capacity of a comparable species as listed in the US National Design Specification (NDS)[20] and the SAA Code indicates a difference of about 2/1 because the NDS code data is computed for a three member joint; this is also the case for the loads in the British Code BS5268[21].

2.2 Allowable Stresses Parallel to Grain

Values of Fcj tabulated in the code are derived from correlations established by Pearson[22] between modulus of rupture, maximum crushing strength (Cg MPa) and basic density (B.D. kg/m^3). It can be shown using Pearson's equations that

$$Cg = 0.058 (B.D.)$$

At the minimum basic densities assigned to the four unseasoned wood joint groups (J1 to J4) defined in the earlier timber engineering code AS1720 (1975), the allowable bearing stress Fcj and Cg are related exactly by

$$Fcj = 0.38 Cg$$

The same factor was used therefore in extending the data to the J5 and J6 groups for AS1720.1-1988 and the traditional multiplier of 1.25 was used to derive the 'Fcj' values for seasoned wood.

A correlation between maximum crushing strength and density at 12% moisture content (Cd, MPa) can also be established for seasoned wood at the six joint group minimum densities, and using the same factor that was applied to green wood of 0.38, a set of allowable stresses can be established which are higher than adopted in AS1720.1-1988. These are compared in Table 1. Because Mack's[19] work showed that the maximum test load capacities of a number of JD4, and JD5 species were of the correct order according to the draft revision of the SAA Fastener Code AS1649 (1974), DR 83020[23] (i.e., ratio of maximum test load to basic working load was about 4), no advantage has been taken of the apparently higher allowable values of Fcj indicated above.

Table 1: Comparison of derived values of allowable bolt bearing stress 'Fcj' parallel to grain and values in AS1720.1-1988

	Minimum Group Density at 12% moisture content kg/m^3	Maximum Crushing Strength (at 12% m.d.) Cd (MPa)	Derived Value of Fcj = 0.38 Cd (MPa)	Code Value of Fcj (MPa)
JD1	940	68.5	26.0	20.5
JD2	750	58.4	20.7	16.5
JD3	600	51.0	19.4	13.0
JD4	480	44.5	16.9	10.5
JD5	380	38.8	14.7	8.3
JD6	310	34.5	13.0	6.6

2.3 Allowable Stresses Perpendicular to Grain

Code values of bolt capacities for perpendicular to grain loading, particularly for the lower density species, have generally been regarded as being of a low order of magnitude (Fpj is 0.2 to 0.25 of Fcj for green wood) and designers have suggested that they are too low for practical use.

In deriving new data for inclusion in AS1720.1-1988 for the J5, JD5 and J6, JD6 groups a reassessment of the values of Fpj for dry wood was made rather than adopting the simple 1.25 multiplier used previously.

Pearson's correlations between modulus of rupture (Rg, MPa) and the compression stress at the limit of proportionality in the radial direction (Lg, MPa), and between Rg and basic density ('B.D.', kg/m^3) permit Lg to be determined at the joint-group lower densities. Table 2a lists the ratio of the allowable stresses stated in AS1720.1-1988 (which are the same as in AS1720-1975 for J1 to J4) to the derived values of Lg; the ratio varies from 0.73 to 0.67 for the first four groups and is close enough to the value of 0.75 which was suggested by Pearson *et al.* (17) as a basis for determining unit stresses under long duration loading of green timber perpendicular to the grain. A factor of 0.7 was adopted to extend the data for green wood to the J5, J6 groups.

For drywood the correlations provide:

Ld = 0.0154 (D.D.) 2.1 and

and it is assumed

Fpj (dry) = 0.7 Ld

where Ld is the stress (MPa) at the limit of proportionality in a standard perpendicular to grain test and 'D.D.' is the density at 12% moisture content.

Using these equations the data of Table 2b were obtained. In parenthesis with the Code values of Fpj are the stresses obtained by multiplying the green values of the allowable stress by 1.25.

For the JD1, JD2 groups the differences are minimal, but for the commercially more important JD4, JD5 groups significant advantages (i.e., higher values) were obtained. From experiments on radiata pine joints (Lhuede[11]) it was concluded that code values of basic working load could be increased by a factor of at least 1.5 and this supported the decision to change the basis for determining 'Fpj' for bolted joints in dry wood.

Table 2a,b: Comparison of derived values of allowable stress perp. to grain, 'Fpj' for green and dry species groups

Joint Group	Min. Group Densities Basic or 12% (kg/m^3)	Derived Comp. Perp. at Limit of Propn. Lg or Ld (MPa)	Code Values of Fpj (MPa)	Ratio of of Fpj / Lg, Ld
(a) Green Wood				
J1	750	9.01	6.6	0.73
J2	600	6.62	5.2	0.79
J3	480	4.71	3.3	0.70
J4	380	3.12	2.1	0.67
J5	310	2.00	1.4	0.7
J6	245	0.97	0.7	0.7
(b) Dry Wood				
JD1	940	12.4	8.7 (8.3)*	0.7
JD2	750	9.47	6.7 (6.5)	0.7
JD3	600	7.13	5.0 (4.1)	0.7
JD4	480	5.30	3.7 (2.6)	0.7
JD5	380	3.73	2.6 (1.8)	0.7
JD6	310	2.64	1.8 (0.9)	0.7

* Values in parenthesis are 1.25 x Fpj for Green Wood.

23 Alternative Basis for Determining Bolt Load Capacity

English speaking countries have generally adopted Trayer's method for the design of bolted-timber connections, while in Europe the 'Plastic-Yield' model has been the basis for design. This model was first documented by Johansen[24] and later extended and refined by Moller[25], Meyer[26] and Larsen[27] and it continues to be used to reassess Trayer's results. (McLain and Thangjitham[28]; Soltis *et al.*, [29]; and Hilson and Whale[30]). Soltis *et al.* [29] concluded that the yield-theory predicted measured joint strengths 'reasonably well' and also that Trayer's empirical data

also fits the results 'reasonably well'. A major value of the model is that it provides an indication of the changes in load capacity that will result with changes in joint geometry and material properties and it enables the constraint imposed by washers to be assessed; it does not accommodate splitting as a mode of failure or take account of the load-displacement characteristics of the connection.

It may be assumed that the Australian code values will be assessed against the yield model at some stage.

3. SPLITTING FAILURE OF JOINTS LOADED PERPENDICULAR TO GRAIN

3.1 Assessment of Test Methods

The load capacity of joints loaded perpendicular to the grain has generally been determined by a three member test assembly as shown in Figure 1. Failure (i.e., maximum) loads obtained by this method at smaller values of the ratio t/D (t is member thickness, D is bolt diameter) depend on the geometry and dimensions of the assembly, and initial splitting occurs near the centreline of the bolt hole at a lower load than ultimately sustained by the assembly. Design data established from the ultimate or failure load may over-estimate the bolt capacity for other types of loading (Lhuede[11,12]). Proportional limit loads are measured effectively at lower t/D ratios (i.e., up to $t/D = 6$). For three member joints with large t/D (= 10) dimensions the method is unsatisfactory, and this is discussed in a later section.

Cruciform or tee-joint assemblies of various geometries have (Figure 2) been tested in a tension mode which provide reproducible results at t/D values of about 3/1 and minimum test dimensions can be specified for the main member. Some preferred values are shown in Figure 3, and test results obtained by this method on three species have been reported (Lhuede[11]).

Gerrard and MacIndoe carried out linear-elastic finite element analyses of the joint and these were compared with experimental results (Lhuede *et al.*, [13]); the analyses derived a maximum value of the tensile stress perpendicular to the grain at the bolt-hole periphery (the 'Critical Stress' in the analysis) and changes in this parameter were compared with maximum loads measured experimentally.

There was good agreement between experimental results and the analyses and the linear-elastic finite element model was considered to be a good predictor of the behaviour of the Tee-section loaded in tension. Some comparative results are listed in Table 3 and Figure 4; a 20% (approx.) load capacity reduction occurred experimentally as the support bolt span (S) was reduced from 40 bolt diameters to the position where support and loaded bolts were in line (i.e., S = 0). This could be compared with the finite-element analytical results where the 'Critical Stress' increased from 1060 kPa to 1360 kPa for similar changes.

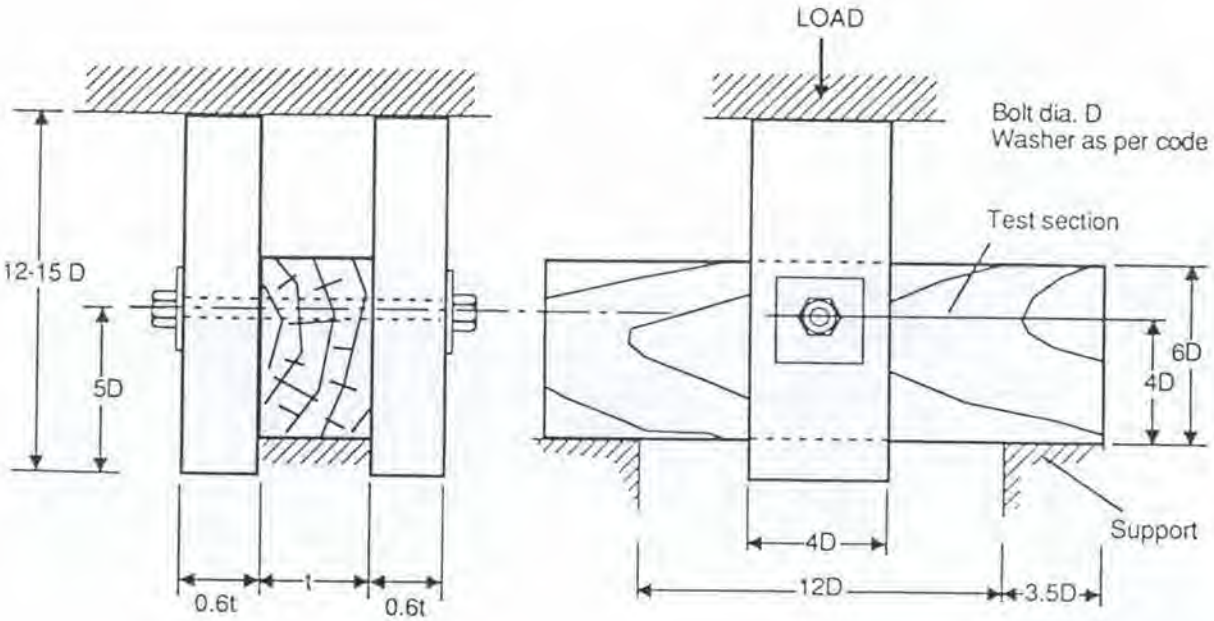


Figure 1. Schematic arrangement of test assembly for measuring perpendicular to grain load capacity of bolted timber connections, with spacing details as per SAA Draft Code DR83020(23).

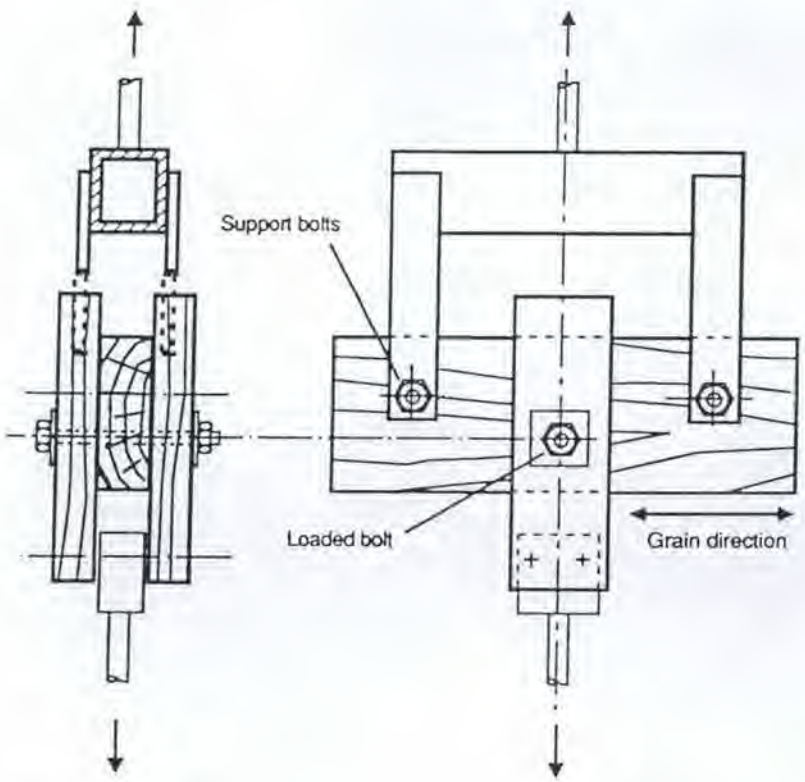
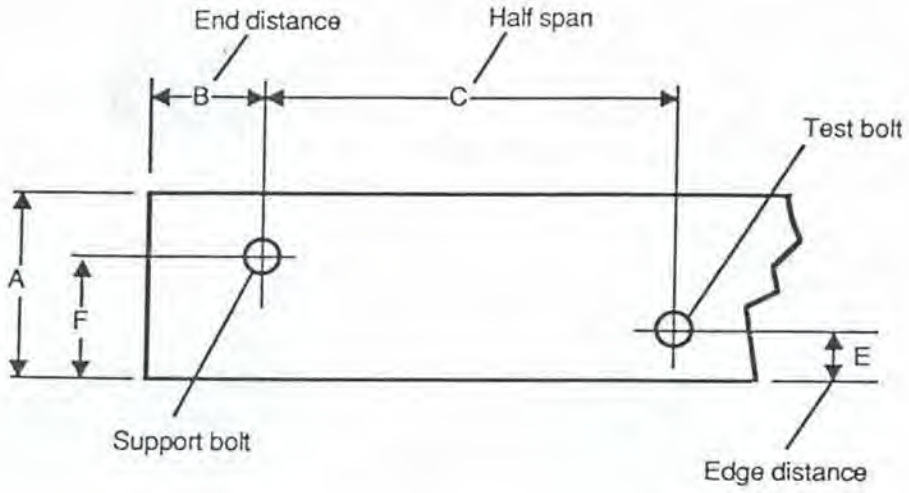


Figure 2. Method of measuring perpendicular to grain load capacity of bolts in 'Tee'-joint configuration.

Table 3: Some values of 'critical stress' derived for differing tee-joint dimensions.



Configuration listed in original paper(13)	Dimension in Bolt Aias.	Critical Stress kPa
(III)	F > E, C = 5	1160
(IX)	F = E, C = 18	1060
(VI)	F > E, C = 0	1320
(X)	F < E, C = 0	750
(XV)	F < E, C = 5	870

Note: A low value of critical stress accords with a higher load at failure.

Further development of this model would be worthwhile for predicting changes in load capacity of joints with varying geometry.

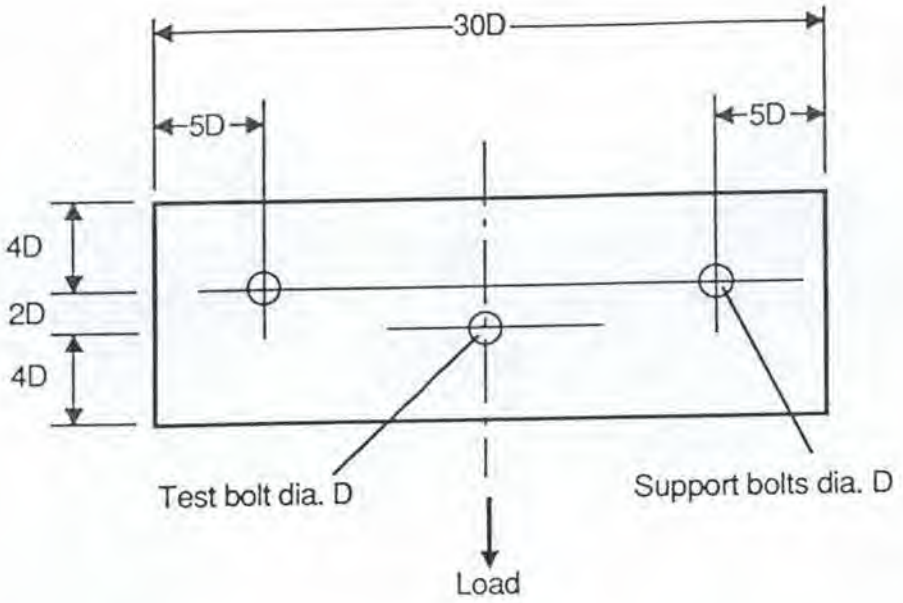


Figure 3. Dimensions of centre test section for a 'Tee'-joint loaded perpendicular to grain. Suitable up to thickness of three to four bolt diameters.

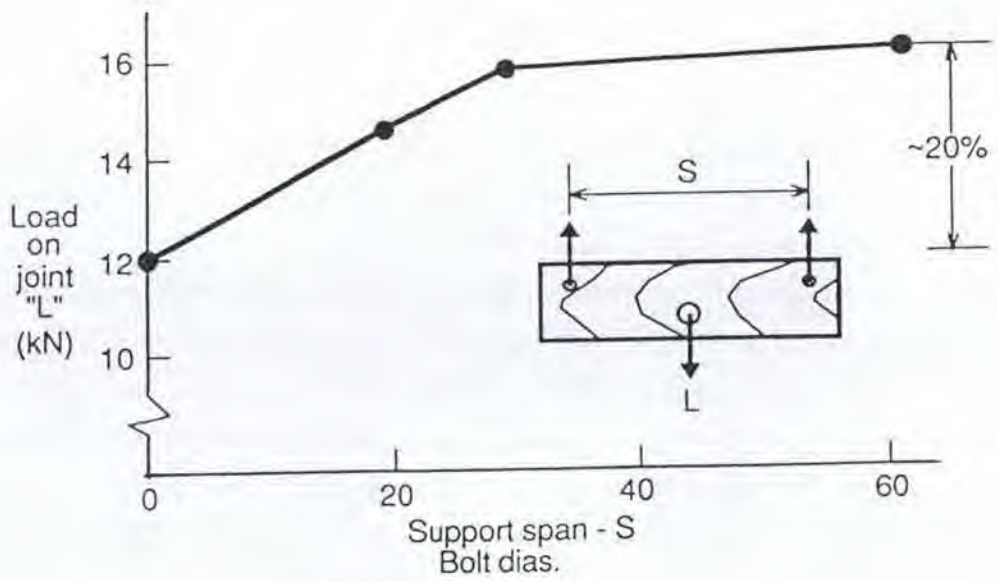


Figure 4. Effect on load capacity of shortening span of a Tee-joint test specimen. Compare results with Table 4.

3.2 Single Bolted Connections Near the End of Beams

To simulate the perpendicular-to-the grain loading that occurs with bolted connections near the ends of beams (i.e., by illustrated in AS1720.1-1988), a three member joint in radiata pine has been tested at varying end and edge distances; the assembly, referred to as a 'propped-beam', is shown in Figure 5 and results of tests with single (16 mm diam.) bolts have been reported (Lhuede *et al.*, [13]).

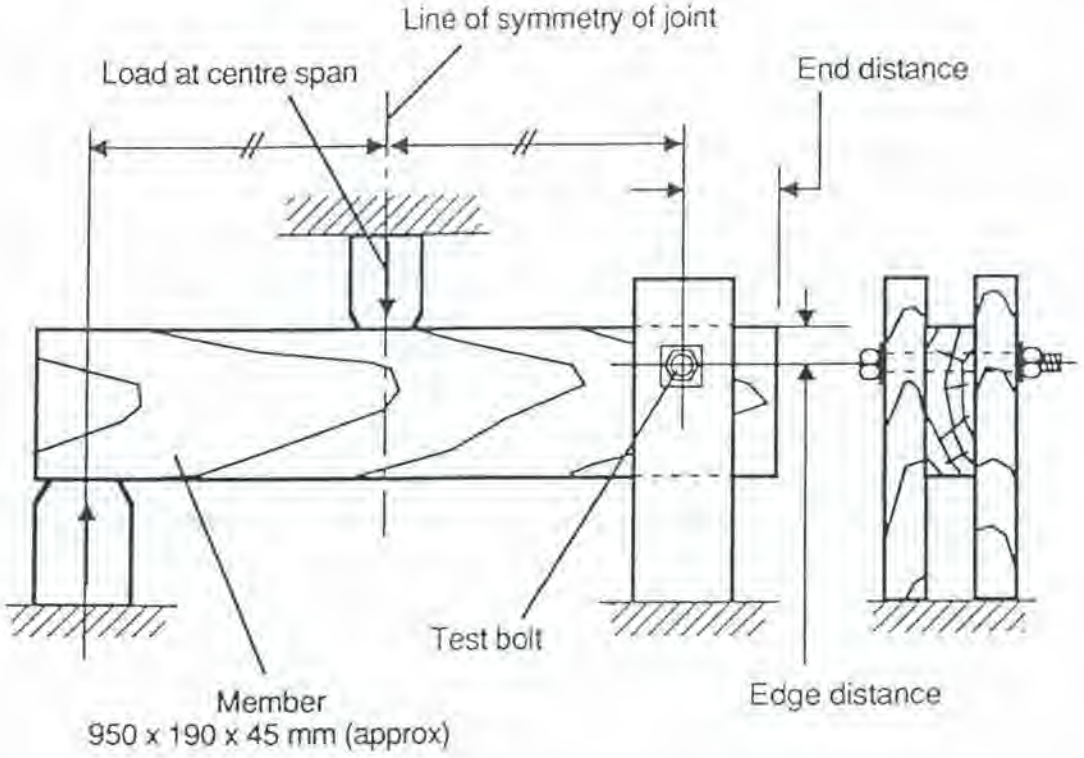


Figure 5. General arrangement of 'propped-beam' test specimen for investigating effects of end and edge spacings on bolt load capacity.

Load capacity is determined by splitting at the bolt and is found to decrease rapidly as end distances are reduced below 5 bolt diameters (5D); according to Walker *et al.* [9] the variability of the fracture load increases with decreasing end distance.

Maximum load capacity was developed in these tests at between 8D and 10D and typically for 45 mm thick radiata pine and a 16 mm dia. bolt ($t/D = 3/1$) the load is 15-16 kN. At 5D spacing the load is 10-12 kN; the system capacity as determined from AS1720.1-1988 is approximately 2.7 kN which shows that the ratio of the 5 minute test load to the code value is about 4, which is of the correct order according to the SAA Draft Code DR.83020[23]. This 'load factor' contains the 5 minute duration of load multiplier (1.75) and it may be questioned whether a load factor of 4 is appropriate to the brittle fracture mode where the failure occurs over a short time interval, i.e., less than 1 second.

Consideration may be given to increasing the allowable end distance for this type of joint, to

obtain maximum capacity.

3.3 Two Bolt Connections Near the End of Beams

The Code AS1720.1-1988 permits the use of a number of bolts at the end of a 'propped beam' assembly. Because of the weakness of such joints along the grain direction two different types of two-bolt joints were tested and were compared with the single bolt connection. The connections were made in matching pieces of radiata pine 535 kg/m^3 density, using 16 mm dia bolts in 16.27 mm dia holes; 50 mm square x 5 mm thick washers were placed under the nut and head of the bolt. The testing was as described in papers already referenced, although these results have not previously been reported. Figure 6 shows the general dimensions of the joints and Table 4 compares the splitting loads developed.

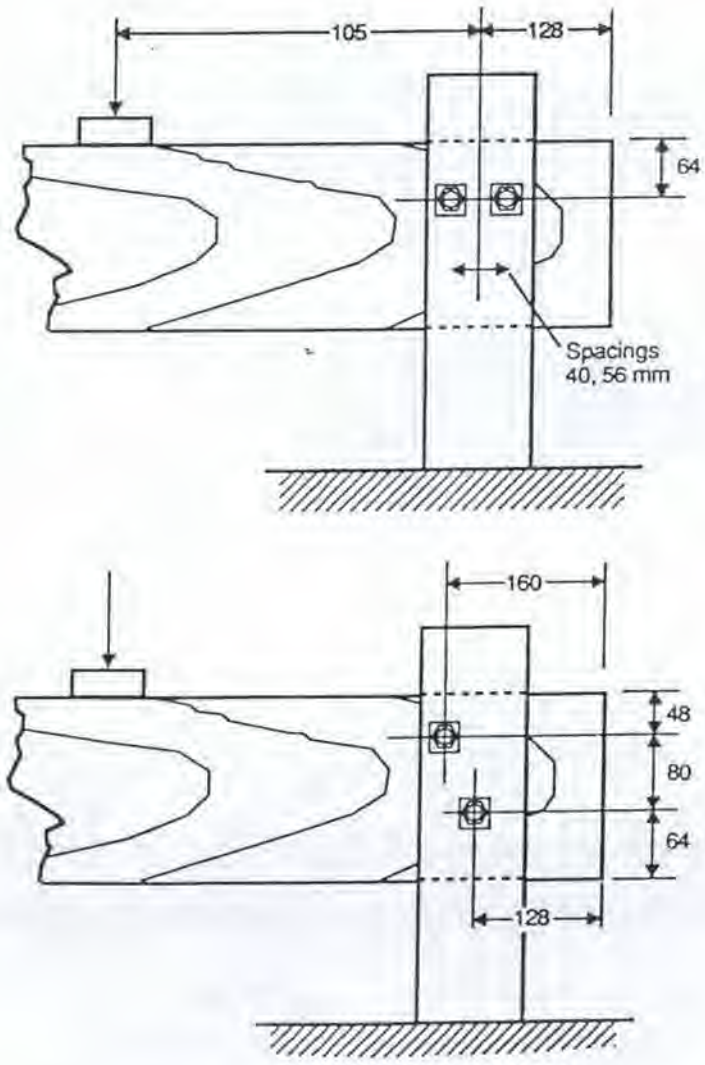


Figure 6. Dimensions of joints tested at the ends of 'propped-beam' with two bolts in the connection. Bolt diameter 16 mm.

The in-line bolts were first tested at a spacing of 40 mm which is less than the Code stipulation of 2.8 bolt diameters (45 mm) and then at a spacing of 56 mm which exceeded the minimum code value. The wider spacing increased the load capacity by about 10%, but the failure by splitting between the bolts was the same in each set of tests and marginally different from the value for a single bolt.

With the vertically staggered bolts the load capacity increased significantly, but was not twice the value of a single bolt.

It is concluded from these tests that the provisions of the Code 1720.1-1988 should be revised in relation to the spacings of multiple bolt connections made near the ends of beams; the use of two bolts in line, which would probably not be favoured by experienced designers is unsatisfactory and two staggered bolts each have approximately 75% of the value of a single bolt.

The rotational restraint imposed on the end of the beam by the two bolts is considered to be the likely cause of the loss in load capacity which will be accentuated for the in-line configuration.

Table 4: Load capacity of 2 bolt joint near the end of a 'propped-beam' compared with single bolt connection

Joint Detail End Distance 8D	No. of Pieces tested	Max Load on Joint (kN) Mean and C.O.V. (%)	Notes
2 bolts in line 40 mm spacing	10	15.4, 10.7	All joints split between bolts and along grain
2 bolts in line 56 mm spacing	10	17.0, 11.5	" " " "
2 bolts staggered	9	24.2, 12.8	One beam failure. Some primary failure at one bolt
Single bolt data at 8D end distance	11	16.0, 17	From tests reported in this paper, Section 5

4. CAPACITY OF SINGLE BOLTED CONNECTION WITH $t/D = 8.6$, LOADED PERPENDICULAR TO GRAIN

The tests already discussed were conducted at low t/D values, i.e., thickness (t) 38, 45, 50 mm and with bolt diameters (D) 12 mm, 16 mm; the experiments described in this section were undertaken to verify the code data where the joint load capacity is considered to be determined by bolt bending. Radiata pine was the species used and to obtain a section in dry wood of about 150 mm thickness three pieces were glue-laminated together. A 16 mm bolt was loaded normal to the glued faces, and large washers used.

Joints were tested by the tee-section tension test and also by the Code (DR 83020) method (under compression loading), as shown in Figure 7. A list of test results is shown in Table 5.

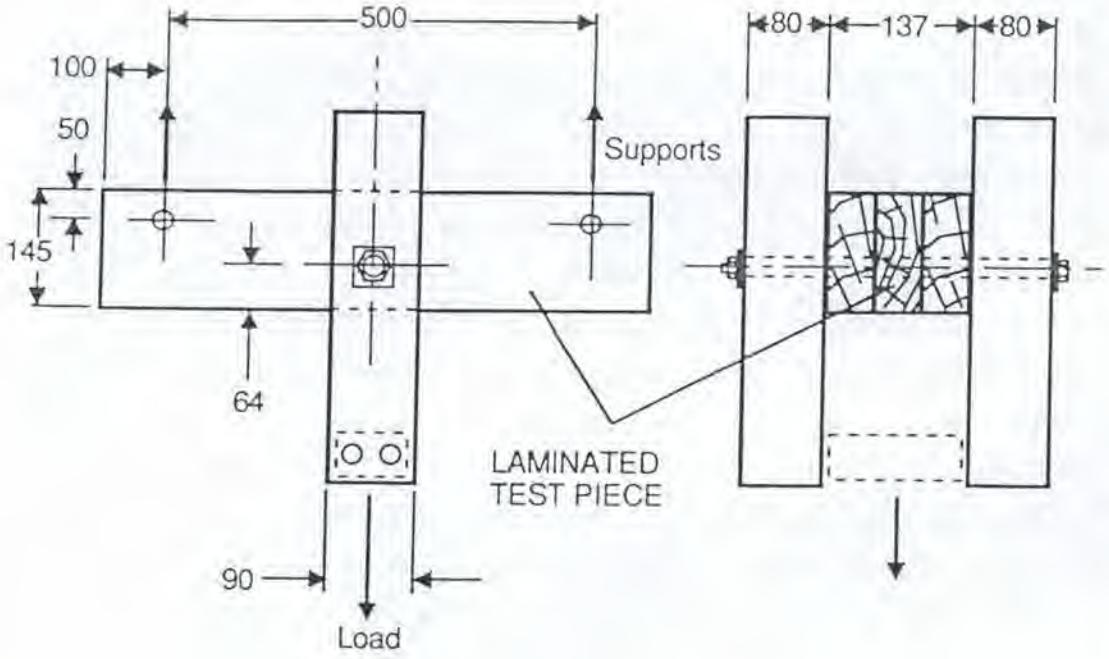


Figure 7. Dimensions of Tee-joint with thickness of main timber 137 mm and 16 mm dia. bolt.

Table 5: Loads sustained by 16 mm dia bolt in 137 mm wide test sections of laminated radiata pine

Test Detail	No. Tested Tested	Max. Load Mean (kN) and C.O.V. (%)	Limit of Proportion. Load (kN) at Displ. mm	Notes
Tee-joint tension	10	61.0, 12.9%	13. at 0.85 mm	3 Joints failed at test bolt, 7 at support bolts.
Standard compression test	5	71.4, 6.6%	12 at 1.1 mm	2 joints failed at test bolt, 2 side supports split, one beam failure

For this thickness of laminated timber it was difficult in either a tension or compression loading mode to achieve failure at the test bolt, even with reinforcement around the support bolts or at the end face of the section (i.e., by using 14 gauge tooth plate connectors). The load sustained at the test bolt was approximately 70 kN, which corresponds to a basic working load of about 8.8 kN according to the SAA Draft Standard DR83020. Using the design equations of Section D3 of the Design Code AS1720.1-1988 for the JD4 species a basic working load of about 4.0 kN is calculated with a system capacity of 2 x 4 = 8.0 kN.

The maximum load sustained in the tests is of twice the order to be expected from code provisions and accords with a JD1 or JD2 species group capacity and the typical brittle behaviour experienced with thinner sections was not evident.

In all the tests the final loads were accompanied by extensive plastic deformation of the main bolt and crushing of the timber near the edges of the main member; splitting along the grain and through the cross section appears to be inhibited by the lamination interfaces. The important role of the thick washer was clearly indicated by the constraint imposed on the bolt-head rotation.

With the compression loaded joints, failures of the vertical members, i.e., those loaded parallel to the grain, occurred in two tests; this result is predictable from code data as the maximum load capacity of the system according to the design code should be about (4 x 10.8 =) 43 kN. It was assumed when designing the test joint that the member stressed perp. would fail before this load.

There is a need to re-evaluate the basic working loads tabulated in the Design Code AS1720.1-1988 for the higher t/D's under perp. to grain loadings. An increase of about 2 seems to be indicated, at least for radiata pine.

5. LOAD CAPACITY OF TWO AND THREE MEMBER JOINTS

5.1 Parallel to Grain Loading

In AS1720.1-1988 a significant change was made to the effective thickness of two member joints loaded parallel to the grain. In the earlier Code AS1720-1975, for joints with t/D values up to 4, the effective thickness was specified as '2t' and resulted in two member and three member joints with the same thickness of the critical member having the same load capacity. In the later code the effective thickness was reduced to 't' and thereby reduced the capacity of two member joints to about half of the three member for low t/D values.

This change was recommended by Wilkinson[31] based on measurements of proportional limit loads. The reduction can also be justified by the yield theory which shows that the two member joint load capacity may be between 0.4 to 0.5 of a 3 member joint depending on the end fixity of the bolt (due to washers) and the 't/D' of this joint.

Some comparative tests of two and three member joints, loaded parallel to grain, show that the maximum load capacities are roughly equal, but the joint deformations are not comparable. Some details for one species (dry alpine ash) are shown in Table 6 and these may be regarded as a general indication of the higher deformation of two member assemblies. Axial tensile forces develop in the

bolt at these high joint deformations and significant friction forces between the two members are generated.

The Code Committee decision to reduce the effective thickness of two member joints will reduce deformation under design load conditions, although test data suggests that this deformation may be greater than associated with three member assemblies.

A code method needs to be developed for reducing test data obtained on two member joints to basic working loads.

Table 6: Load capacity and deformation of two and three member joints loaded parallel to the grain in a compression test

Bolt diameter	12 mm
Timber thickness (actual)	45, 45 mm (2 memb.); 45, 2 x 25 mm (3 memb.)
Species	Dry Alpine Ash
No. tested	10 each test

Ultimate load P_{MAX} (kN) and Displacement (mm) @ P_{MAX}		Test Displacements at Design Loads	
3 member	2 member	3 member @ 6.5 kN	2 member @ 3.2 kN
40 kN @ 4.5 mm	37.5 kN @ 12 mm	0.9 mm	1.4 mm [1.9 mm @ 6.5 kN]

5.2 Perpendicular to Grain Loading

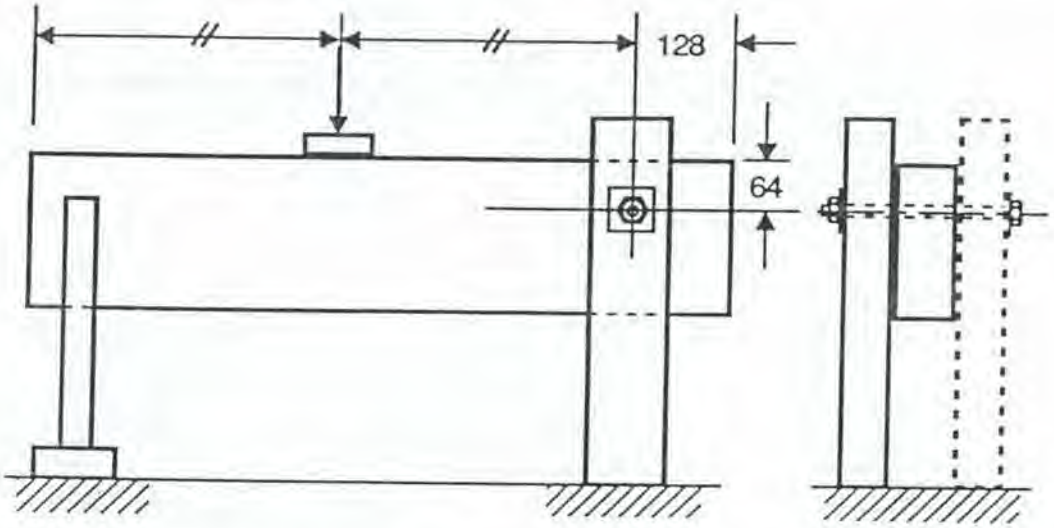
The '2t' effective thickness was retained in AS1720.1-1988 for two member joints for perp. to grain loading; halving of the effective thickness would have halved basic working loads for the lower t/D joints and this was criticised by Australian timber design engineers.

Results from a considerable number of tests on two and three member tension loaded Tee-joints (Lhuede, 1987) showed that maximum loads were similar and failure occurred due to splitting. Joint stiffness for the three member assemblies was about three times that of the two member.

Further experiments on 'propped-beams' (Table 7) with single and double vertical side supports show that the maximum loads for these joints are similar, 16 kN for three member and 14.5 kN for two member, but joint stiffness for the three member is approximately 8 times the two member assembly. There is no clearly defined limit of proportionality for the two member assembly and the initial or 'bedding-in' displacement is generally 2-3 times higher (in the two member assembly). Analyses using the yield theory show that the two and three member assemblies may have similar load capacities and these are compared in Table 8.

The retention of the '2t' factor for perp. to grain loading is justified in terms of joint safety both experimentally and by analyses but the deformation of the two member joint at design load can be expected to be higher than a similar size of section in a three member assembly.

Table 7: Comparative tests of three and two member joints using 'propped-beam' configuration



Main member
1000 x 192 x 50

Sides
2 - 90 x 35 or
1 - 100 x 50

Material:

Radiata pine, matched beam sections 520 kg/m^3, coV 13%
Bolt: 16mm dia., in 16.2 mm hole
Washers: 50 mm x 50 mm x 3 mm

	3 member	2 member
Max. Load (ML) kN	16, (CoV 18%)	14.3 (CoV 10%)
Displacement at ML (mm)	5.8	12 approx.
Limit of Proportion (LP) kNa	6.9 (CoV 22%)	Not defined
Displacement at LP (mm)	1.9	–
Stiffness kN/mm	4.9	0.6
Initial Displ. (mm)	0.5-0.8	1.0-3.0

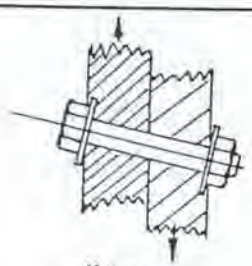
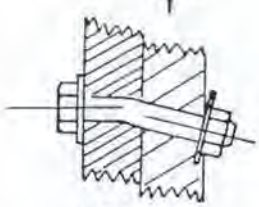
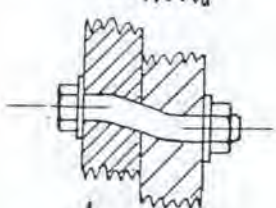
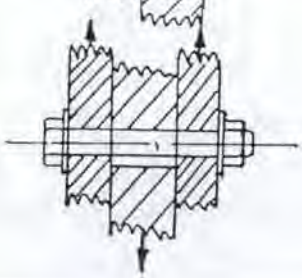
5.3 Displacement of Bolted Connections

The SAA Code AS1720.1-1988 provides a basis for calculating the deflection of bolted connections; this is based on the assumption that a linear load-displacement behaviour occurs after an initial deformation.

For three (or more) member joints this calculation accords with experimental data, but it is not applicable to two member connections.

Table 8: Analysis of Joints Using Yield Model
Using Larsen's[27] formulae for observed test joint failures:

ß (assumed) = 0.3
α = 1 (2 member), 1.4 (3 member)
fe, embedding stress (measured) for P. radiata = 40 MPa
γ, Bolt Yield Sress + f_e = 7
t,d, member thickness, bolt diameter

Larsen's Yield Models	Joint Load Capacity
	Fij = 0.25 (fe.t.d) = 8.0 kN
	Fij = 0.42 (fe.t.d) = 13.4 kN
	Fij = 0.40 (fe.t.d) = 12.8 kN
	Fij = 0.43 (fe.t.d) = 13.7 kN
Test Loading at Failure 3 member joint	16.0 kN

6. Use of Washers on Bolted-timber Connections

From industry enquiries received it is apparent that there is some confusion among timber design engineers regarding the necessity and purpose of using the large dimension washers on bolted connections, which are specified in AS1720.1-1988.

Washers under the heads of bolts and nuts serve two functions; they provide increased bearing area where axial forces are applied to, or are developed in the bolt, and they limit the rotation of the head and shank at the large deformations which occur near the ultimate load capacity of some joints.

Harding[32] referenced the work of Noren[33] and Vermeyden[34] which showed that the maximum lateral load capacities of two member joints, of low t/d, were highly dependent on washer dimensions.

Gerlich[1] suggested that there was an average 20% reduction in capacity of a range of two member joints for two washer sizes (50 mm square x 3 mm and 32 mm dia. x 3 mm). His results showed maximum displacements of about 45 mm and reported higher initial stiffness for the larger washers. The differences were most apparent with green wood.

Some limited experimental results on three species (Lhuede, unpublished) are outlined in Table 9. These compare the load capacities of two member joints loaded in compression parallel to the grain; the standard square washer was compared with a smaller washer than used by Gerlich[1]. Matching data for a three member joint with the large washer is also listed.

The data shows that up to 30% reduction in ultimate load may result with two member joints where there are large differences in washer dimension. The failure of the three member joints occurred at relatively lower deformations, with bending of the bolt and washer, which suggests that the washer dimensions may influence the maximum loads obtained for these joints. More data could be obtained for the three member joint.

For perpendicular to the grain loading, experiments have indicated that washer sizes can be expected to influence the capacity of two member joints, at low 't/d' values; for three members, particularly those loaded in tension, failure occurs at low joint displacement and it seems unlikely that washer dimensions would influence maximum load capacity at low 't/d' values. At higher 't/d', as indicated from the experiment discussed in Section 4, washers influence the degree of indentation into the outer members, but their effect on the load capacity of the inner member is open to speculation.

As a general rule, for all joints, the use of larger dimension washers will increase ultimate load capacity and where they are not used, a reduction in basic working load of 30% should be considered.

Table 9: Comparison of maximum loads for 2 member joints with two washer sizes, and reference load for 3 member joint

General Details:

Species: Green (eucalyptus) hardwood, Dry Alpine Ash, Dry Radiata Pine
Bolt Dia: 12 mm
Members: 45 mm
No. tested: 10 matched pairs per species
Loading: Parallel to grain, compression

Washer Size (mm)	No. of Members in joint	Max. Load kN (CoV%)	Displacement at Max. Load (mm)	Comment
		Green Hardwood		
50 x 50 x 3	2	31.5, (12%)	48	Bolts and washers deformed
25 dia x 1.5	2	20.1, (25%)	41	" "
50 x 50 x 3	3	23.8, (13%)	18	Bolts and washers deformed, inner leg split
		Dry Alpine Ash		
50 x 50 x 3	2	37.5, (17%	42	Bolts and washers deformed
25 dia x 1.5	2	34.0, (10%)	43	" "
50 x 50 x 3	3	39.8, (9%)	5.2	Inner leg split, bolts and washers deformed
		Dry Radiata		
50 x 50 x 3	2	26.4, (14%)	36	Bolts and washers deformed
25 dia x 1.5	2	18.9, (12%)	39	" "

7. Other Literature on Bolted Timber Connections

The survey by Harding[32] provided a comprehensive list of technical reports, conference papers, Standards and codes available up to 1982. In a paper to the 1984 Pacific Timber Engineering Conference Harding and Fowkes[2] extended some of the research areas discussed in the earlier paper and the conference provided a forum for other research on bolted connections.

Smith *et al.* [35] discussed modelling of the load-slip behaviour of laterally-loaded dowel type

fasteners and studies of the stress distribution under dowels/bolts have been reported by Hirai[36]. Ehlbeck and Werner[37] have measured the load capacity of multiple-dowel-fastened timber joints.

Papers to the 1989 Pacific Timber Engineering Conference by Rodd et al.[38] and Yttrup and Law[39] dealt with the embedment of bolts in epoxy resin, and the load enhancement provided by this technique.

Salinas[40], at the 1988 International Conference on Timber Engineering, discussed the changes in the Canadian Timber Design Code, from a working stress design basis to a limit states format, and the effect these changes have had on bolted joint design; it may be expected that this discussion will be relevant to projected changes in the Australian code.

Conclusions

For two and three member bolted connections, loaded either parallel or perpendicular to the grain, the test maximum or failure loads are of the same order. Conversion of this data to basic working loads for three member joints is well established but the treatment of data for two member joints needs further consideration.

The deformation of two and three member assemblies may differ by a factor of at least 4 and code provisions for calculating deflections should not be used for two member joints.

Current basic working loads provide adequate joint safety but take no account of joint deformation. Experiments on joints near the ends of beams with loading perpendicular to the grain indicate that current end spacings of bolts do not provide the full load capacity of the connection. Where multiple bolts are used in this situation the code load is not obtained for each bolt and code provisions need to be changed for this detail.

The failure of bolted connections in relatively thick laminated sections suggests a different mode to that normally encountered and further examination of such joints will be worthwhile.

Except for joints where failure occurs by splitting at small displacements, the use of washers of the sizes specified in the code should be used on all joints to obtain the safety factor associated with the basic load specified for the joint. Where smaller washers are used a load reduction should be incorporated.

There is current interest in a number of research centres with the measurement and enhancement of the bearing stresses under bolts. A knowledge of the stress-deformation characteristics of the important Australian species under circular dowels will be required for yield model and other analyses.

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References

1. Gerlich, J.T. (1988). 'The performance of bolted timber joints with departures from New Zealand Code requirements', *Building Research Association of New Zealand Study Report SR10*, Judgeford.

2. Harding, N., Fowkes, A.H.R. (1984). 'Bolted timber joints', Proc. Pacific Timber Engineering Conference, Auckland, May, Institution of Professional Engineers New Zealand, Wellington.

3. Spurr, D.D. and Phillips, M.H. (1984). 'Testing of bolted timber joints', Proc. Pacific Timber Engineering Conference, Auckland, May, Institution of Professional Engineers New Zealand, Wellington.

4. Patton-Mallory, M. (1988). 'End distance effects comparing tensile and compression loads on bolted wood connections', Proc. 1988 International Conference on Timber Engineering, Seattle, Wshington, Forest Products Research Society, Madison, Wisconsin 53705.

5. Soltis, L.A. and Wilkinson, T.L. (1987). *Bolted Connection Design*, General Technical Report FPL-GTR-54, Madison WI, USDA, Forest Service, Forest Products Laboratory.

6. Hirai, T. (1983). 'The effect of end distances on the lateral resistance of bolted wood-joints loaded perpendicular to the grain', *Journal of the Japan Wood Research Society*, 29 (2):118-122.

7. Mack, J.J. (1981). *The Strength of Bolted Joints in Australian Timbers*, Technical Paper, CSIRO Division of Building Research (Second Series), No. 45, Australia.

8. MacKenzie, C. (1986). 'Design for high-wind areas', Proc. 22nd Forest Products Research Conference, CSIRO Division of Chemical and Wood Technology, Vol. 1, Clayton, Australia.

9. Walker, G.R. and Morrow, N.K. (1988). 'Transverse strength of bolted timber joints located near the ends of members', Proc. 1988 International Conference on Timber Engineering, Seattle, Washington, Forest Products Research Society, Madison, Wisconsin, 53705.

10. Lhuede, E.P. (1986). 'Research on timber connectors in CSIRO'. Proc. 22nd Forest Products Research Conference, CSIRO Division of Chemical and Wood Technology, Vol. 1, Clayton, Australia.

11. Lhuede, E.P. (1987). 'Loads in bolted timber joints stressed perpendicular to the grain', *J. Inst. of Wood Science II*, 1, 17-25.

12. Lhuede, E.P. (1987). 'Tests for bolted timber joints loaded perpendicular to grain', *Proc. First National Structural Engineering Conference 1*, Melbourne, 26-28 August 1987, 325-329.

13. Lhuede, E.P., Gerrard, C.M. and Macindoe, L. (1989). 'Comparison of finite element analyses and experimental tests of bolted timber connections loaded perpendicular to the grain', *Proc. The Second Pacific Timber Engineering Conference*, Auckland, August, Institution of Professional Engineers New Zealand, Wellington.

14. Standards Association of Australia (1988). *Australian Standard 1720.1-1988, SAA Timber Structures Code Part 1 - Design Methods*, Standards Association of Australia, Sydney.

15. Langlands, I. and Thomas, A.J. (1948). *Handbook of Structural Timber Design*, Council for Scientific and Industrial Research, Division of Forest Products, Government Printer, Melbourne.

16. Trayer, G.W. (1932). 'The bearing strength of wood under bolts', US Department of Agriculture, *Tech. Bulletin No. 332*, Government Printing Office, Washington, DC.

17. Pearson, R.G., Kloot, N.H. and Boyd, J.D. (1971). *Timber Engineering Design Handbook*, CSIRO in association with the Jacaranda Press, Melbourne.

18. Standards Association of Australia 1975. *Australian Standard AS1720-1975, SAA Timber Engineering Code*, Standards Association of Australia, Sydney.

19. Mack, J.J. (1981). *The Strength of Bolted Joints in Australian Timbers*, CSIRO Division of Building Research, Tech. Paper (Second Series) No. 45.

20. National Forest Products Association (1986). *National Design Specification*, Washington, DC: National Forest Products Association, 87 pp.

21. *BS 5268 Structural Use of Timber: Part 2: Code of Practice for Permissible Stress Design, Materials and Workmanship*, London, British Standards Institution, 1984.

22. Pearson, R.G. (1965). *The Establishment of Working Stresses for Groups of Species*, CSIRO Division of Forest Products, Technological Paper No. 35.

23. Standards Association of Australia (1983). *Draft Australian Standard for Comment. Methods for the Determination of Basic Working Loads for Mechanical Fasteners in Timber DR83020 (Revision of AS1649-1974)*, Standards Association of Australia, Sydney.

24. Johansen, K.W. (1949). 'Theory of timber connections', International Association for Bridge and Structural Engineering, 9:249-262.

25. Möller, T. (1951). En ny metod för beräkning av spikförband, Chalmers Tekniska Högskolas Handlingar, No. 117, Göteborg.

26. Meyer, A. (1957). Die Tragfähigkeit von Nagelverbindungen bei statischer Belastung. Holz als Roh- und Werkstoff, pp. 96-109, Bd. 15.

27. Larsen, H.J. (1979). 'Design of bolted joints', *Proc. CIB W18 Woking Group Meeting*, International Council for Building Research, Studies and Documentation, Working Commission W18, Bordeaux, France.

28. McLain, T.E. and Thangjitham, S. (1983). 'Bolted wood joint yield model', *Journal of the Structural Division, American Society of Civil Engineers*, 109(8):1820-1835.

29. Soltis, L.A., Hubbard, F.K. and Wilkinson, T.L. (1986). 'Bearing strength of bolted timber joints', *Journal of Structural Engineering, American Society of Civil Engineers*, 112(9):2141-2154.

30. Hilson, B.O. and Whale, L.R.J. (1990). 'Developments in the design of timber joints', *The Structural Engineer*, Vol. 68, N. 8, April, pp. 148-150.

31. Wilkinson, T.L. (1978). *Strength of Bolted Wood Joints with Various Ratios of Member Thicknesses*, Res. Pap. FPL 314, Madison, WI: US Department of Agriculture, Forest Service, Forest Products Laboratory, 8 pp.

32. Harding, N. (1982). *Bolted Timber Joints: A Literature Survey*, Building Research Association of New Zealand, Research Report R39, Judgeford.

33. Noren, B. (1951). *Strength of Bolted Wood Joints. Especially the Influence of Washer Size on Strength and Stiffness in Single Shear*, Commonwealth Scientific and Industrial Research Organisation, Australia, Translation No. 9737 (Translated from Svenska Traforskiningsinstitutet, Tratekniska Avdelningen, Meddelande 22 B).

34. Vermeyden, P. (1980). *Tests on Bolted Joints*, CIB Report No. W 18, 13-7-7, Otaniemi.

35. Smith, I., Whale, L.R.J. and Hilson, B.O. (1988). 'An integrated approach to modelling load-slip behaviour of timber joints with dowel type fasteners', Proc. 1988 International Conference on Timber Engineering, Seattle, Washington, Forest Products Research Society, Madison, Wisconsin 53705.

36. Hirai, T. (1989). Basic *Properties of Mechanical Wood-Joints. 2. Bearing Properties of Wood Under Bolt*, Faculty of Agriculture, Hokkaido University, Vol. 46, No. 4, 967-988, Sapporo, Japan.

37. Ehlbeck, J. and Werner, J. (1988). *Design of Joints with Laterally Loaded Dowells. Proposals for Improving the Design Rules in the CIB-Code and Draft Eurocode 5*, CIB Working Commission W18 - Timber Structures, Vancouver Island (BC), Canada, September.

38. Rodd, P.D., Hilson, B.O. and Spriggs, R.A. (1989). 'Resin injected mechanically fastened timber joints', *Proc. The Second Pacific Timber Engineering Conference*, Institution of Professional Engineers New Zealand, University of Auckland.

39. Yttrup, P.J. and Law, P.W. (1989).'Epoxy injected bolts in shear', *Proc. The Second Pacific Timber Engineering Conference*, University of Auckland.

40. Salinas, J.J. (1988). 'Reliability bounds for bolted connections', *Proc. 1988 International Conference on Timber Engineering*, Seattle, Washington, Forest Products Research Society, Madison, Wisconsin 53705..

MECHANICAL STRESS GRADING OF TIMBER IN AUSTRALIA

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ABSTRACT

The history of mechanical grading in Australia is summarized and the principles of operation of the three different types of grading machines used in Australia are shown in detail.

The recent expansion of the technology into non-traditional sectors of the industry is discussed and indications of future developments are given. Likely changes to Australian Standards for mechanical stress grading are detailed.

INTRODUCTION

Mechanical stress grading[1] is recognized in Australia as a normal production process in the plantation softwood industry and can be regarded as a classic example of the successful transfer of useful technology from research laboratory to industry. The distinctive, colour marked timber, seen in many applications throughout the country particularly in roof trusses and house frames, has made significant inroads into the market place over the past 18 years. It is estimated that approximately 85% of locally grown, seasoned structural softwood timber is now mechanically graded. In addition to the local supply, mechanically stress graded, plantation grown timber is imported into Australia from New Zealand and Fiji.

After a reasonably stable period for machine grading of about 18 years, there has been increasing interest from other sectors of the timber industry. This has led to some recent developments, some of which will be addressed in detail, including:

1. The design, manufacture and application of a new range of stress grading machines.
2. The expansion of the technology into the hardwood, cypress pine and roof truss industries.

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[1]For a general discussion on current stress grading methods i.e. visual, mechanical and proof grading see Appendix A.

3. Revision of the Australian Standard for mechanical stress grading to cover all machine types and to assist third party product certification scheme coverage of grading operations.

BRIEF HISTORY OF MECHANICAL STRESS GRADING IN AUSTRALIA

Mechanical stress grading was introduced to Australia in 1964 after the development of a machine, called the Microstress, at the then Wood Technology Division, Forestry Commission of N.S.W.(1).

The Microstress was a dual-pass machine requiring two passes of the timber before the assignment of a grade could be made. For a number of reasons this requirement was seen as a disadvantage in a production situation and further development took place at the Wood Technology Division, with the effort concentrating on the production of a single pass machine.

The result was the Computermatic, first manufactured in 1967 by Isles Forge and Engineering of Coffs Harbour. The Computermatic was redesigned in the early 1970's by Plessey Telecommunications of Sydney, in conjunction with the Wood Technology Division. This combined effort culminated in the production of the PIV and PIVa Computermatics.

The machines proved a major success and by the end of the decade most large Australian pine mills were machine stress grading their structural timber using either a PIV or PIVa. A large export market for the Computermatic opened up in England and Europe and production of the Computermatic was eventually transferred to England where it is still being manufactured by Measuring and Process Control Ltd.

In Australia, Plessey continued to maintain the Computermatic machines until early this year when Eldeco Pty. Ltd. took over the role. This latter company also produces replacement controllers, tranducers and other components for the Computermatics.

In 1989, Eldeco commenced the development of their own stress grading machine called the Dart. The first prototype underwent mill trials in mid 1990. Production models are now in operation. The company produces a number of models servicing the various market sectors, ranging from the low speed requirements of truss manufacturers who wish to grade their own timber through to high production softwood mills.

Two commercial grading machines were developed in the United States about 1962(2)(3). One of the machines, the Continuous Lumber Tester (CLT)(4) manufactured by Metriguard Inc, will be discussed in detail as it is in use in a number of Australian mills. The first local installation of the CLT was in

1984 in South Australia[4].

Mechanical grading systems were initially used in Australia to address the problems associated with the visual grading of plantation grown softwoods. Much higher grade yields could be achieved with mechanical grading[1][2]. The incentive of higher mill grade recoveries and thus higher financial returns is still the main driving force for most applications of the technology in Australia[5]. As we enter the 1990's the increased reliability provided by the use of mechanically graded timber will be of increasing importance to timber users and will probably lead to more market driven applications of the technology, especially for engineered structures.

THE COMMERCIAL GRADING MACHINES

There are currently three different commercial machines in use in Australia:

1. The Computermatic machine currently manufactured by Measuring and Process Control in England. Total number in use 17 as at 10/90.
2. The Continuous Lumber Tester manufactured by Metriguard in the United States of America. Total number in use 4 as at 10/90.
3. The recently introduced Dart machine manufactured by Eldeco in Australia. Total number in use 3 as at 10/90.

Figure 1 shows the location of the grading machines.

Figure 1. Location of the grading machines. One dot per machine.

The Computermatic

Machine Description. The machine is illustrated schematically in Figure 2. Timber passes through the machine with its wide face in the vertical direction. The timber is loaded with a constant force, on the wide face, in an arrangement designed to simulate simple three-point bending.

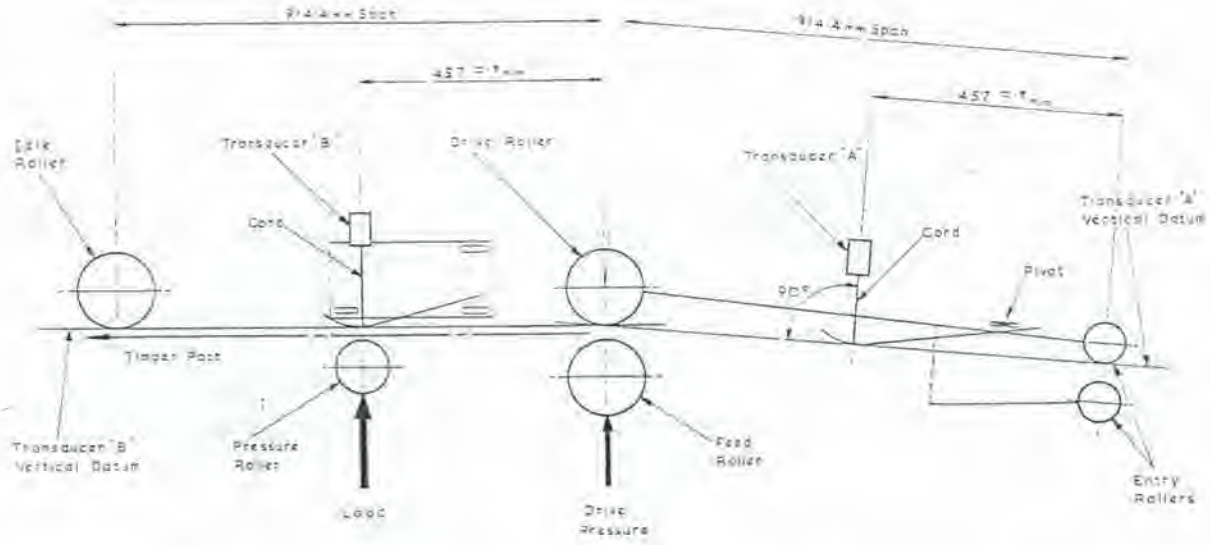

Figure 2. Schematic of the Computermatic (vertical view).

The timber loading system is based on two parallel, vertical support rollers 914 mm apart. One support roller is driven (drive roller) and the other idle (idle roller). A feed roller forces the timber against the drive roller to ensure there is minimal slippage of the timber as it is driven through the machine. A pressure roller is positioned at the mid point between the support rollers. This roller applies a constant force with the aid of a low friction multistage pneumatic cylinder. Cylinder pressure is monitored with a pressure gauge.

A linear displacement transducer is positioned opposite the pressure roller and is used for monitoring the timber deflection under load (D_1). Pivoted on the drive roller is an arrangement to measure the natural curvature or bow over a distance of 914 mm (D_n). Provided identical datums are used when the machine is calibrated then the true deflection under the constant force (i.e. independent of bow) can be determined by subtracting D_n from D_1.

Horizontal rollers are used to locate the timber in a constant vertical position and to assist the movement of timber through the machine. They are

designed to provide minimal resistance to the applied force.

The local or short-span modulus of elasticity (E) is determined using Equation 1. For the Computermatic, the span, applied force, thickness and width are all assumed constant during any grading run resulting in the E being assumed inversely proportional to the measured deflection.

$$E = \frac{SPAN^3 \times FORCE}{4 \times WIDTH \times THICKNESS^3} \times \frac{1}{DEFLECTION} \quad \text{.....(Equation 1)}$$

A special design digital control unit is used to control the machine, determine deflection values and to compare the measured deflection with preprogrammed deflection limits. Sprays are used to indicate the short-span E range at individual points along the timber.

Speed and Accuracy. The machine is designed for feed speeds up to 150 m/min and has been shown to be capable of measuring the short-span E with acceptable accuracy and repeatibility at that speed[6].

Some measurement inaccuracies can be introduced if the machine is fed incorrectly due to excessive whipping of the tail of the timber. In high throughput applications, automatic feeding systems are recommended as they have been found to minimize this effect and thus enhance in-mill performance of the machine[7].

The Continuous Lumber Tester

Machine Description. The machine is illustrated schematically in Figure 3. Timber passes through the machine with the wide face horizontal. The timber is forced, flatwise, into preset deflections in two series spans, firstly in one direction and then in the opposite direction. The machine uses a series of clamping rollers to isolate the two test spans from one another and from static and dynamic moments caused by overhangs on the infeed and outfeed[4].

The two forces produced by the induced deflections are measured with the aid of load cells. Delayed bending force measurements from the first bending section are averaged with the bending force measurements in the second bending section such that errors arising from deviations in straightness are cancelled[4].

The effective test span in the CLT is 1220 mm.

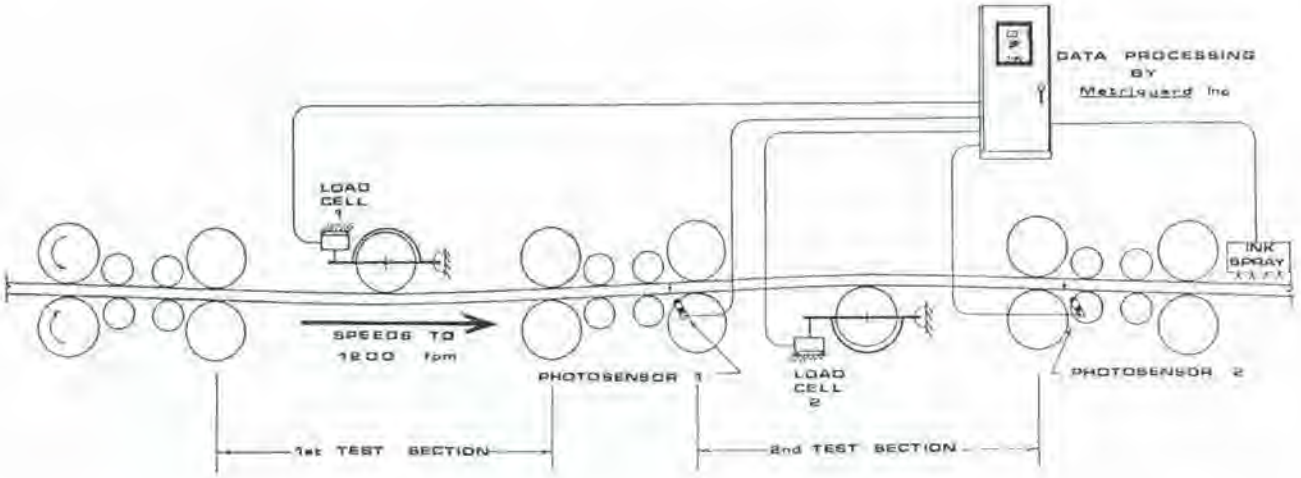

Figure 3. Schematic of the Continuous Lumber Tester (horizontal view).

The setup of the clamping rollers is critical in this design as explained in the following paragraph. Note the 'simply supported' approximation described below is strictly valid only if the timber being tested has uniform E[8]. Therefore, defects present in the timber may change the nature of the deflection curve and introduce errors into the estimate of short-span E when comparison is made with estimates determined by simple static bending.

"The clamp roll sections are set at angles in the machine frame equal to the deflection angle at the ends of a simply supported, centre-loaded bending span with the centre span deflection set at approximately 7.9 mm. During the initial adjustment, the actual deflection is set such that a test bar engaging only the span-end rolls produces the same bending force as another test bar which engages all eight clamp rolls on each end of the bending span. In this way, the bending moment at the ends of the bending span is zero, and the deflection curve is identical with that of a simply supported centre-loaded bending span. The deflection curve is monotonic within the bending span"[4].

The short-span E is determined using Equation 1. For the CLT the span, thickness, width and deflection are all assumed constant during any grading run resulting in the short-span E being assumed proportional to the measured average force.

Vertical rollers are positioned to prevent movement of the timber in the horizontal plane.

Control electronics are of special design and are based on analogue

principles. Two sets of E limits can be programmed, low point E and average E. Sprays are used to indicate grade.

Speed and Accuracy. The machine is designed for feed speeds of up to 365 m/min, however, speeds in excess of this are being used in some North American plants[9]. Close correlation between CLT measured average E values with values obtained from offline stress wave E measuring equipment is claimed, as is the CLT's ability to measure short-span E accurately[9][10].

The Dart

Machine Description. The machine is illustrated schematically in Figure 4. The Dart can be compared directly with the Computermatic as it is a further development of the basic concepts used in that machine. The most obvious difference between the two machines is the position of the shape measuring arm. It is positioned on the infeed side in the Computermatic and on the outfeed side in the Dart.

Timber passes through the machine with its wide face in the vertical direction. The timber is loaded, on the wide face, in an arrangement designed to simulate simple three-point bending. The applied load is not constant in this design.

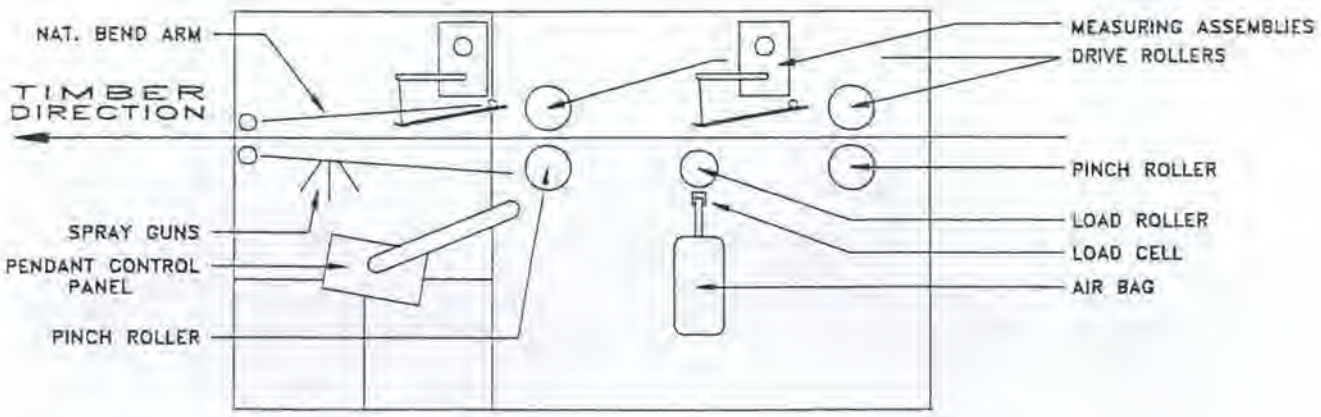

Figure 4. Schematic of the Dart (vertical view).

The timber loading arrangement is based on two parallel, vertical support rollers 914 mm apart. Both support rollers are driven. Feed rollers

force the timber against the drive rollers to ensure there is minimal slippage of the timber as it is driven through the machine. A pressure roller is positioned at the mid point between the support rollers. This roller applies a force with the aid of an air bag. The force is monitored with the aid of a load cell.

A linear displacement transducer is positioned opposite the pressure roller and is used for monitoring the timber deflection under load (D_1). Pivoted on the rear drive roller is an arrangement to measure the natural curvature or bow over a distance of 914 mm (D_n). Provided identical datums are used when the machine is calibrated then the true deflection under the applied force (i.e. independent of bow) can be determined by subtracting D_n from D_1.

The short-span E is determined using Equation 1. For the standard Dart machines the span, thickness and width are all normally assumed constant during any grading run resulting in the E being assumed proportional to the ratio of measured force to measured deflection. For Dart models with size measuring equipment (see below) only the test span is assumed constant in this equation. A stainless steel, low friction, plate is used to locate the timber in a constant vertical position during the measuring process.

A programmable controller is used to control machine operation and to determine short-span E values. It is also used to compare the measured E with preprogrammed E limits and to control sprays to indicate the short-span E range at individual points. The programmable controller is claimed to provide benefits for the user including ease of calibration and operation of the machine, provision of verification information, production reports etc.

A unique feature of the Dart is the availability of equipment to monitor the cross-section size of the graded timber. The programmable controller is used to calculate short-span E using the actual timber size. This feature enables the machine to be used for the processing of timber that has not been sorted into cross-section size groups.

Speed and Accuracy. The machine is designed for feed speeds up to 300 m/min. The Dart design offers a general improvement over the standard of accuracy of the Computermatic design. In the Dart the shape measuring arm is positioned on the outfeed side of the machine to improve measurement accuracy during feeding and to eliminate the possibility of damage to the arm during feeding. Another novel design feature of the Dart is the introduction of an air actuator to produce the force required to deflect the timber. This, and the mechanical design of the loading system, has an important role to play in

improving measurement accuracy. The applied load varies as the deflection of the timber varies. As deflection increases the applied load decreases and vice versa. This results in less movement of the timber during the grading process and thus less whipping of the timber. It also has the added advantage of applying less stress to the lower stiffness (lower strength) sections. Failure of very weak timber in the machine should therefore be negligible.

Monitoring of the applied force with a load cell during grading also assists grading accuracy.

MACHINE GRADING PROGRAMS

Over the years grading programs[1] have been developed in Australia for the Computermatic for both softwoods and hardwoods including radiata pine, slash pine, Douglas fir, alpine ash, mountain ash, jarrah and karri.

The programs were developed from the results of mechanical tests based on the methods described in AS 1749(11) i.e. the expected weakest point along each sample stick of timber is selected for test. Short-span E is measured with the timber on the flat in three point bending over a simply supported span of 914 mm. Bending strength is determined at the same point with the timber loaded on edge and with the worst edge in tension. Span to depth ratio is about 14 to 1 for the strength test.

Grading programs developed for the Computermatic are directly applicable to the Dart machines because they evaluate short-span E over an identical span.

The grading programs are, however, not directly suitable for use in the CLT machine because of differences in testing spans and because of differences in machine design. The CLT measures over 1220 mm and the traditional methods specify testing over 914 mm. Research has shown that for radiata pine, E measured over a 1220 mm span is higher than that measured over a 914 mm span(12) with the average difference ranging from about 5% for the higher grades to about 10% for the lower grades[2].

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[1]Grading programs specify short-span E limits for the various stress grades (see reference 14).

[2]These figures are based on static laboratory testing with timber loaded in simple bending, therefore the corrections may not be directly applicable to individual machines without appropriate verification.

AUSTRALIAN STANDARDS FOR MECHANICAL STRESS GRADING

The Australian Standards are currently being redrafted. The revision is necessary to bring the standards in line with other standards currently issued or being drafted, and to update the machine control methods to incorporate ideas learned from the practical application of the technology and to accommodate new machine control systems. The new draft standards affecting the machine grading standard cover in-grade testing requirements and initial and continuous verification procedures.

Revised Standard Part 1 - Product Specification

Replaces AS 1748 and sets out the requirements for timber that is graded by machine measurement of its flexural stiffness over a short span, followed by visual inspection. It specifies grade characteristics, dimensional tolerances, branding requirements, visual inspection requirements, and mechanical property requirements.

Revised Standard Part 2 - Code of Practice

Replaces AS 1749 and sets out requirements dealing with the supervision of grading operations, applicable machines, machine verification, grading programs, machine calibration, and verification of graded timber. Two types of machine control are specified, Type 1 (similar to the method specified in the current Australian standard) for machines with identical performance and Type 2 primarily for machines with non-identical performance.

The Type 2 control proposal is similar to the system used in North America where mechanical stress grading standards do not specify grading programs. In North America the average E, lower 5th percentile E and lower fifth percentile strength are specified for each grade[9]. Producers in North America are required to carry out in-mill quality control testing to verify that specified values are being met. Unlike the current requirements in Australia there is no specific requirement in North America covering the programming or performance of the individual machines (J. Logan, pers. comm.).

Adoption of in-mill testing as part of the quality assurance system may provide advantages for timber producers because it will permit individual operators to set their own program limits and therefore provide a mechanism for optimizing individual mill grade recoveries.

Summary of changes to existing Standards

The revised documents draw on the British[13], New Zealand[14] and

Australian[11] Standards, on North American grading agency requirements and on local practice in Australia. The main changes to the current Australian standards will probably be as follows:

- Visual inspection requirements for mechanically graded timber are to be independent of stress grade.
- Mechanical property requirements for each grade are specified as well as requirements for verification of mechanical properties on a continuous basis.
- Third party QA by an independent agency is specified (unfortunately, this may not be possible under current SAA policy). This QA is designed to meet accepted standards for third party certification schemes.
- In-mill, static, short-span E testing is specified for type 1 control systems to provide continuous evaluation of machine performance.
- Actual grading programs are listed for type 1 control systems. Methods for the preparation of grading programs are included. It is intended to also include conservatively biased grading programs to enable material to be graded on a trial basis for fast tracking the approval process.
- Type 2 control is introduced (type 1 control is similar to the current control used in Australia). With this form of control, conformance with the mechanical property requirements is monitored by in-mill testing of E and in-mill proof loading. Adjustments to grading programs are then made on the basis of the test results. The methods used follow the cumulative sum technique detailed in the British standard[13].

NEW APPLICATIONS

Hardwood

Mechanical stress grading has been introduced into the hardwood industry at two mills in N.S.W.

One mill is processing alpine ash from the Southern Tablelands[5]. The mechanically graded product is sourced mainly from low grade logs containing significant defect due to large branches that generally produce timber only suitable for scantling applications or pulpwood. Mechanical grades currently being produced are F22, F17 and F8. Mechanical grading produced significant better grade yields than visual grading for this type of material.

Another mill is processing mill-run, seasoned, mixed hardwood from the Northern Tablelands. Significant improvements in grade yields are being achieved at this mill when compared with visual grading. Because of the

species mix being processed, machine grading has the advantage of producing graded timber with highly reliable mechanical properties, something that is difficult to achieve with visual grading without the application of conservative grading criteria.

Cypress Pine

Mechanical stress grading at a cypress pine mill in N.S.W. is expected to commence in October 1990. Significant improvements in grade yields and grade reliability are expected. From the results of previous work it is expected that stiffness will be used as the grading criteria for this species. Cypress pine has a relatively low stiffness to bending strength ratio and therefore direct measurement of stiffness is potentially the most suitable grading method. A Dart machine with size measuring equipment will be used at this mill.

Douglas Fir

North American Douglas fir is again being mechanically stress graded in Australia. A truss plant in Queensland is using the method for it's truss components. In-house grading ensures a continuous supply of material of guaranteed quality without the normal reliance on outside suppliers.

For some ten years the technique was used by a truss manufacturer in South Australia.

FUTURE DEVELOPMENTS

It is anticipated that significant further development of the mechanical grading concept will take place in the next few years.

With the current availability of a machine capable of grading timber of any cross-section there is the possibility of introducing the sorting of green timber off saw. This may have some advantages, such as presorting for density before kiln drying or to eliminate from further processing material below acceptable grade standards.

Programmable controllers are becoming popular in machine control and provide increased flexibility not considered previously. For example, full use can be made of the stiffness profile information provided by the machine for determination of stress grade. Early research in this area indicates that this information may be useful for improving the utilization of low density plantation softwoods and cypress pine.

The new controllers will also permit additional equipment to be used as

an aid to more accurate stress grade determination. This additional equipment could, for example, be for simple size measuring purposes or for evaluating properties of the timber other than stiffness e.g. knot size and position.

The possibility of using microwave techniques for the evaluation of defect size and position is currently being explored.

CONCLUSION

Mechanical stress grading is undergoing extensive development in Australia. New machinery and standards are being developed to satisfy the requirements of both timber producers and end users.

Machine stress grading is being adopted by sectors of the industry that traditionally used visual grading techniques. These sectors include the local hardwood and cypress pine industries.

REFERENCES

1. Booth, H.E. 1964. Machine stress grading assures timber's future as a structural material. Australian Timber Journal 30(2): 78-84.

2. Booth, H.E. 1964. The machine grading of timber. Australian Timber Journal 30(8): 81-89.

3. Bendtsen, B. and Youngs, R.L. 1981. Machine stress rating of wood: an overview. Proceedings of the XVII IUFRO World Congress Division 5, Japan. IUFRO Secretariat, Austria.

4. Logan, J.D. 1985. Machine stress rating in North America. Proceedings of the Symposium on Forest Products Research International- achievements and the future. National Timber Research Institute. Republic of South Africa.

5. Grant, D.J. and Weir, G. 1990. The machine stress grading of alpine ash. N.S.W. Forestry Commission, Technical Paper (in press).

6. Grant, D.J. 1986. Computermatic timber grading machine - laboratory evaluation of performance with respect to feed speed and the dynamic/static relationship. New Zealand Journal of Forestry Science 16(2):187-96.

7. Radiata Pine Research Institute. 1985. Repeatibility and accuracy of mechanical stress grading machines. Sydney. Australia.

8. Bechtel F.K. 1985. Beam stiffness as a function of pointwise E with application to machine stress rating. Proceedings of the Symposium on Forest Products Research International- achievements and the future. National Timber Research Institute. Republic of South Africa.

9. Logan, J.D. 1990. Getting started with machine stress rating. Metriguard Inc. Pullman, Washington, U.S.A.

10. Logan, J.D. 1978. Machine Stress Rating. Proceedings of the Fourth Nondestructive Testing of Wood Symposium. Washington State University. USA.

11. AS 1748, AS 1749. 1978. Mechanically stress graded timber and Rules for mechanical stress grading of timber. Standards Association of Australia.

12. Grant, D.J. 1987. Effect of span on apparent modulus of elasticity. Forestry Commission of N.S.W. unpublished report.

13. BS 4978. 1988. Softwood grades for structural use. British Standards Institution. London, England.

14. NZS 3618. 1984. Mechanical stress grading of timber. Standards Association of New Zealand.

15. Standards Association of Australia, 1986. Timber - Classification into Strength Groups. AS 2878, Sydney, Australia.

16. Standards Association of Australia, 1988. SAA Timber structures code Part 1 - design methods. AS 1720.1, Sydney, Australia.

17. Standards Association of Australia, 1979. SAA Timber framing code. AS 1684, Sydney, Australia.

18. Standards Association of Australia, 1990. Draft Australian Standard, Timber - Machine Proof Grading, Sydney, Australia.

19. Standards Association of Australia, 1986. Timber - Softwood - Visually stress graded for structural purposes. AS 2858, Sydney, Australia.

APPENDIX A

DISCUSSION OF CURRENT STRESS GRADING METHODS

General

The classification of timber species into Strength Groups[3] and the sorting of timber into stress grades[4] are fundamental requirements of the Australian timber design Codes(16)(17).

Two methods are commonly used for sorting timber into stress grades. These are known as visual stress grading and mechanical stress grading. A third method used in Australia for producing stress graded timber is called proof grading.

Proof Grading

The term proof grading refers to a process that relies, for all practical purposes, on visual or mechanical presorting and subsequent proof testing of the sorted population. The proof testing is aimed at ensuring that the sorted population has a basic working stress in bending that meets the requirements of a particular stress grade. Proof grading can therefore be regarded, primarily, as a procedure for checking the bending strength of a sorted population(18). An Australian Standard is currently being prepared for proof graded timber.

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[3]Strength Groups are generally determined from the results of tests on small clear properties of particular timber species(15)

[4]In stress grading, each piece of timber is allocated a specific stress grade or it is rejected. The timber so allocated implies that it may be safely used with several design properties specified in AS 1720.1(16). In addition to bending strength, other design properties such as tension strength and modulus of elasticity are guaranteed.

The process of stress grading timber incorporates three essential operations-

(a) Selection of a parent population of timber.

(b) Sorting of this parent population into sub-populations that are then designated to specific stress grades.

(c) Checking structural properties of each stress grade from the graded timber.

Visual Grading

Visual grading relies on the visual intepretation of defects by trained personnel. The timber is sorted into various classes as defined in written grading rules which specify the limiting characteristics that may occur in timber in each class. In Australia, the various classes are called Structural Grades.

Stress grades are normally assigned to the Structural Grades in accordance with the Strength Group of the species of timber being graded. This process requires a general assumption that there is a fixed relationship between the Structural Grade, the Strength Group and the stress grade (see for example reference 19).

Australian Standards are available for the visual grading of most commercial species of timber.

Mechanical Grading

Mechanical stress grading aims at providing a non-destructive method of sorting timber into stress grades which is more objective and precise than visual sorting alone.

The grading machines monitor flexural modulus of elasticity (E), on the flat, over a short span. The minimum short-span E measured on each stick of timber is then generally used as the sorting criteria. The overall result is the production of two, three or four sorted classes from the parent population.

The two main structural properties that are considered in mechanical grading systems are flexural stiffness and bending strength. The timber stiffness is evaluated directly by the grading machine as described previously, and bending strength is indirectly considered with the aid of the known correlation between stiffness and bending strength.

Verification of the adequacy of stiffness and strength in each class is based on the results of tests on full size samples of timber taken from the sorted classes.

Visual inspection is required after the mechanical sorting to detect defects not measured by the machine. These include distortion, checks, detection of defects in the ungraded ends etc.

The correlation between short-span stiffness and bending strength varies with timber species, size and distribution of defects, age of the wood, variations in wood density etc. For example mature radiata pine timber with relatively large defects may have a high correlation coefficient and immature

radiata with relatively small defects may have a low coefficient. The correlation coefficient is also affected by any presorting that occurs prior to sampling. Therefore, the grade controlling parameter for any individual machine grading application may be bending strength or bending stiffness.

For a more accurate estimate of average E the short-span E can be averaged by the grading machine for each individual stick of timber and thus provide a stiffness for design purposes on an individual stick basis.

Verification of Graded Timber Properties - In-grade Testing

Visually graded timber has not been subject to extensive in-grade testing so the method of assigning stress grades described above has not been extensively verified for most visual grading applications. However, results of in-grade bending tests that have been performed on visually graded timber generally indicate adequate stiffness and bending strength. The exception is generally inadequate stiffness in the Structural Number 1 grade.

Neither initial or continuous in-grade verification of mechanical properties is specified for any current visual grading standard, a major failing which should be addressed in future revisions of the standards.

Both mechanically stress graded timber and proof graded timber have been subject to extensive in-grade testing during their developmental stages, at least for stiffness and bending strength. Continuous in-grade evaluation of bending properties is specified under the current Australian standard for mechanically graded timber and in industry standards for proof graded timber.

Both initial and continuous verification of mechanical properties will be required by the new Australian Standards for mechanical grading and proof grading. These new requirements cover tension as well as bending properties.

The results from in-grade testing work tend to indicate that the current stress grade specification of AS 1720 does not provide the necessary flexibility required to achieve optimum use of our structural timber resource, an effect that has become more obvious as we refine our grading systems. It is anticipated that future revisions of AS 1720 will address this issue.

DURABILITY – A STRUCTURAL APPROACH

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INTRODUCTION

The rigorous methodology developed for the design of timber structures fails to apply where such structures are exposed. As with other structural materials, the rules for the design of timber structures are based on sophisticated concepts of structural reliability theory. In AS 1720.1 – SAA Timber Structures Code: Part 1 – Design Methods[1] the design stresses for timber used under protected conditions have been derived so as to achieve a target in-service reliability against structural collapse[2]. This requires the use of quantitative data related both to the statistics of loads and strengths, and to the statistics of the uncertainties involved in the design process[3]. For example, to define the design bending strength of radiata pine, samples sizes comprising several hundred specimens for each stress grade have been tested[4]. Similarly, to obtain data on the deterioration in strength due to long-term loads, thousands of sticks of timber have been tested[5]. Unfortunately, such a rigorous base of theory and test is not available for the case of timber structures that are exposed to a potential loss of strength due to weathering, decay and/or insect attack.

This paper will discuss the development of a formal design process for exposed timber structures. The process is written in the form of a design procedure for structural engineers. The numbers shown represent a first attempt and are given solely to illustrate the format of the procedure.

Because this paper is addressed to a mixed audience, some matters need to be clarified at the outset. To the wood technologist, it should be pointed out that the numbers in an engineering code cannot be used to predict the properties of a particular structure; the engineer appreciates that any structural prediction is associated with uncertainty; however, if the uncertainties have been correctly assessed, then the design procedure leads to a structure with adequate reliability. It is reliability and not prediction that is the aim of structural engineering.

On the other hand, structural engineers often fail to appreciate that wood technologists are concerned with a variety of applications for timber, and hence many of the properties measured are not directly applicable for engineering purposes. Important parameters such as 'durability', 'resistance', 'performance' and 'life' are not defined in engineering terms. In addition, engineers often fail to appreciate that the biological causes for the deterioration of wood involve many agents (e.g. fungi, termites, insects) and that their impacts are not always correlated.

However, before commencing to describe a possible design procedure, a brief summary will be given of the information available for other structural materials. This is useful as a guide to the choice of matters that should be included in the proposed design process.

OTHER MATERIALS

Steel

The standard AS 2312 – Guide to the Protection of Iron and Steel Against Exterior Atmospheric Corrosion[6] is aimed at the design of protective coatings for steel structures. The target specified performances are given in Table 1; these are stated in terms of the duration of protection given by a specific coating system. The performance predicted depends on both the coating system used, the structural detailing and the environmental hazard. Parameters chosen for the environmental hazard include climate and proximity to the coast and/or industrial activity.

TABLE 1: PERFORMANCE CRITERIA FOR PROTECTIVE COATINGS ON STEEL STRUCTURES (AFTER AS 2312[16])

Performance classification	Miniumum duration of protection (years)
Short-term protection	2
Medium-term protection	5
Long-term protection	10
Very long-term protection	15

Once the protective coating is lost and corrosion of the structural steel occurs, there is still residual strength, depending on the degree of corrosion. Prediction equations for corrosion rates have been given by many researchers such as Sereda[7] and Haynie and Upham[8]. The hazard parameters used include relative humidity, wetting time, and specimen orientation quantity of particulates of sulfates and chlorides suspended in the atmosphere. For many areas, detailed corrosivity maps are available; an example of this is the corrosivity map for Melbourne by King *et al.*[9].

Reinforced Concrete

The standard AS 3600 – Concrete Structures[10] provides rules to obtain a design life of 40–60 years for exposed structures designed according to this standard. Hazard parameters used include climate type, exposure, ground contact conditions, water contact conditions and proximity to the coast and industrial zones. The design durability is obtained by control of concrete strength and depth of cover to the reinforcement.

The design rules of reinforced concrete codes have been derived from prediction theories that are largely related to the corrosion of the reinforcement due to carbonation[11]. Environment parameters that affect the rate of corrosion include exposure to rain and air concentrations of sulfate and chloride particulates. Material parameters that affect the rate of corrosion include cement type, water-cement ratio, extent of curing, concrete cover and surface coatings.

A METHODOLOGY FOR TIMBER STRUCTURES

From the examination of methods used for steel and reinforced concrete structures, it would appear that the development of a suitable methodology for the design of exposed timber structures should comprise the following four basic steps:

- definition of target structural performances,
- development of methods for predicting such performances,
- a field calibration of the prediction methodology so as to assess the associated uncertainties, and
- formulation of design rules.

In the following, each of these four steps will be discussed in the light of current knowledge.

TARGET PERFORMANCES

Timber is used for a great range of structures. It may be used for buildings, with a design life of 50 years and for which a structural failure would involve a risk to life; it may also involve secondary rural structures with a design life of only a few years, and where failure is of little economic or social consequence. Accordingly a range of target performances is desirable.

Table 2 is a proposal for defining target performances of timber structures. It is based on the expected failure rates of structural elements.

TABLE 2: PROPOSED PERFORMANCE CRITERIA FOR TIMBER STRUCTURES

Performance rating	Time to failure* (years)		
	For 50% of beams	For 5% of beams or 50% of joints	For 5% of joints
1	2	1	0.5
2	10	5	2
3	50	20	10
4	100+	80	50
5	100+	100+	100+

* For structures loaded to the maximum permissible load according to permissible stress codes.

PREDICTION METHODS

Prediction of strength loss due to exposure is the critical part in developing a design methodology. It should be emphasised again that it is not the purpose of a prediction algorithm to provide an accurate prediction for any particular structure. The aim is to provide a suitably reliable prediction for all structures. This is achieved through making due allowance for the uncertainties associated with the prediction algorithm.

For countries where there is little prior information on durability, predictions could be erratic; in some instances the only basis for prediction may be to use a climate classification for the hazard and to use timber density to estimate the natural durability of heartwood. Examples of useful climate classifications are given by Trewartha[12] and Scheffer[13]. At the other extreme of knowledge, highly reliable predictions of performance can be obtained through local knowledge of specific species.

For Australia, probably the most obvious starting point is the set of natural durability studies by CSIRO reported by Thornton *et al.*[14,15] and Johnson *et al.*[16]. In these studies, 50 x 50 x 450 mm heartwood stakes were buried 300 mm deep in the ground. Altogether 77 species were tested at 5 sites. Another potential source of useful information is the above-ground durability trials being directed by CSIRO[17] and the Queensland Forestry Service (M. Cause, private communication).

On the basis of the CSIRO studies, a natural durability classification has been allocated to the heartwood of various species. The definition for this classification is given in Table 3. Furthermore, information obtained during the course of these formal studies, together with information obtained in the course of field inspections of engineering structures may be used to develop maps of hazard zones, such as those for air, ground and water contact as given in Figures 1–3.

TABLE 3: DEFINITION OF DURABILITY CLASSIFICATIONS (AFTER TAMBLYN[18] AND JOHNSON *ET AL.*[16])

Durability class	Representative species	Effective resistance to decay and termite attack* (years)
1	Red ironbark (*Eucalyptus sideroxylon*)	25–50
2	Yellow stringybark (*Eucalyptus muellerana*)	15–25
3	Messmate (*Eucalyptus obliqua*)	8–15
4	Radiata pine (*Pinus radiata*)	1–8

* 40 mm thick untreated heartwood in ground contact at a low hazard location such as Mulgrave[14].

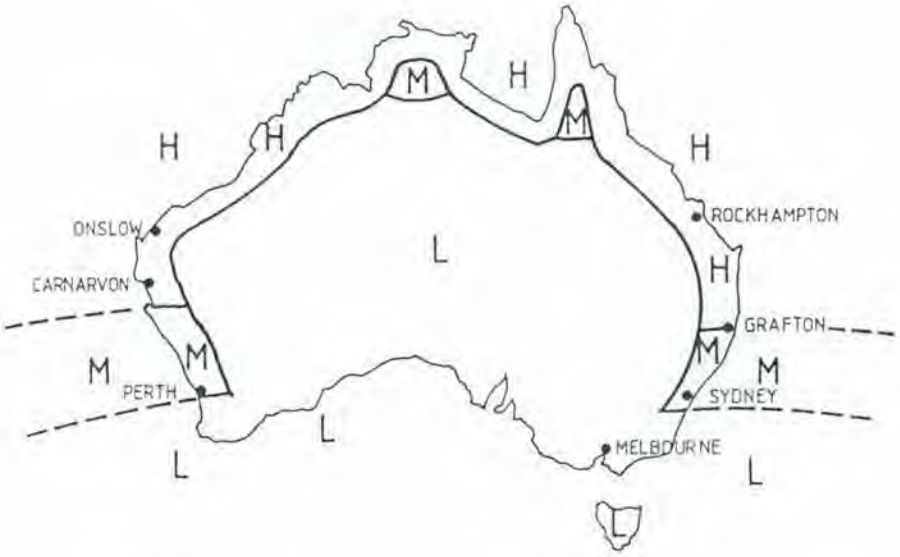

Figure 1. Above ground hazard zones (H = high, M = medium, L = low).

Figure 2. Ground contact hazard zones (H = high, M = medium, L = low).

Figure 3. In-water hazard zones (H = high, M = medium)

To predict the performance of a structure, use is made of the data from both natural durability studies and field experience. From an estimate of the amount of timber destroyed, an estimate is made of the structural performance of a loaded structure. The following is a summary of assumptions made in predicting the performances defined in Table 2:

(a) 50% of beams will have failed when 30% by volume of the total timber exposed has been destroyed,
(b) 5% of beams and 50% of joints will have failed when 10% by volume of the total timber exposed has been destroyed, and
(c) 5% of joints will have failed when 5% of the surface of the total timber exposed has been destroyed to a depth of 5 mm.

From these considerations the method proposed for predicting the performance of structures fabricated with untreated timber is as follows. First, as shown in Table 4, the natural durability classification together with information on the zone of the tree from which timber was cut is combined to give a 'base performance rating', i.e. the performance rating if the timber was heartwood, in ground contact, and at a mild site such as Mulgrave[15]. Then this base performance rating is combined with the hazard classification according to Table 5 to produce a performance rating.

TABLE 4: BASE-PERFORMANCE RATING FOR UNTREATED TIMBER

Natural durability class	Base performance rating		
	Sapwood	Heartwood*	Pith or inner heartwood
4	1.0	1.0	1.0
3	1.0	2.0	1.0
2	1.0	3.0	1.0
1	1.0	4.0	1.0

* The performance rating may be lower for the heartwood from trees that have experienced rapid growth, or that are hardwoods less than 70 years old.

TABLE 5: PERFORMANCE RATING FOR UNTREATED TIMBER

Situation	Performance rating							
	Low hazard location				High hazard location			
	BPR 1.0	BPR 2.0	BPR 3.0	BPR 4.0	BPR 1.0	BPR 2.0	BPR 3.0	BPR 4.0
Above ground, sheltered	5.0	5.0	5.0	5.0	1.5	2.0	2.5	4.0
Above ground, exposed	1.5	2.5	3.5	4.0	1.0	2.0	3.0	3.5
In water	1.5	2.5	3.0	4.0	1.0	1.5	2.5	3.0
In ground contact	1.0	2.0	3.0	4.0	0.5	1.0	2.0	2.5

BPR = base performance rating, Table 4. For hazard location refer to Figures 1–3.

For treated timber it is assumed that the procedures specified in AS 1604 – Preservative Treatment for Sawn Timber, Veneer and Plywood[19] are intended to lead to a uniform performance rating regardless of species and hazard location; for example, the CCA treatment specified for the sapwood of softwoods as shown in Table 6 would appear to be in line with this contention. With this assumption, together with observation from field experience, Table 7 has been derived for predicting the performance ratings of treated timber.

TABLE 6: SPECIFIED CCA TREATMENT FOR SOFTWOODS ACCORDING TO AS 1604

Hazard	CCA treatment for softwoods* (kg/m^3)
Above ground, not exposed	0.0
Above ground, exposed and kept well painted:	
– moderate hazard location	5.6
– severe or tropical location	8.0
Above ground, unpainted:	
– moderate hazard location	8.0
– severe or tropical hazard location	12.0
Ground contact:	
– moderate hazard location	12.0
– severe or tropical hazard location	20.0
In sea:	
– below 20°S	32.0
– above 20°S	50.0**

* Based on single treatment using Tanalith C.
** An estimate, condition not specifically covered by AS 1604.

TABLE 7: PERFORMANCE RATINGS FOR TIMBER TREATED IN ACCORDANCE WITH AS 1604

Natural durability class (heartwood only)	Base performance rating			
	Sapwood		Heartwood	Pith or inner heartwood
	Hardwood	Softwood		
4	3.0	4.0	1.5	2.0
3	3.0	4.0	2.5	2.0
2	3.0	–	3.5	2.0
1	3.0	–	4.0	2.0

CALIBRATION OF PREDICTION METHODOLOGY

Only limited checks have been made to assess the effectiveness of the prediction methods described above. It would appear that they are roughly correct. However, for use in a reliability formulation it is also necessary to have at least a rough quantitative estimate of the uncertainty associated with the prediction methodology. First attempts at estimating the uncertainty of the prediction model suggest that the predicted performance rating is correct within a factor of ±0.5 for roughly 80% of the cases. The CSIRO study on the service life of railway sleepers[20] is one of the few examples that provides a quantitative measurement of the uncertainty associated with the structural deterioration of timber.

FORMULATION OF DESIGN RULES

The prediction methodology used is summarised by the application of Figures 1–3, Tables 4 and 5 for untreated timber, and Table 7 for treated timber. Once the uncertainties of the methodology have been quantified, conventional reliability concepts may be used to select target performances for various end uses, and then to formulate the relevant design rules.

It should be obvious that if additional parameters are used in the assessment, then the prediction becomes more accurate and correspondingly the derived design rules will be less conservative. Some obvious factors that would be worth considering are as follows.

(a) *The orientation of the structure* (for example, Huggins *et al.*[21] found in a survey of timber bridges in Canada, that bridges aligned north-south degraded faster than those aligned east-west).
(b) *The structural detailing, particularly at joints* (timber will decay considerably faster where water can seep into the contact area between two surfaces),
(c) *Thickness of timber elements* (many deterioration processes work in from the surface, and hence thicker members are likely to survive longer).
(d) *The use of coatings.*
(e) *The use of inspection and maintenance activities.*

One matter that should be stressed is that the parameters used in the prediction model should be limited to parameters that are under the control of the design engineer and/or construction supervisor. Thus, while it may be acceptable to distinguish between heartwood and sapwood (provided suitable chemical indicators are available), it would not be acceptable to use parameters such as permeability (if these could not be enforced in construction supervision).

CONCLUDING COMMENT

For most structural engineers, their information on the performance of unprotected timber structures is based only on information obtained from sales representatives for various products. There are no formal or codified procedures for the design of such structures, and as a result engineers are reluctant to be involved in such design. Development of a formal design procedure, such as that outlined in this paper will go a long way towards instilling the required confidence. Moreover it provides a useful framework against which information obtained from field experience can be checked and hence, as time goes by, lead to increasingly reliable design recommendations.

It may be that for exposed structures the high degree of structural reliability associated with the normal use of AS 1720.1, can be obtained only for a few types of designs. Even if this is so, the existence of a formal design procedure will assist in giving engineers the same degree of confidence in designing exposed timber structures as they now have in designing exposed steel and reinforced concrete structures. This in turn, will lead to an increase in confidence in the design of timber structures generally.

REFERENCES

1. Standards Association of Australia 1988. AS 1720.1 – SAA Timber Structures Code: Part 1 – Design Methods. Sydney, Australia, 85 pages.

2. Leicester, R.H. 1990. On developing an Australian Limit States Code. *Proc. 1990 International Timber Engineering Conference*, Tokyo, Japan, 9 pages.

3. Pham, L. and Leicester, R.H. 1979. Structural variability due to the design process. *Proc. 3rd International Conference on Applications of Statistics and Probability in Soil and Structural Engineering*, Sydney, Australia, 586–600.

4. Leicester, R.H., Grant, D.J., Rumball, B.L. and Young, F.G. 1988. *Structural Engineering Properties of Machine Stress-graded, Australian-grown Radiata Pine.* Technical Report TR88/1, CSIRO Division of Construction and Engineering, Melbourne, Australia, 46 pages.

5. Barrett, J.D., Foschi, R.O., Vokey, H.P. and Varoglu, E. (Eds) 1986. *Proceedings of International Workshop on Duration of Load in Lumber and Wood Products.* Special Technical Publication No. SP-27, Forintek Canada Corp., Vancouver, Canada, 115 pages.

6. Standards Association of Australia 1980. AS 2312 – Guide to the Protection of Iron and Steel Against Exterior Atmospheric Corrosion. Sydney, Australia, 66 pages.

7. Sereda, P.J. 1974. Weather factors affecting corrosion of metals. *Corrosion in Natural Environments*. ASTM STP 558, American Society for Testing of Materials, 7–22.

8. Haynie, F.H. and Upham, J.B. 1974. Correlation between corrosion behaviour of steel and atmospheric pollution data. *Corrosion in Natural Environments*, ASTM STP 558, American Society for Testing of Materials, 33–51.

9. King, G.A., Martin, K.G. and Moresby, J.F. (1982). *A Detailed Corrosivity Survey of Melbourne.* CSIRO Division of Building Research Report, Melbourne, Australia, 13 pages plus map.

10. Standards Association of Australia 1988. AS 3600 – Concrete Structures. Sydney, Australia, 105 pages.

11. Somerville, G. 1986. The design life of concrete structures. *The Structural Engineer*, **64A**(2), 60–71.

12. Trewartha, G.T. 1943. *An Introduction to Weather and Climate*. McGraw-Hill.

13. Scheffer, T.C. 1971. A climate index for estimating potential decay in wood structures above ground. *Forest Products Journal*, **21**(10), 25–31.

14. Thornton, J.D., Walters, N.E.M. and Saunders, I.W. 1983. An in-ground natural durability field test of Australian timbers and exotic reference species: I. Progress report after more than 10 years' exposures. *Material und Organismen*, **18**(1), 27–49.

15. Thornton J.D., Johnson, G.C. and Saunders, I.W. 1983. An in-ground natural durability field test of Australian timbers and exotic reference species: II. Progress report after approximately 13 years' exposure. International Research Group on Wood Preservation, IRG Doc. No. IRG/WP/1189.

16. Johnson, G.C., Thornton, J.D. and Saunders, I.W. 1986. An in-ground natural durability field test of Australian timbers and exotic reference species. III. Results after approximately 15 years' exposure. *Materials und Organismen*, **21**(4), 251–264.

17. Creffield, J.W., Johnson, G.C., Thornton, J.D., Pahl, P.J. and Ellis, B. 1989. An Australian test for decay in painted timbers exposed to the weather for a total of six years. *Forest Products Journal*, **39**(1), 61–66.

18. Tamblyn, N. 1966. Natural durability ratings. *Forest Products Newsletter*, No. 335, Nov.

19. Standards Association of Australia 1980. AS 1604 – Preservative Treatment for Sawn Timber, Veneer and Plywood. Sydney, Australia, 22 pages.

20. Tucker, S.N. and Barnacle, J.E. 1983. Railway sleeper service life distributions in an Australian rail-track and their likely effects on maintenance strategies. *Proc. 5th International Rail Track Conference*, Rail Track Association, Newcastle, Australia, 242–256.

21. Huggins, M.W., Palmer, J.H.L. and Aplin, E.N. 1966. Evaluation of the effect of delamination. *The Engineering Journal (Canada)*, February, 3–12.

Finger Jointing of Hardwoods

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ABSTRACT

This paper describes some of the factors which affect the structural performance of finger joints. Many of the statements apply generally to both hardwoods and softwoods but the experimental findings were made during the course of research into the finger jointing of southern Ash species. Finger joint performance is discussed in relation to both localised failure (commonly referred to as wood failure) and overall finger joint strength. It is emphasised that wood failure is largely controlled by the quality of the glueline and that overall strength is related to finger joint geometry. The paper concludes with a list of options which can be followed by manufacturers in the production of finger joints.

1 Introduction

The producers of hardwood finger jointed structural components experience difficulty in consistently manufacturing a high quality product as measured by the accepted quality indicators - wood failure and strength. Wood failure varies erratically from joint to joint for no apparent reason with a large proportion of joints exhibiting low wood failure. Finger joint strength tends to be far less variable but, taken alone, is not universally accepted as indicating that the joint is well made.

The strength criterion provides assurance that the member can support the stresses imposed by the applied loads. The requirement is clearly necessary as there exists a fundamental need in engineering design for members to have known load carrying capacity. The need for a wood failure criterion is less obviously necessary but, there exists a rationale which says that, if the wood can fracture the glueline rather than the other way around, then failure may occur in practice due to action of moisture induced shrink-swell stresses.

It is interesting to note, however, the inconsistent manner in which the criteria are treated in national, international and industry standards in common use.

Australian Standard, AS1328, Glued Laminated Structural Timber, makes no QC provisions for wood failure in finger joints. A manufacturer is required to test end joints of each production batch in bending or tension and meet prescribed minimum f'_b or f'_t values equal, respectively, to 2.3 times F'_b (the basic allowable stress in bending) and F'_t (the basic allowable stress in tension).

Likewise, the Draft ISO Standard on Finger Jointing contains no wood failure provisions although, compared to AS1328, its QC strength criteria are derived in a much sounder manner which can be summarised as follows:

- undertake pre-qualification bending or tension tests to determine the strength applicable to the particular production line, joint etc,

- assess a characteristic strength value as the mean less two standard deviations (5% fractile value),

- test 3 joints per shift and accept production provided all joints test at above the characteristic strength value.

On the other hand, the Timber Promotion Council in Victoria have issued an industry standard in which both strength and wood failure (stated as 50% but consideration being given to reducing it to 30%) criteria are included as QC procedures. It is known that the wood failure criterion has not been established by objective assessment of test data but, rather, it is an estimate of what the industry can achieve under conditions currently viewed as good practice.

In a similar vein, the American Standard calls for strength QC procedures of a type similar to those in the ISO Standard and an additional 50% wood failure criterion for wet use adhesives used with hardwoods.

Of the two criteria, many argue that wood failure is the more important but, in reality, adequate performance on both counts is necessary. High wood failure does not guarantee high strength as is self evident in the case of the finger joint shown in Fig 1, since, even with 100 percent wood failure, its strength would be low. While this is an unusual finger joint geometry, there exists the possibility that the selection of poor finger joint geometry of a more conventional type can seriously downgrade load carrying capacity. Table 1 contains geometric details for a range of finger joint profiles in use and proposed by the author. Some have poor strength characteristics while others, with excellent structural strength, have fingers so long that considerable difficulty will be experienced in maintaining a sharp cutter.

2 Factors Affecting Wood Failure

Any statement concerning wood failure can be viewed from either a failure criterion or fracture mechanics perspective. Furthermore, it can describe either the situation prevailing at the time of manufacture and shortly thereafter or the situation prevailing at some time in the future when the glue may have deteriorated chemically by hydrolytic change. Hydrolytic change will not be considered further; it will be taken for granted that hydrolytically stable glues are required for wet use.

Wood failure percentage is affected by a number of factors including:

i) the extent to which the wood and glue adhere to one another (secondary intermolecular bonds and mechanical interlock) which are, in turn, affected by factors such as glue viscosity, glue reactivity rates, surface wetability, etc.,

ii) the inherent or cohesive strength of the glue,

iii) the strength of the wood at the micro-level viewed from either a failure criterion or fracture mechanics perspective,

iv) the slope of the wood grain and the angle of the glue face relative to the grain.

Control of some factors included in items i) and ii) is a matter for the glue chemist who, to some extent, can adjust parameters such as molecular and bulk viscosity, reactivity rates and the modulus of elasticity of the glue. The adherend (wood) is fixed by whatever the manufacturer must glue but control of a number of the manufacturing parameters, such as the timber moisture content, open and closed assembly times, end pressure etc are in manufacturer's hands. However, it seems reasonable to conclude that the erratic wood failure results obtained by hardwood finger joint producers at present in tension and bending tests, especially with the stiff and brittle RF, UF, MUF glues in common use, indicates that substantial improvements in glue performance are necessary to obtain higher wood failure levels. It is difficult to believe that, given the wide range of manufacturing practices employed, a higher success rate would not have been achieved before now with hardwood gluing if the glues in current use were adequate.

The factors included in items iii) and iv) are matters for the engineer/stress analyst who can regard a well made glueline as having a defined strength and then adjust finger geometry to obtain overall strength levels of at least 75 percent of clear wood strength.

2.1 Experiments on RF Glues

In a series of experiments at the Monash Timber Engineering Centre an effort was mounted to improve RF glue performance in finger and scarf joints. Three companies (Timbachem, ICI and Bondtite) modified their existing resins in various ways. The Centre subsequently tested the resins by tensile testing of both finger and scarf joints cut in southern Ash type eucalypts. Both strength and wood failure data were recorded. In general the results were disappointing with some of the changes clearly resulting in a lowering of glueline strength and with the performance of the best of the glues not noticeably better than the current best on the market.

In the scarf joint tests, carried out using Timbachem A3 resin and P4 hardener, Milner *et al* (1989), a range of glue face angles were investigated. It was found that the gluelines could resist a stress vector of 16MPa in tension and that this strength remained essentially constant for glue face angles in the range 15° - 90°. Below 15°, wood failure occurs so that the tests measure wood rather than glueline strength. Since there is no reason to believe that the glueline is any weaker at these lower face angles it is assumed that the 16MPa figure continues to apply in the 5° - 15° range. Any wood capable of mobilising stresses of this magnitude in a glueline will crack it, provided the mechanism is available to generate that stress. Such a mechanism could be either moisture movement or applied load. The cracking strength will reduce if the glue undergoes chemical deterioration.

2.2 Wood Failure from a Failure Criterion Perspective

A failure criterion approach is useful in explaining wood failure phenomena observed during tension testing, Milner *et al* (1989). It was shown that, in a tension field, the glueline failure criterion is

$$F_{tg} \leq \frac{16}{\sin\theta} \qquad 1$$

where θ = slope of the glue face relative to the tension field
F_{tg} = wood tensile strength needed to crack the glueline
16 (MPa) represents the glueline fracture strength.

The value of 16MPa is somewhat higher than the value cited in the original paper but is justified by an appropriate interpretation of the test data.

It is possible now to describe the conditions for wood failure where sloping grain is present. A modified von Mises criterion is commonly accepted as describing wood failure and is given by $(f_L/F_L)^2 + (f_N/F_N)^2 + (f_S/F_S)^2 \leq 1$ where F_L, F_N, F_S are the longitudinal, cross grain and shear strengths when only that stress component acts. Leicester (1983) recommended that $F_L = F_t$, $F_N = 0.026F_t$, $F_S = 0.067F_t$. If the tension field is parallel to the timber longitudinal axis and the grain slopes at angle α to the longitudinal axis, then $f_L = F_{t\alpha}\cos^2\alpha$, $f_N = F_{t\alpha}\sin^2\alpha$, $f_S = -F_{t\alpha}\sin\alpha\cos\alpha$. Substitution into the von Mises criterion leads to the wood failure expression,

$$F_{t\alpha} = \frac{F_t}{\sqrt{(\cos^4\alpha + 1480\sin^4\alpha + 225\sin^2\alpha\cos^2\alpha)}} \qquad 2$$

where $F_{t\alpha}$ is the failure strength of wood in tension with grain slope α. If the wood failure stress is equated to the glueline failure stress ($F_{t\alpha} = F_{tg}$) then, for load parallel to the wood longitudinal axis, the criterion for wood failure becomes,

$$F_{tL} \leq \frac{16\sqrt{(\cos^4\alpha + 1480\sin^4\alpha + 225\cos^2\alpha\sin^2\alpha)}}{\sin\theta} \qquad 3$$

This expression is symmetric in α and thus predicts an equal possibility of wood failure for both faces of a finger, a phenomenon which does not occur in practice. With sloping grain, timber failure occurs, initially, according to the von Mises criterion by splitting across the grain. If this sloping grain persists along the length of the test sample and the glueline is sufficiently strong then failure occurs away from the finger joint and across the tension specimen as a whole. Often such samples fail at relatively low loads and typify a "weak wood" case; see Fig 2. If the grain slope is local, then this initial split will relieve the normal to the grain stresses f_N and shear stresses f_S, splitting the wood in the region of the finger joint into a series of filaments which are anchored into straight grained wood in the body of the test specimen; see Fig 3. The small wood wedges left when the grain slope is in sympathy with the glue face slope pull away in accordance with eqn 4. The filaments attached to the other glue face can exert large forces on that face and the fail the glueline. Eqn 4 gives values of wood tensile strength necessary.

$$F_{tL} \leq \frac{16}{\sin|\theta - \alpha|} \qquad \alpha \leq 0 \qquad 4$$

The same analysis may be repeated for tension stress applied normal to the wood longitudinal axis as are imposed in the chisel test. The relevant expression is obtained by replacing α and θ with $(90 + \alpha)$ and $(90 + \theta)$ respectively in eqn 3 leading to

$$F_{tN} \leq \frac{16\sqrt{(\sin^4\alpha + 1480\cos^4\alpha + 225\sin^2\alpha\cos^2\alpha\chi)}}{\cos\theta}) \qquad 5$$

Using eqns 3, 4, 5 the values of Table 2 can be derived.

θ deg	α deg	F_{tL} MPa	F_{tN} MPa	
5	5	305	614	
5	2	207	617	
5	0	184	618	
5	-5	92	614	
5	-5.7	86	612	Structural Grade 2 (1:10)
5	-7	77	609	Structural Grade 3 (1:8)

Table 2: Values of F_t required to fail a glueline

The following conclusions may be drawn:

a) a test in which tension is applied parallel to the axis of the timber is more demanding of the glueline than a test in which load is applied normal to the axis because the stress which the wood is capable of applying to the glueline is much greater,

b) for tension parallel to the axis very weak wood can fracture a glueline when the grain slopes at an adverse (negative slopes in Table 2) angle to the glue face and consequently very different patterns of wood failure occur on the upper and lower faces of a finger.

It follows from (a) that a tension or bending test of a finger joint is far more demanding than a chisel type test; this is borne out in practice with finger joints. Any attempts to make a chisel split a finger joint glueline commonly results in the split transferring to the wood except for extremely poor joints.

A philosophical problem arises with respect to evaluating the quality of finger joints; do we use a cleavage or longitudinal tension type of test to evaluate wood failure? Drying shrinkage applies a cleavage type stress in the radial or tangential direction and only a chisel test can siimulate that effect. A longitudinal tension test (axial load or bending) simulates the effect of applied load and it is arguable that wood failure should not be demanded in such circumstances. Accordingly it is proposed herein that AS1328 should remain largely in its current form without a wood failure criterion for the tension and bending testing of end joints. There should be included, however, a joint cleavage (chisel) test with a 70 percent wood failure requirement designed to determine the ability of the glueline to resist shrink/swell.

It follows from point (b) that there can be 100% wood failure on one face of a finger and zero on the other ie erratic wood failure can be expected. Also the spacing of growth rings is commonly in the range of 5mm to 10mm which corresponds to the pitch of fingers. Thus it is common to observe strips of failed wood fibres corresponding to the bands of the weaker early wood across the finger face or to have some fingers with 100% and others with zero wood failure.

2.3 Wood Failure from a Fracture Mechanics Perspective

As stated above, gluelines in service are required to resist the stresses imposed by both applied load and water induced shrink-swell movement. Any stress concentration caused by poor finger joint geometry or curing shrinkage (7% in the case of RFs) can propagate and completely fracture the glueline. Under the fracture mechanics approach measurements are

made of the ability of the glueline to resist the further development of such cracks.

The classical approach to such experimental determinations is based on work by Griffith (1920) who postulated that there exists a critical value of fracture energy per unit width, G, which is released when a crack extends a unit length. It has the units energy (FL)/ width (L)/ unit crack length (L) = FL^{-1} but is commonly expressed as joules(Nm)/m^2 (FL/L^2). By measuring this fracture energy on a standardised test specimen, accurate measures of the relative resistance of glues can be obtained. The test specimen has to be designed to inhibit wood failure.

It is necessary to select a test which focuses on the appropriate fracture type. There are three standard fracture types recognised in fracture mechanics,

Mode I: Cleavage tension or direct tension (typical of the chisel test)

Mode II: Sliding shear (typical of the block shear test)

Mode III: Anti-plane shear (not used in wood testing)

It is usual to measure glueline fracture properties in cleavage, ie Mode I stress application. Mode I is the type of fracture which occurs when the chisel test is applied to face gluelines of glued laminated beams and is typical of the fractures induced by moisture movement effects. The chisel test can be viewed as a primitive Mode I fracture test which compares the fracture energy of the adherend and glueline. External loading of glued laminated beams usually places finger joint gluelines in shear but this is not the form of stress associated with the cleavage stresses which affect durability. In finger joints, tension and compression loading on the joint leads to the glueline being predominantly in shear but drying shrinkage places the glueline in cleavage. As stated by Ebewele *et al* (1979) "the rationale for a cleavage test, therefore, is to evaluate the peripheral stresses encountered on glued wood specimens during weathering. These stresses exert a prying or wedging effect."

The tests are carried out using a tapered double cantilever specimen defined in ASTM D3433 - 75, Fig 4, for which G can be shown to be given by

$$G = \frac{4P_c^2 m}{Eb^2} \qquad 5$$

where

P_c = critical load necessary to extend the crack

a = crack length

b = width of test beam

$m = [\frac{3a^2}{h^3} + \frac{1}{h}] = 3.54mm^{-1}$ for the standard tapered double cantilever

h = height of specimen at crack tip

The specimen is shaped in such a way that m (= $3.54mm^{-1}$) is constant. Samples are glued together so that the grain angle slopes into the glue face at an angle of 15° of adverse slope which has the effect of inhibiting wood failure and forcing the fracture into the glueline. This angle is lower than the value chosen by Ebewele, who used 20°, but was selected on the basis of maintaining gluing conditions not totally dissimilar to those of finger joints (5° slope) formed in wood having a grain slope of 7°. Ebewele had

indicated that the results for 15° and 20° grain slope were essentially the same. To obtain G, it is also necessary to measure E on an adjacent wood sample having a 15° grain slope. Under test, the sample is loaded at a constant strain rate such that it fails in approximately I minute and a plot of load versus displacement is produced automatically. This results in a characteristic saw-toothed load-displacement curve from which P_c is obtained and G computed using eqn 5. The saw tooth curve peaks and troughs represent the crack initiation and crack arrest loads; the crack initiation loads are the most relevant and it has an associated fracture energy value given by G_{IC}.

2.4 The Performance of Various Glues

Various glues have been investigated by the fracture mechanics approach in the work carried out at Monash covering RF, UF, MUF and polymer isocyanate (PDI) glues. Some of the RF glues had glass beads of a carefully known size added to control glueline thickness. Work by Ebewele on RF glues indicated that gluelines of 90μ were optimal in terms of fracture performance resistance. Typically, finger joint gluelines, where no attempt is made to control glueline thickness, are 25μ - 30μ thick. It was reasoned that the use of appropriate size glass beads might hold the surfaces apart and produce increased fracture resistance.

The test results of table 3 show that the fracture resistance of RF, UF, MUF gluelines are essentially the same in the short term. There is little merit in switching from one to another to improve short term performance.

Glue Designation	Type	G_{IC} Nmm^{-1}
EN23A	RF	90
R15	RF	140
R25	RF	130
A3	RF	120
KB137	PI	570
DPL357	UF	123
DPL412	MUF	100
R15 + CPO3	RF	190

Table 3: Fracture energies of a selection of commercially available and chemically modified glues

RF = resorcinol formaldehyde
UF = urea formaldehyde
MUF = melamine urea formaldehyde
PI = polymer isocyanate
CPO3 = coated glass beads (< 55μ diameter)

For the RF glues, the mix was 100 parts resin to 25 parts hardener. CPO3 was added as an additional 30 parts where used. It has only a minor effect on viscosity. All other glues were mixed in accordance with the suppliers recommendations.

The most interesting aspect to note is the excellent performance of the polymer isocyanate glues (G_{IC} = 570Nmm^{-1} compared to G_{IC} = (90 - 180)Nmm^{-1} for the remainder. Under test, even with grain to glue face angles of 15°, there was evidence of wood failure. Furthermore, there is evidence to suggest that the isocyanates will weather extremely well and

not lose strength under normal operating conditions. Johns (1989) states that "isocyanates have been repeatedly shown to provide mechanically sound, hydrolytically stable joints at very low glue spreads." Given their considerable capacity to resist fracture they warrant further investigation especially given the long standing difficulties which have persisted with native hardwoods. However, problem is the handling of substances which present a health risk. As early as 1962, Skeist (1968) pointed out that "reasonable caution in the use of materials containing free isocyanate, including adequate ventilation in use areas and the prompt cleansing of body areas contacted, is recommended by all isocyanate suppliers."

3 The Overall Strength of Finger Joints

It is possible to have low overall strength with high wood failure. It is only necessary for the finger tips to be so wide that the finger joint becomes the largest defect. This leads to overall failure in the wood at the finger joint. Such a joint would be regarded as exhibiting 100 percent wood failure. It is a desirable aim to design finger joints to be as strong as possible by the elimination of stress concentrations and other shortcomings adversely affecting finger strength.

Milner *et al* (1989) have shown that the following geometric relationships apply to finger joints.

$$L = (P - 2t + \tan\theta)/2\tan\theta$$

or $$P = 2t + 2L\tan\theta - 2c\tan\theta$$

$$A_g = b(L - c)N/\cos\theta \text{ (Profile cut across dimension d)}$$

$$N = 2d/P$$

$$A_e = bd(1 - t/P)$$

$$t_c = t - 2c\tan\theta = P/2 - (L - c)\tan\theta$$

$$\tan\theta = (P/2 - t_c)/(L + c)$$

$$V = Lbd$$

where
V = volume of wood removed in forming fingers

All other variables defined in the Table 1 Legend.

3.1 Short Fingers versus Long Fingers

It has become the practice in Europe and North America to use short, fine tipped fingers in structural applications. Australian manufacturers argue that this approach cannot be applied to native hardwoods because the fine tipped cutters will either wear excessively or overheat.

If the work performed by the various cutting surfaces of a cutter are examined it is possible to deduce that each mm width of a cutter tip removes a volume of wood equal to 1mmxL. Doubling the width does not alter this fact but shortening the finger results in each mm width of the tip having to do less cutting. Likewise, if we concentrate on the last 1mm of the cutter, then the volume of metal available per unit width of the tip to absorb heat and act as a heat sink is 1mmx1mm. This volume is unaffected by tip width although more heat is introduced if the finger is longer.

In the event that cutter wear is a problem the simplest remedy is to reduce finger length or use materials which are more wear and heat resistant.

Attempts to manufacture long length, fine tipped cutters are doomed unless special materials such as tungsten carbide are used.

Typically Australian sawmillers use 24mm long fingers and operate on a tip width of 1mm - 1.5mm.

3.2 Tip Width Effects and Longitudinal Tension Stress Concentrations

If the gaps at the tips of the fingers are approximated as a series of circular holes of diameter equal to the tip width, t, spaced at centres equal the pitch, P, then for a uniform tension stress, σ, the stress concentration factor (σ_{max}/σ) for t/P in the range 0 - 0.4 varies from 3 to 3.1, Peterson (1974). With t = 0.5mm and P = 4mm it eventuates that t/P = 0.125 and there is little possibility of magnifying longitudinal tension stresses significantly through using larger tip widths.

3.3 Tip Width Effects and Glueline Stress Concentrations

Tip width has a quite profound effect on the levels of shear stress induced in finger joint glueline. Milner and Yeoh (1990) have undertaken finite element analyses of three profiles in which the principal objective was to examine both the variation of shear stresses along the finger joint and to observe the effect of tip width on stress levels of joints under uniform tension of 1MPa.

In Profile (a); the pitch was 7.14mm, slope 5.1° and tip width of 0.5mm and 1.5mm and in Profile (g)ii the pitch was 3.7mm, slope 4.8° and tip width 0.5mm. In all cases it can be expected that the glueline shear stresses will average approximately 0.09MPa. In practice there exists a sharp concentration of shear stress near the tip of the finger although right at the tip the shear stress is actually zero. Shear stress rises sharply closely to the tip but settles rapidly to the 0.09MPa value in the central three-quarters of the glueline; see Figs 5-7. Wide tipped fingers exhibit substantially larger stress concentrations than fine tipped fingers. The following results highlight the point. τ is the maximum glueline shear stress.

	Profile	Glue E MPa	Glueline t	P mm	t mm	L mm	θ deg	τ MPa
Fig 5	(a)i	6900	30	7.1	1.5	21	5.1	0.90
	(g)iii	6900	30	5.1	0.5	21	5.1	0.50
	(g)ii	6900	30	3.7	0.5	15	4.8	0.45
	(a)i	3000	30	7.1	1.5	21	5.1	0.59

Table 4: Maximum shear stresses in finger joint gluelines

The effect of the wide tip is clearly evident and highlights why such fingers perform badly. As short fine tipped cutters are also serviceable there is little reason why finger joint geometry should be chosen as other than Profile (g)ii.

In reading the glueline shear stress concentrations it will be noted that the peak value for Profile (a)i is 0.9 MPa, see Fig 5, when the modulus of

elasticity and rigidity are taken respectively as 6900 MPa and 2674 MPa., Glueline thickness is taken as 30μ. In Fig 7 it can be seen that, with the same (a)i profile but E = 3000 MPa and G = 1162 and 30μ glueline thickness, the peak shear stress reduces to 0.59 MPa illustrating how a more flexible glueline reduces glueline shear stress concentrations. Assuming the glueline is 60μ thick is equivalent to halving the glue modulus.

Work at Brighton Polytechnic in the UK indicates that the MOE of sRF glues is of the order of (3000 - 4000) MPa, a value which is difficult to measure. Further it is possible that effective glueline thickness could be as high as 50μ or 60μ which further reduces stress concentrations. It is important to emphasise therefore that the results presented in Figs 5 - 7 should not be interpreted too literally from a quantitative perspective. The results are useful however for relative companions.

4 Recommendations and Conclusions

4.1 Finger Profile (g)ii minimises shear stress concentrations, has reasonable overall strength and the cutters needed to cut this profile should remain serviceable for lengthy periods of continuous use. Its use is recommended.

4.2 A finger profile should exhibit the following characteristics.

4.2.1 The slope should be of the order of 5°. This enables an RF glue to mobilise a local wood stress of 184MPa of longitudinal tension in straight grained wood. It should be noted that the clear wood strength of many Australian hardwoods exceeds this value.

4.2.2 Select a geometry for which the shear stress concentration factor in the glueline is as small as possible. This means keeping the tip thickness to pitch ratio small, say $t/P < 0.15$. There seems to be no reason why t/P should not be zero except for the fact that toolmakers of the author's acquaintance claim they are unable to grind it accurately.

4.3 A finger profile with $t/P = 0.15$ and slope of 5° can be expected to have the following characteristics.

4.3.1 If the glueline is infinitely strong and the wood clear the joint will fail in tension at approximately 85 percent of the clear wood strength.

4.3.2 If the wood is infinitely strong and the glueline strength is given by eqn 5 then, assuming a peak shear of say 0.3 MPa for each 1MPa of joint tension, the joint could activate a tension stress of 16/0.3 = 53 MPa.

4.4 Manufacturers should examine closely the use of polymer isocyanate glues for use in structural finger joints.

4.5 Wood failure in finger joints should be examined in connection with a cleavage test. A value of 70 percent wood failure is tentatively proposed. The test should be conducted on specimens docked and the gluelines grooved in preparation for a Chisel test as illustrated in Fig 8.

5 References

Australian Standard AS1328- 1987, Glued-Laminated Structural Timber, Standards Australia.

Ebewele, R, River, B, Koutsky, J, Tapered Double Cantilever Beam Fracture Tests of Phenolic- Wood Adhesive Joints, Part I. Development of Specimen Geometry; Effects of Bondline Thickness, Wood Anistropy and Cure Time on Fracture Energy, Wood and Fiber, 11(3), 1979, pp197 - 213.

Griffith, A A, The phenoma of rupture and flow in solids, Trans Roy Soc London, A221, 163, 1920.

ISO Draft Standard N134 - 1988, Timber Structures - Solid Timber - Finger Jointing, International Standards Organisation.

Manufacturing Requirements and Quality Control Procedures for Finger Jointed Hardwood Wall Framing Material, Timber Promotion Council, 1983.

Johns, WE, The Chemical Bonding of Wood, Chapter 3, Wood Adhesives Chemistry and Technology, Vol 2, ed Pizzi, A, Marcel Dekker, New York, 1989.

Inspection Manual AITC 200 - 83, American Institute of Timber Construction, 1983.

Peterson, RE, Stress Concentration Factors, Wiley, New York, 1974.

Structural Glued Laminated Timber, American National Standard, ANSI/AITC A190.1-1983.

Leicester, RH, Characteristics of structural timber, Australia-UNIDO Workshop, Melbourne, Australia, 1983.

Skeist, I, Handbook of Adhesives, Reinhold, New York, 1966.

Peterson, RE, Stress Concentration Factors Charts and Relations Useful in Making Strength Calculations for Machine Parts and Structural Elements, Wiley, New York, 1974.

Detail	P	L	t	t_c	c	θ	A_g/bd	A_e/bd	A_g/A_e
Profile (a)									
i	7.14	21.0	1.88	1.52	2.0	5.1	5.3	0.74	7.2
Profiles (b)									
i	9.0	24.8	2.50	2.15	2.0	5.0	5.1	0.72	7.1
ii	6.0	20.0	1.46	1.30	1.0	4.6	6.4	0.76	8.4
Profiles (c)									
i	10.4	38.2	2.41	2.1	2.0	4.4	7.0	0.77	9.1
ii	6.9	24.8	1.62	1.3	2.0	4.6	6.6	0.77	8.6
iii	5.8	20.9	1.41	1.1	2.0	4.5	6.5	0.76	8.6
Profiles (d) - South African Standard									
i	3.0	7.5	0.24	0.02	0.6	10.4	4.7	0.92	5.1
ii	4.0	10.0	0.64	0.40	0.8	8.4	4.6	0.84	5.5
iii	8.0	24.0	1.28	0.81	1.9	7.0	5.6	0.84	6.7
iv	10.0	35.0	1.60	1.01	2.8	6.0	6.5	0.84	7.7
Profiles (e) - German Standard									
i	2.5	7.5	0.45	0.20	1.0	7.0	5.2	0.80	6.5
ii	3.7	10.0	0.83	0.60	1.0	6.5	4.9	0.77	6.4
iii	6.2	20.0	1.20	1.00	1.0	5.7	6.2	0.80	7.8
iv	12.0	50.0	2.16	2.00	1.0	4.5	8.2	0.82	10.0
v	15.0	60.0	2.90	2.70	1.0	4.5	7.9	0.81	9.8
vi	1.6	4.0	0.40	0.40	0	5.7	5.0	0.75	6.7
vii	7.0	15.0	1.92	1.70	1.0	6.4	4.0	0.73	5.5
viii	10.0	30.0	2.20	2.00	1.0	5.5	5.8	0.80	7.3
Profiles (f) - ccb									
i	3.7	8.0	0.85	0.77	0.3	7.4	4.2	0.77	5.5
ii	3.7	10.0	0.60	0.52	0.3	7.3	5.3	0.84	6.3
iii	3.7	11.0	0.40	0.23	0.6	7.9	5.7	0.90	6.3
iv	3.7	15.0	0.50	0.39	0.6	5.4	7.8	0.86	9.1
v	3.7	8.0	0.85	0.85	0	7.1	4.4	0.77	5.7
vi	3.7	4.0	0.40	0.40	0	7.5	6.0	0.90	6.7
vii	3.7	15.0	0.50	0.50	0	5.1	8.1	0.86	9.4
Profiles (g) - Authors									
i	4.0	15.0	0.69	0.50	1.0	5.4	7.0	0.83	8.4
ii	3.7	15.0	0.67	0.50	1.0	4.8	7.6	0.82	9.3
iii	5.1	21.0	0.86	0.50	2.0	5.1	7.5	0.83	9.0

Table 1: Finger joint parameters for a variety of profiles. Profiles (a), (b), (c) are used by Australian manufacturers.

Legend:

b, d = cross-section dimensions
A_g = area of glued faces
A_e= effective (nett) area of joint

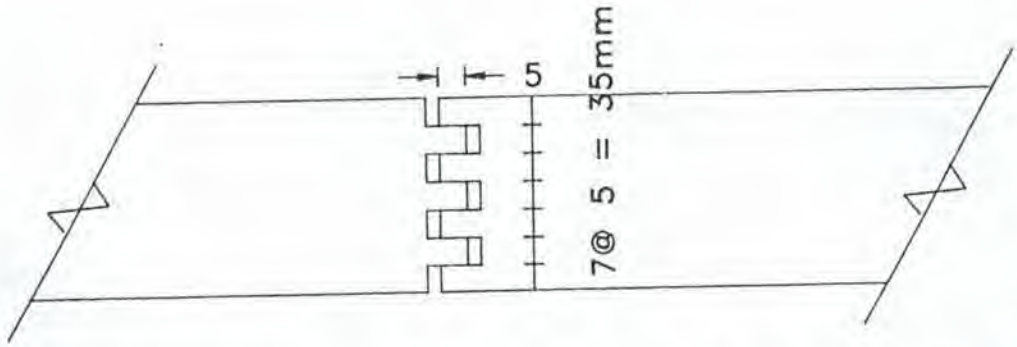

Fig 1: A high wood failure, low strength form of finger joint.(A_g/bd = 0.9, A_e/bd = 0.43)

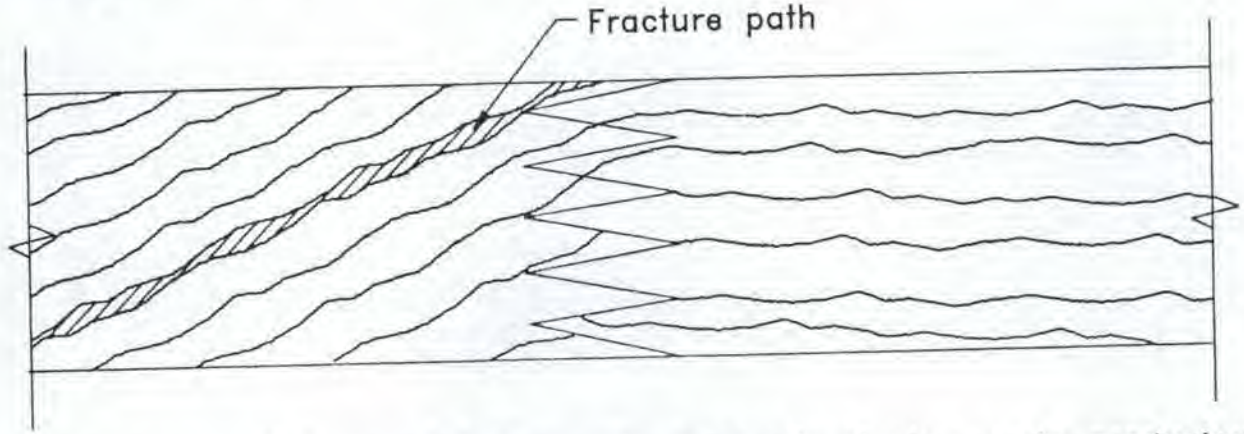

Fig 2: "Weak wood" form of failure with generally sloping grain producing 100 percent wood failure at low load.

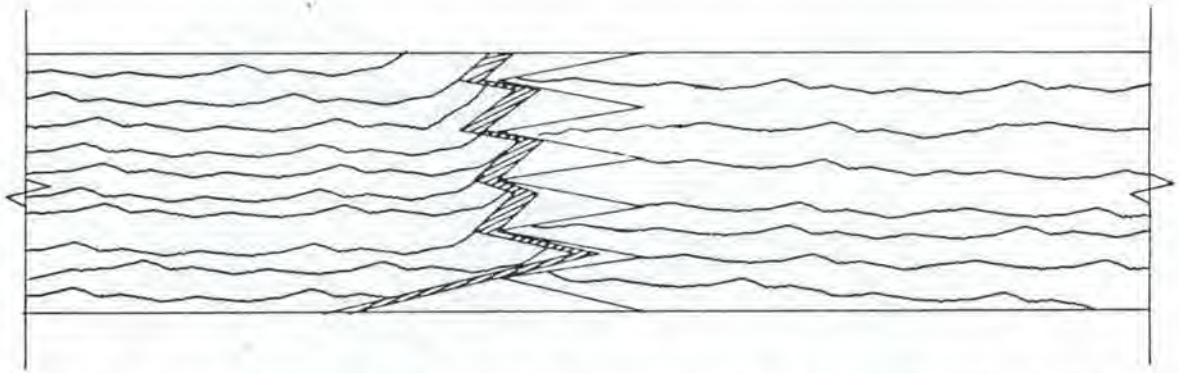

Fig 3: Wood failure pattern with wood grain sloping locally but anchored in main body of wood. Tendency to leave small wedges adhering to the finger face sloping in sympathy with the wood grain.

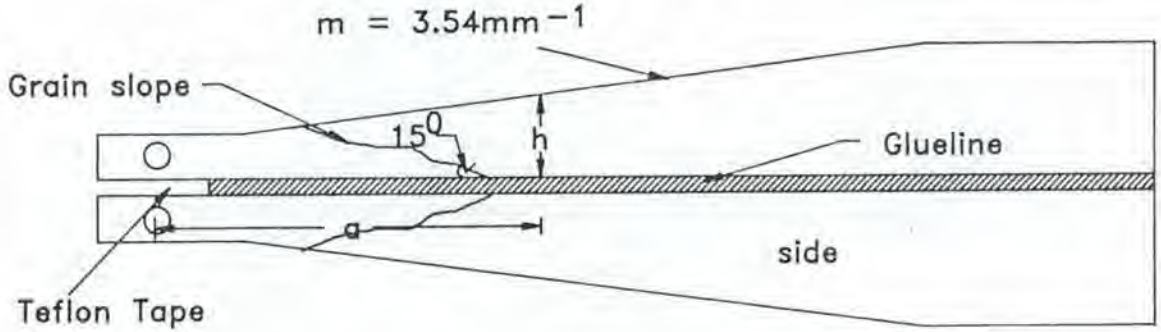

Fig 4: Standard double tapered cantilever beam used to measure the fracture strength of gluelines.

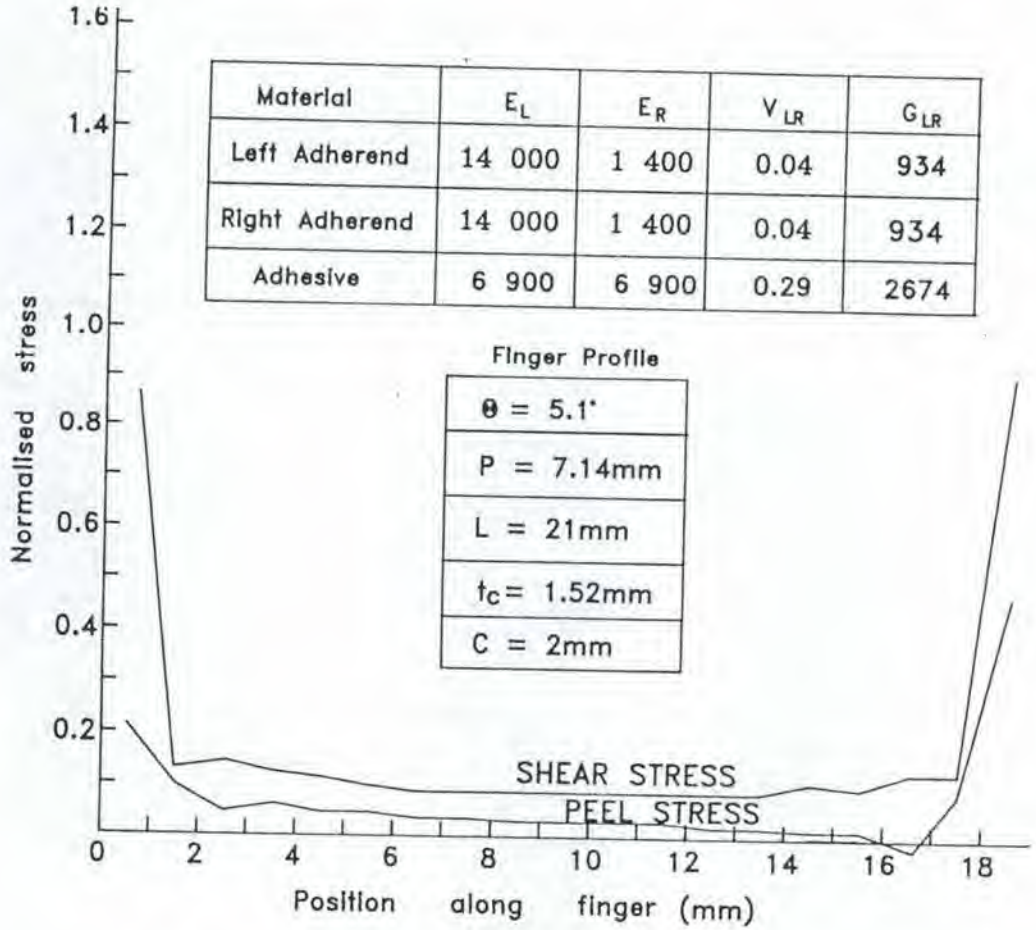

Fig 5: Normalised shear and peel stresses along finger glueline – Profile(a)i.

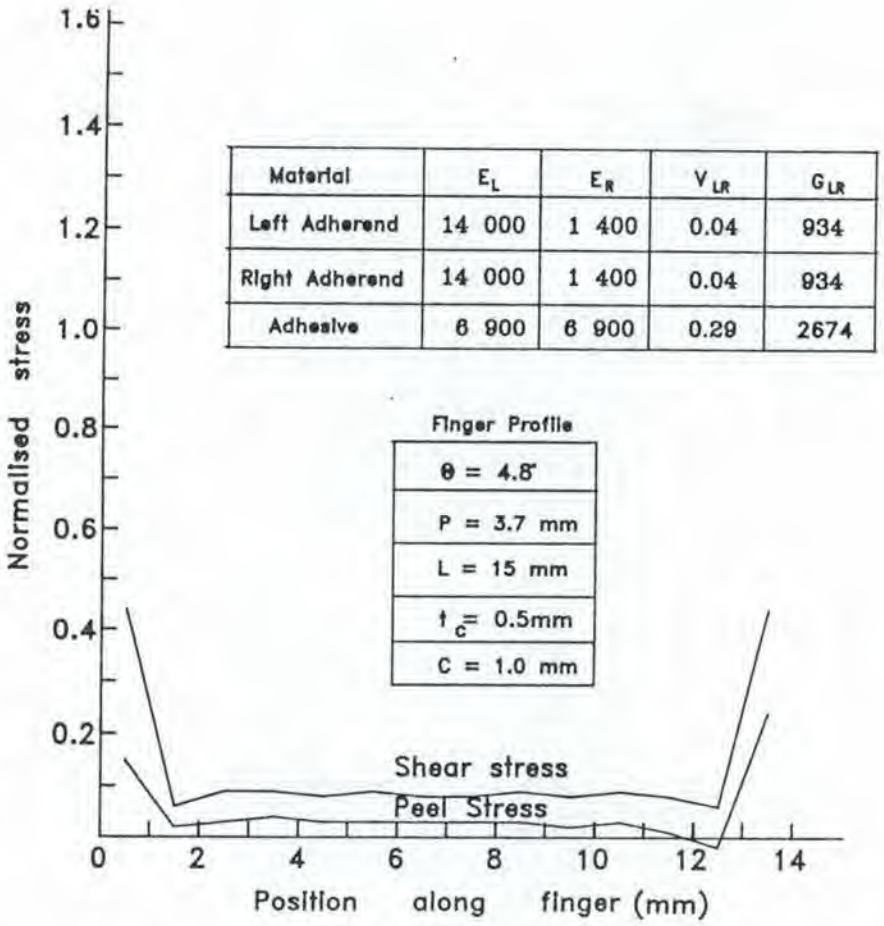

Fig 6: Normalised shear and peel stresses along finger glueline – Profile (g)II.

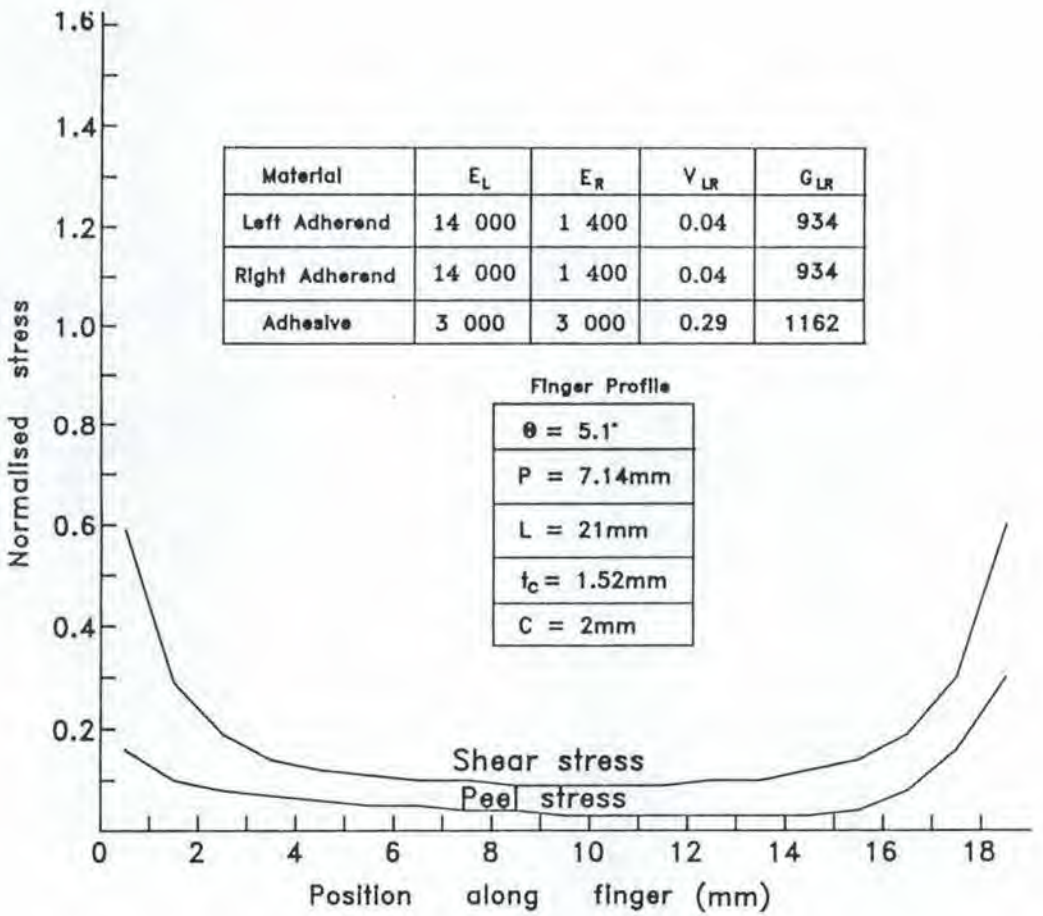

Fig 7: Normalised shear and peel stresses along finger glueline – Profile (a)I.

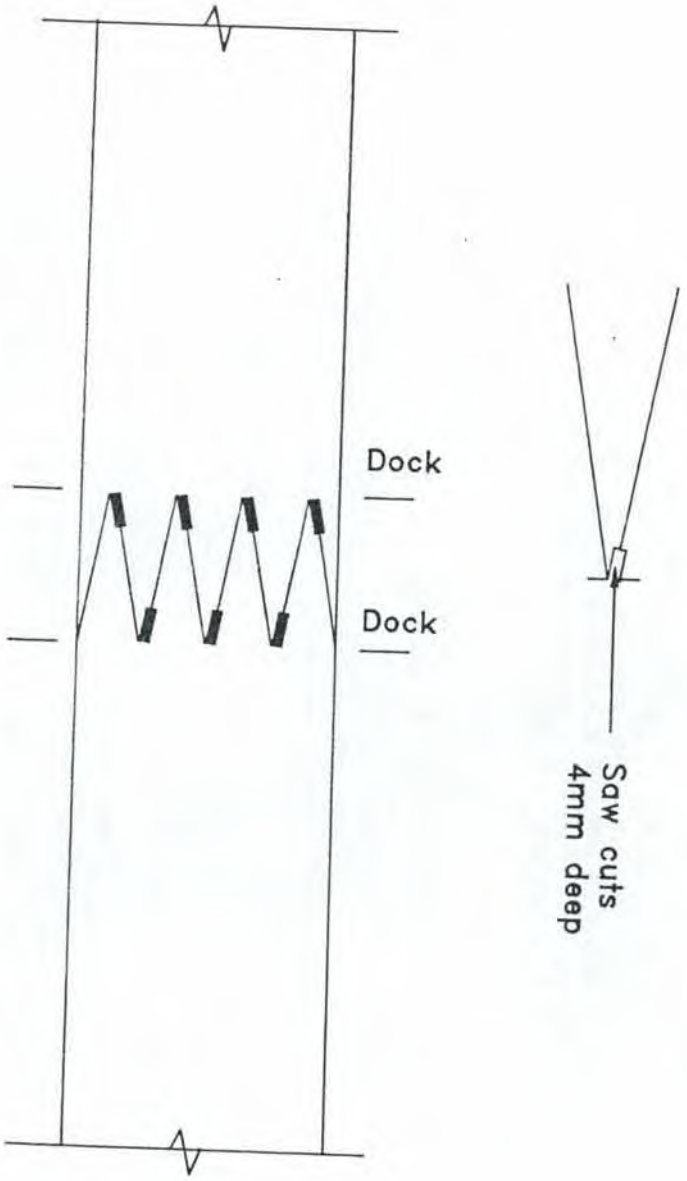

Fig 8: Finger joint cleavage samples.

STOCKPILING AND SAWING REGROWTH EUCALYPTS

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ABSTRACT

A preliminary stockpiling trial indicated that regrowth jarrah (*Eucalyptus marginata* Donn. ex Sm.) logs could be stored under a schedule of 1h on:3h off without adversely affecting log and timber quality, but subsequently regrowth jarrah and karri (*E. diversicolor* F. Muell.) logs were successfully stored under a schedule of 15 min on:165 min off. Assessment of two continuous watering objectives (high volume/high pressure and low volume/low pressure) indicated that the low volume system is more applicable with limited capital and water supplies, and the volume to stockpile is less than 1000 m^3.

Using sawing techniques which reduce the effect of growth stress, the following regrowth species, either native or introduced to Western Australia, were evaluated: jarrah, karri and marri (*E. calophylla* R. Br. ex Lindl.), red mahogany (*E. resinifera* Sm.), rose gum (*E. grandis* W. Hill ex Maiden) and Tasmanian blue gum (*E. globulus* Labill. subsp. *globulus*).

INTRODUCTION

In June 1986 the Department of Conservation and Land Management received a $4.6 million grant over four years for utilisation research on regrowth eucalypts, both native to Western Australia and eastern states species grown in W.A. The funding for this Small Eucalypt Processing Study (S.E.P.S.) was from three sources:- Commonwealth, the State Government and the W.A. timber industry.

The aim of the project was to research new methods of stockpiling, sawing, drying and processing regrowth eucalypts, and evaluating wood properties, with particular emphasis on value-adding.

Research concentrated on regrowth jarrah (*Eucalyptus marginata* Donn ex Sm.), karri (*E . diversicolor* F. Muell.) and marri (*E. calophylla* R. Br. ex Lindl.). Sawmilling studies included the following eastern states species grown in Western Australia: rose gum (*E. grandis* W. Hill ex Maiden), red mahogany (E. resinifera Sm.), and Tasmanian blue gum (E. globulus Labill. subsp. *globulus*). This paper discusses the stockpiling and sawing studies completed during this S.E.P.S. Project.

STOCKPILING

Stockpiling of regrowth jarrah and karri logs using different watering schedules

This study [3] was divided into two parts. In Part I, regrowth jarrah logs were stored under watering treatments ranging from continuous to 1h on:3 h off. The latter treatment was continued for a second summer. The results of Part I indicated that further reductions in watering schedules were feasible, and were used in designing Part 2, which assessed the effect of reduced watering on regrowth jarrah and karri logs. In both studies, degradation of logs stored under reduced watering regimes was compared with that of logs stored under continuous sprays. The effect of reducing the amount of water was assessed by comparisons of log end splitting, surface checking, and insect damage (particularly attack by bardi). Variation in log moisture contents was also estimated. Bow and spring of the sawn flitches and boards from stockpiled logs were compared with that of flitches and boards sawn from recently harvested logs.

PART I (Regrowth jarrah)

Bay A - continuous watering.

Bay B - 1 hour on; 1 hour off.

Bay C - 1 hour on; 2 hours off.

Bay D - 1 hour on; 3 hours off.

Bay E - 1 hour; 1 hour from 0600 then 1 hour on, 3 hours off from 1800.

Figure 1 shows the stockpile design and treatments.

Moisture Contents

The mean moisture contents of regrowth jarrah heartwood were greater than those of sapwood before stockpiling (99 and 80 per cent respectively), and after stockpiling (108 and 85 per cent respectively), taking the average of large and small end values. Heartwood moisture contents in the 1 h on:3 h off treatment (two summers of drying) were 13 per cent less than for one summer of drying, indicating that end drying had occurred. In general, the large standard deviations indicated that statistical significance was not important in commercial practice.

End Splitting

Storing for two summers compared with one at the 1h on: 3h off schedule, resulted in more splitting, and logs sawn fresh had significantly more splitting than logs in the former treatment. This indicated that splits occurring between felling and stockpiling tended to contract during storage. End splits did not present any problem during sawmilling and all logs were cut into 28 mm boards.

The time between felling and stockpiling is very important, because increased time in the forest results in more degrade through end splitting. Reducing the time between felling and stockpiling under water spray to a period of two or three day will limit end splitting. The logs which were sawn fresh were in the forest for approximately one week, which is too long if degradation is to be prevented, particularly in the hot summer months.

Bow and spring

Sample logs were all sawn using the Waugh [4] cutting pattern, to determine the effect of stockpiling treatment on bow and spring.

Storage for 1 h on:3 h off (two summers) resulted in significantly more bow (6.2 mm/m) in boards than found in the other treatments. No significant difference was found between logs sawn fresh and one summer's storage under any of the five watering regimes. This mean bow is within the limits given in A.S. 2082-1979 [5]. For spring, the Kruskal-Wallis test showed significant differences between flitch halves and boards cut from logs from different water spray treatments. However, the mean ranges for flitch halves and boards were 1.3 mm/m and 0.4 mm/m respectively, which is negligible in commercial operations.

General

Operating pumps on a 1h on: 3 h off schedule saves 75 per cent of water and electricity compared with continuous watering.

The success of this trial suggested that the schedule of 1 h on: 3 h off for water sprays, which used the least water and power without adversely affecting log quality, could be reduced further. The second part of the trial was then commenced, using more radical watering schedules.

PART II Regrowth jarrah and karri

The stockpile design and treatments (Fig. 2) show that regrowth jarrah was stored in six bays, and regrowth karri in four bays. The effect of water duration (15 minutes spraying at a time compared with 1 hour) and intensity (the time interval each bay received water) were assessed.

Log degradation

As in Part I, end splitting for regrowth jarrah and karri was not a problem during sawmilling, and all logs were satisfactorily processed into 28 mm boards.

Moisture contents

The initial moisture contents of regrowth jarrah heartwood were greater than those of sapwood before stockpiling (97 and 76 per cent respectively). However, after stockpiling heartwood moisture contents were less than sapwood (85 and 93 per cent respectively), presumably because of some end drying. This was a different result to Part 1 where logs were stockpiled for approximately 6 months less.

Moisture from the heartwood can be restricted from moving to the surface by tyloses concentrated around the heartwood/sapwood boundary, but moisture can readily move along the grain and out of log ends. End drying of regrowth jarrah logs in all bays resulted in heartwood moisture contents decreasing. Sapwood moisture contents still increased as in Part I, owing to diffusion of water through the bark and sapwood cells. Heartwood moisture contents for regrowth karri were greater than those of sapwood before stockpiling (91 and 80 per cent respectively), and after stockpiling (102 and 94 per cent respectively).

Figure 1. Stockpile design and treatments in Part 1 (Bays A to E).

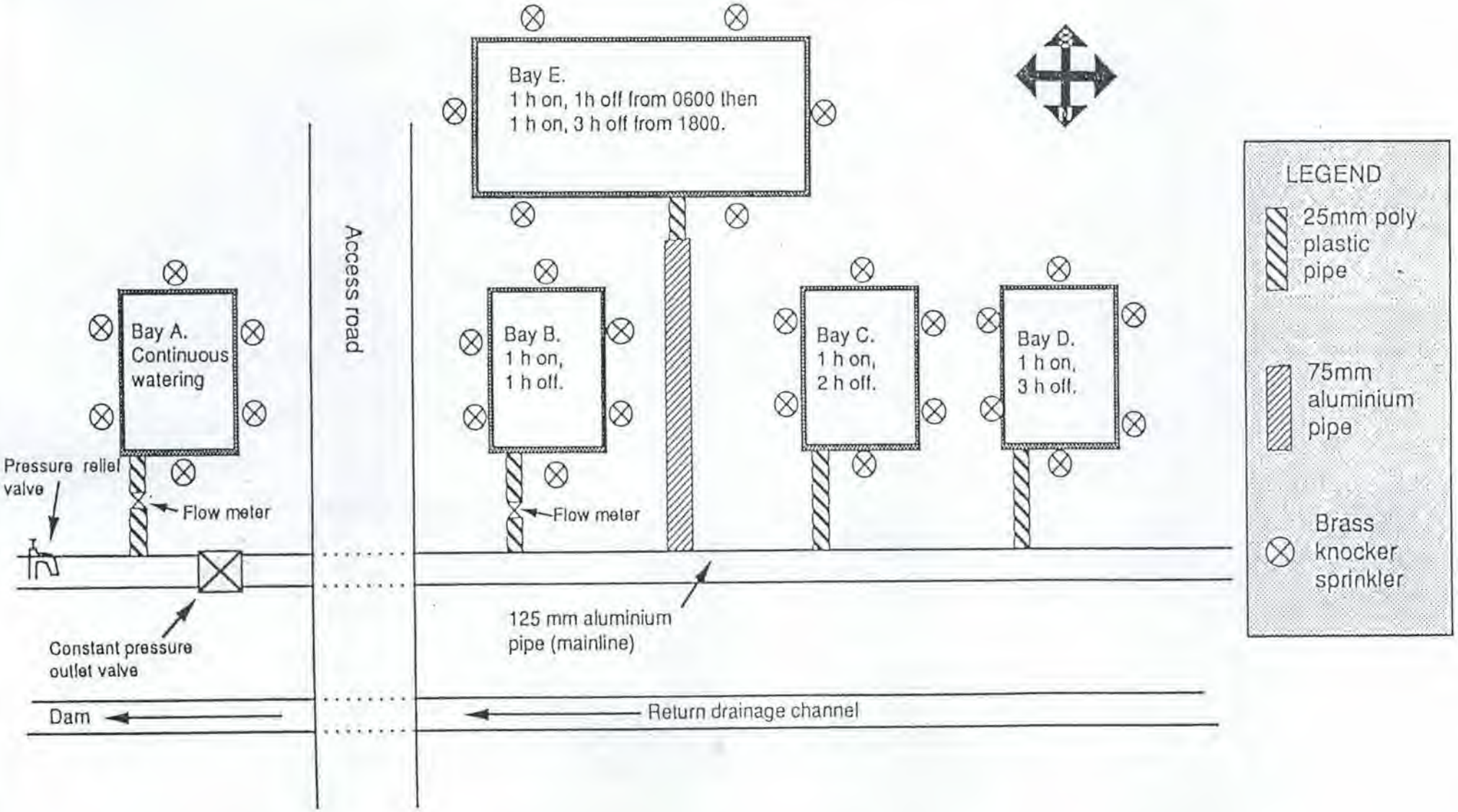
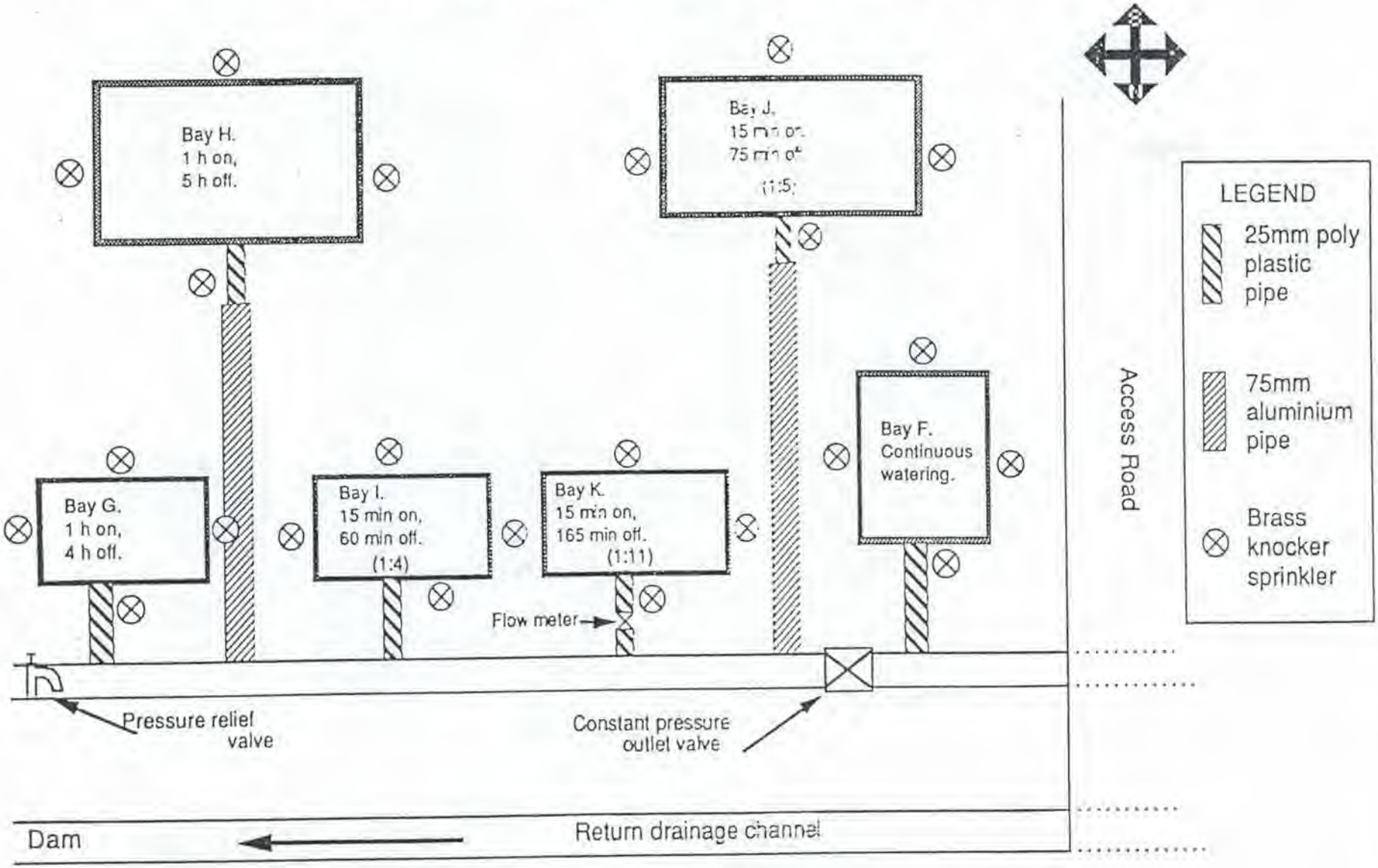


Figure 2 Stockpile design and treatments in Part 2 (Bays F to K).



Sawmilling

Generally the bow and spring measurements in boards in Part II were larger than those in Part I even though the latter logs were stockpiled for 6 months less. This result was not expected. Mean bow of regrowth karri boards in Part II was 6.1 mm/m. This amount of bow is unacceptable for Structural Grades 1, 2 and 3 in A.S. 2082-1979 [5]. Drying of the boards subsequently reduced bow to limits acceptable to AS 2082-1979. For spring in boards, a significant difference was found between bays. However, the mean difference between bays was only 0.6 mm/m, which is not of practical importance.

General

In summary, regrowth jarrah and karri can be successfully stored under a 15 min on: 165 mins off watering schedule, a saving in water and electricity of 92 per cent compared to continuous spraying. Comparison of reduced watering regimes with continuous spraying showed no problems with the amount of end splitting and bow and spring of milled boards based on this trial, sawmills using water sprays to protect stockpiled logs need to determine the watering regime most suited to their water supply, pump capacity and stockpile design. The principles outlined should apply to stockpiling under high pressure water sprays of any regrowth eucalypt logs.

Comparison of low and high pressure watering systems for stockpiling regrowth jarrah logs.

The purpose of this trial was to compare degrade in jarrah logs after six months storage under continuous water spray using:-

1. high pressure/high volume knocker-type sprinklers.
2. low pressure/low volume black polypipe 'soaket' system.

Both systems were assessed using both bark-on and debarked regrowth jarrah sawlogs [6].

Results

Water consumption was approximately four times higher for the high pressure system and it was four times as expensive to operate. Assessment showed increased end splitting in the butt ends of both debarked and bark-on logs in the low volume application. However, the results indicated that both high pressure and low pressure systems are capable of maintaining regrowth jarrah mill logs in good condition. If capital and water are limiting factors, and the volume to stockpile is less than 1000 m^3, then it is considered that the low volume system would be most cost-effective.

SAWMILLING

In the late 1960s most Australian sawmillers regarded eucalypt sawlogs of 50 cm mid-diameter as too small and unprofitable for conversion to general sawn products [7].

The timber industry in Western Australia is already becoming increasingly dependent on smaller logs, and research was directed at investigating methods of sawing small sawlogs and seasoning of the sawn timber. The W.U.R.C. at Harvey had a twin edger for log breakdown and a vertical band resaw which were used in the S.E.P.S. project for sawmilling research. Sawmilling trials were conducted using the following species; regrowth jarrah, karri and marri, red mahogany, rose gum and Tasmanian blue gum.

Regrowth jarrah

Three sawing patterns developed for sawmilling of ash-type eucalypts in south-eastern Australia were assessed:- one by Waugh [4] and two by Machin [8] as shown in Figure 3.

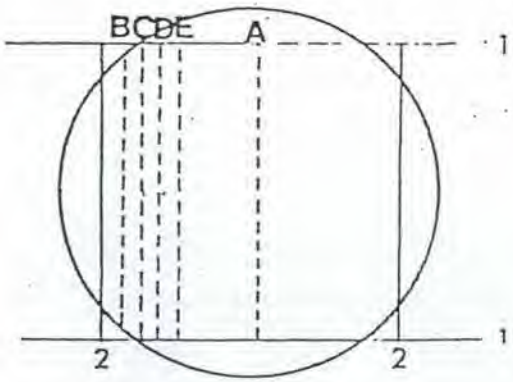
Recoveries were assessed from each of the three sawing patterns from four log length classes and five diameter classes. The data indicated that log length did not affect recoveries of 25 mm thick boards, but as expected, log diameter had a significant effect on recovery with all three sawing patterns. The larger the diameter, the greater the recovery, with a mean recovery of 21.4 per cent for all patterns [9].

The measurements of bow and spring in the flitches indicated that sawing pattern had a minimal effect. In general, the Machin 1 pattern resulted in less bow and spring in flitches and boards than found using the other two patterns. This was consistent in both fresh sawn material and that from logs sawn after stockpiling under water spray for 18 months.

Recovery from regrowth jarrah sawlogs extracted from different locations

The recoveries of regrowth jarrah cut with the Waugh [6] pattern from four different areas are given in Table 1. The mean small end diameter under bark (s.e.d.u.b.) was 20.9 cm and mean log length was 3.8 m for all areas. Mean log diameter showed little variation for logs harvested from the different areas. However, differences in logging methods and equipment had a large influence on log length [10].

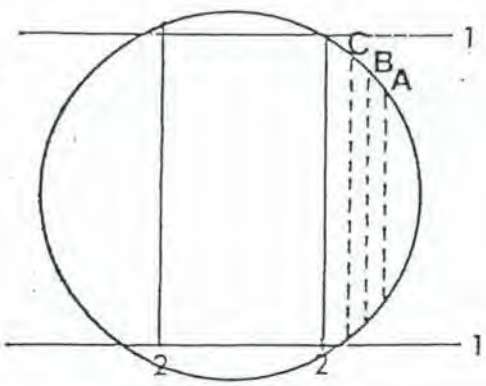
Figure 3. Sawing patterns tested in jarrah sawmilling trial.



Waugh (1980)

1 + 2 Twin Edger Cuts

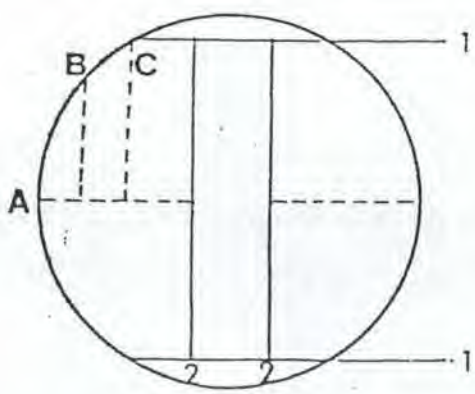
A to E Resaw Bandsaw Cuts



Machin 1 (1981)

1 + 2 Twin Edger Cuts

A to C Bandsaw Cuts



Machin 2 (1981)

1 + 2 Twin Edger Cuts

A to C Resaw Bandsaw Cuts

The mean sawn recovery of regrowth jarrah from four different areas in the northern jarrah forest was 23.2 per cent and ranged from 21.4 to 26.4 per cent. The combined recoveries for all areas by diameter and length classes showed that recovery increased with increasing diameter, ranging from a mean of 14.0 per cent for logs 10-14 cm s.e.d.u.b. to 34.9 per cent for logs 36-40 cm s.e.d.u.b. Length did not influence recovery.

Recovery of logs greater than 25 cm s.e.d.u.b. is comparable with that from 'traditional' sawlogs cut from mature jarrah trees. Below 25 cm s.e.d.u.b. the recovery decreases, although in the present study a recovery of 24.5 per cent was achieved in the 20-24 cm diameter class.

TABLE 1: RECOVERY OF REGROWTH JARRAH FROM DIFFERENT AREAS

Log source	S.e.d.u.b. (cm)			Length (m)			Recovery(%)		
	Mean	S.D.	Range	Mean	S.D.	Range	Mean	S.D.	Range
Banksiadale Rd	21.2	4.3	15-35	3.6	1.2	2.5-5.9	21.6	8.3	5.0-37.9
Kent Block	19.3	3.9	12-31	3.3	0.8	1.2-5.4	21.2	8.4	0.0-41.0
Ross Block	20.9	3.6	15-32	5.0	1.0	2.2-7.8	26.4	8.2	12.5-50.7
Inglehope Plots sawn fresh)	22.8	5.4	14-37	3.4	1.1	1.6-6.0	25.6	10.2	5.9-7.6
Inglehope Plots (Stored for 3-4 months)	20.4	3.4	13-35	3.6	1.1	2.3-6.2	21.4	8.7	6.1-44.9
Mean	20.9	5.3	13-37	3.8	1.2	1.2-7.8	23.2	9.2	0.0-50.

Sawing regrowth karri

Regrowth karri stands (49 to 70-years-old) were thinned to produce data for a utilisation study. Two high, medium and low rate qualities, and dominant, co-dominant, sub-dominant and suppressed trees were assessed [11].

Recoveries were related to log size i.e. the larger logs had higher recoveries, and hence butt logs had greater recoveries than mid and crown logs, and dominant/co-dominant trees had greater recoveries than sub/dominant/suppressed trees. Structural boards were graded to AS 2082-1979 into Structural Grades 1, 2, 3 and below grade, and appearance boards according to the W.U.R.C. grading rules. For all plots the mean recovery was 26.6 per cent, of which 23.5 per cent made structural grades 1, 2 or 3 and 3.1 per cent made appearance grade. Most of the structural boards made grade 3 (42.7 per cent) with high proportions in grades 1 (23.3 per cent) and 2 (16.4 per cent), indicating that inherent defects (particularly knots) in regrowth karri were not a problem when grading to AS 2082.

Brownwood (discoloured heartwood) in karri has been recognised for at least 35 years. It is particularly common in regrowth stands, its cause is unknown and it is not considered to be a defect. Brownwood appears to be a wound response by regrowth karri to fungal invasion. Some of these fungi have the ability to degrade lignin and cause either straw rot in sapwood or white pocket rot in heartwood within a year (Davison, personal communication). In our study samples from trees with signs of fungal attack were taken from the six plots and used in a karri rot study. All 36 trees used in that study had some symptoms of decay i.e. discoloured sapwood, brownwood, white pocket rot, straw rot, discoloured brittle heart or discoloration associated with insect galleries.

Brown rot, white pocket rot and straw rot are secondary and tertiary forms of decay. The small amount of these rots recorded could be due to the young age of these trees as the fungi have not advanced to produce secondary and tertiary decay.

In another regrowth karri sawmilling trial, White [12] found that more than 80 per cent of the sawn production was Structural Grade 3 or better i.e. F11 stress grade or above and the recovery of structural timber was 30.2 per cent. For appearance grades little furniture grade material was produced, with a rejection rate in excess of 50 per cent due to insect damage and associated brownwood.

Sawmilling regrowth marri

Marri timber is straight-grained and pale in colour. The high incidence of kino veins produced as a wound response after insect attack or mechanical damage has limited the use of the species, and sawmillers have not been able to mill it economically. There is increasing interest in using marri for sawn timber, in both structural and appearance grades.

Dr. E. Davison, Department of CALM, Como 6152.

In a sawmilling trial [13], the recovery of 23 per cent in Structural Grade 3 or better, and 3.0 per cent into appearance grade, achieved from log 15-36 cm s.e.d.u.b., were considered satisfactory because larger logs in regrowth karri produced only 30.6 per cent green sawn recovery. More stringent control over log quality would improve the results from logs in the size class 15-19 cm s.e.d.u.b., because many small logs returned recoveries of only 15 to 21 per cent.

Sawmilling trials of Eastern States eucalypts grown in Western Australia

Sawmilling of red mahogany grown on a rehabilitated minesite :

In Western Australia, red mahogany has been extensively planted as an exotic by Alcoa for rehabilitating bauxite minesites. Although the species is used in Eastern Australia for a range of products such as flooring, cladding, panelling, construction, sleepers and poles, there were no data on the quality of Western Australian grown timber.

A sample of 23-year-old red mahogany grown on a rehabilitated minesite, was assessed for its suitability for producing structural grade timber [14]. The logs used came from trees which had minimum silvicultural treatment with no previous thinning or pruning.

Sawing involved two passes of logs o;ver a twin edger with overhead beam feed to obtain a square flitch, and then subsequently resawing on a vertical bandsaw. The product cut was 115 mm x 34 mm green-off-saw boards, with the intention of making Structural Grade 3 for A.S. 2082-1979.

Log quality was poor overall, and the frequency and amount of defect present were sufficient to result in whole boards and in some cases whole logs being rejected. These defects included knots, sapwood, insect attack, gum pockets and rot. The high incidence of decayed wood around branch stubs was of particular concern. Collapse near the heart during seasoning had resulted in downgrading some boards.

Mean recovery of dried dressed Structural Grade 3 board was 12 per cent, with a range from 0 to 34 per cent from specific logs. This recovery was considerably lower than the 25 per cent which local sawmilling achieves from milling jarrah and karri logs, due mainly to small log size and the poor quality red mahogany logs. The poor results of this trial indicated that red mahogany used to rehabilitate other sites should have log quality assessed.

Silvicultural treatments such as pruning could reduce the incidence of defects to a certain extent.

Sawmilling trial of rose gum

A sawmilling study of locally-grown rose gum included assessment of recoveries after initial breaking down of logs with either a Forestor 150 horizontal bandsaw or a timber edger with overhead beam feed [15].

After shrinkage during drying, and dressing, the dried graded recovery of boards sawn by the horizontal bandsaw and by the twin edger were 24.5 per cent and 20.0 per cent respectively. The combined recovery was 22.4 per cent. Grading results were as follows:-

TABLE 2. GRADING RESULTS OF ROSE GUM SAWN INTO 30 MM THICK BOARDS

Grade	Per Cent
Clear	4.3
Feature	18.1
Processing	23.3
Merchantable	52.0
Reject	2.3

The results showed that 50.3 per cent of the boards were downgraded because of knots. In the case of downgrading to merchantable grade, bark-included knots were the major reason, while borers, gum veins and gum pockets were often in the same board, making the board totally unsuitable for furniture use. Clear and feature grades were 22.4 per cent, which was considered a reasonable result.

Rose gum, although easy to saw and dry, tends to have faults such as bark-included knots, kino and borers when grown as an exotic in Western Australia. The grading results indicated that it would be an advantage to prune branches to reduce the number of knots.

Sawmilling trial of Tasmanian blue gum

The W.A. Government and private industry propose to establish Tasmanian blue gum as the major species in approximately 100 000 ha of plantations in the south-west of Western Australia. Although planted primarily as a source of pulp wood, the species can provide significant ecological benefits by reducing the affects of salination and eutrophication through soil rehabilitation, and by providing habitats for fauna .

In addition the species can provide sawlogs for structural or appearance timber if the stands are managed well, and grown for about thirty years.

Thirty-two 24-year-old Tasmanian blue gum trees were harvested and the resultant logs sawn at the W.U.R.C. [16]. Timber is apparently tougher to saw than the regrowth jarrah and karri which are routinely sawn at the W.U.R.C. sawmill, and a slower feed speed through the saws was necessary.

The amount of deflection (generally bow) of sawn timber after milling on the bandsaw was comparable to that of regrowth karri. In most logs the heart was eccentric and associated with kino, brown, straw and white rot and the discolouration known as brownwood. This combination of defects often resulted in discarding of the middle 75 x 75 mm or 100 x 100 mm section of the centre cant containing the heart. Recovery of all timber was 30.5 per cent, with structural timber (i.e. 40 and 50 mm thick) comprising 14.6 per cent and appearance timber (i.e. 30 mm thick) 15.9 per cent.

The results indicated that blue gum timber could be used for structural material, but that appearance grade timber suitable for furniture use must be selected carefully.

REFERENCES

1. Shearer, B.L. and Tippett, J.T. (1989). Jarrah Dieback: The dynamics and management of *Phytophthora cinnamoni* in the jarrah (*Eucalyptus marginata*) foreIst of south-western Australia. Department of Conservation and Land Management, Research Bulletin No. 3.

2. Waugh, G. (1986). Sawing small-diameter eucalypts in Australia. Paper to 22nd Forest Products Research Conference, Melbourne, Victoria, November 1986.

3. Brennan, G.K., Glossop B.R. and Mathews L.R. (1990a). Stockpiling of regrowth jarrah and karri logs using different watering schedules. Department of Conservation and Land Management. W.U.R.C. Report No. 16.

4. Waugh, G. (1980). The potential of plantation eucalypts for sawlog production. CSIRO Division of Building Research, D.B.R. Reprint 1001.

5. Standards Association of Australia (1979). Visually stress graded hardwood for structural purposes. AS 2082-1979.

6. White, K.J. (1990). Comparison of low and high pressure watering systems for stockpiling regrowth jarrah logs. Department of Conservation and Land Management. W.U.R.C. Technical Report No. 14.

7. Page, M.W. (1978). Production of sawn wood from small eucalypt logs. In: Eucalypts for Wood Production, Chapter 15 (Eds. Hillis, W.E. and Brown, A.G.). CSIRO, Griffin Press Limited, Adelaide, South Australia.

8. Machin, J. (1981). The challenge of small diameter regrowth eucalypts. Australian Forest Industries Journal 47(1):48-50.

9. White, K.J. (1989). Regrowth jarrah stockpile and sawmilling trial. Conservation and Land Management. W.U.R.C. Technical Reports No. 7.

10. Brennan, G.K. and Ward S.L. (1990). Recovery from regrowth jarrah sawlogs. Department of Conservation and Land Management. W.U.R.C. Technical Report No. 20.

11. Brennan, G.K., Glossop B.R. and Rayner M.E. (1990). Sawmilling regrowth karri of different ages and dominance classes from different site types. Department of Conservation and Land Management. W.U.R.C. Technical Report No. 29.

12. White, K.J. (1989). Sawmilling of regrowth karri logs. Department of Conservation and Land Management. W.U.R.C. Technical Report No. 8.

13. White, K.J. (1989). Sawmilling trial of regrowth marri. Department of Conservation and Land Management . W.U.R.C. Technical Report No. 6.

14. Raper, S.C. (1990). Sawmilling of red mahogany grown on a rehabilitated minesite. Conservation and Land Management. W.U.R.C. Technical Report No. 19.

15. Hanks W.R. (1990). Sawmilling study of rose gum. Department of Conservation and Land Management. W.U.R.C. Technical Report No. 17.

16. Thomson, A.B. and Hanks, W.R. (1990). Sawmilling study of Tasmanian blue gum grown in Western Australia. Department of Conservation of Land Management. W.U.R.C. Technical Report No. 13.

SEASONING REGROWTH EUCALYPTS

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ABSTRACT

This paper discusses drying research in regrowth eucalypts carried out by the Department of Conservation and Land Management over the last four years. Early research using a progressive tunnel kiln to dry jarrah (*Eucalyptus marginata* Donn ex Sm.) boards provided data subsequently used in development of initial drying schedules for 140 x 40 mm and 140 x 30 mm timber in a batch kiln.

Research on pretreatments to increase drying rates indicated that hot water soaking has potential, and a collapse study in jarrah is reported. High temperature drying can be successfully done when moisture contents are below fibre saturation point.

INTRODUCTION

The Small Eucalypt Processing Study conducted by the Department of Conservation and Land Management's Wood Utilisation Research Centre (W.U.R.C.) was completed on the 30 June 1990. Within the study research was performed on stockpiling, sawmilling, drying, wood properties, and product development. The research was carried out on a range of species, including eastern states eucalypts. This paper will cover the drying research, which was primarily oriented to producing furniture grade timber from regrowth eucalypts.

Drying by Progressive Tunnel Kiln

Early research at the W.U.R.C. included drying studies of mature jarrah boards, which provided useful information which was subsequently used in the S.E.P. Study.

In the early 1970's CSIRO had developed a progressive tunnel kiln for drying timber which, in simple terms, relied upon the timber moisture itself and a flow through of air to create a range of suitable drying conditions. The overall feasibility has been demonstrated by the CSIRO and commercial kilns are operating in Tasmania.

We set out to test a simple modified version of the progressive tunnel kiln at the Wood Utilisation Research Centre (W.U.R.C.) using 75 x 25 mm mature jarrah (*Eucalyptus marginata* Donn ex Sm.) (1). The tunnel kiln was 12m long, 2.4m wide and 0.8m high and held 10 small bundles of approximately 0.5 m^3 . Wet and dry bulb temperature sensors were used to record air entering and exiting the kiln. Unlike the CSIRO design, the timber was oriented across the kiln and the air flowed straight through. Baffling was used to force all air through the bundles. Air velocity was approximately 1 m/sec.

TABLE 1.
DRYING CONDITIONS AND BEHAVIOUR DURING THE FIRST WEEK IN THE TUNNEL KILN.

Period	Av. Temp (°C)*	Av. RH (%)*	Initial MC (%)	Drying Rate (%/day)	Surface† Checking
Spring/summer	17.1	73	72	3.7	44.0
Autumn	16.9	84	75	2.3	11.0
Winter	12.6	88	72	1.1	2.0

* Average of conditions at 0300 and 1500 hrs only.

† Four boards assessed for presence of surface checks.

The frequency of surface checking varied with seasons (Table 1). Air conditions at the green end in the winter were suitable particularly for drying. In autumn, a moderate amount of checking resulted, while in summer severe checking occurred. Thus to reduce checking to a minimum in the first week, the RH should be kept at 84 per cent or greater, or alternatively, control drying rate to 2 per cent per day or slower.

The overall drying time from 70 per cent MC to below 30 per cent took six to eight weeks during winter.

In conclusion, the tunnel kiln was of insufficient length to dry 25 mm mature jarrah successfully in the summer months, while winter drying was successful. The results provided useful information which was subsequently applied in the S.E.P. Study research on timber of greater thickness.

Drying Regrowth Eucalypts using a Low Temperature Batch Kiln

The tunnel kiln study described above indicated that a low temperature, a high RH, and moderate air flow successfully dried mature jarrah. We believed that these conditions would be a good starting point when investigating the pre-drying of regrowth eucalypts in a batch kiln.

A batch kiln with a capacity of approximately 0.5 m^3 of green timber, with accurate monitoring and control, was used for this study [2]. A particular set of conditions was tested for a bundle of mixed species in each run. For most runs the mixture included mature and regrowth jarrah, plus mature and regrowth karri (*E. diversicolor* F. Muell.).

In the early stages of drying all boards were examined each week for the presence of surface checks. A smaller number of sample boards were weighed at each inspection to determine the MC.

The drying conditions began as moderate and were made progressively milder with each successive run until acceptable drying results were obtained (Table 2). Thus Runs 7 and 8 provided acceptable results for 140 x 40 mm regrowth jarrah and Run 10 for 140 x 30 mm jarrah respectively.

Seasoning degrade in Run 8 caused 14 per cent downgrading and 4 per cent rejection (by volume). The acceptable schedule for Run 10 (30 mm) was harsher than the acceptable 40 mm schedule, as expected. Run 10 conditions caused only 6 per cent downgrading due to seasoning defects, and no boards were rejected.

The overall effect of defects and features allowed 60 per cent of the timber to be clear or feature grade (new W.U.R.C. furniture grading rules) in both Runs 8 and 10. The ability to dry furniture grade timber was a result of slow air flow, high RH and low temperature.

Regrowth karri at first appeared distinctly more difficult to season than regrowth jarrah, showing numerous surface checks. After dressing and grading, however, the difference was less discernable. For example, regrowth jarrah had 60 per cent of timber in clear plus feature grades, compared to 56 per cent for regrowth karri. Karri probably has finer, shallower checks, which are removed during planing.

With a suitably stepped schedule, 140 x 40mm regrowth jarrah would dry in about 84 days with minimal degrade. This is approximately 40 per cent longer than that possible for mature jarrah. This altered drying behaviour may be due to regrowth boards having a greater mixture of sawn faces, more juvenile wood, more features and greater growth stresses.

TABLE 2
BATCH KILN SCHEDULES FOR JARRAH AND KARRI
IN THE INITIAL CURING PERIOD

Run No	DBT(°C)	WBD(°C)	RH(%) Velocity (m/s)	Air
140 x 40mm				
1	30	1.6	89	0.5
2	30	2.0	86	0.5
3	32	1.7	89	0.5
4	25	1.5	88	0.5
5	20	0.8	93	0.5
6	20	1.0	91	0.5
7	20	1.0	91	0.2
8	20	1.0	91	0.2
140 x 30mm				
*9	30	3.0	79	0.2
10	30	1.5	89	0.2

DBT - Dry bulb temperature
WBD - Wet bulb depression
RH - Relative humidity

* 2 hours pre-steaming before drying

Pretreatments

Hot-water soaking and pre-freezing were chosen from possible pretreatments to test if drying times could be reduced, and the research commenced with two local species - regrowth jarrah and regrowth karri [3].

The hot water treatment consisted of an 8 h bath in water at 95°C and then a cool down period. The other treatment was 3 h in a domestic deep freeze, ambient warming for 2 h, followed by the same 3 h freezing. These treatments were given to 0.3 m x 100 mm x 30 mm end matched boards.

The initial drying rates of treated boards were significantly greater than their controls, and the data for regrowth jarrah are shown (Table 3). However, these differences were not sustained and in fact as drying progressed, the trend was reversed. Treatment did reduce overall drying time but would be of doubtful practical importance.

TABLE 3
MEAN DRYING RATES AT THREE STAGES AND FINAL EVAPORABLE MOISTURE CONTENTS OF REGROWTH JARRAH (STANDARD DEVIATION IN BRACKETS)

Treatment	Drying Rate (MC%/day)						Final Evap. MC	
	First week		Mid week		Final week		Day 48(%)	
Control (C)	1.39	(0.66)	0.98	(0.23)	0.68	(0.18)	26.0	(8.7)
Hot-water Soaked (HW)	1.63	(0.86)	1.00	(0.27)	0.58	(0.18)	17.3	(6.9)
Frozen (F)	2.30	(0.81)	0.84	(0.21)	0.58	(0.13)	23.2	(7.8)
Paired (HW-C)	4.07	*** *	0.71	-	-6.57	***	-13.93	***
(F-C)	18.29	***	-9.19	***	-6.47	***	- 5.26	***
T-Tests (F-HW)	12.35	***	-6.30	***	-0.39	-	8.10	***

* T value and significance (* = P<O.O5, ** = P<O.01, *** = P<0.001)

An attempt was made to reproduce similar drying curves for the treated boards from Tasmanian Timber Promotion Board's Drywood Model. A close fit was obtained for pre-frozen material by a three fold increase in diffusion coefficient from that of the simulated controls.

This suggests that further work should be done to ascertain whether a harsher drying schedule, and thus faster drying times, can be sustained by pretreated material without further degrade.

Shrinkage, Collapse and Dimensional Recovery of Regrowth Jarrah

While the previous research was based on drying appearance grade timber, studies on structural timber were also carried out. In Western Australia, observations in sawmills had suggested that sawn regrowth jarrah timber has greater shrinkage than mature jarrah, and undulating corrugated surfaces have been observed on regrowth jarrah boards. A study set out to determine the shrinkage collapse of regrowth jarrah, and if this varied from published figures for mature jarrah [4]. Effectiveness of reconditioning at different MCs and temperatures was also tested.

One hundred and twenty boards were cut from 14 regrowth jarrah logs which were approximately 60-years-old. The boards were 1.2 m long, 140 m wide by 40 mm thick. Rather than measuring true tangential and radial shrinkage, dimensional changes were recorded on nominally backsawn pieces due to its ease. Width and thickness were measured at three equidistant points along the length of each board.

Boards were allowed to air dry to 50-60 per cent moisture content, and then dried to 10 per cent using the CSIRO 'AT' schedule [5] recommended for mature jarrah, using an experimental kiln.

Reconditioning of board groups occurred at three different MCs and a control group was not reconditioned. For each MC group three different reconditioning temperatures (70,90 and 100°C) were used. The reconditioning treatment lasted 5-6 hours at the assigned temperature under saturated conditions.

The control groups (non-reconditioned) gave 7.5 per cent shrinkage in width and 5.9 per cent shrinkage in thickness. Kingston and Risdon [6], using 100 x 25 x 25mm specimens, reported mean shrinkage values for jarrah of 7.4 per cent (tangential) and 4.8 per cent (radial). Although not strictly comparable, the difference is not large in a practical sense.

The overall dimension loss depended upon temperature and MC at reconditioning (Table 4). The least shrinkage was obtained from boards reconditioned at 100°C at the 11-15 MC range. This was 4.4 and 3.5 per cent for width and thickness, a considerable improvement upon non-reconditioned boards. Thus a considerable amount of collapse was recovered.

TABLE 4

MEAN DIMENSIONAL LOSS IN WIDTH AND THICKNESS OF BACKSAWN REGROWTH JARRAH BOARDS, EITHER RECONDITIONED AT ONE OF THREE DIFFERENT TEMPERATURES AND MOISTURE CONTENTS, OR NOT RECONDITIONED, BEFORE DRYING TO 8-10 PER CENT MC.

MC Class %	Reconditioning Temperature (°C)					
	70		90		100	
	W	T	W	T	W	T
16-25	4.9	3.5	5.4	3.9	4.8	3.4
11-15	5.9	6.1	4.6	4.2	4.4	3.5
8-10	6.7	5.1	5.6	4.4	5.0	3.9
Non-reconditioned control samples Mean	7.5	5.9				

High Temperature Drying

In other studies we have found that regrowth jarrah can be final dried at high temperatures to produce high quality material. Twenty-five mm material was dried successfully at 105° dry bulb and 70°C wet bulb, 3 m/sec air flow in 16 hours. Pre-steaming and reconditioning were part of the complete schedule.

It was found that bow was reduced by high temperature drying while spring remained unaltered [7].

Concluding Remarks

The progressive tunnel kiln trial revealed that the mild conditions of winter were near optimum for drying mature jarrah boards for furniture. This lead to determining initial drying conditions for regrowth karri and regrowth jarrah. Brennan and Glossop [1] found that 140 x 40 mm regrowth jarrah required an initial drying schedule as mild as 20°C dry bulb, 1°C depression and 0.2 m/sec air flow. An initial drying schedule (down to approximately 50 per cent MC) was also determined for 140 x 30 mm regrowth jarrah. Regrowth karri was found to dry similarly although checking was more frequent. The study needs to be extended to determine the later steps of drying down to FSP before confident commercial use of regrowth eucalypts is possible.

Thomson [3] found regrowth jarrah to shrink 7.5 and 5.9 per cent in backsawn width and thickness respectively, similar to published figures for mature jarrah, which indicated that no adjustment need be made to the normal green sawing size. He also found that reconditioning was best performed at 100°C and in the middle of final drying, confirming previous reconditioning studies upon mature eucalypts. High temperature final drying of regrowth jarrah was a success with overall drying time less than a day for 25 mm timber. These shrinkage and final drying studies appear to be conclusive and commercially applicable for regrowth jarrah. Other regrowth timbers require similar studies.

The pretreatment study by Glossop [3] indicated that initial drying rates could be almost doubled by pretreatment. The Drywood computer model suggested that one of these pretreatments increased the diffusion coefficient three fold with concommitant reductions in strain. Trials are in progress to test this by drying the pretreated timber in harsher schedules and assessing seasoning degrade.

REFERENCES

1. Brennan, G.K. and Glossop, B.R. (1988). Seasoning 25 mm mature jarrah boards using a progressive tunnel kiln. Department of Conservation and Land Management. W.U.R.C. Technical Report No. 1.

2. Brennan, G.K., Glossop, B.R., and Hanks, W.R. (1990). Drying regrowth eucalypts using a low temperature batch kiln. Department of Conservation and Land Management. W.U.R.C. Report No. 20.

3. Glossop, B.R. (1990). Effect of hot water soaking or freezing pretreatments on drying rates and surface checking of jarrah and karri. Department of Conservation and Land Management. W.U.R.C. Report No. 21.

4. Thomson, A.B. (1989). Shrinkage, collapse and dimensional recovery of regrowth jarrah. Department of Conservation and Land Management. W.U.R.C. Report No. 13.

5. Campbell, G.S. (1980). Index of kiln drying schedules for timber dried in Australia. CSIRO Division of Building Research. Report.

6. Kingston, R.S.T. and Risdon, C. June E. (1961). Shrinkage and density of Australian and other south-west Pacific woods. CSIRO Division of Forest Products Technological Paper No. 13.

7. Hanks, W.R. (1988). Effect of high temperature drying on bow and spring in regrowth jarrah. Department of Conservation and Land Management. W.U.R.C. Technical Report No. 4.

Sawn products from regrowth *Eucalyptus regnans*

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ABSTRACT.

Different sawing and drying options, along with modifications to existing product grading specifications are important considerations when processing young, fast-grown eucalypts for sawn products. Sawing simulation techniques were developed in conjunction with field trials to enable the evaluation different processing options. The results of studies to demonstrate the potential to reduce drying degrade problems associated with back-sawing this species are reported and recommendations made regarding the industrial application of suitable drying practices. The findings show that even though drying degrade may be greater, back-sawing strategies for both engineering and appearance products have the potential to provide both higher saw-log yields and higher mill-door values than traditional quarter-sawing practices.

INTRODUCTION.

Regrowth forest is a loose definition based more on traditionally accepted harvesting ages and historical origins, than on any sudden marked change in wood characteristics. In Tasmania, forests of less than one hundred years of age are generally considered as being regrowth. In Victoria, the main regrowth resource, resulted from wild-fires which occurred during the period between the two World Wars. In both states, regrowth is generally used as a term defining forests which have originated since white settlement in the different regions.

Although the wood of *Eucalyptus regnans* is not very durable, it has certain desirable attributes (Bootle, 1983). It is light in colour, varying from pale pink to straw. In addition, growth rings are conspicuous, adding texture to the wood, it is straight grained and it is easily machined for use in appearance products and bent for furniture manufacture.

The traditional demand from the Ash-type eucalypt group (of which *E. regnans* is a member) for high-quality sawn products for both appearance and structural application, would appear to create increased marketing problems for sawmillers utilising the younger resource. Young *E. regnans* generally exhibits relatively little taper (1:100 to 1:150) and trees are very straight when compared to other hardwoods (Waugh 1980a, Waugh, 1980b Flann 1981). However the reduced overall density and strength (Table 1) with knots as a further predominant inherent characteristic, combine to influence product acceptability. In addition, high growth-stresses contribute towards increased end-splitting in logs (Barnacle, 1970), brittle heart and much greater distortion problems during sawing (Waugh, 1980a). Losses caused by kino veins and heart defects resulting from wood-rotting fungi or termites appear greater than when they occur in large logs from mature trees.

Structural and engineering products.

Sawn product quality, dimensional tolerances, and moisture content specifications for dried products are detailed in AS 2028 (S.A.A., 1975). This Australian Standard recognises four visual grades. The relationship between actual stress grades and the structural grade for *E. regnans* is presented in Table 2.

Appearance products.

Although there have been some specific industry standards. The Australian Standard AS 2796 (S.A.A. 1985) recognises four appearance grades, "Clear", "Select", "Standard" and "Utility", all which have greater imperfection restrictions than required for structural products. This standard has only been partially adopted by industry and there is no standard appropriate to young eucalypts.

A set of an 'in-house' set of appearance criteria was developed to more closely reflect current product end-use requirements, and to assist with CSIRO evaluation trials. The existing four industry grades are incorporated in this set of rules which have been used for product evaluation during sawing and drying trials. The broad product requirements are outlined in Table 3.

Sawing technology.

Historically, sawing practices for high-quality sawn products have developed around the judgemental skills of the saw operator in selecting the position of each cut and turning the log as necessary to achieve the products of desired size and quality. Such an operation is called **grade-sawing**. The two major forms of sawing strategies are **back-sawing** and **quarter-sawing**. Back-sawing aims at producing boards with the face tangential to the growth-rings of the tree and quarter-sawn products are cut with the face parallel to the rays. (Figure 1).

Existing appearance product specifications require logs to be quarter-sawn. A minimum log diameter of about 450 mm small-end diameter is required to achieve the range of product cross-sections demanded by end-users. While quarter-sawing does have a role in minimising drying degrade, the use of younger wood means that a high proportion of the logs harvested will be smaller than 450 mm diameter and will need to be back-sawn.
While seasoning degrade may be more difficult to control, back-sawing has advantages in;

(a) enabling both a higher product recovery (CSIR 1936) and higher through-put levels than quarter-sawing.
(b) easier segregation of high-quality wood obtained further-most from the knotty core.
(c) easier handling of growth-stresses as distortion will appear as bow, rather than the spring found in quarter-sawn products.

The sawing operation can be conveniently separated into two stages; Log breaking-down is first carried out on a head-saw, then the cutting of final products on a resaw. During the Young Eucalypt Program, field trials were carried out utilising three different head-saw systems, a conventional high-speed pony carriage, a twin-saw log edger with overhead carriage, end-dogging and a line-bar carriage. The line-bar carriage was found to have

distinct advantages in handling the distortion problems when sawing young eucalypts. The use of the line-bar ensures much better control over the dimensions of the flitch or product being sawn to final dimensions at the head-saw, as the heads on the carriage can maintain pressure against the line-bar when it is set to the desired dimension of the product and the heads can be moved to follow the profile of an already-established reference face on the flitch being resawn. In this way, the sizing of the product is accurately controlled.
Most eucalypt resawing is carried out on equipment derived from the breast bench. Units that had a flitch return belt and "kickers" to remove sawn products and off-cuts, automated outfeeds, remote sizing and radial hob pressing against a 'line-bar' could efficiently produce accurately sawn boards.

Sawing studies.

A problem in trying to examine differences in sawing strategies and products, is the need to carry out large and expensive sawing trials. Computer simulation enables a single batch of simulated logs to be processed a number of times under different simulated sawing strategies.

In this study the sawing results from the field trials together with data from previous work with young eucalypts was used to develop a model for simulating the sawn output. The sawing simulation system which was used consists of three major modules:

(a) log simulation (tree simulation plus log preparation);
The tree simulation model is a refinement of a model developed by Jacobs (1937), who used a regression relationship to describe the shape of the knotty core and knot dimensions in an ash-type eucalypt. The log preparation module basically simulates existing log preparation practices, with constraints on bush-log lengths and length of smaller-diameter mill-logs.

(b) sawing simulation;
The model consists of a number of integrated modules:
Primary sawing;
Growth stress;
Resawing;
Product upgrading.

(c) grading and output simulation.

Five separate sawing trials involving some 130 trees and one multi-site sawmill sampling, (giving a further 400 boards) provided the wood for drying experimentation. These boards and a proportion of the boards from each log were dried under various drying regimes. For each trial, dry boards were assessed for drying degrade and potential recovery for products of various values.

These trials were carried out to:

(a) Examine tree inherent characteristics.
(b) Field-test suitability of sawing equipment and strategies.
(c) Obtain product out-turns.
(d) Obtain sawn wood from diverse location and age source for experimental drying studies.
(e) Validate the results of sawing simulation studies.

The boards from the first trials on Tasmanian material were predominantly back-sawn 40 mm and 50 mm thickness. The sawn material was distributed

among a number of different drying strategies, including predrying, dehumidification drying and the use of a progressive kiln (Table 4).

Drying technology.

Ash-type eucalypts are dried in the industry by a variety of methods. In the past, most products for appearance application have been quarter-sawn from large mature trees and dried by a combination of air-drying, reconditioning and final kiln-drying, or occasionally dried from green in predriers or tunnel kilns.

With the increase of engineered and prefabricated hardwood structural components, Eucalypts are also dried for structural end uses. Structural timbers can be back-sawn or quarter-sawn and are often only given a final kiln-drying ("stabilisation treatment") after air-drying to ambient moisture content.

Wood from the Ash-type eucalypt group shrinks considerably on drying, and it is not uncommon to find total shrinkages of eight to ten per cent on the back-sawn face. The high shrinkage results in severe checking of the wide face of these boards. The wood is also susceptible to collapse which is an abnormal and excessive shrinkage above fibre saturation point. Collapse occurs in the early stages of drying as a result of high liquid tension forces causing cells within the wood structure to crumple. Collapse can cause severe distortion of the cross-section and both surface and internal checking to occur. Much of the shrinkage and distortion due to collapse can be removed by steam reconditioning prior to final drying.

RESULTS

Drying

Initial drying results had very high levels of drying degrade showing as surface and internal checking in a large proportion of the boards assessed. This trial demonstrated that conventional drying methods could not be applied to this material if the aim was to recover appearance grade products. The timber from almost all of the material examined was highly susceptible to drying degrade. Some logs that were part dry before sawing also showed some sawn product degrade due to the incursion of drying checks from the log showing up on the boards cut near the outer surface of the log. Collapse resulting in excessive shrinkage, distortion and the typical corrugated effect on the quarter-sawn face often became evident very soon after sawing. The back-sawn faces were subject to large drying checks even when the boards were exposed to only relatively mild atmospheric conditions. The early drying studies indicated that only low recovery of defect free dry boards would result from most of this resource unless special processes were adopted.

Current drying methods of simple exposed air-drying with a final reconditioning and kiln-drying resulted in much faster drying times than for mature wood of similar cross-section. However, there was an unacceptable amount of drying degrade in these young woods. The degrade was severe enough to exclude some samples from structural appearance or even just structural applications due to large surface checks, excessive loss of cross sectional area, massive internal checking and honeycomb.

Modelling of the drying process shows (Oliver 1986) that if the early part of drying in particular could be slowed down, there would be a reduction

of stress on the surface of the board and a decrease in the resultant surface checking. Collapse and the associated occurrence of large internal checks are also an outcome of stresses imposed by trying to remove moisture too quickly from the wood. The high green moisture saturation levels combined with the low density and different growth structure patterns of these young woods means that they are not able to rapidly accommodate to the strain of the removal of large volumes of liquid.

Following the initial trial, various modifications to normal drying practices were carried out in order to control the drying rate, particularly in the early stages of drying (Table 5). Table 6 shows the levels of drying degrade in conventionally dried *E. regnans* at age 50 years and the results of some of these techniques.

1. Plastic coating individual boards.
2. Air drying.
   (a) Sheltered air-drying:
   (b) Shade-cloth stack shrouds and enclosed air-drying:
3. Drying Boards of thinner cross section.
4. Kiln drying from green: Low temperature (<35°C) and high initial humidity (>90%) conditions with low air-speeds (0.5 m/sec).

Three major sources of young regrowth E. regnans were examined in Victoria. These consisted of a pair of site-matched samples of thinned and un-thinned 1939 regrowth, and a range of samples of 6 boards per tree from 9 trees at each of 5 sites in Victoria.

The Victorian material from Toolangi was either air dried in an enclosed shed with no forced airflow, or kiln dried from green under predrier conditions initially at 35°C dry-bulb temperature with a 2°C wet-bulb depression. All boards were kept in stacks wrapped in plastic from the time they were sawn until stripped out for drying to minimise predrying degrade. One batch of boards was stored block stacked, wrapped in plastic and stored for six weeks prior to air drying.

Drying times for 40 mm material have been approximately 12 to 18 weeks air dried in the air drying shed, and 10 weeks dried in the predrier. All pieces were reconditioned (6 hours) and given a final kiln drying treatment to bring moisture contents to a nominal 12 per cent.

Analysis of the various drying regimes and handling methods revealed some opportunities for reducing drying degrade in the young wood. The careful handling of back-sawn material from the moment of sawing, by use of plastic wrapping of exposed packs and water sprays or enclosed storage sheds, will reduce the amount of surface checking from a rate of over 70 per cent of the boards in material handled conventionally by air/kiln drying to below 30 per cent for material carefully kiln dried from green. Preliminary air drying in an enclosed shed will reduce degrade to below 20 per cent with some further reduction by a period of pre-storage (3-5 weeks, block stacked and wrapped) to equalise moisture gradients. In most pieces dried under the revised conditions, non-recoverable collapse and the incidence of internal checking became minor problems, affecting less than ten per cent of boards. Drying of thinner cross-section boards again reduced the degrade figures.

The results indicate that the drying of back-sawn boards from immature eucalypts requires relatively inexpensive process modifications, a targeting

of the required end use and attention to quality control at all times to recover a product with drying degrade levels little different to traditional stock.

Sawing simulation.

From the drying studies it had to be recognised that there would be a certain amount of drying degrade. A conservative assumption for back-sawn joinery grade was that 25 per cent of product would be re-assigned to select grade, of that total, 15 per cent to standard grade and 5 per cent to utility grade. All green solid wood residue was assumed as having a value of $72 per tonne.

Figure 2 show the mill-door value of trees of different diameters, thinning regimes and processing strategies. The $72 value relates to a chip-only production. The mill-door value applies to all of the saw-logs and pulp-logs from a tree, expressed on a total per cubic metre basis. Trends are similar, but more marked than for saw-log top-heights.

Product quality out-turn for the five processing options are summarised in Table 7, along with a summary of the results of the relevant field validation trials. A direct comparison could be made between field and simulation results for engineering products as all logs down to 250 mm small-end diameter were included in both studies. A comparison of quarter-sawn appearance product out-turns was however much more complex, as logs were sawn to different small-end requirements. It was necessary to adopt a common basis for assessment. The basis which was adopted was for logs meeting the Victorian "B" class saw-log requirement, which is a minimum log specification for a log with the potential to produce dried products. Logs from both the field trial and simulation study were assessed and included if they met this specification. However, at the time the field evaluation was carried out, the assessment criteria (Table 3) were not fully developed and short-length products were not graded. In this table they would have been graded as packaging products, explaining the much higher figure here than for the simulation results.

The poorer quality figures for the "B" class saw-logs when selection was based on economic criteria for quarter-sawn products reflects lower log quality standards. This indicates that the lower range of the "B" class saw-log specification at least, is of greater economic value as chips, rather than quarter-sawing for appearance products.

DISCUSSION.

Quarter-sawing for appearance products.

The results in Figure 2 show that quarter-sawing to the proposed product specifications would be expected to improve log values by about $\$15/m^3$ over sawing to existing specification and reduce the marginal tree diameter from about 850 mm to about 750 mm diameter breast-height. These results also demonstrate the effect of grading strategy. The development of the proposed grading strategy in Table 3 could double saw-log production per hectare.

The potential for back-sawn appearance products.

Even for the largest logs and taking into account higher losses through drying degrade, it did not it appear more profitable to quarter-saw for appearance products, than to back-saw for even structural products.

This study demonstrated the economic potential in utilising a back-sawing strategy for appearance products, even for the levels of drying degrade adopted for this analysis. For a sawmill with a through-put of 20 000 m^3 per year, back-sawing has a potential earning of $1 million per year over quarter-sawing.

Taking into account the additional costs, it can be seen from Figure 2, that back-sawing for appearance products can improve log values by about $30/$m^3$ and reduce the marginal tree diameter, by about 200 mm. Back-sawing enables a much more of the tree to be converted, halving the resource-base needed to support a sawmill and also reducing the high sensitivity to chip values as the chip component is substantially less (about 25% of tree volume).

This economic gain can only be achieved through the sawmiller investing in significant technological change. The form of the extent of the change will differ in different regions and sectors of the industry. While the technology is available in 1990, very little of it is in place in the industry. For example, it would be doubtful if any wood-drying kiln or pre-drier in south-eastern Australia could operate at the low-temperature, high-humidity conditions necessary to achieve the results presented in Table 6. However, in many cases, particularly in Tasmania, the upgrading of kiln control systems, which would be expected to cost less than $50 000 would provide the necessary hardware to dry the wood. But this is only part of the story. In most larger sawmills in Tasmania, it would be necessary to install additional sawing equipment and handle logs and sawn products separately to the existing resource. In Victoria the small-log sawing equipment is readily available, but there is a lack of wood-drying facilities. Therefore, in both cases, the sawmiller could have to invest in excess of $1 million dollars to provide adequate sawing and drying systems.

Any sawmillers who handle back-sawn wood for drying will find that they are going to have to implement a new set of process control procedures and invest heavily in hardware, training and management skills to put it in place. Sawing accuracy and product orientation will need to be subject to much finer tolerances, necessitating more precise equipment installation, maintenance procedures and a greater degree of product sorting and operator training. Green-sawn products will need to be better protected from the environment prior to drying, necessitating investing in additional under-cover storage. There will be a need to invest in greater skills in operators controlling and monitoring the drying of wood and finally, there will be a greater proportion of lower-quality and shorter-length wood that will require greater skills in marketing.

CONCLUSION.

The south-eastern Australian hardwood sawmilling industry will need to re-assess the application of traditional conversion and marketing practices in processing its regrowth forests for sawn appearance products. Existing quarter-sawing practices will give a low level of utilisation and a poor economic return on the resource. Equally important is the need to address the application of product quality specifications. The ability to be able to han-

dle, upgrade and market short-length sawn product to exacting end-user specifications will be a critical element in the utilisation of young, fast-grown eucalypts.

The option of undertaking technological change, to handle smaller diameter logs, using back-sawing techniques and to be able to dry the wood with minimal degrade will require considerable re-investment in capital equipment, the development of more appropriate process control systems, personnel retraining and marketing strategies for a different range of sawn products. However, this will ultimately result in improved resource utilisation and greater economic strength of the industry. This will be essential in competing against imports.

REFERENCES.

Barnacle, J. E. 1970 The incidence and development of felling shakes in round timber. *Aust. For.* **34** (3):161-169

Bootle, K. R. 1983 *Wood in Australia: Types properties and uses.*McGraw-Hill, Sydney. 443pp.

CSIR 1936 Sawing methods: 1. -Quarter sawing. *Trade Circular 34.* CSIR, Division of Forest Products,Melbourne, Australia.

Flann, I. B. 1981 Sawing for profit. *Canadian For. Ind.* Oct., 1981

Jacobs, M. R. 1937 The knotty core of eucalypts. *Aust. For.* 2(1):3-5.

Kloot, N. H. 1957 The mechanical properties of immature Mountain Ash. *Lab. Progress Rep. T.M.5-1.*
Forest Prod. Lab. CSIRO, Melbourne, Australia. Unpublished report, 10 pp., 8 tables, 1 fig.

S.A.A., 1975 Visually stress-graded hardwoods.
Australian Standard AS 2082-1979. Standards Association of Australia, North Sydney, NSW.

S.A.A., 1985 Timber-Seasoned hardwood-Milled products.
Australian Standard AS 2796-1985. Standards Association of Australia, North Sydney, NSW.

Oliver, A.R. 1986 A model to correlate measurements directed towards drying degrade in sawn eucalypt timber *Proc 22nd For. Prod. Res. Conf. CSIRO Divn. Chem. Wood Tech.* Clayton Vic. 17-20 Nov. 1986

Thein, S. 1988 Strength grouping of regrowth *Eucalyptus regnans.* M.Sc. Thesis, ANU, Canberra.

Waugh, G. 1980a The potential of plantation eucalypts for saw-log production. *Australia and New Zealand Institutes of Foresters Conf.* Rotorua, N. Z.

Waugh, G. 1980b The effect of log size on the economics of sawing regrowth eucalypts. *Tech. Report.* Div. of Building Research, CSIRO, Melbourne, Australia.

Table 1
Ratio of immature to mature wood for selected wood properties for *Eucalyptus regnans* (from Kloot, 1957).

Property	Green	Air Dried	A. D. and Recond
Moisture content	1.67	-	-
Density -basic	0.82	-	-
-air dry	-	0.78	0.80
Static bending			
MOR	0.83	0.73	0.75
MOE	0.75	0.69	0.76
Compression			
parallel to grain (MCS)	0.96	0.70	0.73
perp. to grain (at L.P.)	0.97	0.70	0.98
Shear - Max. tangential	0.84	0.79	0.84
Hardness (Janka)-Radial	0.87	0.61	0.65

Table 2
Stress grades for ash-type eucalypt species.

Products	Structural grade 1	2	3	4
Green sawn	F14	F11	F8	F7
Dry products	F27	F22	F17	F14
Based on the findings of Thein (1988), for young, fast-grown wood, dried products should be two grades lower, therefore for immature ash-type eucalypts.				
Green sawn	F11	F8	F7	F5
Dry products	F17	F14	F11	F8

Table 3
Appearance product requirements and assessment criteria.

Scope:

Specifications applies to sawn Eucalypt products for appearance applications and can be applied to dressed, dry rough-sawn or green products.

Assessment criteria:

The following end-product related criteria will be used:

(a) **Polishing grade**: Wood to be used for highly decorative purposes. Very little surface or internal checking can be tolerated and grading will be carried out on all faces. High-value furniture, wood for turning and trim items.

(b) **Moulding grade**: Again, grading on best face and both edges, tolerating minor checking only. Furniture, wood trimmings.

(c) **Select grade**: Boards with minimal checking, not used for moulded products. Graded on best face and both edges. Examples would be lining boards, shelving, strip flooring.

(d) **Standard grade**: Graded on best face, tolerating some defect and internal checking. Lining boards, strip flooring.

(e) **Utility grade**: Graded on best face, tolerating moderate checking and inherent defects. Industrial shelving, strip flooring, industrial lining boards.

(f) **Cutting grade 1**: Capable of recovering 2/3 of total length as short lengths of 1.2 m or longer of a quality equivalent to polishing grade.

(g) **Cutting grade 2**: Same length requirement as Cutting Grade 1, but of moulding grade quality.

(h) **Cover grade**: To be used in the carcase of furniture etc. Not strictly an appearance application, but machined to finer tolerances and of less distortion tolerances than for structural wood. Stiffness is of prime concern. Graded on worst defect.

(i) **Case grade**: Pallet decking etc.

Table 4
Conventional drying regimes for Tasmanian regrowth studies (40-50mm thickness)

Drying regime	Wood moisture content (%)	Dry bulb temp. (°C)	Wet bulb depress. (°C)	Time (days)
Dehumidifier	green 30 20 final	25 30 RECO 40	1 4.5 7	 30
Progressive drier	green final	18 38 RECO	3 - 5 7	 42
Air dry final kiln	green 25 final	ambient RECO 55 - 70	 10 - 20	 160

Table 5
Improved drying regimes for Victorian 1939 regrowth mountain ash 40mm thickness

Drying regime	Wood moisture content (%)	Dry bulb temp. (°C)	Wet bulb depress. (°C)	Time (days)
Sheltered air final kiln	green green 25 final	(stack wrapped optional) sheltered ambient RECO 55	 10	 20-35 80 90-125
Kiln dry	green 25 final	35 (possible ramp temp up) RECO 55	1 10	 <70 <80

RECO = steam recondition @ 100°C

Table 6
Drying degrade of backsawn boards (40-50 mm thickness) from regrowth *E.regnans* aged approximately 50 years.

drying conditions	per cent boards degraded by drying checks	
	internal	surface
a) Conventional industry practice for drying quarter-sawn products from mature eucalypts.		
Air dry exposed, final kiln dry.	43	48
Predrier from green low temp.	42	76
Dehumidifier from green low temp.	NA	43
b) Proposed modified controlled drying conditions for back-sawn regrowth eucalypts.		
Air dried exposed under shelter.	4	67
Air dried in enclosed conditions with final kiln dry.	0	25
Kiln dried from green, low temp high humidity.	12	16

Table 7. Product recoveries.

(a) Back-sawn engineering products.

Grade	simulation study	field trial
Eng 1&2	49.4	54.3
Eng 3	18.6	22.1
Package	19.2	16.4
Residue	12.9	7.2
Tot Sawn	45.1	43.1
Pulpwood	42.2	-

(b) Appearance products.

Grade	Simulation study				field trial
	back-sawn	quarter-sawn exist rules	quarter-sawn proposed rules	"B" class sawlogs	
Joinery	9.1		15.1	8.3	6.2
Select	13.1	28.5	16.1	11.7	8.4
Standard	12.7	17.8	19.3	11.6	19.1
Utility	14.1		18.2	12.6	12.7
Cutting 1	2.5		0.0	4.0	
Cutting 2	8.0		0.0	9.5	
Cover	12.6		10.0	12.3	15.7
Package	14.8	44.0	10.0	16.9	29.3
Residue	13.7	10.5	10.0	13.7	8.6
Tot. sawn	43.4	46.0	44.2	41.5	37.2
Pulpwood	44.1	41.8	43.1	43.5	

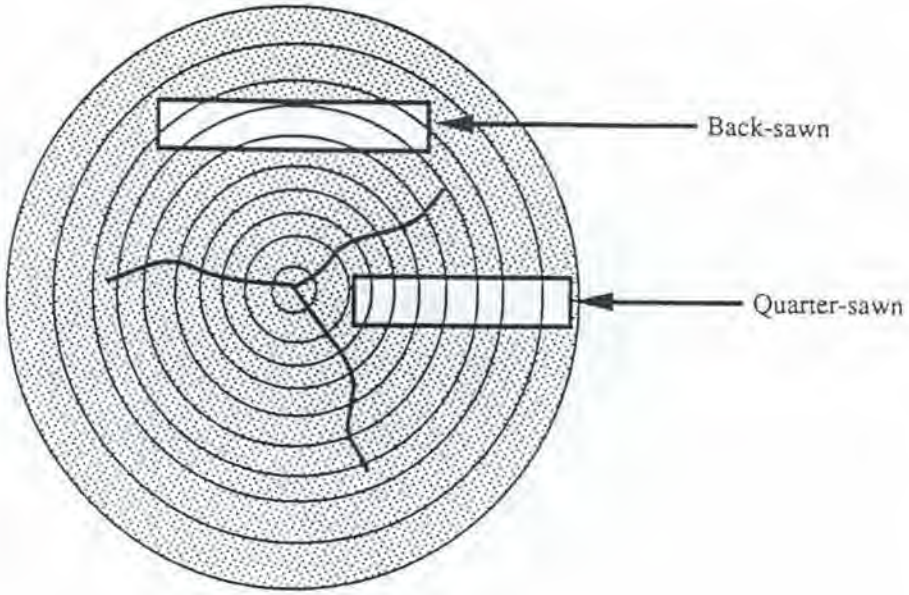

Figure 1
Sawn product orientation

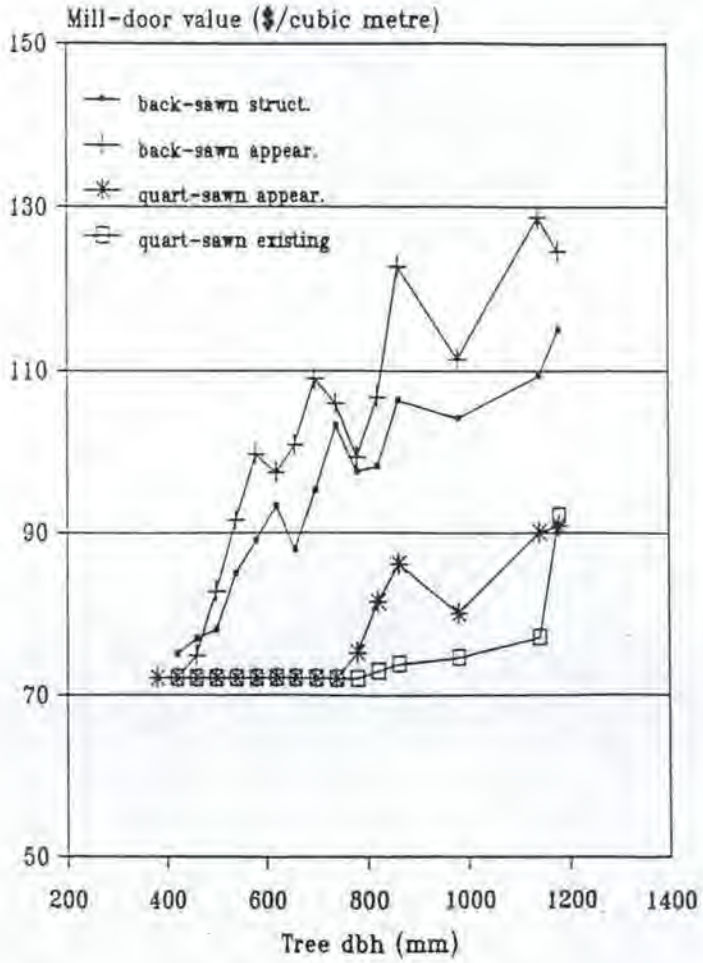

Figure 5
Mill-door value of sawn products

DRYING DEVELOPMENTS IN AUSTRALIA

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SUMMARY

Plantation softwood is overtaking native hardwood as the major sawnwood resource in Australia. Most plantation softwood and an increasing proportion of native hardwood sawnwood is dried. This situation is expected to continue.

Drying of sawnwood from the major sources of supply - native hardwood, plantation softwood, native softwood, and imported sawnwood - is discussed. The paper concentrates on current drying practices, particularly as they result from recent research and development, areas requiring future research, and projected developments in commercial drying practices.

Keywords: drying, kiln drying, seasoning, sawnwood.

INTRODUCTION

Projections of future sawnwood consumption provide a basis for estimating future wood drying requirements. Sawnwood consumption exceeds domestic supply, with the difference provided by net imports which will decrease as Australia approaches self-sufficiency early next century. Consumption for 1971 to 1989, with the contributions of the main sources of domestic supply, is shown in Fig. 1, which also shows the trends of projected domestic supply to 2020.

The main sources of sawnwood are -

Native hardwood (broadleaved) - mostly eucalypts and related genera. Production is decreasing as the resource changes from mature old-growth to regrowth forests, but will increase substantially in the second half of next century as the regrowth forests mature. An increasing proportion will be used in dried products.

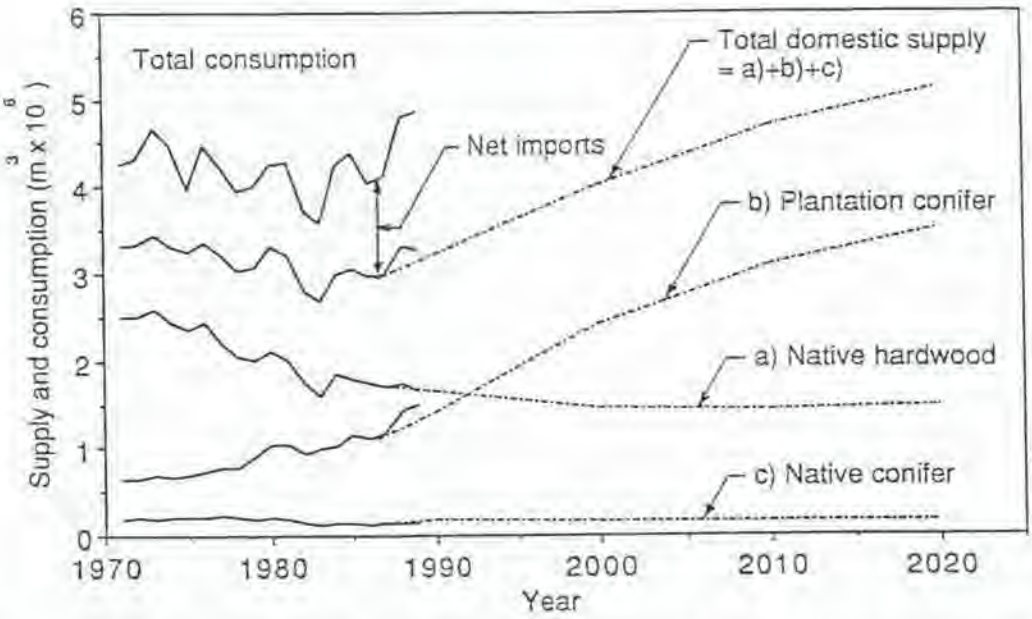

Fig. 1. Consumption, 1971 to 1989, and projected future domestic supply of sawnwood in Australia[1].

Plantation softwood (conifer) - mainly exotic *Pinus* spp., particularly radiata pine (*P. radiata*), but with a significant quantity of native hoop pine (*Araucaria cunninghamii*). This is the principal source of the increasing domestic supply. Most sawnwood is dried.

Native softwood - the most important is cypress pine (*Callitris* spp. - mainly *C. columellaris*). Supplies are expected to remain relatively constant, but an increasing proportion will be dried.

Imported sawnwood - principally softwood from the west coast of North America, radiata pine from New Zealand, and hardwood from Malaysia. Only a small proportion is dried in Australia before use.

The drying of sawnwood from each of these sources is considered separately below. Discussion is confined to the drying of solid sawnwood in Australia, with particular attention to current and future research needs and commercial developments.

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1 Consumption data: sawnwood supply (excluding railway sleepers) - Timber Supply Review, Aust. Bureau Agricultural & Resource Economics, Canberra.
Projected future domestic supply: consumption data for year ended 30 June 1987 extrapolated in the ratios of

(projected sawlog availability)/(removals 1986/87),

p. 38, Australian Forest Resources - Present Areas and Estimates of Future Availability of Wood, Aust. Forestry Council, Canberra, Feb. 1989.

NATIVE HARDWOOD

Resource

The mature forest resource is nearing the end of its first harvesting cycle and is being replaced by regrowth forest of similar species composition, with a minor contribution from plantations of selected species. The most important hardwood forest groups (types and locations as in FORWOOD 1974, which lists the major species) are -

Moist eucalypt (Queensland (Q) and New South Wales (NSW)), plus spotted gum (Q and NSW) and some stringybark (northern NSW) and dry eucalypt (Q and NSW). Most are medium- to high-density species that do not collapse appreciably during drying.

Ash (Victoria (V), Tasmania (T) and NSW) and silvertop (V and NSW), with associated stringybark (V and southern NSW) and mixed eucalypt (T). Most are low- to medium-density species that collapse significantly.

Karri and jarrah (Western Australia) - medium- to high-density species that do not collapse appreciably.

Most Tasmanian ash sawnwood is dried for appearance and structural products, but the bulk of Australia's hardwood production traditionally has been used as green structural timber, with only a small amount used in dried products. This situation is changing, and an increasing proportion is being dried for both structural and high-value appearance products. This trend is expected to continue and, together with the change from mature to regrowth sawlog resource, is the major challenge facing the native hardwood industry.

Drying Characteristics

The drying characteristics of wood from both mature and regrowth or plantation eucalypts were discussed by Campbell and Hartley (1978). The most important forms of drying degrade are surface checking, internal checking, and the effects of collapse.

Most species have a marked tendency to check on back-sawn surfaces early in drying. Checking is caused by high drying stresses, may be aggravated by collapse, and is worse in thick material than thin. It can be minimised by slow, controlled early drying, in very mild conditions.

Radial internal checking is likely to occur later in drying unless the wood temperature is kept below a threshold value until the moisture content (MC) throughout is below the fibre saturation point (FSP). Reported threshold temperatures range from 25° to 40°C for collapse-susceptible ash to 50° to 55°C for regrowth blackbutt (*Eucalyptus pilularis*) (Alexiou 1989).

Collapse and its recovery by reconditioning were reviewed by Kauman (1964). It is likely to become more significant as regrowth and plantation grown material replaces the old growth, due to the generally lower mean density of the wood of the younger trees, although little difference in density has been found in jarrah (*Eucalyptus marginata*) and karri (*E. diversicolor*). The smaller ray and pore size in the wood produced in the first 20 years of growth may also be a contributing factor.

Honeycombing, caused by collapse in earlywood, tends to be most severe in back-sawn material, due to the greater restraint from latewood and higher drying stresses in the tangential direction. A contributing factor is large differences in density (and strength) between earlywood and latewood. Collapse in undamaged fibres close to the surface can also initiate or contribute to surface checking (Wilkins and Wilkes 1987).

Drying Requirements

There are no major problems in drying hardwood for structural purposes with degrade within specified limits. However, surface checking may reduce its acceptance for 'appearance' structural grades and internal checking must be limited. Careful early drying may be necessary to prevent unacceptable degrade in some cases, e.g. regrowth ash. Drying is slower and costs are higher than for plantation softwoods. This reduces the advantage provided by the smaller sizes required for structural applications.

Drying appearance grade material is more difficult, particularly in thicker sizes. One method of minimising degrade has been to quarter-saw. This is normal practice with ash, mainly in Tasmania, but is becoming less practicable due to decreasing average log size and the presence of wood defects. Back-sawing is preferred for convenience and greater sawn recovery. It also provides a more attractive figure for appearance products.

The major problem in hardwood drying is to develop economical ways of drying appearance grade back-sawn timber, free of degrade, in both board and thicker sizes. This is the object of much topical research and development (R & D). Related studies have aimed at developing accelerated schedules for kiln drying structural back-sawn timber from green (Alexiou 1989). The knowledge gained from this work is providing a better understanding of the mechanisms involved in drying and the development of degrade in a broad range of wood drying situations.

Research Studies and Modelling

Schaffner's (1981) investigation of drying stress and surface checking in back-sawn ash led to the development of a surface coating system (Ralph *et al.* 1984) to reduce moisture gradients near the wood surface and reduce or eliminate surface checking. Schaffner's analysis was developed by Oliver (1986) into a one-dimensional model of drying from the

surface of wide boards under constant conditions. The model is the basis of a computer program called 'DRYWOOD' (Mills *et al.* 1987).

'DRYWOOD' includes strain components due to mechano-sorptive and mechanical creep, as well as unconfined shrinkage and instantaneous strain due to stress. Non-linear relationships are included. The value of the model for predicting surface checking is limited by the assumptions used and lack of data about many of the factors involved. However, it is a valuable tool for demonstrating the effects of the early drying conditions on stress and check development. It also indicates areas where research is required to improve the understanding and modelling of the processes involved, particularly -

Effects of collapse.

Effects of temperature and MC on the effective diffusion coefficient.

Relationships between the temperature, relative humidity, and form and velocity of the air flow over the surface, wood surface temperature and MC, and heat and mass transfer between air and wood.

Mechano-sorptive and mechanical creep perpendicular to the grain, in both tension and compression, including recovery under conditions of stress reversal, and the effects of temperature.

Some studies have been made of the visco-elastic properties of hardwoods perpendicular to the grain (Alexiou *et al.* 1989, Schaffner 1981, Kippo 1987), and Wu (1989) has investigated boundary layer flow, heat and mass transfer and temperature difference at the surface of the drying wood, and heat conduction within the wood. More research is required in all these areas.

Other R & D programs are investigating non-destructive methods for measuring MC early in drying using ultrasonics, and moisture distribution in sample boards using x-ray/gamma ray densitrometry.

Humidity cycling early in drying also requires research. Reports indicate that it re-establishes moisture flow after marked reductions in drying rate in jarrah with no increase in checking, and it may also be a way of using mechano-sorptive creep to reduce drying stress. However, opinions are divided, as it may deepen existing checks and reduce tensile strength perpendicular to the grain.

Commercial Drying

Drying methods for appearance products are more critical and more costly than for structural timber. Freshly sawn wood must be selected and sorted for the intended product and drying process, which may be different for back- and quarter-sawn material. The selection should ideally extend to the sawlogs.

Traditional practice for early drying from green to below FSP has been to air dry. Alternatives, mainly used where air drying is too slow and costly, are pre-driers (Brennan *et al.* 1966) or, more recently, progressive driers (Fricke 1983, Lembke 1984). Air drying is generally satisfactory for structural products, but is often too severe for more critical requirements.

Various approaches are used for protecting green timber from exposure to severe conditions, and providing the mild early drying necessary for preventing degrade. They have been used in trials and are being adopted in general commercial practice. The particular approaches taken are chosen to suit the drying operation, and may include -

Enclosed, controlled environments at the sawmill outfeed and stack construction area.

Wrapping packs of green sawn timber to prevent drying before stacking.

Surface coating of thick, high-value timber with a semi-permeable polyvinyl chloride film attached with a polyvinyl acetate adhesive (Ralph *et al.* 1984).

Shrouding stacks with polyethylene sheet, which is removed when the critical early drying period has passed.

Open-sided air drying sheds that can be baffled with shade cloth to reduce air circulation.

Enclosed holding, or 'curing' sheds for initial drying. They are generally without forced air circulation, but may have evaporative coolers to lower the temperature and raise the humidity.

Pre-driers - normally operated with closely controlled fairly constant equilibrium moisture content (EMC) conditions throughout.

Progressive driers - which have the advantage of the evaporative cooling effect giving low temperature, high EMC conditions at the green end, with the conditions becoming progressively more severe along the drier. However, they lack the flexibility necessary for many operations as they require a regular supply of similar green material.

Conventional kilns - usually low cost, operating at closely controlled, low temperature conditions during early drying.

High Temperature Final Drying

Temperatures limited only by the kiln capacity (c. 100°C) accelerate the final drying of ash in conventional kilns without increasing degrade (Christensen 1985). Similar results have been obtained with jarrah and blackbutt and 'high-temperature' final drying has become normal practice in some plants. Less conclusive results have been obtained in trials with some other higher density species, possibly due to wide variation in initial MC.

It appears that many hardwood species will tolerate high final drying temperatures (120°C or more) without degrade, provided the MC throughout is below FSP. These conditions are likely to cause severe internal checking at higher MC's. They may also lead to large moisture gradients in the dried timber, and make stress relieving and/or MC equalising by final high humidity treatments less effective. Further R & D is necessary to determine the method's limitations, as it is likely to find increasing commercial acceptance.

Special Drying Methods

Vacuum drying

Trials have been conducted into drying native hardwoods in commercial vacuum drying systems, mostly using radio-frequency heating. The results have not been satisfactory, with drying slower than claimed for 'equivalent' northern hemisphere hardwoods, and unacceptable degrade. The process may have application for high-value thick material, but suitable schedules have yet to be established.

Low-temperature vacuum drying, with wood temperatures not exceeding c. 40°C early in drying, could be an alternative, particularly for temperature sensitive species of the ash group. Considerable development would be required, as appropriate systems are not currently available.

Drying thin boards

The problem of degrade can be reduced by drying in thin sections. Faster, more severe drying conditions can be used, at least for most non-collapsing species. An economical continuous drier, similar to a veneer drier, may be practicable.

The dried boards can be glued together to make the desired final sizes, allowing appearance grade material to be selectively included. A process of this type, known as 'VALWOOD', has been developed for producing high-value appearance jarrah products. Other species could also be used.

PLANTATION SOFTWOOD

Resource

Radiata pine is the major plantation softwood in Australia and is grown in New South Wales, Victoria, South Australia and Tasmania. Hoop pine, slash pine (*Pinus elliottii*) and Caribbean pine (*P. caribaea*) are grown mainly in Queensland and some maritime pine (*P. pinaster*) and radiata pine is grown in Western Australia.

Fig. 2. shows the rapid increase in the establishment of softwood plantations in Australia since the late 1960's. Limited planting commenced about 60 to 70 years ago but it was not until the mid 1930's, and again after World War II, that the areas planted each

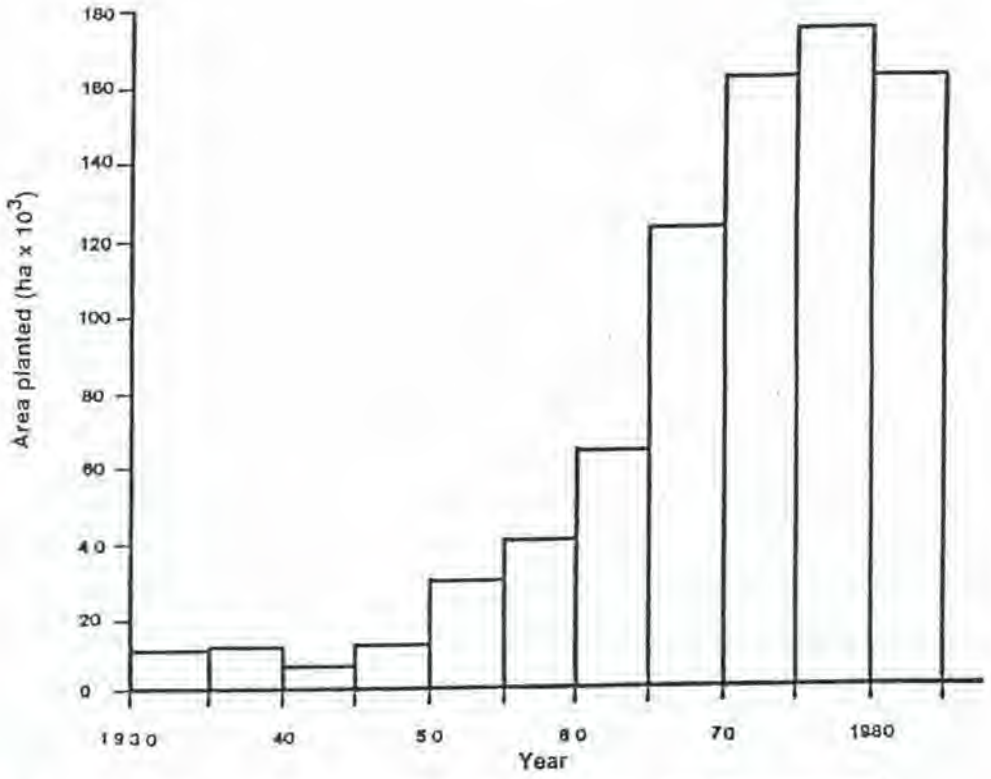

Fig. 2. Softwood plantation established in Australia - five-year classes[2]

year became significant. However, the main impetus came in 1967 with the Softwood Forestry Agreement when it was realised that Australia needed a much larger plantation estate if it was to aspire to self-sufficiency in timber by the year 2000. Under this agreement, funding assistance was provided by the Federal Government to the various State Forest Services for plantation establishment over a 16-year period. The rate of new establishment has declined slightly over the past five years but increased log production is already apparent, as shown in Fig. 1. In addition, the ratio of final crop stems to lower volume thinnings is also improving, as more stands reach rotation age. At this stage, it appears that net self-sufficiency in sawn timber will be achieved by about 2020 and that the sawlog volume of plantation softwoods will equal that of the native hardwoods by 1992.

Development of High Temperature Drying

During the early days of plantation forestry, most of the sawnwood from thinnings was used in low value products, such as fruit cases and boards for covered flooring, etc. The presence of a central core of twist-prone, juvenile wood was well recognised. Producing straight, stable framing sizes from these thinnings, using conventional low temperature kiln drying or air drying was almost impossible and Kloot and Page (1959) recommended that

2 Adapted from: Fig. 2, Australian Forest Resources - Present Areas and Estimates of Future Availability of Wood, Aust. Forestry Council, Canberra, Feb. 1989.

scantlings from radiata pine be produced only from the timber outside the central 100 mm core.

Work in the USA on high temperature drying of *Pinus* species in structural sizes by Kimball and Lowery (1967) on lodgepole pine (*P. contorta*) and by Koch (1969, 1971) on southern yellow pine, stimulated the development of high temperature drying techniques for Australian requirements. Crook (spring) appeared to be the major problem in the USA but, in Australia, it was twist.

The first high temperature drying in Australia on plantation softwoods was done on slash pine studs (D.K. Gough 1970, unpublished report). The techniques used were optimised by Christensen and Gough (reported 1975). At the same time, Mackay and Rumball (1971) undertook similar work on radiata pine and Gough (1973) reported work on hoop pine.

The Australian technique of the early 1970's used a simple batch kiln, modified to provide high air flow through the stack and high temperature, with rapid heating. Recommended drying parameters were -

Dry bulb temperature - 120°C. Wet bulb temperature - 70°C.

Air flow - 5 m/s through the stack. 2-hourly fan reversal.

Sticker thickness - 29 mm. Sticker spacing - 760 mm. Stack width - 1.2 m.

Stack restraint - concrete slabs giving about 980 kg/m^2 of stack area.

Pre-steaming - 4 hours. Post-steaming stress relief - 4 hours.

Restraint maintained for 24 hours after final steaming.

By applying the above, it was possible to dry 50 mm timber from green in less than 24 hours and to recover at least 90% of pieces within acceptable limits of twist, spring and bow from timber which, until then, was largely unacceptable for framing. High temperature drying was found also to improve stability under changing EMC conditions and, because of the limited time the timber itself was at temperatures exceeding 100°C, there was no appreciable loss of strength.

High temperature drying of plantation grown softwoods was a most successful and timely development, coming as it did when supplies from the native hardwood resource were starting to decline and when the volume of pine thinnings was expanding rapidly.

In the years since its initial development, high temperature drying has become the standard industry method for drying most of the sawnwood from softwood plantations in Australia. It is increasingly being adopted in New Zealand for drying radiata pine sawnwood, mainly for export, and it should find increasing acceptance in other countries such as South Africa and Chile.

The increasing proportion of final crop stems is producing a decrease in the proportion of juvenile wood and the need to control drying distortion. However, high temperature drying is still widely used because the short drying times and reduced energy use are more economical than drying at conventional temperatures.

The only area where high temperature drying is not successful is in the re-drying of timber treated with water-borne preservatives. Permeability becomes severely reduced, high moisture gradients develop, long drying times are required and severe internal checking, embrittlement and strength loss develop.

Considerable design work has been done by Christensen and Northway (1982) on a high volume continuous drying unit to run at up to 200°C. Although this unit has great potential, it has yet to be accepted by industry. Apart from this possibility, the future for high temperature drying of plantation softwood is expected to lie in the optimisation of design and operating parameters for batch kilns. Mathematical modelling to develop optimum parameters would be ideal but, as yet, insufficient work has been done.

Present Softwood Drying

Most sawn plantation softwood is now dried using high temperature conditions. In some cases, boards 25 mm and less may be air dried and timber thicker than 50 mm may be dried at low temperatures, sometimes in dehumidifier kilns, to avoid the incidence of internal checking. High temperature drying of framing sizes, however, is almost universally applied, because high temperature drying in totally restrained stacks is the only economical way to ensure that a straight stable product will be produced from timber that has a high probability of containing juvenile wood.

The parameters that were originally established and are listed above have been modified since. The changes have often been determined empirically, and have led to the following established commercial practice -

Dry bulb temperature - 150°C has been used. Higher temperatures reduce drying times but 130° to 140°C seem to have general acceptance.

Wet bulb temperature - wet bulb control is not critical and 70°C, which gives a good result, can be achieved with the kiln vents open.

Air flow - increased temperatures require increased air flow. 140°C requires 7 m/s through the stack, at least in the early part of drying. Some installations are using two-speed fan motors to reduce power consumption in the later stages of drying when the rate of evaporation has slowed. Fan reversal times of 2 hours are still commonly used.

Sticker thickness - some operations use stickers about 20 mm thick and claim good results but a minimum of 25 mm is recommended.

Sticker spacing - this varies from 450 to 750 mm.

Stack width - radiata pine is commonly dried in 1.8 m stacks and sometimes 2.4 m. Slash pine and hoop pine appear to have lower permeability and 1.2 m wide stacks are still generally used, although 1.8 m wide is used at one installation.

Stack restraint - various alternatives to concrete slabs have been examined. Slabs have some disadvantages, yet they remain a simple, cheap and effective system to use. The most acceptable and effective weight appears to be a reinforced concrete slab about 400 mm thick, giving a top loading of around 1000 kg/m^2 of stack area for 50 mm thick timber. Stack weights less than this (700 kg/m^2) have been used successfully for 38 mm thickness.

Pre-steaming - although pre-steaming was used in the early developments, Hillis and Rozsa (1978) confirmed that heating wood while it was still wet caused plasticisation of the lignin and hemicellulose constituents and reduced the incidence of distortion, especially twist. It is often advised that pre-steaming be undertaken in a separate chamber but good results can be obtained in the kiln by closing the vents and injecting live steam to accelerate heating.

Post-steaming - this is best achieved in a separate chamber and consists of a high humidity treatment, i.e. steam injected to achieve about 90°C for four hours to relieve drying stresses and reduce moisture gradients. Improved long-term stability is achieved by kiln drying to a target of 8 to 9% MC and then steaming to obtain a final MC of about 10 to 11%.

24 hour maintenance of stack restraint - experience has shown that restraint must be left on after drying, but it can be lifted after about 12 hours.

Monitoring of MC was done initially using embedded electrodes connected to an external moisture meter. Using six electrode pairs per charge, it was generally possible to conclude drying when the highest meter reading had reached 23%. The internal temperature in the wood, obtained with embedded thermocouples (Nester and Panow 1983), has also been used, drying being terminated as the lowest reading rose above 100°C. The most common indicator now is time based on experience, in combination with the temperature drop across the load. This has limitations as it is subject to changes in the density and MC of the timber, and to alterations in the kiln operating conditions. To help overcome the problem, Miller and Riley (1989) have produced a kiln monitoring system which uses measurements of temperature, EMC and total energy into the system to monitor drying progress. This has been incorporated in kiln supervisory software known as 'DRYSPEC' which includes a library of kiln schedules and alarm sets, etc. It is expected that computerised systems such as these will be used increasingly in future.

Another recent development (A.M. McNaught 1989, unpublished report) has reduced the incidence of internal checking and is expected to be of value for thick sections, particularly where such sizes are to be used in furniture components. It involves the use of a separate steaming treatment when the core of the timber is still above FSP. It is in this area that the mechano-sorptive theory being developed for hardwood drying is likely to have application in high temperature softwood drying.

Future Softwood Drying

As mentioned earlier, it is possible that a high volume, continuous high temperature dryer may be built, but it is expected that batch kilns will continue to be installed for some time.

Future drying of plantation softwoods is expected to see an improvement in moisture distribution within individual pieces and within complete kiln charges. This will be possible with the application of optimised kiln design and kiln operation, involving electronic monitoring and decision making. Faster drying may be possible but, at the drying rates being achieved in relatively simple batch kilns (8 hours' drying time for 38 mm radiata pine at 150°C), this is not considered to be of great importance.

A satisfactory final MC is important in order to achieve trouble-free, long-term stability. One development being used already to some extent is the in-line, capacitance type moisture meter. These instruments are of great value in providing quality assurance feedback and their use will expand as both producers and consumers become more sophisticated.

NATIVE SOFTWOOD

Logging of the native softwood resource is now limited almost entirely to cypress pine, which is a slow growing, dense and knotty softwood. It occurs in fairly pure stands to the west of the coastal ranges in New South Wales and Queensland where the rainfall is between about 500 and 900 mm per year. Fig. 1 illustrates the size and sustainability of this resource.

Cypress pine is used green for scantling but it is often seasoned for use as board products, such as feature panelling, flooring and cladding. The cypress industry is quite scattered and the sawmills are relatively small. Air seasoning has been practiced successfully because the prevailing rainfall and relative humidity are quite low. However, kiln drying provides more flexibility in the market and kilns are beginning to gain acceptance. Some dehumidifier kilns have been installed in New South Wales, and there are some glass-house type, solar kilns in Queensland, based on the design developed by Gough (1981).

IMPORTED SAWNWOOD

The largest volume of sawnwood imported green and dried in Australia is western red cedar (*Thuja plicata*) from the west coast of North America (mainly Canada) used for cladding, lining and exterior (window) joinery. Small quantities of meranti (*Shorea* spp.) from south-east Asia are also dried in Australia, but most is imported already dried - often as milled products. Both timbers dry easily with little degrade, and are air dried and/or kiln dried in the metropolitan timber yards of the importers or manufacturers.

Kiln drying is usually at low temperature in conventional or dehumidifier kilns. The latter appear to be particularly suitable for the uncritical requirements of these drying operations, and may be used increasingly in the future.

Minor quantities of other imported species are air dried for some specialist products, e.g. Douglas fir (*Pseudotsuga menziesii*) for scaffold planks, ladder stiles, etc.

CONCLUSION

The production of dried timber in Australia will continue to increase. Most of the increase in sawn softwood will be kiln dried, and the proportion of sawn native hardwood that is kiln dried will increase, for use as dried structural timber and in value-added appearance products.

The main objectives in kiln drying any species are -

To reduce the mean MC of a kiln charge to a nominated target value, with minimal variation in MC throughout the charge or within individual pieces. The target MC should normally correspond to the anticipated service EMC to minimise subsequent movement.

To restrict drying degrade - warp, checking, the effects of collapse, and residual drying stresses - to limits appropriate for the intended use.

To achieve these aims in the most cost effective way.

Severe drying conditions - high temperature drying - are, and will continue to be, used for most plantation softwood sawnwood and, increasingly, for the final drying of native hardwood from below FSP. Excellent results can be achieved, but the tolerance for error is less than with slower, less exacting drying processes. A combination of good kiln design and good kiln operation is essential. Both are becoming more attainable using computer-aided performance modelling in kiln design, and programmable, computerised kiln monitoring and control systems. The only concern is that commercial considerations in many cases result in compromises - (a) in kiln design, to obtain the construction contract and (b) in operation, to reduce drying times and costs.

An ongoing commitment to research and development in kiln drying is necessary to provide -

A better understanding of the processes involved, with more information about the properties of individual species, enabling improved modelling and leading to better control of the drying process.

Continuing development of commercial drying operations.

This should ensure the successful future growth in the production of dried sawnwood.

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LITERATURE CITED

Alexiou, P.N., 1989: Accelerating the kiln drying of regrowth blackbutt *Eucalyptus pilularis* Sm. Proc IUFRO Wood Drying Working Party Symp, 23-28 July, Seattle, USA. pp. 116-125.

Alexiou, P.N., Zhao, S. and Marchant, J.F., 1989: Effect of moisture content and basic density on the viscoelastic properties of regrowth blackbutt *Eucalyptus pilularis* Sm. in tension across the grain. Proc IUFRO Wood Drying Working Party Symp, 23-28 July, Seattle, USA. pp. 71-78.

Brennan, L.J., Fricke, K.W., Kauman, W.G. and Wright, G.W., 1966: Predrying in Australia. *Aust Timber J* **32**: 360-364, 366.

Campbell, G.S. and Hartley, J., 1978: Drying and dried wood. Chapter 16, Hillis, W.E. and Brown, A.G. (Ed.): Eucalypts for wood production. CSIRO, Aust.

Christensen, F.J. and Gough, D.K., 1975: Control of drying distortion in framing from young plantation slash pine. Report No. 44, Division Building Research, CSIRO, Aust. 38 pp.

Christensen, F.J. and Northway, R.L., 1982: The evolution of the continuous-feed kiln for sawn timber. Research Review, Division Chemical Technology , CSIRO, Aust. pp. 11-27.

Christensen, F., 1985: High temperature drying of hardwoods increases kiln throughout. Forest Products Newsletter, New Series No. 2, Division Chemical & Wood Technology, CSIRO, Aust. pp. 1-4.

FORWOOD, 1974: Forestry and Wood-based Industries Development Conference, Report of Panel 2 - Forest Resources. Aust Forestry Council, Canberra.

Fricke, K.W., 1983: The CSIRO low temperature, low cost, progressive kiln. *Aust. Forest Industries J* **49**(3): 14-16.

Gough, D.K., 1973: Drying to minimise warp in plantation grown conifers. IUFRO Working Group on Wood Drying, South Africa. 5 pp.

Gough, D.K., 1981: Timber seasoning in a solar kiln. Tech Paper No. 24, Queensland Forestry Dept. 6 pp.

Hillis, W.E. and Rozsa, A.N., 1978: The softening temperature of wood. *Holzforschung* **32**: 68-73.

Kauman, W.G., 1964: Cell collapse in wood. *Holz als roh- und Werkstoff* **22**: 183-196, 465-472, DFP Reprint No. 566, Division Forest Products, CSIRO, Aust.

Kimball, K.E. and Lowery, D.P, 1967: High temperature and conventional temperature methods for drying lodgepole pine and western larch studs. *Forest Products J* **17**(4): 32-40.

Kippo, H., 1987: The mechanical creep of jarrah. Whittakers Ltd Research and Development. 9 pp., Appendices.

Kloot, N.H. and Page, M.W., 1959: Distortion in radiata pine scantlings. Tech Paper No. 7, Division Forest Products, CSIRO, Aust. 24 pp.

Koch, P., 1969: Southern pine studs can be dried and steam-straightened in 24 hours. *Southern Lumberman* **219**(2723): 26, 28, 29.

Koch, P., 1971: Process for straightening and drying southern pine 2 by 4's in 24 hours. *Forest Products J* **21**(5): 17-24.

Lembke, C.A., 1984: Kauri - new progressive kilns - F17 product development. *Aust Forest Industries J* **50**(2): 8, 10-12, 14-15.

Mackay, J.F.G. and Rumball, B.L., 1971: Drying of distortion prone juvenile core radiata pine for house studs. *Aust Timber J* **37**(6): 43-57.

Miller, W. and Riley, S., 1989: Computer control of softwood drying. Proc IUFRO Wood Drying Working Party Symp, 23-28 July, Seattle, USA. pp. 169-174.

Mills, R., Ralph, K. and Carson, J., 1987: Timber seasoning model - educational programs. Tasmanian Timber Promotion Board, Aust. 14 pp.

Nester, M.R. and Panow, S., 1983: Heat transfer along thermocouple wires inserted in timber. Res Note No. 38, Department of Forestry, Queensland. 8 pp.

Oliver, A.R., 1986: A model to correlate measurements directed towards reducing drying degrade in sawn eucalypt timber. Proc 22nd Forest Products Research Conf, 17-20 Nov, CSIRO, Melbourne.

Ralph, K.J., Weeden, S.C. and Goodwin, S.A., 1984: Commercial-scale seasoning trials on backsawn Tasmanian oak. Proc 21st Forest Products Research Conf, 19-23 Nov, CSIRO, Melbourne.

Schaffner, R.D., 1981: Fundamental aspects of timber seasoning. Research Report 81/1, Mech Eng Dept, Faculty of Engineering, University of Tasmania.

Wilkins, A.P. and Wilkes, J., 1987: Observations on the mechanism of collapse in wood. *J Inst Wood Sci* **11**(2): 89-92.

Wu, Q., 1989: An investigation of some problems in drying of Tasmanian eucalypt timbers, ME Sc Thesis, University of Tasmania. 237 pp.

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VALWOOD® FOR VALUE-ADDING IN REGROWTH EUCALYPTS

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ABSTRACT

The VALWOOD® process was developed by the Department of Conservation and Land Management as part of a major research project on value-added products from regrowth eucalypt thinnings. The major species assessed has been jarrah (*Eucalyptus marginata* Donn ex Sm.), but other species such as karri (*E. diversicolor* F. Muell.) and Tasmanian blue gum (*E. globulus* Labill. subsp. *globulus*) have also been studied.

The process involves edge-and face-gluing of 10 mm thick dried dressed boards to produce furniture blanks as the major product. The thin boards are dried quickly with minimum degrade, and defective material can be included in inner laminates to increase recoveries considerably. Urea formaldehyde was considered to be the most suitable adhesive for furniture blank production.

Structural products such as crossarms for transmission poles and laminated box beams, as well as large cross-section pieces for Departmental signboards, have been constructed using resorcinol formaldehyde to produce waterproof bonds.

The economic potential of VALWOOD® has been realised, with a Western Australian company contracting to use part of the Department's Wood Utilisation Research Centre as a pilot plant. Quality control is an essential feature. Future research will include assessment of other species and adhesives.

INTRODUCTION

The Wood Utilisation Research Centre (W.U.R.C.) of the Department of Conservation and Land Management (CALM) carried out a major research project from 1986 to 1990, to assess new methods and techniques for increasing the value-added component from regrowth eucalypt thinnings. The Small Eucalypt Processing Study was funded by the Commonwealth Government through a Public Interest Project, by the State Government, and by the Western Australian timber industry.

Most research was done on native Western Australian regrowth eucalypts, particularly jarrah (*Eucalyptus marginata* Donn ex Sm.) and karri (*E. diversicolor* F. Muell.), on the basis that the principles developed in the study would be applicable to other eucalypt species.

However, species such as Western Australian-grown Tasmanian blue gum (*E. globulus* Labill. subsp. *globulus*), were also studied.

The research program included assessments of stockpiling, sawing, timber drying, and wood properties evaluation, but the major emphasis was on processing and value-added components, and VALWOOD® was developed.

DEVELOPMENT

The initial research on sawmilling at the W.U.R.C. indicated that conversion of small regrowth eucalypt logs into structural timber was not economic. The market-driven approach was considered, and an obvious niche was supplying high quality timber to furniture manufacturers.

The production of furniture blanks (edge-jointed boards), which are widely used in the U.S.A. [1], was suggested as an efficient way to increase the value-added component from regrowth eucalypts. A survey of furniture manufacturers indicated that the solid timber sizes required for furniture production were substantially smaller than the sizes supplied by local sawmillers [2]. Although the maximum length required for furniture manufacturing was 2200 mm, 84 per cent of lengths were less than 1000 mm. Ninety-five per cent of components were less than 35 mm thick, with 70 per cent being under 25 mm, and 76 per cent were less than 100 mm width.

The advantage of furniture blanks was that several components could be cut from the width, with considerable increases in recovery. For example, a curved chair leg used by one local manufacturer was cut from a 150 mm x 20 mm board, which resulted in 70 per cent waste. Seven legs could be cut from a 600 mm wide panel, reducing the waste to 30 per cent. Panels could be cut to the required length with no end docking waste.

A high quality adhesive bond is required for this type of construction, and a trial assessed five different adhesives for gluing jarrah and karri furniture blanks [3]. These adhesives were all used at that time by local manufacturers. The panels were assembled using the W.U.R.C.'s 'Orma' glue press, with oil-heated platens at 90°C, operating at 1500 p.s.i. (10.3 MPa) and lateral pressure of 250 p.s.i. (1.7 MPa). The press produces a 2.4 x 1.2 panel in 6 minutes.

Dry cleavage tests on samples cut from the panels were based on AS1328-1987 [4], and gave the following percentages of wood failure:

Urea formaldehyde	90.1 per cent
Resorcinol formaldehyde	88.5 per cent
Melamine fortified urea formaldehyde	87.2 per cent
Melamine formaldehyde	84.4 per cent
Polyvinylacetate	8.7 per cent

The colourless glueline of urea formaldehyde adhesive was an additional factor to recommend its use in manufacturing furniture blanks. Resorcinol formaldehyde, with its darker glue line but superior waterproof qualities, was recommended for exterior use.

VALWOOD®

The VALWOOD® concept was suggested by Mr P.N. Shedley, Manager of the W.U.R.C. Although furniture blanks resulted in increased efficiencies, the drying of boards for a finished 20 mm thickness still required considerable time, and losses due to seasoning defects occurred. However, producing thin boards which were edge- and face-glued to produce panels would result in even more efficiency in producing value-added products. Thin boards dry faster with less risk of seasoning degrade.

A 10 mm board thickness was used initially, and the boards could be assembled into multiples of 10 mm to 200 mm thickness, although the time required for heating to cure the adhesive in any thickness over 100 mm would be restrictive. Based on the results of the furniture survey [2], most panels would be 30 mm thick or less.

A pilot trial by Mathews [5] on production aspects of VALWOOD® used through- and-through sawing to produce 16 mm or 13 mm thick boards to assess shrinkage and dressing losses. However, there were problems with bark-to-bark boards cut near the heart, with differential shrinkage between the outer wood and the heart and excessive and splitting. Many boards required end-docking and each board required edge trimming.

The boards were strip-stacked and air-dried under shelter to e.m.c. in three weeks. They were then high temperature dried to reduce moisture contents to 6-8 per cent, using a schedule of 30 min steaming, 1 h drying at 110°C, and 30 min steam reconditioning. There was negligible degrade.

The grading showed that boards with outer wood had fewer end splits, fewer face checks, and less cupping than juvenile core-affected wood:

	Outer wood	Core-affected
% with no end splits	29.7	1.9
% with no face checks	51.4	17.6
% with no cup	40.9	36.2

However, because the outer wood tended to be backsawn and the core-affected quarter sawn, Mathews [5] found that recoveries (sapwood as percentage by weight of original dry boards) tended to even out, with 84.5 per cent from outer wood compared to 84.0 per cent from juvenile core wood. The overall recovery of dried dressed boards was 33.4 per cent.

Following Mathews' research [5], the process has been modified. These results indicated that a better sawing pattern could have boards cut from each side to leave a central flitch, which was turned 90° and sawn into boards with parallel edges. This basic backsawn pattern would reduce the problems of differential shrinkage and increase recoveries.

Drying of 15 mm thick boards has been assessed using alternative methods. A commercial veneer dryer was used in one trial to assess high temperature drying. The results were promising enough to justify a Curtin University student project in designing and constructing a jet impingement dryer [6]. Research trials using this dryer have just commenced.

Another method assessed was drying in a commercial high temperature kiln with air velocity of 5 m/s. Although there was no added heat, the temperature in the kiln increased by 15°C over an ambient 25°C, because of frictional effects. The 15 mm boards dried to below e.m.c. in less than two weeks, with negligible degrade.

The 15 mm green boards are dressed to 10 mm thickness after drying, and graded on the basis of clear faces and edges. The allowance for shrinkage and dressing would be determined for each species.

The edges of the bark-to-bark boards are now taper trimmed on a machine developed at the W.U.R.C. The board is aligned for turning one edge parallel to the grain with minimum waste, then realigned and the record edge is cut as the saw returns. Taper is usually small, but boards could be end-for-ended if required. The parallel grain improves any colour matching required.

Stability tests of jarrah and karri panels in controlled environment rooms at 6 per cent or 20 per cent e.m.c., including cyclic testing, have indicated that VALWOOD® panels are stable products [7].

Sawmillers and furniture manufacturers in the Eastern States have shown considerable interest in VALWOOD® production using their local species. Panels have been constructed from regrowth mountain ash (*E. regnans* F. Muell.) and blackwood (*Acacia melanoxylon* R. Br.), and small pieces of furniture constructed. Western Australian timbers, including the Eastern Goldfields species Dundas blackbutt (*E. dundasii* Maiden), have had limited testing.

A major feature has been the development of a Quality Control Manual, which is essential for efficient and economic production. Research data for each species assessed will be included in the Manual provided to the licencee.

Structural VALWOOD®

Structural products have also been assessed. The State Energy Commission of W.A. (S.E.C.W.A.) has problems in buying sufficient crossarms of satisfactory quality and dried to e.m.c. Thirty jarrah and thirty karri VALWOOD® 100 x 100 mm crossarms suitable for power poles were constructed from ten 10 mm thick boards, using resorcinol formaldehyde. The crossarms were strength tested by Curtin University of Technology under contract to assess modulus of rupture (MOR) and modulus of elasticity (MOE) [8]. The results were:

	MOR (MPa)		MOE (MPa)	
	Mean	S.D.	Mean	S.D.
Jarrah	99.3	13.0	15 750	760
Karri	127.3	9.4	20 705	1328

The small standard deviations indicated very uniform products. The results showed that half the 100 mm x 100 mm jarrah and all of the karri crossarms were able to take a greater load than the 100 x 125 mm solid jarrah. Accelerated weathering tests of sections of these crossarms have commenced at the A.N.U. under Dr Philip Evans.

Research in VALWOOD® box beams commenced with a final year Civil Engineering project by Mr Jan Karpinski at Curtin University of Technology [9]. He has continued the project.

Other products

Signboards for the Department of CALM's regions and districts have been manufactured using the VALWOOD® process, with resorcinol formaldehyde as the adhesive. The cost is similar to that of imported South-east Asian timbers which have been used for signboards because local sawmillers had difficulty in providing large cross-sections of jarrah. In addition, VALWOOD® has great potential for turnery and craftwood.

General

The Department of CALM has satisfied the Commonwealth that research results from the Small Eucalypt Processing Study have been communicated to industry representatives in other states, with the Technology Exchange Workshops held in Adelaide, Melbourne,

Sydney, Brisbane in July, and Launceston in August. Reports on the research projects are readily available.

The first commercial licence was given to Karrivale Pty Ltd (associated with Timber Traders Cockburn Pty Ltd), who were the successful tenderers for the licence and access to a regrowth jarrah resource. Under the agreement, the W.U.R.C. will produce VALWOOD® in a pilot plant for up to three years. A network, including the Department of CALM, the Department of Trade Development, Karrivale, and associated furniture manufacturers, has been established.

There is an ongoing need for research and development to assess different species and different adhesives. As stated previously, VALWOOD® panels have been constructed from jarrah, karri, marri, Tasmanian blue gum, mountain ash, blackwood, and some eucalypt species from the Eastern Goldfields of Western Australia. Further research is required on most of these, because VALWOOD® licences will not be allocated until problems such as species/adhesive interactions are assessed. The advantage of VALWOOD® is producing value-added timber from small diameter trees, and it showed that the market-driven approach has considerable potential.

REFERENCES

1. Araman, P.A., Gatchell, C.J. and Reynolds, H.S. (1982). Meeting the solid wood needs of the furniture and cabinet industries: Standard-size hardwood blanks. U.S. Department of Agriculture Forest Services Research Paper NE-494.

2. Challis, D.J. (1989). Survey of solid wood sizes used by the furniture industry in Western Australia. Department of Conservation and Land Management. W.U.R.C. Report No. 9.

3. Newby, P. and Siemon, G.R. (1989). Adhesives for manufacture of furniture blanks. Department of Conservation and Land Management. W.U.R.C. Report No. 12.

4. Standards Association of Australia (1987). Glued-laminated structural timber. AS1328-1987.

5. Mathews, L.R. (1990). VALWOOD® processing - a preliminary investigation. Department of Conservation and Land Management. W.U.R.C. Report No. 17.

6. Burgess, K. and Ellery, M. (1989). Design of a jet impingement wood dryer. Curtin University of Technology. Department of Mechanical Engineering. Bachelor of Engineering Project Report.

7. Newby, P. (1990). Stability of VALWOOD® furniture blanks manufactured from jarrah and karri. Department of Conservation and Land Management. W.U.R.C. Technical Report No. 27.

8. Siemon, G.R. (1990). Strength properties of laminated jarrah and karri crossarms. Department of Conservation and Land Management. W.U.R.C. Technical Report No. 33.

9. Karpinski, J. (1989). Structural uses of regrowth jarrah. Curtin University of Technology. School of Civil Engineering Projects. Limited distribution.

MOLECULAR DESIGNING OF WOOD ADHESIVES

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INTRODUCTION

With an increasing population and a rising standard of living in the world, greater demand for wood and wood-based products will continue. In addition, for environmental and ecological reasons, the availability of large-diameter logs of high quality will continue to lessen. In this situation, it is important to more fully utilize forest resources. The manufacture of reconstituted wood products offers a viable and more efficient alternative for this purpose. Thus the need for adhesives for such products as plywood, particleboard, laminated timber including laminated veneer lumber (LVL) and so on.

The Wood Adhesives Group at CSIRO, Division of Forestry and Forest Products has been deeply involved in the Australian reconstituted wood products industry and in developing more efficient wood adhesive systems in collaboration with adhesives manufacturing companies and the Plywood Association of Australia. One project is related to the gluing of high density and "difficult to glue" wood species such as blackbutt (*Eucalyptus pilularis*) and has resulted in adhesives able to successfully glue this and other species. During this development, our traditional approach has been gradually replaced with a new approach called "molecular designing of wood adhesives".

This paper reviews the types of adhesives for wood, the state-of-the-art in bonding wood, particularly in plywood, which is used as a most convenient example to examine what is going on at the glue/wood interface, and finally describes briefly a concept of "molecular designing of wood adhesives", where adhesives based on phenolic resins are being studied because of their durability under exposure and stress conditions.

CLASSIFICATION OF WOOD ADHESIVES

Wood adhesives can be divided into two main classes - Natural polymers and Synthetic polymers (Table 1). Most adhesives based on natural polymers have existed for a long time. Although some of them such as lacquer are still being used

for specific purposes because of their appropriate properties, these natural polymer adhesives largely have been replaced with synthetic polymer adhesives. However, because natural polymer adhesives are renewable, some of them still excite interest for replacing synthetic adhesives.

Synthetic polymer adhesives are divided into four groups - thermoset, thermoplastic, elastomer and composite. Major thermoset adhesives such as phenol-formaldehyde (PF), resorcinol-formaldehyde (RF), melamine-formaldehyde (MF), urea-formaldehyde (UF) or their combinations when reacted with formaldehyde are used as common wood adhesives. These thermoset adhesives, once cured, give a rigid glueline that will not replasticise even when heated and are generally considered not to creep under conditions of long term stress. On the other hand, thermoplastic adhesives will replasticise when heated and creep under long term stress. The most common thermoplastic adhesives are polyvinylacetates (PVA). Highly cross-linked PVA's are more durable and creep less than normal PVA's. They are sometimes used in end-jointing veneer and overlaying plywood or particleboard with decorative veneers. The normal PVA's are also used as furniture adhesives. Elastomers are rubber-based adhesives which have excellent gap-filling properties. The contact adhesives are mainly polychloroprene solutions and are widely used in furniture manufacture for securing overlays. Composite adhesives consist of two or more major components to produce new and improved properties that incorporate the advantages of each component material. For example, the structural performance and water-resistance of PVA is improved in the composite PVA-phenol adhesives. Since there are great possibilities to develop new properties, much research effort has been made in making composite adhesives in recent years.

Wood adhesives commonly used in the Australian reconstituted wood industry and their generally accepted durabilities are summarized in Table 2. This was originally prepared by Lyngcoln (1) on the basis of his experience and discussion with researchers at CSIRO, Division of Building Research, the literature on durability of adhesives published by Forest Products Laboratory, Princess Risborough, England based on the work by Knight (2) and more recently continued by Dinwoodie (3).

According to the Australian Plywood Bond Type Classification (4), those gluelines bonded with synthetic phenolic and tannin adhesives are classified as Type A which can pass a 72-hour boil test. The gluelines can be expected to survive for

more than 50 years, virtually indefinitely, under fully exposed and long term stress conditions. Phenol-formaldehyde (PF) resins have been and still are the most commonly used Type A wood adhesives for producing structural products.

PHENOL-FORMALDEHYDE RESINS

Phenol condenses with formaldehyde in the presence of alkali, initially to form a methylol phenol and then a dimethylol phenol. The initial attack may be at the 2, 4 or 6 position but the product is such that the dimethylol is substantially 2, 6 with only a small proportion of 2, 4. The second stage of the reaction involves the reaction of the methylol groups with further phenol and hence, with unsubstituted phenols to the formation of a much branched tree structure (Fig. 1).

With acid catalysis, and a molar ratio of formaldehyde to phenol of less than one, novolak resins are obtained. These have a largely branched but not cross-linked structure and no free methylol groups exist (Fig. 2). To complete resinification, further formaldehyde, usually as hexamethylenetetramine(hexamine), is added to fully cross-link the resin.

With alkaline catalysis and excess formaldehyde, resols are obtained of varying molecular size but of the general form shown in Figure 3.

When these methylol derivatives have accumulated in the system, these compounds react initially to form dibenzyl ethers which, on further heating loose formaldehyde producing methylene linkages (Fig. 4), with sufficient heating a resitol may be formed. A resitol is viscous and swells but is not dissolved in organic solvents. When the condensation reaction of resitol is further continued either by heating or with an acidic hardener at lower temperature the macromolecular and three dimensional resite is formed, which is completely insoluble and does not melt at any temperature. At this stage the resin is hardened and the condensation reaction is completed (Fig. 5).

Resin manufacturers can provide PF resins as resol or novolak to users, but resols are the most common type in the reconstituted wood industry.

FACTORS AFFECTING BOND FORMATION

Considering the gluing of veneers with a phenolic resin, the resin is applied to wood as a solution the solvent usually being aqueous alkali. As soon as the adhesive solution contacts to the wood, the solvent "wets" and then penetrates and

adsorbs into the wood, even without pressure, leaving most of the phenolic resin solids on the wood surface. The rate of the loss of solvent depends on the moisture content of the wood, roughness of the surface and the inherent attraction between wood and solvent. Application of pressure to adhesive-loaded veneers spreads and transfers the increasingly viscous adhesive and causes bulk flow of adhesive solids and solvent through the wood surface into the large pores and capillaries in the wood, thus reducing the thickness of the glue film. If too much adhesive penetrates into the wood, the film is discontinuous on the wood surface.

Cure of the adhesive involves two interrelated processes; solvent loss and chemical cross linking. A high solvent content of the adhesive retards cross linking. Too rapid loss of solvent makes the immobile solids incapable of forming a crosslinked film. Heating increases both solvent loss and cross linking, although each rate increases differently with temperature.

Most of the gluing parameters are affected by time, temperature, pressure and wood properties, so that conditions can be manipulated to attain a good bond. However, the process of wetting is less amenable to manipulation than other gluing parameters.

(a) Wettability

It is common knowledge that freshly prepared surfaces, as a rule, result in better glue joints than aged surfaces, and that the gluability of a wood surface depends very much on its prehistory, that is, its mode of preparation, drying, storage, and its possible contamination by atmospheric grime from substance such as the products of combustion from oil or gas-fired dryers.

Determination of surface-free energy of woods

The critical surface energy is the surface tension of a liquid which will just spread on the surface with zero contact angle.

Various studies have to be conducted using non-aqueous (5) and aqueous solutions to estimate the critical surface tension (6,7,8).

These show that critical surface tensions of wood vary considerably. The highest values reported are for freshly prepared surfaces of wood low in extractives content. The presence of non-polar extractives, aging of the surface, and heating and drying of the woods all decreased surface-free energy and wetting.

The Bond quality has been found to be correlated to wettability using urea-formaldehyde resins (9,10,11). On the other hand, many studies with alkaline phenolic resins show little or no relationship between bond quality and wettability (12,13) and even some improvement in the bond quality as wetting decreased (14).

(b) Wood moisture content

Although many wood surface characteristics such as anatomical roughness, porosity and microfracture influence bonding, wood moisture content is the most important factor because it influences wetting and solvent loss from the adhesive, which affect "glue flow" in the glueline at hot pressing. Glue flow is usually described in terms of glue penetration.

Insufficient penetration will result in reduced chemical adhesion due to the reduced area of the glue/wood interface and loss of any mechanical adhesion. On the other hand, excess penetration has been found to be undesirable as the resin from the glue migrates into the surrounding wood so far that the glueline loses continuity resulting in poor glueline cohesion. When the wood moisture content is high, wetting with aqueous adhesives occurs readily but the amount of water absorbed from the glueline is low so that excess penetration during pressing occurs resulting in poor bond quality. In practice, at any specific wood moisture content, the assembly time and to a lesser extent glue spread may be adjusted to optimize bonding conditions.

(c) Wood density

It is generally accepted that the greater the wood density, the greater is the gluing difficulty. According to Sellers *et al* (16), wood densities, which are defined as high density hardwood species in the USA, are greater than 0.52 (up to 0.75). Greater substrate strength, increased dimensional instability, and reduced permeability are the primary cause of difficulties in gluing these high density hardwoods. For comparison, the wood density of blackbutt (*Eucalyptus pilularis*), on which CSIRO has been working, ranges from 0.72 to 1.0 and its average density is 0.87.

(d) Extractives

Some tropical hardwood species such as kapur (*Dryobalanops* sp.) and apitong (*Dipterocarpus* sp.) are known as "difficult to glue" wood species. These wood species usually contain relatively large amounts of extractives which are

soluble in n-hexane, ether and benzene. Some compounds in these extracts retard penetration of the resin into wood substrates due to decreased wettability (13) and the presence of 1% ferulic acid in the ether extracts from kapur also inhibits curing of the resin (17). Furthermore, an ether-soluble fraction of the alkaline extract from kapur causes gluing problems, since carboxylic acids lower the pH, thereby decreasing resin solubility and retarding both cure rate and penetration (18). Hydrolyzable tannins also can cause a significant reduction in the bond quality of PF adhesives (19). The older oaks were shown to have a higher extractive content with a lower pH value and higher buffering capacity. In this case, the acidity of the extractives had a detrimental effect on bonding (20). Lower density, extractive-free hardwoods can be bonded with the same ease and expectations of good bond performance as with soft wood species.

(e) Adhesive properties

It is known that the optimization of gluing conditions such as wood moisture content, glue spread, open and closed assembly time and hot-press pressure, temperature and duration is required to produce high quality bonds with a PF resin. A low quality resin may be defined as a resin that has low tolerance to such gluing parameters, whereas a high quality resin may be far more tolerant to mill variations.

CHARACTERIZATION OF PHENOLIC RESINS

In the past, viscosity, molar ratio of formaldehyde to phenol, gelation time and total solids content of an adhesive were the primary parameters used to characterise phenolic resins and related to gluebond quality. However, with the development of chemical analytical techniques such as NMR and GPC, resins can be characterized in more chemical detail which in turn will allow a prediction of their gluing parameters.

Nuclear magnetic resonance (NMR) spectroscopy is defined as the absorption and emission of electromagnetic radiation by the nuclei of certain atoms when they are placed in a magnetic field. In order to absorb electromagnetic radiation, nuclei must possess a non-zero magnetic moment. The majority of the elements in the Periodic Table have at least one isotope capable of nuclear magnetic resonance. For NMR spectroscopy, the sample must be placed in a magnetic field before the absorption of electromagnetic radiation can occur. The basic components of any NMR spectrometer include a strong magnet, into which the sample is placed, a radio-frequency transmitter and a receiver system connected to some type of data display or storage device (Fig. 6).

The ^{1}H nucleus (i.e. the proton) is by far the most commonly studied nucleus by NMR spectroscopy, primarily because of the ease of observation, and its high natural abundance. Despite its low natural abundance (1.1%), ^{13}C is also an important nucleus because carbon forms the backbone of all organic compounds and structural information can be obtained by NMR analysis.

Gel permeation chromatography (GPC), which is also known as size exclusion chromatography, is based on the ability of controlled-porosity materials (particles) to sort and separate the sample mixture according to the size and shape of the molecules of the sample. The particles in the column have various pores and pore networks which permit the passage of certain molecules through them. Small molecules can permeate the packing particles (i.e., diffuse into all the pores) whereas large molecules cannot enter the pores and are physically excluded (Fig. 7). As expected, the molecules of larger size (higher molecular weight) elute first, followed by smaller and smaller molecules. The column or column set is calibrated using standards to provide a relationship of elution volume and molecular weight. Samples of unknown molecular weight are then run, and molecular weight data is calculated using the calibration data by a computer.

CSIRO, Wood Adhesives Group has established methods to characterize phenolic resins by ^{1}H and ^{13}C NMR and GPC analysis. Since more detailed information regarding the analysis of phenolic resins by these NMR and GPC is presented as poster papers in this conference (21,22), only a few specific properties are briefly mentioned here.

Figures 8 and 9 illustrate examples of a ^{13}C NMR spectrum and GPC chromatogram of a phenolic resin. Based on chemical shifts and integration of peaks in the ^{1}H and ^{13}C NMR spectra, information regarding methylol content, degree of polymerization, patterns of methylene linkages (o-p, p-p' or o-o') and molar ratio of reacted formaldehyde to phenol in the PF resin can be obtained. Furthermore, based on the GPC analysis, information regarding the molecular weight distribution of a phenolic resin, such as the weight average molecular weight, the number average molecular weight and the dispersity, can be obtained.

Thus, information obtained from NMR and GPC now allows us to characterize PF resins in terms of the chemical structural characterization and molecular weight distribution.

"GLUE-FLOW" IN THE INTERFACE BETWEEN GLUE AND WOOD

Assessment of bond failures at CSIRO and the PAA Laboratory has shown that 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-penetrated 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.

It has been found that ordinary parameters used to characterize resins such as total solids content, viscosity, gelation time and pH affect "glue flow" but sometimes in quite different ways. Furthermore, it has been our experience that phenolic resins having the same values of these parameters sometimes behave quite differently in their "glue flow" characteristics.

MOLECULAR DESIGNING OF PHENOLIC RESINS

At present, there are neither universal wood adhesives which can glue all wood species covering from softwoods to hardwoods nor any wood adhesives for gluing over a wide range of wood moisture contents, e.g. 0-25%, even in one wood species. This indicates that the performance of phenolic resins is still insufficient to completely overcome the effect of variables derived from wood properties such as wood species, density, moisture content, extractives and anatomical features on gluebond quality.

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 resins for obtaining high bond quality, compared with preparing universal resins. CSIRO has established that "glue flow" in the glueline at the time of hot pressing is one of the most important parameters to be monitored for maximizing gluebond quality, "glue flow" is now being defined in such molecular terms as the molecular weight distribution, methylol content, degree of polymerization and P:F ratio.

Using this "molecular designing" concept, our Wood Adhesives Group has developed a gluing system for high density and "difficult to glue" wood species such as blackbutt. The gelation time of resins can be used as an indication of the cure

rate of adhesives and a differential scanning colorimeter (DSC) has allowed evaluation of the relationship of time and temperature to cure. We have established a method to characterize PF resins using the DSC. As expected, it has been shown that the molecular weight distribution and methylol content of a resin are important parameters affecting the gelation time of resins. The specific requirements of phenolic resins for each individual application are most likely to be related to those chemical characteristics which are easily described in chemical terms. Furthermore, it is believed that the accumulation of information regarding chemical characterization of resins from each individual case of wood gluing would be the basis for the development of wood adhesives able to tolerate a much wider range of gluing parameters.

ACKNOWLEDGEMENT

We would like to acknowledge Chemplex Australia Limited for their support for this work.

REFERENCES

1. Lyngcoln, K.J. (1989). Adhesives for wood, CSIRO/PAA Plywood Production Course, Lecture Notes Vol. 2. 1-13.

2. Knight, R.A.G. (1968). The efficiency of adhesives for wood. Ministry of Technology, For. Prod. Res. Bull. No. 38, HMSO London.

3. Dinwoodie, J.M. (1979). The properties and performance of particleboard adhesives. Building Research Establishment, Princess Risborough Laboratory.

4. Australian Standard, (1977). Method of Test for Veneer and Plywood. AS 2098.2. Bond Quality of Plywood (Chisel Test).

5. Zisman, W.A. (1962). Constitution effects on adhesion and adhesives in Adhesion and Cohesion. P. Weiss, editor. Elsevier Publishing Co., New York, NY.

6. Gray, V.R. (1962). The wettability of wood. For. Prod. Jour. 12(6): 452-461.

7. Herczeg, A. (1965). Wettability of wood. For. Prod. Jour. 15(10): 499-504.

8. Nguyen, T. and W.E. Johns (1979). The effect of aging and extraction on the surface free energy of Douglas-fir and redwood. Wood Sci. Techn. 13: 29-40.

9. Freeman, H.A. (1959). Relation between physical and chemical properties of wood and adhesion. For. Prod. Jour. 19(12): 451-458.

10. Chen. C. (1970). Effect of extractive removal on adhesion and wettability of some tropical woods. For. Prod. Jour. 20(1): 36-41.

11. Elbez, G. (1978). Study of the wettability of wood. Holzforschung 32(3): 82-92.

12. Asano, S. (1967). Studies on adhesion in the manufacture of plywood I. The effect of physical properties of veneer on bond strength of plywood. Wood Industry 22(7): 318-323.

13. Jordan, D.L. and J.D. Wellon (1977). Wettability of dipterocarp veneers. Wood Sci. 10(1): 22-27.

14. Hse, C.Y. (1972). Wettability of southern pine veneer by phenol formaldehyde wood adhesives. For. Prod. Jour. 22(1): 51-56.

15. Gardner, D.J. (1990). Personal communication.

16. Sellers, T. Jr., J. M. McSween and W.T. Nearn (1988). gluing of eastern hardwoods: A review. Gen. Tech. Rep. SO-71. New Orleans, LA:USDA, Forest Service, Southern Forest Experiment Station. 1-30.

17. Imamura, H., T. Takahashi, M. Yasue, M. Yagishita, H. Karasawa and J. Kawamura (1970). Effect of wood extractives on gluing and coating of kapur wood. Bull. Gov. For. Exp. Sta. 232: 65-96.

18. Abe, I. and N. Akimoto (1976). The inhibitory effect of kapur wood extractives on the curing reaction of the resol. Mokuzai Gakkaishi 22: 191-196.

19. Plomley, K.F., W.E. Hillis and K. Hirst (1976). The influence of wood extractives on the glue-wood bond. I. The effect of kind and amount of commercial tannins and crude extracts on phenolic bonding. Holzforschung 30: 14-19.

20. Roffael, V.E and W. Rauch (1974). Extractives of oak and their influence on bonding with alkaline phenol-formaldehyde resins. Holz Roh-Werkst. 32(5): 182-187.

21. Reilly, M., P.J. Collins and Y. Yazaki (1990). Characterization of phenolic resins by nuclear magnetic resonance spectroscopy (NMR). The 23rd Forest Products Research Conference 1990.

22. Terrill, S.D., P.J. Collins and Y. Yazaki (1990). Characterization of phenolic resins by gel permeation chromatography. The 23rd Forest products Research Conference 1990.

Table 1. Classification of wood adhesives

	Comp. system	Hardening		Performance	
		Temperature	Mode	Struct.	Water-proof
NATURAL POLYMERS					
Tannins	1	Heating	Thermochemical	Yes	V.High
Lacquer	1	Mild heating	Chemical	Non	Low
Starch	1	Ambient	Solvent evap.	Non	No
Casein	1	Ambient	Chemical	Semi	Low
Soybean glue	1	Ambient	Chemical	Non	No
Animal glue	1	Ambient	Cooling solid.	Non	No
SYNTHETIC POLYMER					
Thermoset					
Phenolic (resol)	1	Heating	Thermochemical	Yes	V.High
Phenolic (novolak)	2	Ambi. or heat.	Catalytic chem.	Yes	V.High
Resorcinol	2	Ambi. or heat.	Addition reaction	Yes	V.High
Melamine	2	Heating	Catalytic chem.	Yes	Mod.
Urea	2	Ambi. or heat.	Catalytic chem.	Semi	Low
Epoxy	2	Mild heating	Addition reaction	Yes	Mod.
Isocyanate	1	Heating	Chemical	Yes	Mod.
Thermoplastic					
Polyvinylacetate (PVA)	1	Ambient	Solvent evap.	Non	No
Acrylic	1	Ambient	Solvent evap.	Non	Mod.
Ethylene PVA copolymer	1	Ambient	Solvent evap.	Non	Low
Polyurethane	1	Ambient	Chemical	Non	Mod.
Cyanoacrylate	1	Ambient	Chemical	Non	Mod.
Elastomer					
Polychloroprene	1	Ambient	Solvent evap.	Non	Low
Composite					
PVA-resorcinol	1	Ambient	Addition chem.	Semi	Mod.
PVA-phenol	2	Ambient	Addition chem.	Semi	Mod.
Aqueous vinylurethane	2	Ambient	Bridging chem.	Semi	Mod.
α-olefin-maleic anhydride	2	Ambient	Bridging chem.	Semi	Mod.

* Comp. system, Component system; Ambi. or heat., Ambient or heating; Struct., structural; Solvent evap., Solvent evaporation; Cooling solid., Cooling solidification; Chem., Chemical.

Table 2. Wood adhesives commonly available in Australia

	Glueline durability		
	Under exposure	Under stress	Application
Phenolic Phenol-formaldehyde Resorcinol-formaldehyde Co-polymer Tannin-formaldehyde Tannin-copolymer	Provided the resin will meet a 72-hr boil test, these resins are considered permanent under fully exposed condition; 50 years and more	Although there is some drop off in strength with age, the glueline is considered permanent under long term stress; 50 years and more	All structural wood composites or structural wood panels where applications involve long term stress or exposure
Aminoplastic Melamine-formaldehyde Melamine-urea-formaldehyde	Provided the resin will meet a 6-hr boil test, these resins are considered semi-permanent i.e. fully exposed 2 years maximum or protected from the weather, permanent i.e. 50 years	These resins deteriorate with time. Loaded under exposed conditions 2 years or loaded under protected conditions 25 years and more	Structural wood panels or composites where exposure to weather will be 2 years maximum. Concrete formwork, or in structures with max. of 25 years life if protected, e.g. caravans, transportable home
Epoxy Bisphenol Epoxy-novolak Epoxy-phenol	No scientific short term test. Semi-durable if exposed to the weather	Long term loads in excess of 25 years in a fully protected environment	Similar to those limited for melamine adhesives
Protein Casein	Non-durable under exposure or wet or damp environments. Attacked by fungal micro-organisms at m.c. above 25%	Durable under long term load in fully protected, well-ventilated environments	Non-exposed fully protected structural application
Amino plastic Urea-formaldehyde	Non-durable	Non-durable	Interior fully protected non-structural application

Figure Captions

Figure 1. Reactions of phenol with formaldehyde

Figure 2. Synthesis of novolak

Figure 3. General form of a low molecular weight resol

Figure 4. Formation of a methylene linkage

Figure 5. Hardening of phenolic resins

Figure 6. Basic components of a NMR spectrometer

Figure 7. Gel permeation mechanism

Figure 8. ^{13}C NMR spectrum of a phenolic resin

Figure 9. GPC chromatogram of a phenolic resin

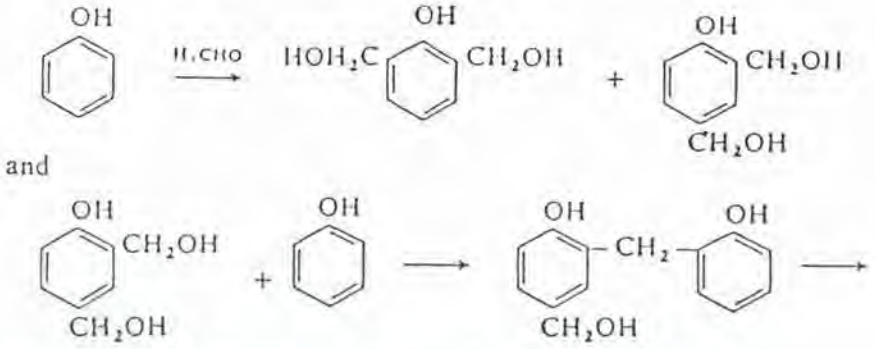

Figure 1. Reactions of phenol with formaldehyde

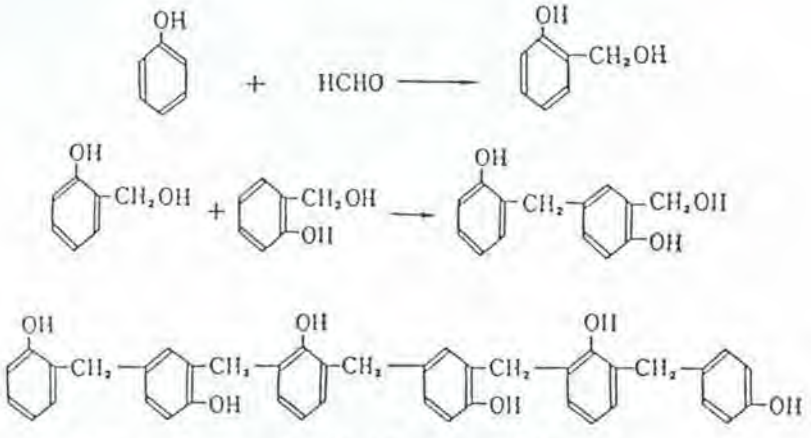

Figure 2. Synthesis of novolak

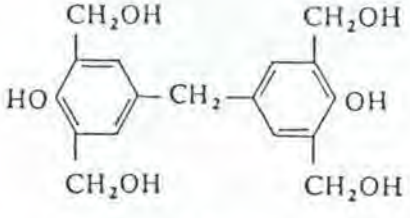

Figure 3. General form of a resol

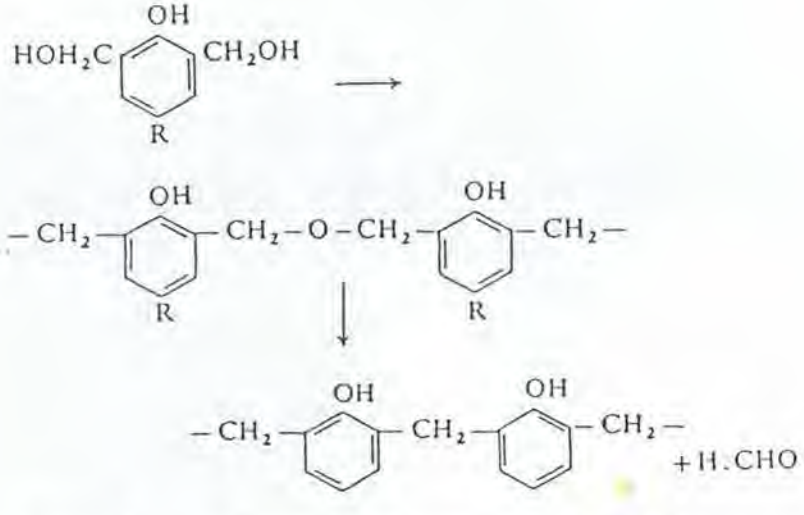

Figure 4. Formation of a methylene linkage

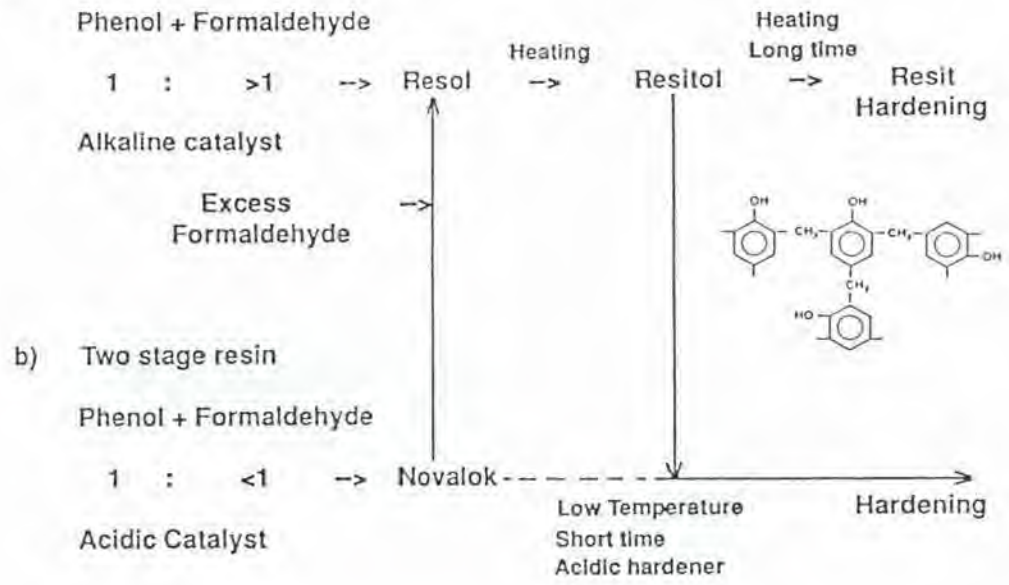

Figure 5. Hardening of phenolic resins

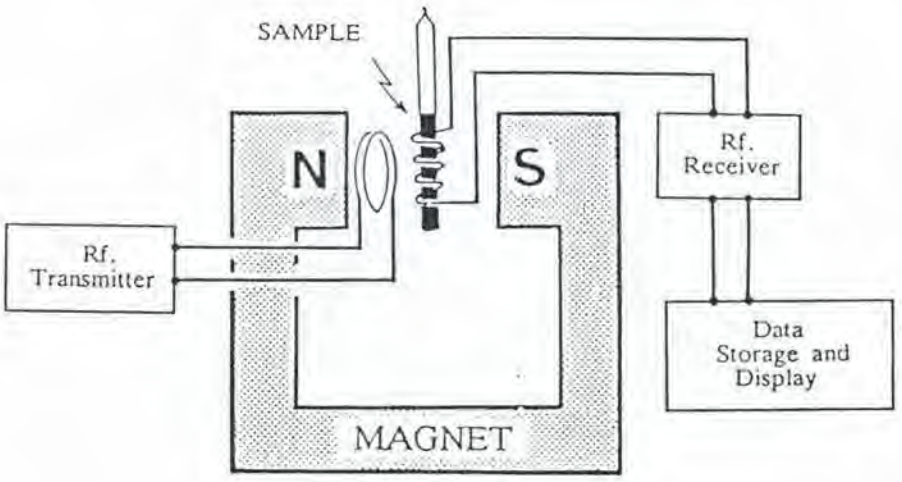

Figure 6. Basic components of a NMR spectrometer

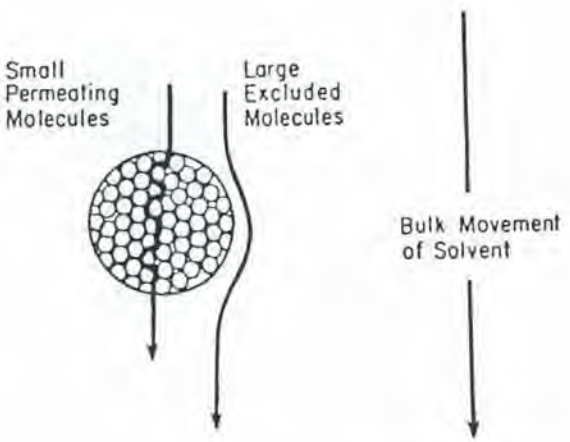

Figure 7. Gel permeation mechanism

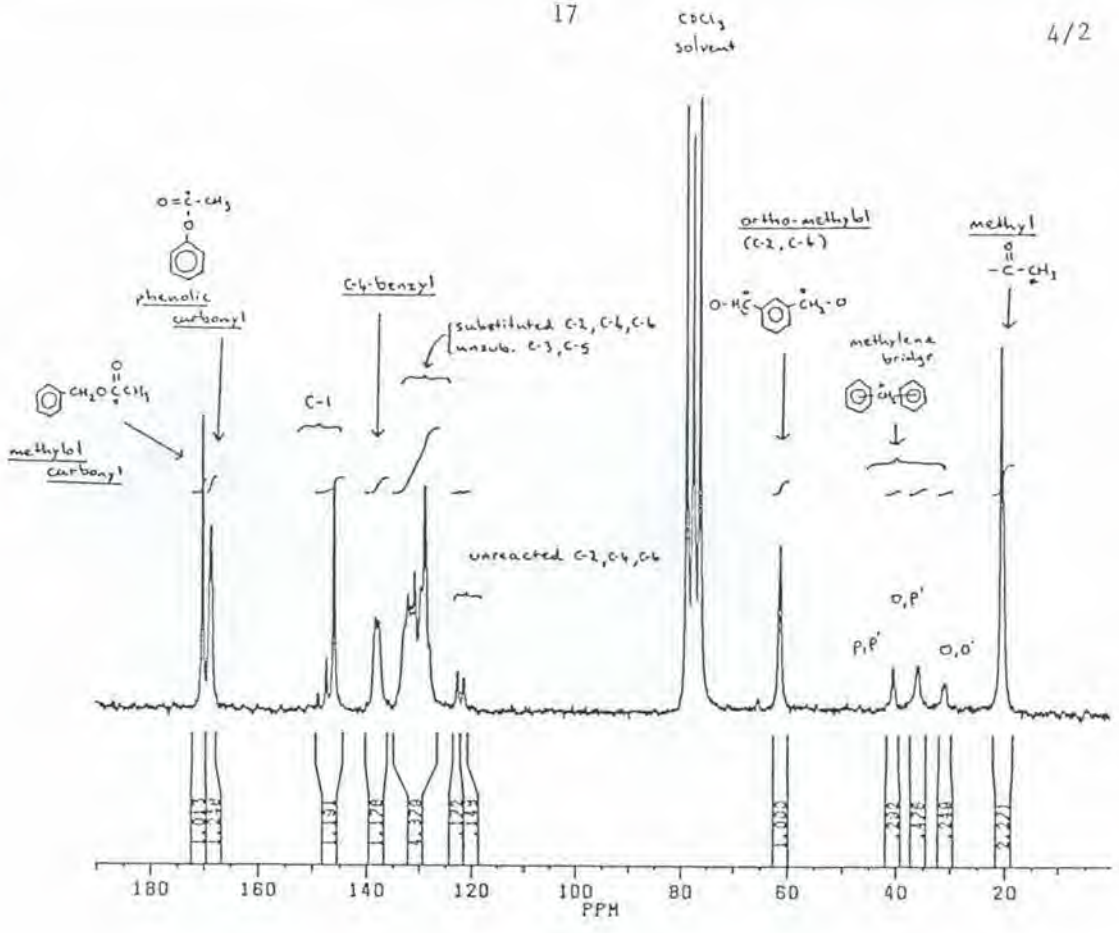

Figure 8. ^{13}C NMR spectrum of a phenolic resin

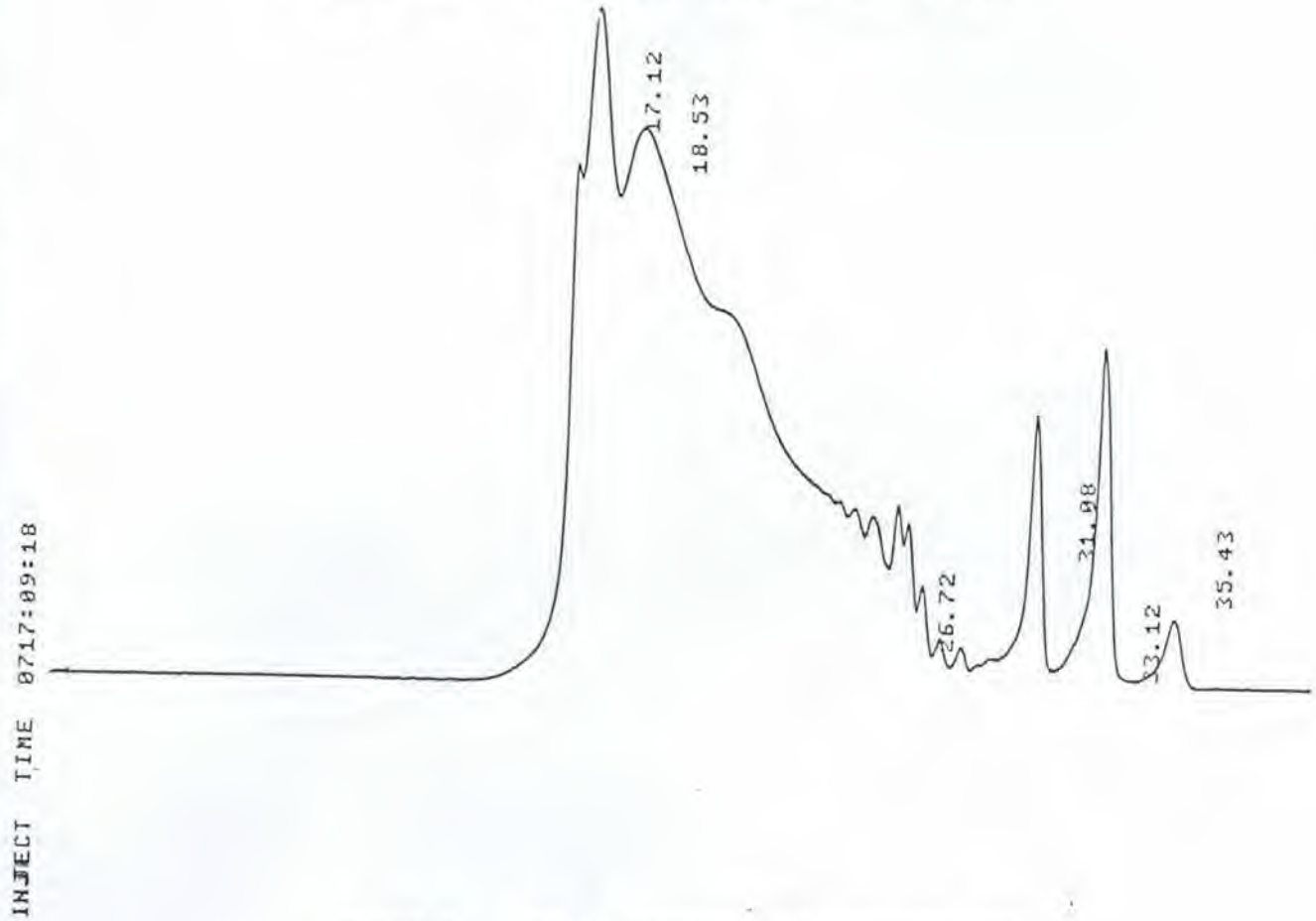

Figure 9. GPC chromatogram of a phenolic resin

THE DESIGN AND CONSTRUCTION OF STRESSED SKIN PANELISED FLOOR SYSTEMS

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ABSTRACT

The purpose of this paper is to provide a "state of the art" report on the "low profile floor" (LPF) and its percieved position within the spectrum of timber floor construction. Development, current research and the situation with regards to design methodology and practical applications are also presented.

INTRODUCTION

Timber floors of the bearer/joist type have been used in dwelling construction and other types of buildings for hundreds of years. In recent years, the concrete slab-on-ground has become popular in low rise construction. This development has resulted in a need for the re-assessment of the future use of timber floors, particularly in low set dwelling construction. It is not the intent herein to pursue the comparative virtues of concrete and timber floors, but the reader is reminded timber floors offer many advantages, e.g.:

- **flexibility of construction** with regards to site conditions, i.e. for sloping and reclaimed sites;
- **user friendliness,** being easy on the legs, particularly those of the aged;
- **environmental friendliness** in that they use a renewable resource which can be produced on a sustained yield basis;
- **aesthetic appeal** because of their ability to be polished and featured;
- to develop **diaphragm action** where required for structural purposes.

The obvious question now arises as to why a LPF should be any better than the tried and proven conventional bearer/joist system. To answer this question, it is necessary to provide herein

a definition of the LPF. Briefly, such a system consists of planar bearers and joints (of the same cross-section usually) interconnected by glue/nailing plywood sheathing to their upper surface. The advantages to be gained from the LPF include:

- **overall shrinkage** is reduced by having members planar rather than one upon the other;
- **economical** use of the plywood and timber framing resulting in the development of composite action and lateral load transfer;
- a **reduction** in the number of courses of bricks required in brick veneer construction;
- a **lowering** of the floor system (by the depth of the bearer) compared with the bearer/joist system.

Since the LPF also satisfies the previously stated advantages of the timber floor, there seems every reason why its development for commercial use should be encouraged.

HISTORY

During the middle 1970's, the writer promoted the idea of an "Engineered Whole House" to the current Executive Engineer of the Plywood Association of Australia (PAA). Such a concept was well received and in the late 1970's financial assistance was forthcoming from PAA to support a number of final year Civil Engineering projects at University College of Central Queensland (UCCQ) to study "whole house response" to simulated wind forces.

In 1978, the first of these projects, by Kanak[1], considered wall racking with particular attention being paid to the effects of openings. This work was followed over the next three years with projects by McKee[2], Cherritt[3] and Vincent[4] and Uni[5] investigating respectively:

- Wall/Floor/Partial Ceiling Interaction;
- End Diaphragm and Folded Plate Roof Action;
- Wall/Floor/Roof Interaction

The LPF was derived from a "grillage concept" again supported by PAA and researched by McDowall[6] to show floors consisting of planar members, in two directions normal to each other, constituted a viable structural form. However, the fact that the system required the members to be notched (each to half depth) was not overly appealing. Therefore, it was desirable a structural configuration making more efficient use of the two-way spanning properties of the plywood, be sought.

In 1985, from funds provided by PAA and the then Australian Timber Research Institute (ATRI), work commenced on the development of a **panelised** (capable of being fabricated in sections) **floor** through a project headed by McDowall[7]. This work was described "as the first phase in the development of the **"Engineered Whole House"** and the first stage in producing a more structurally efficient floor than the bearer/joist system. The main thrust of this initial research was to:

(i) construct and implement a test program to evaluate static and dynamic response of a 2.4m wide x 7.2m long, three bay planar floor system. Confining bearers and joints to the same plane was effected by means of steel joist hangers;

(ii) compare the panelised system performance to that of a bearer/joist system of identical span, materials and subject to the same loading conditions as described by McDowall, et al[8];

(iii) use plantation pine having a stress grade of F5 for all tests.

The initial attempt at producing a panelised floor as described by McDowall[9] resulted in exposing areas requiring review. Some such areas included the need to:

- eliminate the joist hangers which proved labour intensive to accurately position to ensure a flush top surface across bearers and joists:

- construct less than a three bay floor in subsequent test programs to minimise costs;

- Ensure any floor developed could be constructed on site following conventional building procedures.

Solution to the joist hanger problem resulted in the tee-beam bearer described in detail by McDowall et al. [10]. The member consists of the normal bearer with a timber flange glue/nailed to its underside thus providing a landing for the joists as shown in Figure 1.

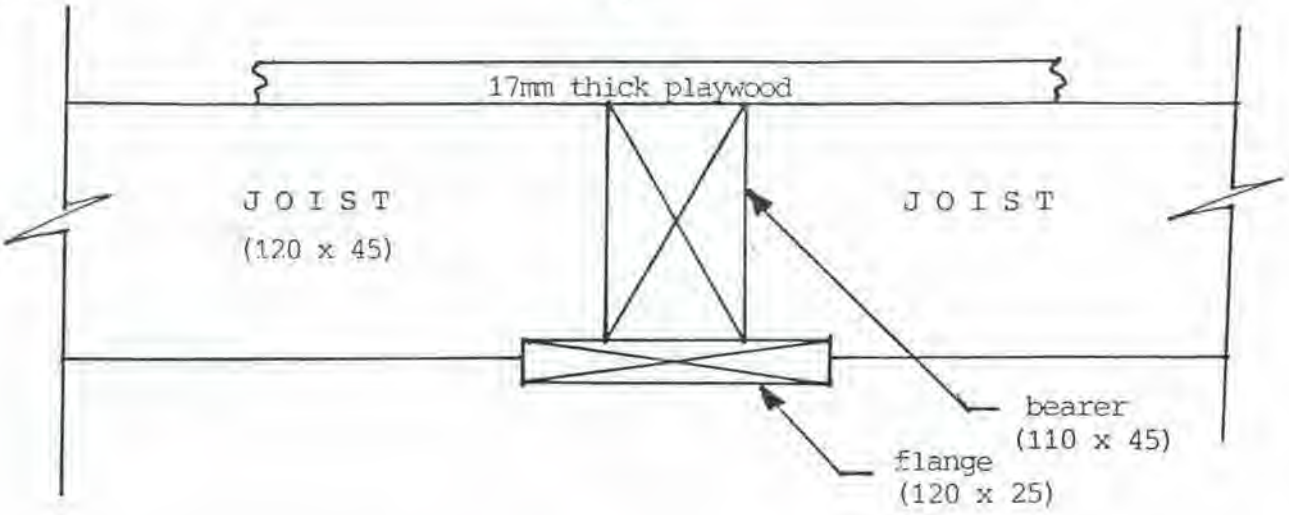

FIGURE 1: TEE-BEAM BEARER

It was shown in (9), that two bays of floor were sufficient to investigate the influence on continuity of shear and moment, due to connecting the plywood to the timber framing.

Finally, all subsequent floors have been constructed with conventional systems in mind rather than with any view to producing modules.

RESEARCH

When the floor research was commenced in 1985, it was believed development of a floor system would take minimum time when viewed within the total spectrum of producing an "Engineered Whole House". This did not seem an unreasonable assumption at the time having the knowledge timber floors have been around for a long time.

However, as research progressed, it became clear little work had been done on floors, particularly with regards to dynamic response and ultimate limit states. Since the tee-beam bearer LPF system is unique, it was not expected to find research information directly related to its performance. It was expected, however, to at least find a consistent and coherent coverage of criteria to be satisfied to ensure satisfactory dynamic response of general floor systems.

Research Profile

Prior to commencement of the floor development program, discussion between all parties concerned with establishing research guidelines concluded any research undertaken should be:

- responsible and in line with modern thinking regarding conservation, i.e. the use of plantation pines should provide the main research thrust in developing a LPF;

- directed towards satisfying, as nearly as possible at the experimental stage, the **static live load** requirements of AS.1170.1 - 1989(II) through application of a:

  - **concentrated load** of 1.8kN applied at mid-span of all beam elements for the various stages of construction;

  - **uniformily distributed loading** (udl) of 1.5kPa applied to the floor to produce the most adverse effect;

- capable of quantifying the **dynamic response** of individual members and the total floor system at various stages of construction;

- examine the **ultimate limit state** performance of the floor;

- consider the **creep** associated with a boundary bearer subjected to a uniformily distributed loading simulating a sustained load from a tiled roof;

- directed towards having the LPF concept included in a **conventional low-set dwelling** and implimenting a testing program to evaluate dynamic response of the floor at various stages of construction;

- investigate the influence of **span** on floor system member sizes;

- concerned with the **practicalities** of construction either as a factory built modular type system or as a conventional stick built floor.

Structure Specifications

Since construction of two bay floors for experimental purposes is time consuming and expensive, the research profile dictated as much useful data as possible must be obtained from any floors constructed. For the study of **basic structural responses** (serviceability and ultimate limit state), the LPF construction was as follows:

- **floor size** was 2.4m wide x two bays each 2.4m long;

- **timber framing** was all F5 seasoned pine with:

  - joists 120 x 45mm notched 10mm at each end;
  - bearers 110 x 45mm
  - flanges 120 x 25mm

- **decking** was tongue and groove 17mm thick x F11 structural grade radiata pine

flooring;

- **adhesive** was H.B. Fullers' Maxbond;
- nails to effect interconnection between the plywood sheathing and timber framing were 2.8mm diameter, galvanised flat head.

To investigate **creep effects** a similar floor to that previously described was constructed, except in this instance the edge bearer cross-section was modified from the shape shown in Figure 2(a) to that of Figure 2(b). For further information, see McDowall[12].

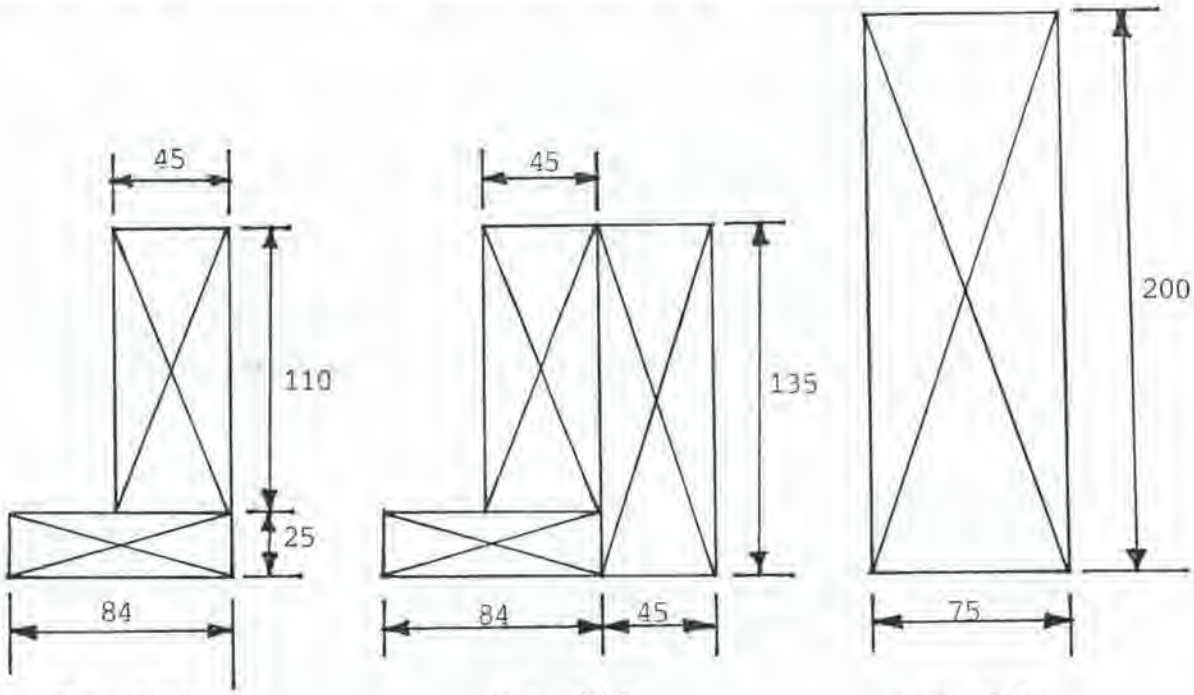

Fig. 2(a) Fig. 2(b) Fig. 2(c)

FIGURE 2: BEARER DIMENSIONS FOR CREEP TEST

To facilitate application of a sustained uniformly distributed loading to the reinforced L-edge bearer, and to maximise test data, a solid bearer, required to perform the same function, was loaded simultaneously. Figure 2(c) shows the cross-sectional dimensions of an F5 radiata pine beam sized according to the Light Timber Framing Code[13] requirements.

A total roof dead load of 0.9kPa was applied to the pair of bearers through a plywood sheathed stringer system spanning the two members. Concrete blocks giving a total load of 20kN, i.e. 10kN/bearer, was then applied to the load spreading deck in two (2) increments. Dial gauges located at the mid-span of the two bearers recorded the instantaneous elastic deflections. Deflections were then measured daily for the next week, then weekly for a total period of 310 days.

A conventional low-set brick veneer dwelling was made available in the Rockhampton area for assessing the **dynamic response** of the LPF at five stages of construction. The results of this research has been fully reported by McDowall and Van Wollingen[14 & 15].

The floor contained in the dwelling differed quite considerably from those tested in the laboratory. The main differences between the two floors were:

- bearers were constructed from 2 x 170 x 35mm x F17 gum top box members glue/nailed together with one of the two members of a section curtained to allow overlapping from a matching member. Such a procedure allowed the webs of bearers to be fabricated in manageable lengths with interconnection being completed on site.

  Flanges were formed by connecting 70 x 35mm x F17 gum top box members either side of the two vertical laminates of the bearer beam section;

- joists were 100 x 50mm x F17, visually graded unseasoned mix of blue gum and spotted gum at 400mm centres;

- decking was tongue and grooved F11 structural pine flooring 15mm thick.

A program to evaluate **span effects** is currently in progress and will not be discussed herein.

RESEARCH RESULTS

As would be expected, much data can be generated over a period of some five (5) years of constant effort and only that considered informative for this exercise is presented.

First Tee-Beam Bearer Floor

Phase 1 - Stage 1 results obtained from comparative tests on the three bay, bearer/joist floor and the three bay, panelised Pryda joist hanger floor are not given.

Table 1 summarises the **static and dynamic test data** resulting from the test program carried out on the first, two bay, tee-beam bearer floor constructed.

TABLE 1

STATIC AND DYNAMIC RESPONSE AT VARIOUS CONSTRUCTION STAGES

CONSTRUCTION STAGE	JOIST		TEE-BEAM BEARER	
	Average Stiffness*** (N/mm)	Reson. Freq. Centre Joist (Hz)	Stiffness (N/mm)	Reson. Freq. (Hz)
Unsheathed Framing	230	15	694	20.5
Tee-Beam Bearer only sheathed	288	15.5	1418	24
Partially sheathed	479	16	1370	20.5
Fully sheathed	729*	16.5	1538**	20
Fully sheathed ⅓ live load (1.8kPa) applied in an end bay	-	11.5	-	-

NOTES: * Sheathed joist stiffness is 3.13 times unsheathed.

** Sheathed tee-beam bearer stiffness is 2.2 times unsheathed.

*** Stiffness is defined as the force required at mid-span to produce a 1mm deflection at mid-span.

For **uniformly distributed loading** of 1.5 and 3kPa:

- joist and bearer deflections were well within the limit of $\ell/300$.

The **ultimate limit state** dictated by a uniformly distributed loading applied in an end bay resulted in initial failure of the glueline at the beam/plywood interface of an end bearer at a load of 9kPa. After load redistribution, final failure occurred at 13kPa.

Second Tee-Beam Bearer Floor

Table 2 gives a highly curtailed version of the **creep** data taken for the solid timber bearer and the LPF reinforced edge bearer.

TABLE 2: CREEP DEFLECTIONS FOR BEARERS

LOAD	WEEK NO.	BEARER DEFLECTIONS				
		SOLID		REINFORCED		AS1720.1 - 1988
		(mm)	Δ/Δo	(mm)	Δ/Δo	
12 concrete blocks @ 80kg = 9.4kN	1	3.15	-	3.00	-	
60 blocks @ 17.3 kg = 10.2kN	1	6.98	Δo	6.18	Δo	
	20	11.13	1.59	11.25	1.82	
	43	12.17	1.74	11.75	1.90	
	52					2

Conventional Dwelling Test

Figure 3 shows a floor plan of the dwelling tested for **dynamic response** at various stages of construction. The important points to be noted are:

- the three joist and two bearer positions of the mechanical shaker;
- position of the internal walls;
- location of brick piers and internal tee-beam bearer supports.

Shaker positions chosen were in expected stiff areas (1J and 1B) and where the influence of internal walls could be assessed (2J, 3J and 2B). Other factors considered in choosing shaker positions were minimising the number of holes needed to be drilled in the floor and keeping inconvenience to the carpenters to a minimum.

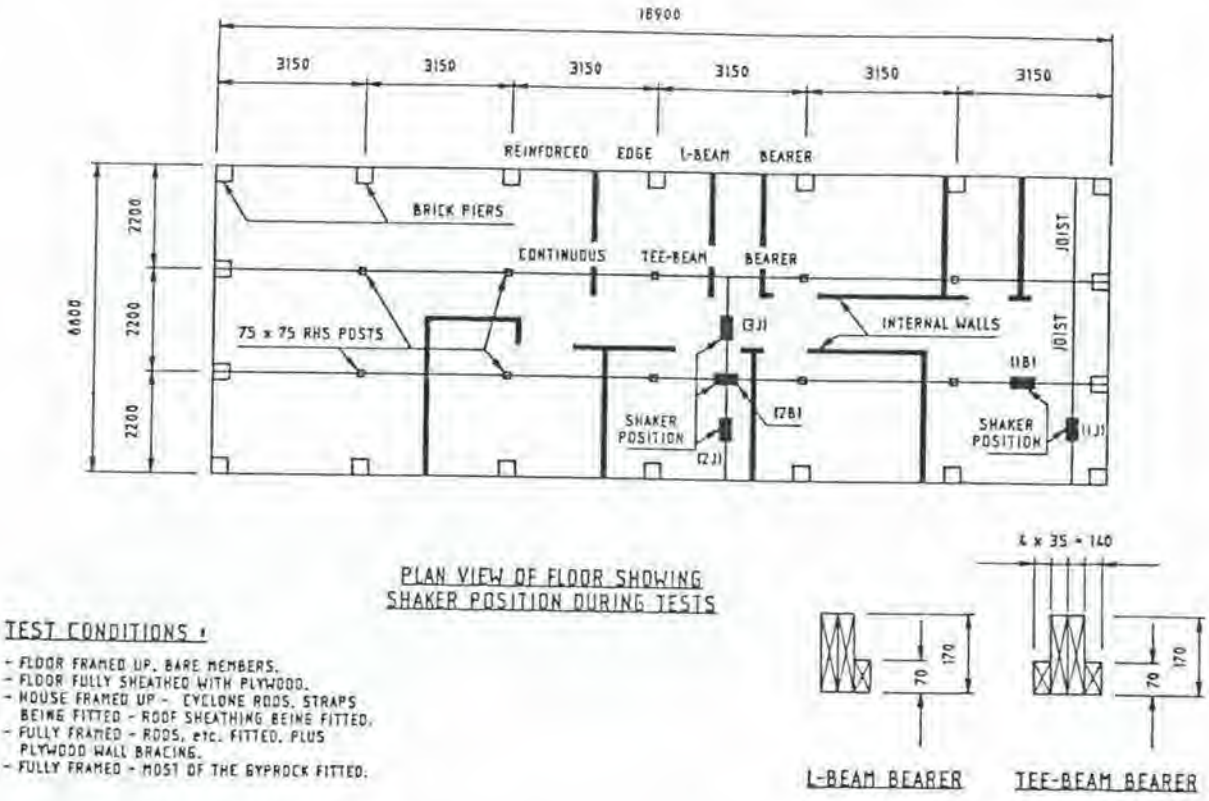

FIGURE 3: SHAKER POSITIONS ON BEARERS AND JOINTS

Table 3 gives the bearer or joist resonance frequencies and vibration emplitudes for **five stages of construction**, i.e. for the the floor system:

(i) framed-up but with **no plywood sheathing** connected.

(ii) **fully sheathed** and a number of wall frames positioned with temporary braces;

(iii) fully sheathed with the **remainder of the house framed-up** with:

- cyclone rods fitted but not tightened;
- steel straps connecting trusses to top plates;
- plywood bracing not fitted;
- roof sheathing partially connected;

(iv) fully sheathed, cyclone rods tightened, straps fitted, plywood bracing and roof sheathing fully connected;

(v) fully sheathed and as for (iv) with most of the gyprock wall and ceiling cladding fitted but with no brickwork above floor level.

TABLE 3: CONSTRUCTION STAGE

CONSTRUCTION STAGE										
Floor	1		2		3		4		5	
Location	freq Hz	amp mm	freq Hz	amp mm	freq Hz	amp mm	freq Hz	amp mm	freq Hz	amp mm
1B	18	2	18	0.6	22	0.9	21	0.6	21	0.4
2B	17	2.5	17	1.2	14	0.7	16.5	0.7	20.5	0.4
1J	13	8.5	>26*	2.5*	>26*	2.5*	>26*	2.5*	>26*	1.5*
2J	11	8.5	15.5	2.5	17.5	2	18	2.5	18	2.0+
3J	11.5	11.5	16	2.5	17.5	0.3	17	0.3	18	0.3

Note: Construction stages 1 through 5 refer to those described in the section of this paper headed Test Procedure.

* No resonance condition attained

\+ test aborted

RESULTS OF RESEARCH

When required to ascertain the strength/stiffness properties of a given timber species, it is necessary to test 20-30 individual sticks of structural size members. This, of course, is a right and proper approach since each individual member may be required to perform as a structural entity at some stage of its design life. For members such as rafters, purlins and battens, this individual usage applies particularly to the early stage of construction when the members will invariably be used to provide a thoroughfare for carpenters during roof construction.

In the case of a LPF floor, where structural elements are interconnected together to produce a system, the number of tests required to provide a meaningful result will be much less than 20 to 30. Although information exists for testing some structural systems, as described by EBS, TR440[16], there is no such information available regarding the testing of floors. It is not the purpose of this paper to:

- **state criteria** to be satisfied for the testing of floor systems although it may well be that the research does provide a reasonable guide for any future work;

- determine **how many floors** should be tested under a specified loading regime before a statistically significant result can be ascertained;

- specify the nature of the **force regimes** to be applied to a floor system to constitute a complete testing procedure.

On the basis of the above lack of scientific data pertaining to requirements for floor testing, it is difficult to make many pragmatic statements regarding research findings. However, with regard to the usual factors found by the general public to constitute a good floor, it is believed fair to say:

"THE LOW PROFILE FLOOR WORKS"

Reasons the LPF discribed herein is considered to be a viable proposition are:

(i) **static deflection criteria** for concentrated and uniformly distributed live loading requirements to AS1170.1 - 1989 have been satisfied by not exceeding span/360;

(ii) floor system **reasonance frequencies**, even when subjected to 1/3 uniformly distributed live loading are greater than 8Hz which compares favourably with published research requirements;

(iii) **informal opinions** of people who have walked on the floor have confirmed its acceptability;

(iv) **strengthwise** the floor system has shown itself to be more than adequate as indicated by the test to failure;

(v) provided the edge bearer configuration is modified to that of the **reinforced edge bearer**, any creep associated deformations can be controlled. In a properly engineered house, walls would be made to act as "deep beams" thus eliminating the need for reinforcing the edge bearer.

DEVELOPMENT

Part of the development program could have been considered to be evaluation of the dynamic response of the floor at various stages of construction as per the Rockhampton house. However, this exercise has already been correctly categorised as part of the research program.

At this point in time, the early development work done is the result of a house conceived

by Mr. Bert Heitbaum, a Quantity Surveyor in Maroochydore. The basic structure consists of a hexagonal (in plan) pod with segments of prefabricated LPF interconnected to treated timber stumps to provide the flooring platform.

The roof consists of eight triangular sections of similar construction to the floor (i.e. of stressed skin construction) covered with a coloured ultra violet resistant waterproof membrane. Roof tie-down was effected by nailing the plywood wall sheathing to edge roof and floor members thus eliminating the need for steel straps.

The advantages of this type of structure are:

- panels are prefabricated in a workshop environment and transported to the site, thus requiring unskilled labour to effect construction;
- initially only one pod has to be built with others being added as the need adrises;
- difficult sloping sites can be easily built upon;
- corrosion problems are minimised when building near the ocean;
- the hexagonal pod allows full advantage to be taken of the views.

ANALYSIS AND DESIGN

The only attempt at analysis of the LPF thus far has been by Boyce[16].

Idealisation of the floor system, even excluding the contribution due to plate action, is difficult because if the mathematical model is to be meaningful it is required to account for:

- **composite action**, i.e. how much the plywood flange contributes to beam action;
- the effect of **shear lag** within the plywood flange;
- **continuity of spanning**, i.e. what degree of continuity does the plywood develop in the timber joists over two bays;
- **material effects** resulting from the timber and plywood spanning orthogonally;
- **boundary fixities**, or lack thereof at the supports.

From a design viewpoint dynamic response of the floor system is influenced by:

- **flooring** (sheathing) **stiffness and strength** which also controls the difference between successive natural frequences, i.e. of the harmonics, which depend upon the ratio of stiffnesses in the two major orthogonal directions of the floor;

- **joist stiffness** which is the main factor controlling system fundamental natural frequency;

- **resonance frequency** of the floor.

Criteria defined to control the vibration characteristics of a floor system usually refer to flooring and joist stiffness. Table 4 gives load/deflection criteria, together with the source of reference, as a possible means of controlling flooring response.

TABLE 4: FLOORING LOAD/DEFLECTION CRITERIA

Flooring Load	Allowable Flooring Deflection	Source	Year
450N/walker	< 0.5mm	Isaacs, D.V., The Structural Sufficiency of Domestic Buildings, Bulletin No. 1, Department of Works and Housing, Commonwealth Experimental Building Station, North Ryde, Sydney.	1946
330N	< span/600	Boyd, J.D., Minimum Strength and Stiffness Necessary for Wooden Floors in Houses, Division of Forest Products, Technical Paper No. 34, CSIRO, Melbourne.	1964

Table 5 lists criteria suggested by a number of researchers to control the dynamic response of joists located on unyielding supports at each end. It should be noted however, the joists of a LPF rest on elastic supports provided by the tee-beam and reinforced L-edge bearers.

TABLE 5: JOIST STIFFNESS TO CONTROL FLOOR VIBRATIONS

Joist Load	Allowable Joist Deflection	Joist Stiffness	Source	Year
1.9kPa	< span/360	-	Boyd, J.D., Minimum Strength and Stiffness Necessary for Wooden Floors in Houses. Technical Paper No. 34, CSIRO.	1964
1kN at mid-span	Δ_{max} = 1.75mm for spans < 3m $(6.7/L^{1.22})$mm for spans > 3m	0.57kN/mm for spans < 3m	Onysko, D.M., Performance criteria for Residential Floors Based on Consumer Response, Proceedings of the 1988 ICOTE (Vol.1), Seattle, USA.	1988
1kN at mid-span	1.5mm at mid-span	0.67kN/mm	Ohlsson, S.V., A Design Approach for Footstep-Induced Floor Vibrations, Proceedings of the 1988 ICOTE (Vol. 1), Seattle, USA.	1988
Live Load	span/180 through span/360 to span/480	-	Ellingwood, B. and Tallin, A., Structural Serviceability: Floor Vibrations, Journal of the Structural Division, ASCE, Vol. 110, No. 2.	1984
2kN at mid-span	1mm at mid-span	2kN/mm for offices, libraries, school rooms, etc.	Ellingwood, B. and Tallin, A., Structural Serviceability: Floor Vibrations, Journal of the Structural Division, ASCE, Vol. 110, No. 2. 1984	1984

From Table 5, it can be seen that on the premice stiffness can be used to control dynamic response, the range of 0.57 to 2kN/mm is considerable. This, of course, may imply a range of stiffnesses depending upon function is required.

With regards to dynamic response, system resonance frequencies to be avoided to ensure **human comfort**, lie within the range:

- 3 to 10 Hz.

CONCLUSION

For convenience of reference a recap of research completed thus far shows:

- a LPF using F5 plantation pine members has been satisfactorily developed with:
  - joists spanning 2.4m;
  - tee-beam and reinforced L-edge beam bearers providing centre and edge supports respectively for the two bay floor system and also spanning 2.4m;
  - joist spacings of 600mm centres;
  - 17mm thick x F11 structural plywood, glue/nailed to the timber framing members, providing the deck;
- a test program has been undertaken which verifies satisfactory **static and dynamic response** of the system under service conditions;
- **ultimate limit states** requirements to be more than adequate;
- the implimentation of a **creep test** program to validate long term deflection limits of an edge bearer subjected to a dead load simulating a tiled roof;
- the concept applied (with some modifications) to an **actual dwelling** produces a structurally acceptable floor.

Current research involves an investigation into the influence of span on both static and dynamic response of the LPF. The span chosen for this work was 3.6m which should approach the limits of readily available member cross-sections for plantation pines.

Areas requiring further research effort include:

- an investigation to assess floor system sensitivity to (EI) with regards to vibration response, in particular;
- defining limits to be applied to relevant parameters (frequency, stiffness etc.) to allow the designer to be able to control dynamic response;

- investigating implications associated with extending the LPF concept to include commercial and industrial floors;

- develop analytical models at both the sophisticated and basic levels for applications in research and design.

Although further research and development is required there is no reason why floors of the dimensions referred to herein could not be used in dwelling construction.

ACKNOWLEDGEMENTS

The writer wishes to offer his sincere thanks to the Plywood Association of Australia for its continued moral and financial support to the total project. Financial support from the Australian Timber Research Institute (now defunct) during the initial development and the Radiata Pine Research Institute for the recent creep work is also appreciated.

REFERENCES

1. Kanak, J.M. 1978. The Effects of Openings in Shear Walls for Domestic Structures, Project Thesis, Capricornia Institute, Rockhampton, Queensland, Australia, November.

2. McKee, N.T. 1979. Floor - Wall - Ceiling Interaction of Domestic Dwellings Under Simulated Wind Loadings, Project Thesis, Capricornia Institute, Rockhampton, Queensland, Australia, November.

3. Cherrett, G. 1981. Structural Response of End Diaphragms in a Folded Plate Roof System for Domestic Dwellings, Project Thesis, Capricornia Institute, Rockhampton, Queensland, Australia, December.

4. Vincent, S. 1981. Structural Response of Folded Plate Roof System for Domestic Dwellings, Project Thesis, Capricornia Institute, Rockhampton, Queensland, Australia, December.

5. Unie, G.T. 1982. The Investigation of the Methods of Action of the Components of a Plywood Sheeted, Timber Framed, Four Walled House System with Partial Ceilings and a Folded Plate Roof, During Simulated Wind Loadings, Project Thesis, Capricornia Institute, Rockhampton, Queensland, Australia, November.

6. McDowall, C.G. 1984. Tests Results for a 3 x 3m plywood Sheathed Pine Grillage Floor System, Timber and Wood Products Research Centre, (TWP) Report No. 112, Capricornia Institute, Rockhampton, Queensland, Australia, September.

7. McDowall, C.G. Phase I - Stage I Engineered Whole House. Comparison of Static and Dynamic Response of a 2.4m Span Continuous Bearer/Joist Floor to an Equivalent Panellised Low Profile System, TWP Report No. 127, Capricornia Institute, Rockhampton, Queensland, Australia.

8. McDowall, C.G., Carson, J., Lyngcoln, K.J. and Van Wollingen, F. 1987. Planar Stressed Skin Floors: A Load Response Comparison, First National Structural Engineering Conference, Melbourne, Australia.

9. McDowall, C.G., 1987. Phase II, Stage I, Engineered Whole House. Low Profile Floor - Static and Dynamic Response of Tee-Beam Bearer System, TWP Report No. 139, Capricornia Institute, Rockhampton, Queensland, Australia, July.

10. McDowall, C.G., Van Wollingen, F., Carson, J., MacKenzie, C. and Lyngcoln, K.J. 1988. Low Profile Timber Floors: Load Response Characteristics of the Tee-Beam Bearer System, Queensland Master Builders' Association Housing and Construction in the Age of Technology, International Conference, June 26-July 2, Surfers Paradise, Queensland, Australia.

11. Standards Australia, AS1170.1-1989. SAA Loading Code Part 1: Dead and Live Loads and Load Combinations.

12. McDowall, C.G. 1989. Low Profile Floor Boundary Bearer Check Under Sustained Load, TWP Report No. 160, Capricornia Institute, Rockhampton, Queensland, Australia, December.

13. Standards Association of Australia, AS1684 Timber Framing Code.

14. McDowall, C.G. and Van Wollingen, F. 1989. Dynamic Response of a Low Profile Timber Floor Incorporated in a Convention Low-Set Brick Veneer Dwelling, TWP Report No. 157, Capricornia Institute, Rockhampton, Queensland, Australia, October.

15. McDowall, C.G. and Van Wollingen, F. 1990. Low Profile Timber Floor - Influence of Construction Stage of Dynamic Response in a Dwelling, 12th Australasian Conference on Mechanics of Structures and Materials, University of Queensland, Brisbane, Queensland, Australia, September.

16. Experimental Building Station, Technical Record 440, Guidelines for the Testing and Evaluation of Products for Cyclone-Prone Areas, EBS, Department of Housing and Construction, P.O. Box 30, Chatswood, NSW, 2067.

BRIDGEWOOD®, APPLICATION OF VERY THICK PLYWOOD

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ABSTRACT

Methods used in the structural analysis of BRIDGEWOOD® panels are reviewed.

Plane statics and plane stress approaches require effective width estimation along with the more usual assumptions.

Shear induced deflections for the spans of approximately 10 times section depth are significant. Experimental results are correlated with theory to suggest predictive methods for the rigidly supported orthotropic beams.

It is noted that a whole of structure perspective is needed to determine service expectations.

NOTATION

X = Direction along span and face grain.
Y = Direction of loads and deflections.
Z = Direction perpendicular to X & Y.

x = Distance or displacement in the X direction.
y = Distance or displacement in the Y direction.
$\triangle y$ = Veneer thickness.

l = span of beam (in direction X).
d = thickness of plywood panel (direction Y).
b = width of beam or effective width of beam (Z direction).

L = Direction in wood parallel to grain.
U = Direction in wood perpendicular to grain (Radial-Tangential).

Q = First moment of area.
I = Second moment of area.
Z = Section modulus.

E = Young's modulus of elasticity.
G = Shear or Bulk modulus.

P = Point Load or assumed Z axis Line Load.
V = Shear Force.

σ = Bending stress.
T = Shear stress.

SPECIFIC USES

Maintenance and rebuilding of timber bridges on Australian roads indicated a need for alternative construction components. By application of contemporary materials and manufacturing, faster timber bridge building and improved serviceability has been achieved. Since the mid 1980s structural plywood decking, headstocks, and other components have been included in the structure of over 100 timber bridges.

Other applications as wharf decking, retaining walls, and in bulk materials storage structures are in service.

AREAS FOR EXPECTED ECONOMY

On Flat

Structural economy may be found with plywood slabs in beam applications under non-uniformly distributed loads. Figure 1(a) shows the typical load and support configuration of a vehicular bridge application. Effective widths under near point or patch loading extend beyond the loaded width. This lateral stiffness is afforded by veneers with grain in the lateral direction, and thickness for thickness performance with narrower strips of higher strength material under similar concentrated loading results.

On Edge

The shear capacity of plywood in plane of sheets can by used to advantage where high loads close to supports lead to shear stress being the governing criterion. Figure 1(b) shows such a situation in a bridge headstock which transfers girder loads to adjacent piers.

In General

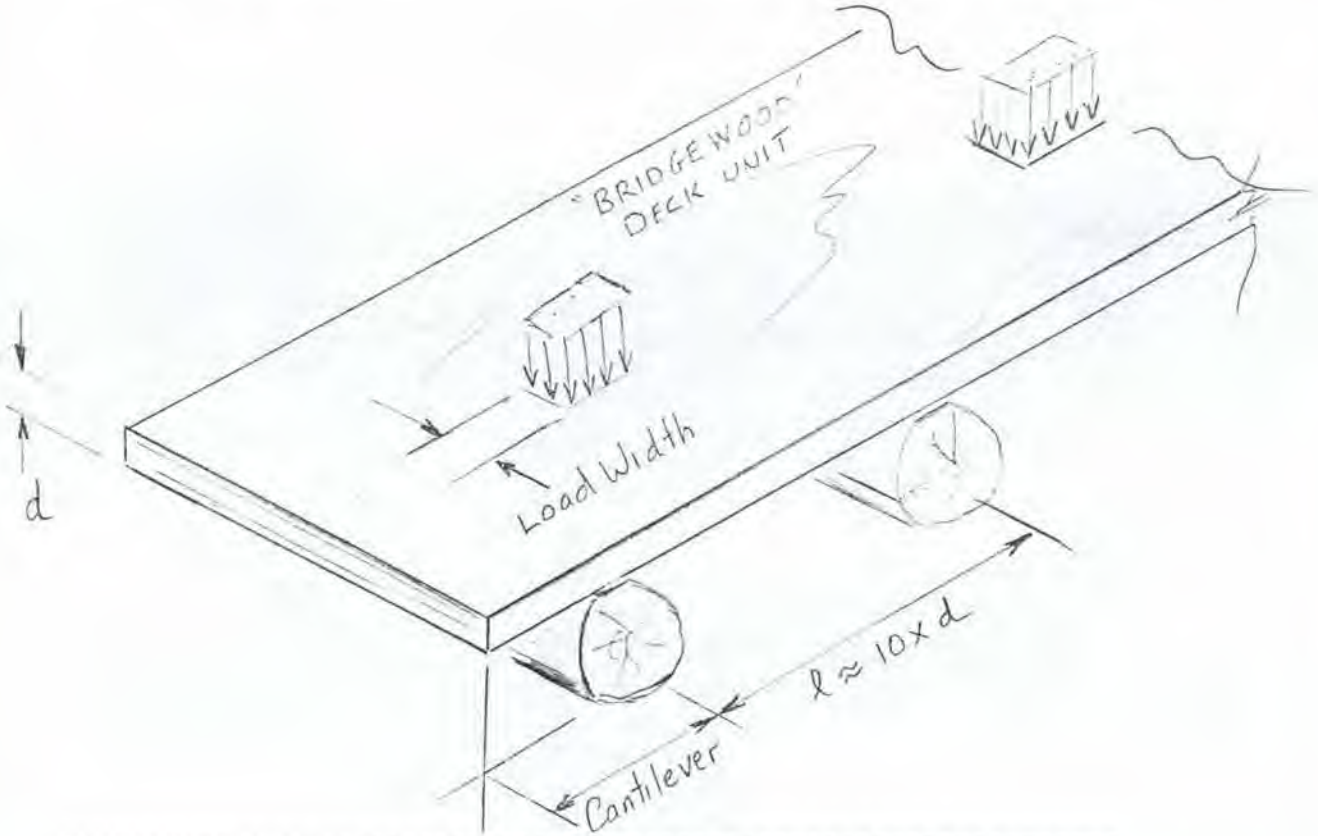
Other practical considerations include supply, consistency, treatability for immunity against fungal and insect attack, construction time savings, and fastener savings. Such considerations may indicate economies in applications outside those exhibiting the analytical advantages above.

SPECIFIC USE STRUCTURAL INTEGRITY

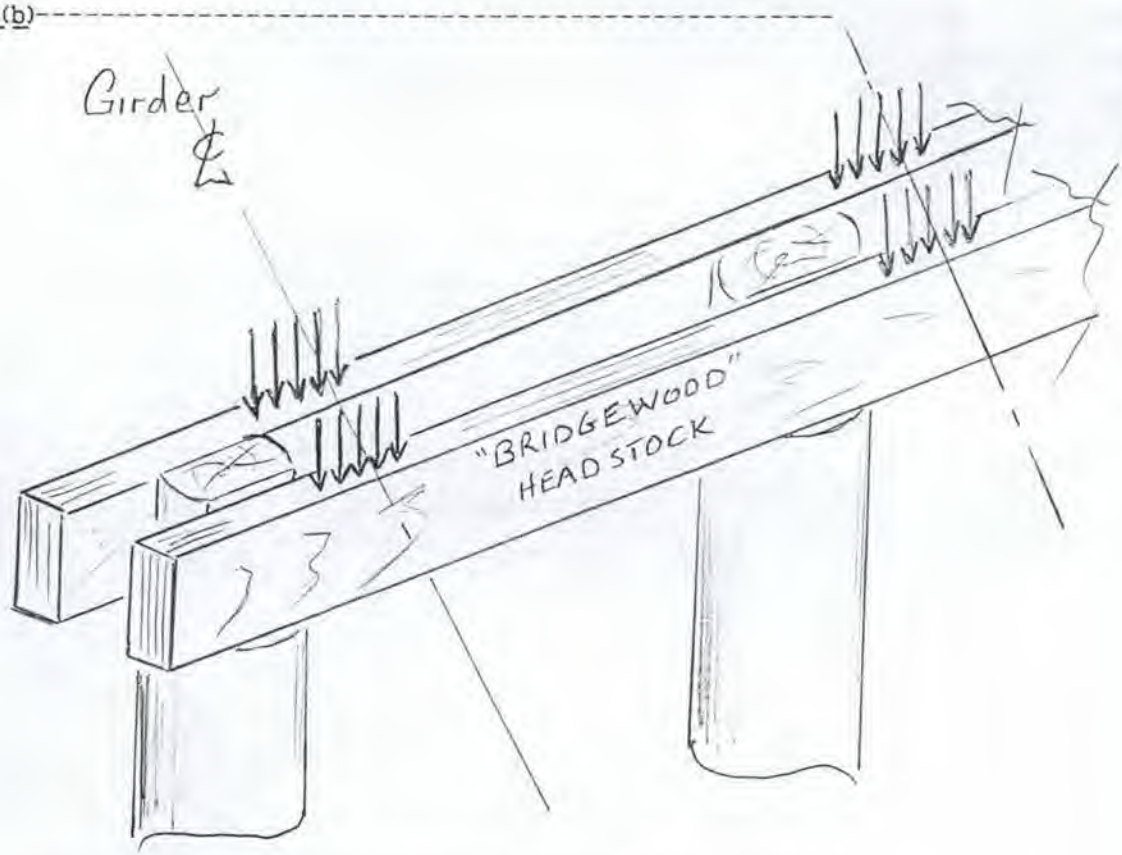
Initial calculations in accordance with AS1720 assuming a plane stress plywood beam with 600mm effective width indicated a 125mm thick construction of veneers could act as a deck under design wheel loads when supported on girders at 1300mm spacings. Performance testing confirmed the calculated expectations of strength and that stiffness and strength compared favourably with those for the alternative solid timber deck material[1].

Field trials with the Main Roads Department of Queensland followed for the tested system. The application of similar calculation methods has lead to alternative thicknesses and veneer constructions being applied to a variety of structures, with different support and design load conditions.

-----FIGURE 1(a)----------



-----FIGURE 1(b)----------



STANDARD BRIDGEWOOD® SECTIONS

Table 1 shows the section properties for standard 1200mm wide panels. The lowest section modulus occurring at a section through internal butt joints of the 31mm sub units is given for bending strength calculations.

The reader is referred to AS2269 and AS1720 for calculation method.

-----TABLE 1----------

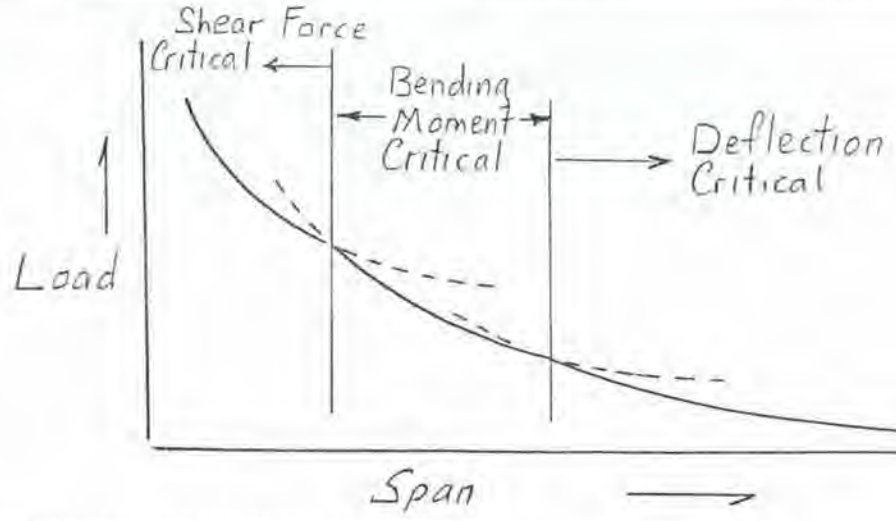
Thickness nom. dry (mm)	Second Moment of Area Parallel to Face Grain (mm^4 per mm width)	Section Modulus Parallel to Face (mm^3 per mm)
31	1989	126
63	13498	426
95	43645	883
125	101218	1377
155	194607	1983

ON FLAT ANALYSIS

Normally one of the three conditions of Shear Stress, Bending Stress, and Deflection Under Load is calculated to limit the allowable load/span combinations as with any beam element.

Loads, load positions, support positions, material properties, section properties and allowable deflections will result in one of the three conditions shown in Figure 2 governing the element selection.

-----FIGURE 2----------



EFFECTIVE WIDTH

The application of plane statics for calculations of the interdependent functions describing shear forces, bending moments, and deflection integrals in beams is well documented.

The analysis of thick plywood slabs, with uniformly distributed loads or full width line loads perpendicular to the span, would be consistent with a plane stress approach.

For loads not extending for the full panel width, such as applied by vehicle wheels, an Effective Width of panel can be assumed to act according to the plane stress model.

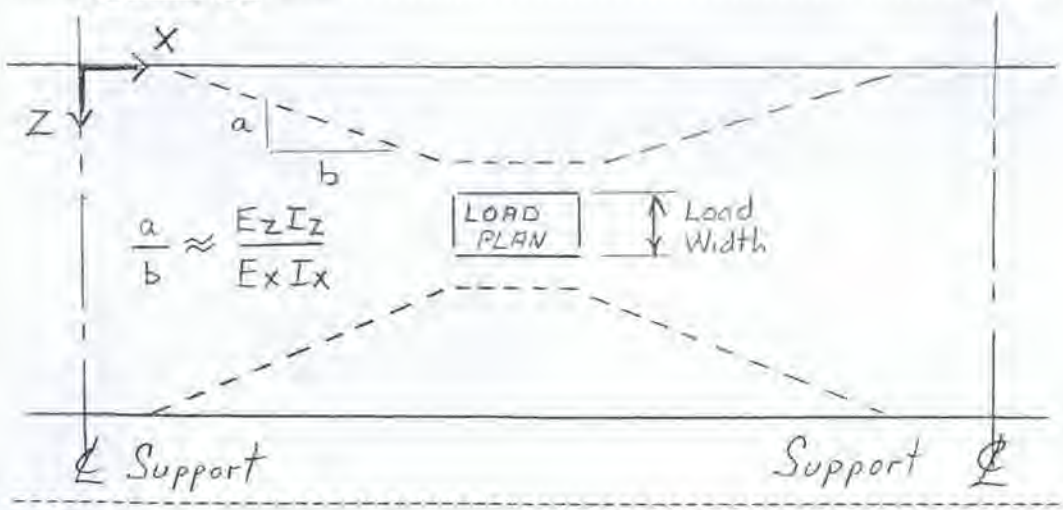
Deflection comparisons in laboratory trials[2], and in field tests by Law Matheson Yttrup consulting engineers, related to load widths of approximately 200mm. Effective widths of about 450mm for loads at edge and in excess of 1000mm for loads at centre of panel width would be consistent with the observed deflections. The use of a 600mm effective width remaining constant along the beam still serves as the design model for road bridge decks. Duration of loading and/or impact allowance can be adjusted to satisfy the condition with load at panel edge.

As applications are expanded, the approximate nature of the original design model should be kept in mind.

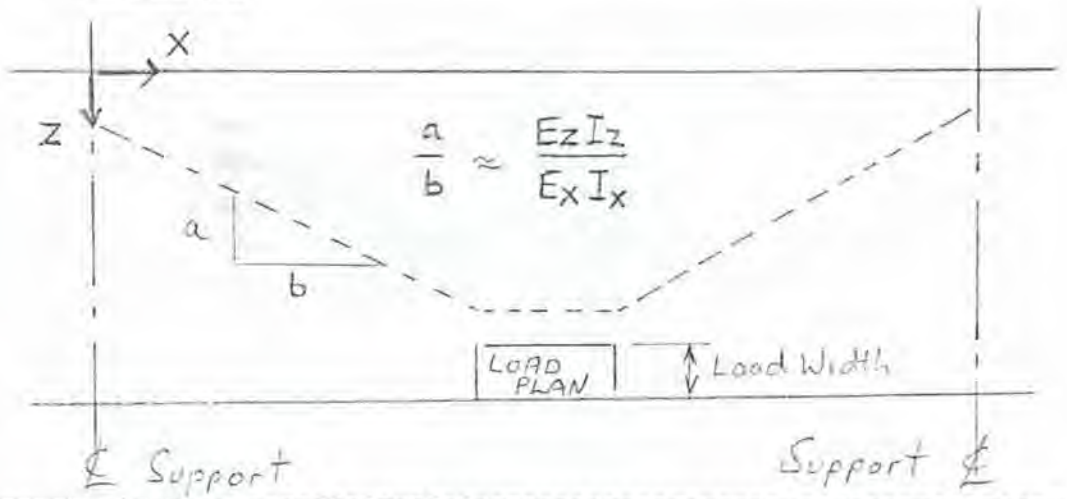
POSSIBLE ALTERNATIVE STRESS DISTRIBUTION MODEL

Lane op.cit. observed that effective widths increase with span. It is also reasonable to expect that lateral distribution of load would depend on the lateral stiffness. Figures 3(a) and 3(b) set out an "hour glass" distribution of stress, the shape depending on loading geometry and relative stiffness in the span and lateral directions. These or similar tapered sections may serve as more accurate models with plane stress involving different beam widths along the beam length. More work would be needed to establish if such a model would predict stresses and deformations without recourse to orthotropic plate analysis.

FIGURE 3(a)



-----FIGURE 3(b)----------



Graphical integration or moment area methods could be applied to proposed tapered beams to arrive at deflections relative to those expected for full width loads. Experimental ratios of full width load and patch load deflections could be compared to the predicted ratios.

RELATIVE STIFFNESS PARALLEL AND PERPENDICULAR TO SPAN

To enable determination of the variation in beam width according to the relative stiffness approach above, Table 2 shows relevant section properties.

-----TABLE 2----------

Thickness nom. dry (mm)	Second Moment of Area Parallel to face grain (mm^4 per mm width)	Second Moment of Area Perpendicular to face (mm^4 per mm width)
31	1989	618
63	13498	7357
95	43645	26741
125	101218	65621
138 *	137400	88176
155 #	194607	131252

* The non-standard section tested by Lane op.cit.

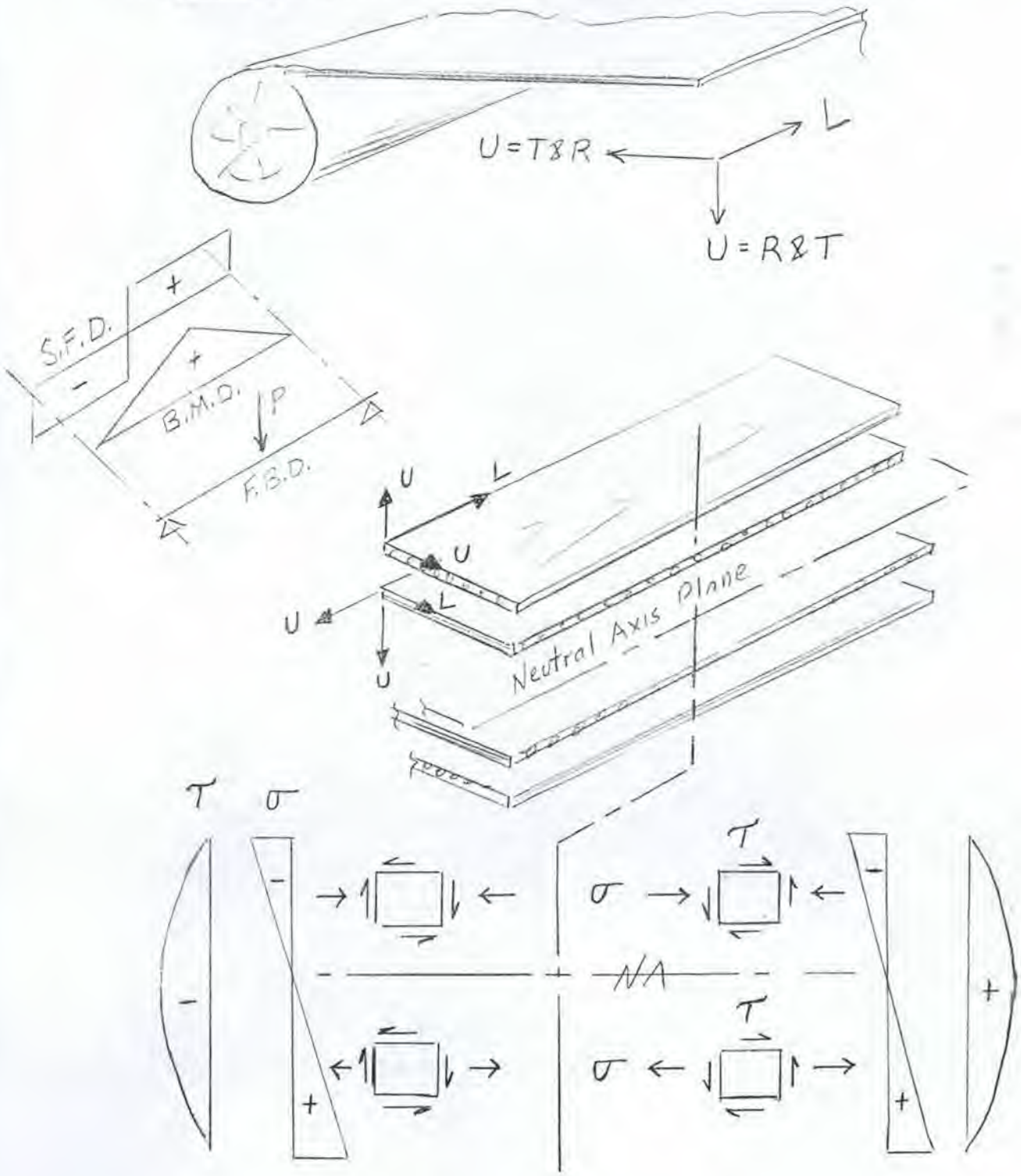
\# The section tested by Law Matheson Yttrup

SHEAR CONSIDERATIONS

Figure 4 shows the origin and arrangement of the grain directions together with the plane statics and plane stress diagrams for simple three point bending.

The orthogonal grain directions of Longitudinal, Tangential and Radial are reduced to L and U where the U direction represents the combination of Radial and Tangential found across the grain in rotary peeled veneer.

-----FIGURE 4----------



SHEAR STRESS

Hall[3] outlines the application of section properties transformed for E to analyse non-linear stress-strain conditions. The method would be equally valid for non-linear stress-strain expected through the thickness of plywood veneer orientations.

Shear stress would be calculated as $T = VQ'/I'b$ where Q' and I' are the first and second moments of area transformed for an E_L basis.

The usual approach is to assume the parabolic shear stress distribution of a rectangular section which, at the central maximum position, effectively replaces Q'/I' with 1.5/t. BRIDGEWOOD® Sections can have the innermost cross laminated veneers displaced from the centre line thus reducing the Longitudinal Shear Between Plies. Table 3 shows the calculated section properties for the standard thicknesses of Table 1.

TABLE 3

Thickness Theoretic (mm)	I' transformed for E * (mm^4/mm)	Q' transformed for E * (mm^3/mm)	I'/Q' (1/mm)	1.5/t (1/mm)
31.2				
inner L veneer	1989	64.8	0.0325	0.0480
inner U veneer N/A	1989	87.4	0.0439	0.0480
62.4				
inner L veneer N/A	13498	305.1	0.0226	0.0240
inner U veneer	13498	205.0	0.0152	0.0240
93.6				
inner L veneer N/A	43645	681.2	0.0156	0.0160
inner U veneer	43645	616.2	0.0141	0.0160
124.8				
inner L veneer N/A	101218	1184.2	0.0116	0.0120
inner U veneer	101218	1080.9	0.0106	0.0120
156.0				
inner L veneer N/A	194607	1829.5	0.0094	0.0096
inner U veneer	194607	1722.7	0.0089	0.0096

* The AS2269 figure of $E_U = 0.03E_L$ was used

The veneer constructions of sub units making up the above thicknesses are as follows, with the letter indicating the orientation of the particular thickness veneers :-

Outers 2.4L 2.4L 2.4U 2.4L 2.4U 2.4L 2.4U 2.4L 2.4U 2.4L 2.4U 2.4L 2.4L
Inners 2.4L 2.4U 2.4L 2.4U 2.4L 2.4U 2.4L 2.4U 2.4L 2.4U 2.4L 2.4U 2.4L

It is evident from Table 3 that the 1.5V/bd calculation of stress for Longitudinal Shear between plies (AS1720 Section 5) applied to sections with offset inner cross bands (U veneers) may be conservative for panels with multiple long bands (L veneers) at the neutral axis (N/A). The avoidance of shear stress constraints by extending this effect occurred in the design of an "LVL" cored deck for The Queensland Forestry Department. The 100mm panels have 20mm of L veneers between the neutral axis and the first U veneer and were installed on Bridge 13 of the Kirrima Range road west of Cardwell in 1987.

DEFLECTION DUE TO SHEAR DEFORMATION

To satisfy equilibrium, vertical and complementary horizontal shear stresses must be zero at the upper and lower surfaces of the plywood with a maximum between these limits.

Shear stresses induce a maximum deformation of rectangular elements at the plane of highest (shear stress/shear modulus) ratio. The deformation graduates to zero at the surfaces and induces warping of the section. In areas of constant shear stress, the warping rotates the plane of beam axis. In areas of changing shear stress, curvature (distinct from the bending stress curvature) of the beam axis will be induced by differential warping.

Experimental work at Queensland University of Technology[4] was commissioned with the aim of correlating observed deflections under 3 point bending with calculations for same.

THEORY

Beams with distributed loading and hence subject to shear curvatures mentioned are discussed by Hall, op.cit.p120 but will be ignored in this paper. The methods below seek to establish relative rotations between loads and thereby shear deflection. For practical purposes, distributed load problems could be reduced to point loads and associated rotations.

Leicester[3] notes typical relative magnitudes of Elastic and Shear Moduli and Bodig and Jayne[6] published figures for Slash pine. For the orthogonal axes, elastic properties were expected to have relativity :-

$$G_{LU} = 0.055E_L \text{ to } 0.075E_L$$
$$G_{UU} = 0.007E_L \text{ to } 0.020E_L$$

Method 1

Todd[7] suggests a reasonable estimate of rotation is

$$dy/dx = Tmax / G$$

Integrating for symmetrically loaded beams yields

$$y = 1\ Tmax / 2\ G$$

Which reduces, for the 3 point bending case, to

$$y = 1.5\ P\ 1 / 4\ (\ G\ bd\ )$$

(The parabolic shear distribution is assumed)

Other formulae can be derived for different step functions of shear stress. The total deflection may be a summation of (slope x length segments).

From Leicester op.cit. G_{UU} is about $0.24G_{LU}$ As the slope is T/G, the lower shear modulus material in the U veneers would deform more for all sections in table 3 even though the stress may be slightly lower.

The maximum deflection equation for the 3 point bending is from this approach :-

$$(V Q'/I'b)(P/2)/G_{UU} + (P 1^3/48 I)/E_L$$

Method 2

Hall op.cit. p116 derives rotation due to warping of the whole section. Using this approach :-

$dy/dx = g/0.5d$ where g is the warp from a perpendicular through the neutral axis. And d is the section thickness.

$$g = \int_0^{d/2} T/G \, dy$$

substituting $T = (6 V/bd)(1/4 - (y/d)^2)$ (the parabolic shear)

$$\text{hence } dy/dx = 1/0.5d \int_0^{d/2} (6 V/bd)(1/4 - (y/d)^2)/G \, dy$$

for the veneer assemblies of Table 3, a stepwise integration was done by summing the following equation :-

$$dy/dx = 12 V /bd^2 \sum_{N/A\ r_0}^{d/2} (1/4 - (y/d)^2)(\Delta y /G)$$

Two terms (one for G_{UU} veneers and one for G_{LU} veneers) were calculated for each of the sections in Table 3. The maximum deflection equation for 3 point bending from this method is :-

$$(\text{Term 1})/G_{UU} + (\text{Term 2})/G_{LU} + (Pl^3/48)/E_L$$

EXPERIMENT

Four samples of 295mm width for each of the Table 3 sections were subject to 3 point bending and deflections measured. The span (l) for each section was 10 times the section thickness. Linear regression was used to establish the mm of deflection per kN for each section. The results, summarised on page 11, are equated to the method 1 (left) and method 2 (right) equations for the sections.

Section	Method 1	Exp.	Method 2
31-	$11.62/G_{UU} + 1078/E_L$	=0.1535=	$3.94/G_{UU} + 4.53/G_{LU} + 1078/E_L$
63-	$8.16/G_{UU} + 1333/E_L$	=0.1517=	$3.43/G_{UU} + 5.05/G_{LU} + 1333/E_L$
95-	$11.20/G_{UU} + 1327/E_L$	=0.1445=	$3.63/G_{UU} + 4.82/G_{LU} + 1327/E_L$
125-	$11.29/G_{UU} + 1356/E_L$	=0.1506=	$3.74/G_{UU} + 4.73/G_{LU} + 1356/E_L$
155-	$11.70/G_{UU} + 1378/E_L$	=0.1573=	$3.79/G_{UU} + 4.67/G_{LU} + 1378/E_L$

The above equations were modified to equate to 1 by through multiplication and least sum of error squared approach used to find the suggested values of the unknown material properties for each method. The best fit values are shown below.

Method 1	Method 2
E_L = 15023 MPa	E_L = 12493 MPa
G_{UU} = 165 MPa	G_{UU} = 97 MPa
	G_{LU} = 497 MPa
$G_{UU} = 0.011E_L$	$G_{UU} = 0.008E_L$
	$G_{LU} = 0.040E_L$

Method 1 is simpler and fits the expected relative magnitudes of E & G well. Removing the shear allowance in E from the AS1720 figures to derive E_L suggests F17 material would have E_L averaging 14730 MPa. As similar material under machine stress grading often exceeds F17, then the Method 1 E_L would be reasonable.

It should be noted here that the design stress grade for BRIDGEWOOD® is F14 and no change is suggested.

SHEAR DEFORMATION PERSPECTIVE

Method 1, code values for E_L = Code E/0.95, and 10 to 20% E as a value for G_{UU} could be used to allow for shear deflections.

The spans of 10 times thickness under 3 point bending indicated shear deflections exceeding 40% of the magnitude of bending deflections.

Bodig op.cit. p157 shows theoretical shear deformations for solid timbers under these conditions as being 20% of the bending deflection.

A practical approach would be to double the shear deflection suggested in Bodig's solid timber diagram for shear in thick plywood slabs.

CONCLUSION

Other points relevant to design, such as allowance for scarf joints and effect of inner butt joints, have not been discussed. The deterministic design methods used for the thick plywood slabs and other structural components rely on many assumptions about loads, structural action and material. Where reality departs from these assumptions, complementary conservative and non-conservative errors are relied upon. The interrelated structural actions of the many bridge components, BRIDGEWOOD® being one, is being investigated by Law Matheson Yttrup. As such work proceeds, better component knowledge and component analysis methods may be required.

REFERENCES

1. Nicol, R.L. Technical Report - Hancock Bridgewood
Hancock Bros. Pty.Ltd. November, 1986.

2. Lane, F.H. Bridgewood Contributing Strip Width Determination
Hancock Bros. internal report. June, 1988.

3. Hall, A.S. An Introduction To The Mechanics Of Solids
John Wiley & Sons Australasia. 1974.

4. Green, D.M. Test Report No. CET 3040
School of Civil Engineering, Queensland University of Technology. September, 1990.

5. Leicester, R.H. Characteristics of Structural Timber
Workshop on Timber Engineering
Melbourne, Australia. 1983.

6. Bodig, J.,Jayne, B.A. Mechanics of Wood and Wood Composites
Van Nostrand Reinhold Company. 1982.

7. Todd, J.D. Structural Theory and Analysis
The Macmillan Press Ltd. 1974.

DEVELOPMENT OF CSIRO ACTIVATED WOOD PELLET CARBON FOR GOLD EXTRACTION

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ABSTRACT

The CSIRO Division of Forestry & Forest Products has developed a new, composite activated wood pellet carbon designed specifically for the recovery of gold. Manufactured from charcoal produced from the CSIRO fluidised bed carbonisation process using *E. marginata* wood residues, it is expected to be price competitive with imported commercial activated carbons based on coconut shells and peat. It has gold performance properties at least equivalent to the premium grades of imported carbons such as hardness, gold adsorption kinetics, gold stripping behaviour and thermal reactivation. Pilot plant development and production is in progress for eventual commercialisation of the carbon which will add value to the wood residue resource.

INTRODUCTION

Although the utilisation of sawmill residues has improved over the last decade, many mills are still incinerating or dumping significant quantities. Studies in the carbonisation of wood residues commenced in 1975[1] with the development of a fluidised bed system of carbonisation which converts sawdust and woodchips into charcoal fines and lump charcoal. The volatile products of carbonisation burn within the bed and enable heat to be recovered for power generation through a steam turbine alternator and process heating such as the kiln drying of timber. This combination could optimise wood utilisation *in situ* to dispose of the total mill residues, upgrade it to a saleable product, provide all the energy requirements and eliminate smoke pollution. The work then focussed on the uses for wood charcoal with studies on its application for silicon smelting[2], activated carbon[2], fuel[3], electrodes[2] and filler for rubber[4].

In Western Australia, the *Eucalyptus marginata* resource produces structural timber and sleepers, but is not suited for pulping. However, this species is known to produce a high grade metallurgical carbon. Early this year, a silicon smelter commenced operation utilising the

Jarrah residue resource based on over-mature logs, forest residues and some solid sawmill residues for metallurgical carbon. However, large quantities of sawdust and wood fines remain unutilised.

It was clear that a value added product such as activated carbon could provide considerable benefits although the utilisation of the residual resource is less extensive than that demanded by the silicon industry in Australia(5).

Australia currently imports its total activated carbon requirements of 5 142 tonnes/year in 1989/90 (Table 1) which was less

TABLE 1: ACTIVATED CARBON IMPORTS - JUNE 1989/1990

COUNTRY	QUANTITY (kg)	VALUE ($)
Belgium	116 716	270 272
China	800 200	774 011
Denmark	300	1 141
France	364 624	1 268 367
Germany (FRG)	1 438	12 905
Hong Kong	14 185	23 774
Italy	740	2 973
Japan	1 078 985	2 285 168
Malaysia	22 000	27 163
New Zealand	16	164
Netherlands	372 760	1 319 585
Philippines	1 125 895	2 515 433
Singapore	12 000	20 497
Sri Lanka	794 505	1 824 725
Sweden	1	300
Switzerland	2	54
Taiwan	12 607	31 321
United Kingdom	48 674	126 442
U.S.A	376 192	962 088
TOTAL	5 141 841	11 467 473

than the previous year. The Gold Industry is the largest single user with an estimated consumption of 3 000 - 5 000 t/y. This industry employed the carbon-in-pulp and variations of this technology in the early 80's which allowed the profitable extraction of ores with grades as low as 1 g/tonne of ore. This has revolutionised gold mining by opening up vast reserves of low grade, finely disseminated gold ores. Gold production has been at its highest level on record over recent

years. The Gold Industry has been a major export earner but derives its carbon from coconut shell in the Philippines and Sri Lanka and from peat sources in the Netherlands. The activated carbon commands a price in the range $3 500 – $6 500/t.

Description of the Carbon -In - Pulp Process

In the carbon – in – pulp process, the ore is crushed finely and leached with sodium cyanide solution in the presence of sparged air. The combined oxidation of the gold by atmospheric oxygen and the complexing with cyanide solubilises the gold together with a range of other metals. When activated carbon is added, the gold (aurous) cyanide complex attaches itself strongly to active sites on the carbon surface thereby concentrating the gold. In practice, the carbon is loaded up to 1 - 3.5 kg gold/tonne of carbon which is only a fraction of the saturation value due to the uneconomically long time required. The loaded carbon is separated from all the unwanted slurry by screening and the gold cyanide is then stripped off the carbon with fresh sodium cyanide solution at elevated temperatures and pressure and high pH. By electrolysis of the resulting cyanide solution, metallic gold is recovered. Because of the high cost of carbon, the adsorbent is thermally regenerated, screened and reused.

STUDIES ON THE PRODUCTION OF GRANULAR ACTIVATED JARRAH CARBONS

The Division was successful in producing activated carbons from bagasse for sugar decolorisation and from *E. camaldulensis* for water treatment. Early studies on activated carbon from *E. marginata* using chemical and steam activation methods produced carbons which had excellent gold adsorption properties such as fast gold loading rates onto the carbon and stripping of gold from the carbon[6]. The major problem however, was the low hardness. ASTM ball pan hardness numbers for the Jarrah carbons were 90 and 89 for steam and chemically activated material respectively[7]. Commercial coconut shell carbons were in the range 94-98. It was argued at the time that the activated granular Jarrah carbon could be used as a low cost, once through, throw away carbon. Certainly, gold is lost if fines are produced which will pass through the screens. However, attrition of granular carbon is also a function of its residence time in the adsorption process being directly proportional to the residence time. Because the rate of adsorption of

gold was so fast for the wood based carbons, typically 1.9 - 2.4 times faster for both steam and chemically activated Jarrah carbon than for commercial coconut shell carbons, it was argued that the fines generation could be maintained at about the same level as the coconut carbon without added loss of gold by reducing the residence time of the carbon according to the inverse of the relative gold loading rate. If one considers a price of $4 500/t for regenerable carbon, its equivalent price for a once-through carbon would be in the range $570 -$1 620/t. At these prices, it would be possible to profitably produce granular activated Jarrah carbon[6].

When the Gold Industry was approached with a low cost, once-through carbon with lower hardness, they were reluctant to depart from their current practice since it meant a different gold recovery system would need to be used involving incineration of the carbon and the smelting of the ash to recover gold. This would have been a far less complicated process than the stripping-electrowinning process currently used by the Australian Gold Industry. It was practiced in the earlier CIP plants in South Africa when activated carbons were less than $2 100/t and was used once through[5].

COMPOSITE JARRAH CARBON

It became clear that to penetrate the activated carbon market with a locally produced wood - based product, it would need to have similar properties to the imported material and be able to directly substitute the existing carbons without plant modifications. Competitive price and improved properties would determine its degree of penetration.

Wood residue based carbon would have a distinct price advantage because of its low cost, particularly if it was produced in conjunction with energy recovery. Local production would cut the high cost of freight. The major gold production is based in Western Australia, the source of the Jarrah.

It was realised that the high macroporosity of the wood carbons which retained the anatomical structure of wood with its inter-communication of fibre and vessel lumen through pits and ray cells was largely responsible for the high adsorption rate. This structure provides a large miriad of interconnecting corridors for molecules to pass, relatively unimpeded, leading to the micropores formed in the cell walls which contain the majority of active sites on which the gold

cyanide complex adsorbs. However, this carbon is of low strength but there would be a likelihood of increasing the hardness and strength of the Jarrah carbon by making a composite. This was undertaken and the CSIRO activated wood pellet carbon (CAWP) was produced.

COMPARISON OF PERFORMANCE PROPERTIES OF ACTIVATED CARBONS

CAWP was prepared from Jarrah carbon produced by the CSIRO fluidised bed carbonisation plant. Laboratory tests were conducted to compare the performance of CAWP with some high grade commercial carbons. Pica G210 AS is a premium grade activated carbon manufactured in France from Sri Lankan coconut shell carbon and is well established for gold recovery. Since CAWP development began, Norit have introduced their pelleted peat based carbon RO 3515 onto the market which commanded a premium price of $6 500/t similar to that of Pica. The following tests were undertaken:

a) Hardness

Based on the ASTM D3802-79 ball pan hardness test[7] the hardness numbers of the various activated carbons were measured and shown in Table 2. Also included in Table 2 are the hardness numbers of the original granular Jarrah carbon produced in our earlier studies[6].

TABLE 2: COMPARISON OF HARDNESS

Carbon	ASTM Hardness No.
CAWP (Jarrah pellets)	99.6
Norit RO 3515 (peat pellets)	99.1
Pica G210 AS (granular coconut shell)	98.1
Jarrah - steam activated (granular)	90.3
Jarrah - chemically activated (granular)	89.0

It can be seen that CAWP with a hardness number of 99.6 exceeds that of the commercial carbons Norit (99.1) and Pica (98.1). The hardness of the composite Jarrah carbon has indeed increased from the low values of 89.0 and 90.3 into a very hard carbon, well suited for gold extraction.

b) Gold Adsorption Kinetics

The kinetics of gold adsorption is shown in Table 3. The tests

conducted were according to the method outlined in reference[6] which directly measures the rate or gold adsorption onto the carbon at various levels of gold loadings relative to saturation. CAWP's kinetics compares favourably with the premium grade coconut shell carbon Pica G210 AS. The initial rate of gold uptake of CAWP (14.9) is only slightly less than that of Pica (15.6). At a higher gold loading on carbon of 50%, the kinetics of both carbons become identical but CAWP showed an improvement over Pica at even higher loadings (3.2 compared to 2.8 at 75% saturation).

TABLE 3: COMPARISON OF GOLD ADSORPTION KINETICS

	Gold loading rate $\frac{d[Au]_c^t}{dt}$ (kg Au/t C/h)			
	% Au on C relative to saturation			
	0%	25%	50%	75%
Jarrah - Chem. activated	36.6	27.1	17.7	8.2
Jarrah - Steam activated	29.2	21.5	13.8	6.1
CAWP	14.9	11.0	7.1	3.2
Pica G210 AS	15.6	11.5	7.1	2.8
Norit RO 3515	12.3	9.0	5.7	2.4

Compared to Norit RO 3515, CAWP is notably faster. However, the extremely fast kinetics of the granular wood carbon has been lost in the conversion into the composite CAWP.

c) Gold Adsorption Capacity

Although not an important yardstick in gold extraction performance, an adequate gold adsorption capacity which allows the

TABLE 4: COMPARISON OF GOLD ADSORPTION CAPACITY

Carbon	K-value (kg Au/t C)	n-value
CAWP	24.9	3.89
Jarrah - Steam activated	21.2	3.30
Jarrah - Chem. activated	13.3	2.75
Norit RO 3515	28.9	3.94
Pica G210 AS	28.5	3.43

carbon to load quickly to some 3.5 kg gold/tonne of carbon is required. Table 4 shows the adsorption capacity for gold of the various carbons based on the K- and n-values of the Freundlich adsorption isotherm. K is a point on the isotherm defined as the adsorption capacity constant which is the mass of gold adsorbed on unit mass of carbon in equilibrium with a gold solution containing 1.0 g Au/cubic metre of solution. The n-value is given by the inverse slope of the logarithmic isotherm.

d) Gold Stripping

The comparison of the gold stripping (elution) behaviour of the carbons was conducted with the following method. A standard weight of the carbons were loaded to 10 kg Au/t C and stripped in 2% sodium cyanide/2% sodium hydroxide (w/v) solution at boiling point (100 - 105°C) for one hour under reflux and the percentage of gold stripped was determined. Since the stripping rate slows considerably as the concentration of eluted gold builds up in the solution, the elution was halted by removing the solution from the carbon and recontacted with a fresh batch of gold free solution. After 5 consecutive one hour strip cycles, the overall percentage gold stripped was also recorded.

The results in Table 5 showed that CAWP performed exceedingly well with 93.5% elution of gold after 5 x 1 h cycles as compared to 74.5% for Pica and 68.6% for Norit. It was less than that of steam activated granular jarrah carbon with a gold elution of 97.0%.

TABLE 5: COMPARISON OF GOLD STRIPPING PERFORMANCE

Carbon	Gold stripped after:	
	1 hour	5 x 1 hour
Jarrah - Steam activated	42.9%	97.0%
CAWP	38.8%	93.5%
Pica G210 AS	27.1%	74.5%
Norit RO 3515	28.6%	68.6%

INDUSTRIAL TRIALS ON CAWP

Because of the promising results shown by the laboratory tests, a comparative trial between CAWP and a commercial carbon was conducted at an industrial carbon - in - pulp operation. The operation chosen

produces 2 300 kg gold/y processing ore with grades averaging 2.8 g Au/t.

To facilitate the test, a vertical rotating cage was designed and fabricated which contained the CAWP carbon in one compartment adjacent to a control carbon. This cage was suspended in the first primary carbon adsorption tank containing the highest gold concentration (Figures 1 and 2). After adsorption, the carbons were removed, stripped of gold by the Anglo method with 3% sodium cyanide and 2% sodium hydroxide at 110°C and thermally regenerated at 650°C. The carbons were then returned to the cage for a further adsorption cycle. Three cycles were performed on both CAWP and the control. The control carbon used was Norit RO 3515.

The gold performance activity of the two carbons were found to be about the same. Similarly, both carbons could be stripped and reactivated to the original activity. However, a mass balance of the carbons over the three cycles showed that whereas the Norit carbon lost 7.0% in mass, CAWP lost only 2.8% confirming its superior hardness which is an important property desired by the Gold Industry.

CURRENT DEVELOPMENTS

Pilot plant construction on the production of CAWP is in progress. The objective is to produce a tonnage quantity of CAWP for large scale industrial trials and process scaleup for a commercial operation.

CONCLUSIONS

The CSIRO activated wood pellet carbon (CAWP) has been demonstrated to be a viable alternative to the imported carbons used for gold extraction. Its gold performance properties are at least equal to the premium grade commercial carbons with improvements in the key property of hardness. The local manufacture of CAWP will not only assist Australia's import replacement but also provide possible exports because of competitive production costs which is estimated to be low. This will upgrade wood residues into a valuable product and improve the overall value of the forest resource and the efficiency of wood utilisation.

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In the industrial trial, Dr Jim Avraamides' program at the Mineral Processing Laboratory, Chemistry Centre, WA Department of Mines undertook the gold activity analyses, carbon reactivation and mass balance on the carbons and Dr Steve La Brooy's team of the Gold Technology Group at the School of Mathematical and Physical Sciences, Murdoch University carried out the stripping of the carbons.

REFERENCES

1. Fung, P.Y.H. 1977. Charcoal production from a fluidised bed combustor. Proc. 18th Forest Products Research Conf., Melbourne.

2. Fung, P.Y.H. and Brown, T. 1986. Properties of carbon from *E. marginata* related to its potential application for activated carbon, electrodes and silicon production. IUFRO 18th Congress, Ljubljana, Yugoslavia.

3. Blowers, M.J., Fussy, D.E. and Liversidge, R.M. 1980. Evaluation of char-oil slurry combustion in a commercial boiler. Report No 1/80. Energy Planning Unit, Dept of Minerals & Energy, PNG.

4. Fung, P.Y.H. and Nowak, Z.T. 1981. Wood charcoal as a filler for rubber. Proc. 20th Forest Products Research Conf., Melbourne.

5. Fung, P.Y.H. 1985. Review of the South African carbonisation industry and the carbon from biomass seminar. Gottstein Fellowship Report.

6. Fung, P.Y.H. 1986. Study on the production and properties of activated carbon from *E. marginata* for gold extraction. 22nd Forest Products Research Conf., Melbourne.

7. American Society for Testing Materials. 1979. Standard test method for ball-pan hardness for activated carbon. ASTM D 3802-79.

FIGURE 1.

Test carbons CAWP and Norit put into the CSIRO stainless steel test cage.

FIGURE 2.

Rotating test cage immersed into the CIP adsorption tank at a commercial gold extraction operation.

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IMPACT OF SILVICULTURAL DECISIONS ON RADIATA PINE LOG QUALITY FOR SAWMILLING

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ABSTRACT

Modern silvicultural options for radiata pine in New Zealand involve a trade off between maximum volume and maximum value production. Decisions on optimum regimes are based on a number of key assumptions regarding future processing costs and market prices. The forester now has a versatile tool in the Radiata Pine Modelling System which enables rational comparisons of the alternative scenarios in both physical and financial terms.

The paper reviews the components of the modelling system relevant to the sawmilling process, indicates how wood quality has been incorporated and gives some examples of the impact of silviculture, processing options and market forces on log quality as defined in terms of log grades, timber grades and financial return to the processor.

INTRODUCTION

New Zealand has traditionally been a forestry and forest products oriented country, endowed as it was with vast natural forests yielding timber of high durability and quality. The temperate climate is ideal for forest growth and both production and consumption of wood based products since European settlement has been high by world standards. Initially, forests were cleared mainly for farm development and local wood products, and little thought was given to long term sustainability of wood supplies. A number of exotic softwoods, including radiata pine were planted in small blocks for shelter and wood production.

In 1913 a Royal Commission on Forestry strongly recommended the establishment of plantations to eventually supplement the natural forest, and this task was undertaken by the New Zealand Forest Service which was formed in 1919.

Sawmilling of plantation softwoods, mainly radiata pine, began in earnest about 1940, and since 1955, when about 50% of production was from these plantations, radiata pine has dominated the wood processing industry. It is now widely accepted as a very suitable medium for the whole range of domestic wood products as well as a valuable export commodity. However, the relatively consistent characteristics of the unmanaged "old crop" had not encouraged the industry to segregate logs into other than very broad product groups.

Log Quality

Hinds [5] in 1962 observed that the link between silviculture and log quality was poorly understood by early foresters. From the early 1960's, however, forest managers had largely moved away from the "maximum volume" philosophy of the unmanaged "old crop" to a "maximum value" approach incorporating thinning and pruning to concentrate growth on final crop stems. Research at the Forest Research Institute started to concentrate on the production of high quality logs (Brown, 1961). However, it is now recognised that even within the sawlog category, the concept of "log quality" varies with the product. Up until the 1980's, sawmills in New Zealand were predominantly production oriented and performed reasonably well on a diet of old crop logs. Now that the product mix from the forest is changing, mills are adapting to the log types available. Specialist mills for processing of either pruned or unpruned logs are starting to appear.

It is widely accepted in New Zealand that future stands will produce smaller logs with different characteristics and a wider range in value. Both wood and log characteristics are crucial in determining the potential timber grade output and hence the potential value of radiata pine logs. A review of FRI research results has identified basic wood density as by far the most influential wood property regarding both solid wood and pulp products. This property has been extensively researched in New Zealand and is known to be influenced by four factors:

* Site. Average wood density is positively related to mean annual temperature.

* Wood age. Average density increases with wood age, both within and between stands.

* Silviculture. Spacing, thinning and pruning have small but predictable effects on wood density.

* Genetics. Different breeds can have varying wood density.

Other wood properties are known to have a significant effect in some cases, but they have so far proved unpredictable other than in a very broad sense. Such features include spiral grain, compression wood and resin pockets.

Of the factors influencing log quality, diameter, branching and shape are recognised as important and are also affected by the above factors. The lower stockings and shorter rotations now in vogue involve a sacrifice in final crop merchantable volume, but provide a different log quality mix, e.g. high quality pruned butt logs and unpruned logs with a range of branch sizes. What has been lacking until recently has been a rational system of evaluating and comparing silvicultural options involving volume/quality trade-offs. There are also significant implications of younger wood and branch size which may affect some end products more than others. Basic to this kind of approach is a good knowledge of the factors affecting both the physical yields of products and the economics of the processes.

Once it is appreciated that "log quality" can be manipulated in different ways, and that "log quality" refers to a specific market, the continuum from resource through processing to market becomes apparent. Following from this is the fact that as technology changes, so can resource requirements - a "quality" log for a small log sawmill is vastly different from a "high quality" pruned log.

There is no shortage of research information on the interactions of the foresters decisions and specific quality, but in most cases there is little emphasis on integrating the effects on all the most important quality factors, including log size and branching characteristics.

LOG GRADING

"New crop" radiata pine refers to a resource covering a wide range in log size and quality as a result of differing silvicultural regimes and rotation ages. The old term "run of bush", implying a relatively predictable log type, is no longer appropriate as a qualitative resource description. Until recently however, apart from export logs, there were no standardised log grades and a wide variety of log specifications existed throughout the country, causing some confusion amongst both sellers and customers.

The work of the Conversion Planning Project Team quantified the influence of the major log variables and allowed national log grading rules to be developed with industry input (Table 1). These recognise the importance of log size, straightness and branching characteristics and are now widely used for resource description and sale purposes. The practicality of segregating into "log assortments" in the forest is now fully accepted, the range of sorts varying with the circumstances.

TABLE 1: LOG GRADE SPECIFICATIONS FOR NZ RADIATA PINE

GRADE	LOG TYPE	SMALL END DIAMETER	DIAMETER OF LARGE BRANCH	SWEEP CLASS [1]
P1	PRUNED	400+	NA	1
P2	PRUNED	300-399	NA	1
S1	UNPRUNED	400+	6	1
S2	UNPRUNED	300-399	6	1
S3	PRUNED/UNPRUNED	200-299	6	1
S4	PRUNED/UNPRUNED	150-199	6	1
L1	UNPRUNED	400+	14	1
L2	UNPRUNED	300-399	14	1
L3	PRUNED/UNPRUNED	200-299	14	1
L4	PRUNED/UNPRUNED	150-199	14	1
I [2]	UNPRUNED	300+	14	1
R	PRUNED/UNPRUNED	100+	NA	1

1 Maximum permissible sweep according to log length as below.

Log Length (m)	<3.7	3.7-4.8	4.9-7.6	>7.6
Sweep Class 1	D/8	D/4	D/3	D/2
Sweep Class 2	D	2D	3D	4D

2 The I (Internode) log grade has a minimum internode length index of 0.6. The sum of internode lengths exceeding 0.6m when expressed as a fraction of log length must be greater than 0.6.

The differentiation between S (small branched - <6 cm) and L (large branched 6-14 cm) logs is seen as important because:

a) The proportion of S:L logs is very sensitive to silvicultural regime, and

b) The yield of structural timber is highly dependent on the presence of S logs.

The pruned log grades are assigned purely on the basis of external appearance, but clearly the "quality" depends largely on the size of the clearwood sheath. Whiteside and Manley [9] in 1987 proposed a classification system (A to E) based on the difference between the small end diameter and the defect core diameter. Other methods are in commercial use e.g. selling logs on the basis of the expected yield of clearwood - P50 giving a minimum of 50% Clears in the sawmill.

Peeler logs are selected from the P1, P2, S1 and S2 categories, and have additional specifications not included in Table 1.

INTEGRATED MODELLING SYSTEMS

Since 1976, the Forest Research Institute has maintained a series of short term multidisciplinary project teams aimed at accumulating and integrating research results in key areas. These include:

* Mensuration Project Team (1976-78)

* Radiata Pine Task Force (1980-83)

* Conversion Planning Project Team (1983-1986)

The Mensuration Project Team under Elliott [4] developed a system for predicting and planning long term yield flow from the forest by broad quality classes and a pre-harvest inventory method (MARVL) to assess crops by log types. The Radiata Pine Task Force, managed by Sutton [8] designed a system (SILMOD) for evaluating silvicultural options based on the expected outturn from sawmilling and pulping. A stand residual value was derived in terms of nett present value (NPV) and internal rate of return (IRR).

From 1984 onwards, the Conversion Planning Project Team has had the responsibility of maintaining and expanding a computer modelling system "linking the output of the forest and the various processing options to market requirements for a full range of forest products" - Kininmonth [7]. Log grades are the building blocks of the system and provide the link through from the forest to the processing plant.

A key component of the integrated modelling system is the suite of models called STANDPAK, described by Whiteside and McGregor [11] which has now replaced SILMOD for stand evaluation. STANDPAK uses log yield models to estimate the value of the resource as input to a range of specific processing options. A Residual Log Value is obtained for each log grade processed in this way.

Important models within STANDPAK include:

a) STANDMOD. This STAND MODelling part of the system grows 1ha of the crop according to the regime specified and predicts the output in terms of standard or user-specified log grades. Average log parameters (small end diameter, sweep, taper, branch size, wood density and defect core size for pruned logs) are assigned to each log assortment.

b) HARPCE. Assigns harvesting and transport costs.

c) PROCESS. A series of log yield models (sawmilling, chipping, log export) to predict the physical and financial yields for each log assortment. The most sophisticated model is SAWMOD (Whiteside and McGregor, 1987) which calculates residual log values for sawlogs.

d) SECMOD. The Stand EConomic MODel, Cox [3], is used to integrate costs and revenues predicted from other models using specific pricing and processing assumptions, and calculate profitability in terms of NPV and IRR.

SAWMOD

The heart of SAWMOD consists of a procedure to predict the physical yields and residual log values of specified log types processed by various means. The conversion to sawn timber can be accomplished in a range of mill designs, using several sawpatterns, conversion standards and grading methods. Products and residues are valued by applying standard price lists or user input. In addition, information on productivity and sawing costs of a range of the mill types has been included as well as suggested timber prices for domestic and export markets.

The flexibility of the model enables more problems to be addressed but necessitates a higher degree of user input than previous versions. The model brings together much of the research on sawing of radiata pine, to the benefit of growers, processors and planners.

In order to take account of the most important factors affecting log quality and, they must be included in the simulation model. Within SAWMOD, the user is given the choice of wood density site classes, for instance, based on the detailed survey work previously carried out by Cown and McConchie [2]. Average wood density is assigned to each log height class according to crop age. Branching characteristics (average size of the four largest branches and internode length) are predicted from the empirical models of Inglis and Cleland [6]. Timber grading options in the model allow the user to compare the yield of structural timber (visually or machine graded) with the recovery of clear lengths, thus maximising flexibility.

One of the most powerful means of assessing the "quality" of a log is to calculate the potential value to the processing plant. In STANDPAK this is done using the concept of Residual Log Value.

Log Residual Value = Value of the products
- Production costs (+ return on capital)

EXAMPLES

The integrated modelling system allows planners to examine the effects of changes in the forest resource, processing methods and markets. The following analyses illustrate some of the potential of the approach and concentrate on the use of SAWMOD to quantify the effects of log and wood variables on processing and markets.

Two contrasting Pinus radiata regimes have been examined using STANDPAK to illustrate some of the uses of the system. The first regime involves wide initial spacing, pruning and low stockings, while the second involves production thinning, no pruning and higher stockings. The basic regimes are outlined in Table 2.

TABLE 2: OUTLINES OF REGIMES

Operation	1. Pruned	2. Unpruned
Plant	1000spha	1400spha
Prune	250 to 2.4m at 6m 250 to 4.3m at 8m	-
Thin	To 250 at 6m	To 700 at 6m To 350 at 18m (for production)
Final Stocking	250	350
Clearfelling Ages	25 or 30 or 35	25 or 30 or 35

Three clearfelling ages were examined for each regime (ages 25, 30 and 35 years).

The site was the same for both stands. It is typical of sites in the central North Island on the pumice plateau. A site index of 30m and medium basal area fertility were assumed and the medium wood density classification selected. On the site index used the production thinning in the unpruned stand occurs at age 12.

Use of STANDPAK allows many issues to be examined, involving both silvicultural and processing aspects of plantation management and utilisation. We have selected a small number of such factors to provide examples of the use of the model.

Log Grade Yield

The forest yield from the two regimes is markedly different. The volume outturn by different log grades is given in Table 3 and illustrated in Figures 1 and 2.

The pruned regime gives larger trees, pruned butt logs but the upper logs have larger branches than those from the unpruned regime.

TABLE 3: LOG VOLUMES PRODUCED (m^3/ha)

	Regime						
	Pruned			Unpruned			
Harvest Age:	25	30	35	12	25	30	35
Log Grades:							
P1+P2	148	167	180	-	-	-	-
S1+S2	25	34	41	-	223	335	420
S3+S4	17	16	21	47	153	128	124
L1+L2	213	314	399	-	50	97	146
L3+L4	92	89	88	6	29	42	33
R	18	26	28	38	33	31	31
Total	512	645	757	92	489	633	754

The processing of the above logs was modelled using the SAWMOD component of the PROCESS model. The base run variables are outlined in Appendix 1.

Timber Grade Yields

The timber grades of green rough-sawn timber yielded by the two stands differ markedly. The grade recovery from the same sawpatterns for each of the log grade aggregations from the two stands is shown in Figures 3 and 4. For this comparison all unpruned logs were machine stress graded.

Both regimes, but especially the pruned regime, produce large proportions of low grade timber. The unpruned regime produces more structural timber while the pruned regime produces more Clears and Cuttings grades.

Conversion to sawn timber is lower for the unpruned stand than for the pruned stand. At age 30, conversion under the sawpatterns adopted are predicted to be 50.4% for all sawlogs greater than 15cm SED for the pruned stand and 53.4% for the pruned stand. Conversions are highest for the larger pruned logs. In the unpruned logs, conversions from the differing log aggregations are a function mainly of log size.

In New Zealand most domestically consumed timber is graded to visual rules while export timber is machine stress graded. The model can make comparisons between both visual and machine grades for logs from the same stand. This can be done by individual log grades or by any aggregation of these. The results of grading the sawn timber outturn from the two regimes are illustrated in Figures 5 and 6. In both regimes the volume of structural timber (F5+ in machine grades and 1F in visual grades) is markedly higher with machine stress grading than with visual grading.

The volume of structural timber produced from one hectare of each stand is given in Table 4. The differences between visual and machine grades vary with the average wood density within the stand. The stands modelled were selected to represent a medium wood density site. If a lower density had been assumed, the improvement in recovery of F5+ with machine grading would have been less than shown in Table 4. (Conversely, the difference would have been greater for a high density site).

TABLE 4: - RECOVERIES OF STRUCTURAL GRADES FROM 1 HECTARE - (m^3/ha - SAWING ALL SAWLOG GRADES)

	Pruned regime		Unpruned regime	
	F5+	1F	F5+	1F
Rotation age (yr):				
25	57	41	97	70
30	67	47	120	89
35	79	54	141	106

Predictions for machine stress grading give a higher recovery of F5 and Better than visual grading because they are based on the actual results of sawing trials which show wood density to be a critical factor. Visual grades assume a conservative "average" wood density and are imprecise for this reason.

Sawmill Factors

Comparisons between sawmill types and operating conditions are possible. In this case it has been accomplished using Residual Log Values. The Residual Log Value represents the maximum price (based on predicted product recovery) that could be paid for the logs at the mill while still meeting capital commitments in the mill (in this case 10% of the capital invested in the mill). The process showing the highest Residual Log Value for a given batch of logs is the one that is the most efficient process to allocate the logs to. Negative residual values indicate that the mill would lose money on sawing the logs (assuming even allocation of costs).

In long term planning sawmillers will attempt to maximise the difference between the sum of the residual values for all the logs being bought and the price of the logs at the mill.

The base runs used a medium sized conventional New Zealand single-band sawmill (Mill A). To illustrate mill effects, a second smaller conventional mill (Mill B) was compared with this (mills 6 and 7 in Cox and Johnston [12]). A common location was assumed for the two mills and conversion efficiency and sawpatterns were held constant.

The residual values for the two mills for each of the log grade aggregations produced by the pruned regime are shown in Figure 7. From this it can be seen that Mill A is better at sawing the pruned logs while Mill B has an advantage with the larger unpruned logs. The results show that under the assumptions made the smaller logs are not worth sawing. Under New Zealand conditions an S3 log is currently a marginal log and L3, L4 and S4 logs are not generally sawn.

The impact of sawmill efficiency is also crudely modelled. Differing levels of mill recovery are modelled, based on a limited selection of kerf size and over-cut allowances. In addition, the effect of differing mill cost levels can be explored. The effect of the sawmill cutting the pruned logs running on 2 shifts, as opposed to 1 in the base example is to increase the average residual value of the 30-year-old pruned logs by $25.80/m3 by decreasing sawing costs by the same amount.

Timber Prices

Differences in markets prices will affect residual log values. This is particularly so where market distortions and transport costs give different at mill returns for sawn timber. An example using New Zealand a domestic price list (list A) and an export price list (list B) from December 1988 was run. The price lists are given in Appendix 2. The results of this are shown in Figure 8. This has use in determining the breakeven price that must be achieved before a given set of logs is worth sawing. It can also be used to improve the allocation of logs to different mills, different markets and different sawpatterns.

DISCUSSION AND CONCLUSIONS

Wood technologists have traditionally tackled the effects of silviculture in a very structured fashion - studying the impact of a "treatment" on a "property". Countless studies worldwide have used this approach, which is now considered in New Zealand to be only the starting point in deciding which quality factors require further investigation. The 1980's have seen the gain in popularity of the modelling approach in many scientific and commercial fields, forestry included. Forest managers are now accustomed to "modelling" alternative management options and we believe that the logic also applies to wood quality in its broadest sense.

Silvicultural decisions affect log quality at several levels - siting, initial spacing, thinning, pruning, rotation age. Each of these effects has been well researched in regard to the impact on specific log characteristics, e.g. wood quality, branching and log size. However, the term "log quality" has different connotations for different wood products and the forester is faced with a multitude of choices. Unless there is some rational procedure for selecting a forest management regime, there is a danger that sub-optimal decisions will be made.

The modelling tools available in New Zealand incorporate the results of extensive research on the sources of variability in wood density of radiata pine, and it is now possible to assign a value to differences in density by choosing the machine stress grading option in STANDPAK. However, by doing so the user is also making use of information on other important quality characteristics such as log diameter, branch size and internode length. It is important to bear in mind that wood properties are only part of the analysis - and perhaps a small part. The business of forestry is ultimately concerned with profitability based on providing material well suited to the prospective end uses. Any quality factors which can be shown to significantly influence the processing or the end product should be part of the modelling system. Wood and log properties are closely linked, and it is no longer satisfactory to consider these in isolation.

Forest management modelling systems enable the planners to test hypotheses regarding the growing, processing and marketing of future crops without making expensive mistakes. Given the uncertainties of long horizons, the objective should be to derive a robust regime which will meet the quality requirements of as many markets as possible. The ability to do this depends on the inclusion of sound research results in the models.

The systematic collection of data for modelling systems is time consuming and expensive, so researchers have a responsibility to ensure that only those with real impact are included. Wood density was the obvious first choice in New Zealand and has now been adequately catered for as far as site and silvicultural effects are concerned. Future extensions of the data base will quantify genetic effects.

Some other properties are fairly well researched (e.g. tracheid length) but have not been shown to exert a measurable effect on major end uses. Others can be shown to be important (e.g. spiral grain), but because of difficulties of measurement, are little understood.

The use of the STANDPAK modelling system also forces the user to consider the effects of both the processing plant and the expected markets for the forest produce. It then quickly becomes evident that "log quality" cannot be adequately defined in isolation of these variables, and in fact is not a fixed concept because:

* Quality requirements vary with product categories

* Quality criteria can change with time

* Changing technology can favour certain quality factors

The selection of silvicultural regimes for radiata pine is a difficult task for a number of reasons:

* Future markets (especially export) are poorly understood

* Foresters often have little appreciation of the parameters important to efficient processing, particularly when growing and conversion are different cost centres.

Computer models such as STANDPAK enable the forester to test a range of regimes quickly and without risk. However, there is a danger of relying too heavily on this approach. The models are based on general research results, and do not have a strong physiological basis. While they account for the most important variables observed in the base studies, there can be harvest planning, market, local environmental or socio-economic factors which also need to be taken into account in certain circumstances. In addition, it requires the user to be familiar with aspects of forest growing, processing and marketing.

REFERENCES

1. Brown, C.H. 1961. The tending of *Pinus radiata* in Southland. New Zealand Journal of Forestry 8(4):623-640.

2. Cown, D.J. and McConchie, D.L. 1983. Radiata pine wood properties survey (1979-1982). New Zealand Forest Service, Forest Research Institute Bulletin No. 50.

3. Cox, O. 1987. Stand economic model. In Proceedings of Conversion Planning Conference (Ed. Kininmonth J.A.). Ministry of Forestry, FRI Bulletin No. 128.

4. Elliott, D.A. 1979. A mensuration planning system for exotic forest plantations. In Mensuration for Management Planning of Exotic Forest Plantations (Ed. Elliott, D.A.). New Zealand Forest Service, FRI Symposium No. 20.

5. Hinds, H.V. 1962. The evolution of tending practices in New Zealand exotic forests. New Zealand Forest service Information Series No.40.

6. Inglis, C.S. and Cleland, M.R. 1982. Predicting final branch size in thinned radiata pine stands. New Zealand Forest Service, Forest Research Institute Bulletin NO. 3.

7. Kininmonth, J.A. 1987. General introduction to the work of the FRI Conversion Planning Project team. In Proceedings of Conversion Planning Conference (Ed. Kininmonth J.A.). Ministry of Forestry, FRI Bulletin No. 128.

8. Sutton, W.R.J. 1984. Radiata Pine Task Force - objectives, achievements and implications. In Proceedings of the 1982 New Zealand Forest products Conference (Eds. Kininmonth, J.A. and Young, G.D.). New Zealand Forest Service, FRI Bulletin No. 86.

9. Whiteside, I.D. and Manley, B.R. 1987. Radiata pine resource description by log grade specifications. In Proceedings of Conversion Planning Conference (Ed. Kininmonth J.A.). Ministry of Forestry, FRI Bulletin No. 128.

10. Whiteside, I.D. 1990. Spacing/thinning requirements for radiata pine in relation to product prices and exchange rates. In James, R.N. and Tarlton, G.L. (Eds.) Proceedings of IUFRO Symposium, New Zealand, April 1989. New approaches to Spacing and Thinning in Plantation Forestry.

11. Whiteside, I.D. and McGregor, M.J. 1987. Radiata pine sawlog evaluation using the sawing log yield model. In Proceedings of Conversion Planning Conference (Ed. Kininmonth J.A.). Ministry of Forestry, FRI Bulletin No. 128.

12. Cox, O. and Johnston, R.A. 1987. Choice of sawmill types: throughputs and costs. In Proceedings of Conversion Planning Conference (Ed. Kininmonth J.A.). Ministry of Forestry, FRI Bulletin No. 128.

APPENDIX 1

VARIABLES FOR BASE PROCESSING RUNS

Sawmill	- Conventional New Zealand bandsaw mills. - Single band headrig; horizontal band resaw; board edger. - Mill A 75,000m^3/annum; Mill B 33,000m^3/annum. - Operating 1 shift with 80% of available sawing time used. - Conversion standard 2. Kerf 4mm, overcut 2mm and minimum length recovered 2.4m. - 70% of residue recovered and sold as chips.
Sawn sizes (*)	- P1+P2. Timber size option 5, sawpattern option 2. - S1+S2, L1+L2. Timber size option 25, sawpattern option 6. - S3+S4, L3+L4. Timber size option 6, sawpattern option 1.
Grading method	- Pruned logs - visual grading for maximum value. - Unpruned logs - machine stress grading.
Price list	- Dec 1988 NZ domestic ex-mill list for green rough sawn timber.
Sawing costs	- Default values for Dec 1988 with a 10% requirement for return on capital.

(*) Timber size and sawpattern options are defined in User Guide for STANDPAK. Forest Research Institute, 1988.

APPENDIX 2

PRICE FOR GREEN ROUGH SAWN TIMBER LISTS USED

($NZ/m^3 EX-MILL)

	List A (NZ Domestic)		List B (Export)	
Grade	<200mm wide	200+mm wide	<200mm wide	200+mm wide
1C	464	516	598	645
2C	357	397	454	492
1 CUT	325	360	414	452
FACTORY	235	280	306	357
F8	322	333	304	362
F5/1F	285	295	268	325
F4/2F	250	230	199	199
BOX/<F4	165	175	174	193
BOARDS	220	250	221	254

Figure 1 – Log Grade Production from Pruned Regime

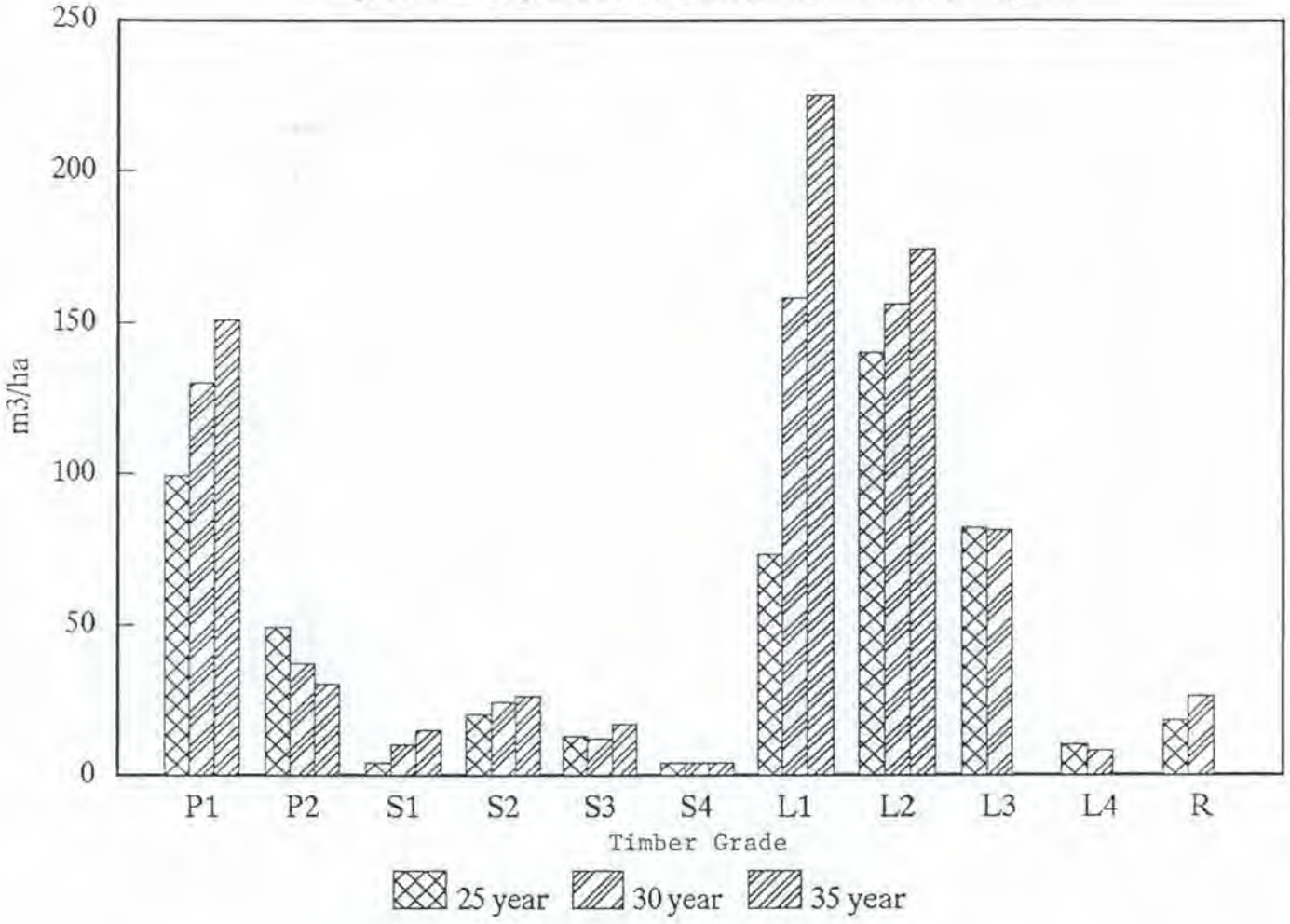


Figure 2 – Log Grade Production from Unpruned Regime

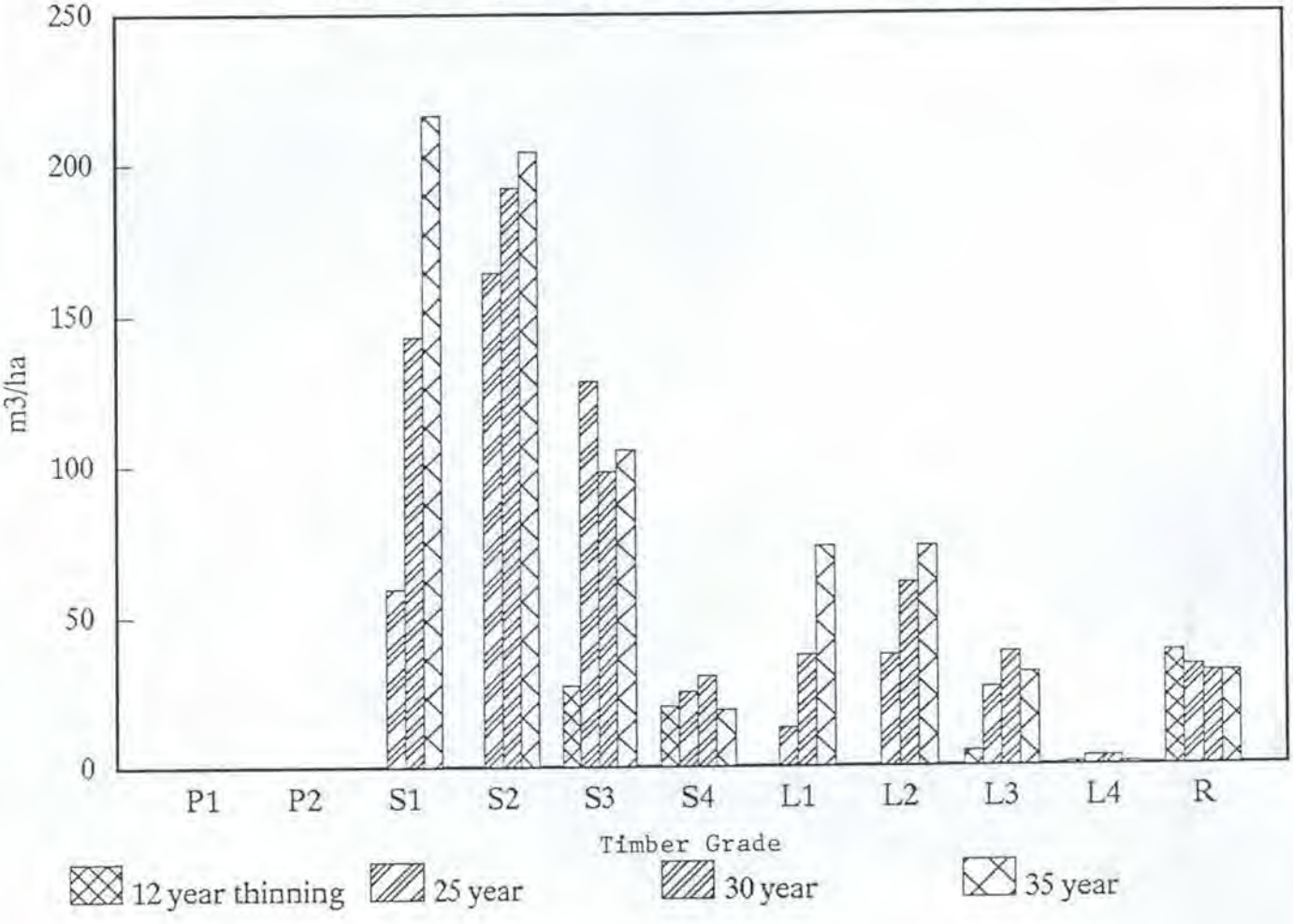


Figure 3 – Timber Production from Pruned Regime

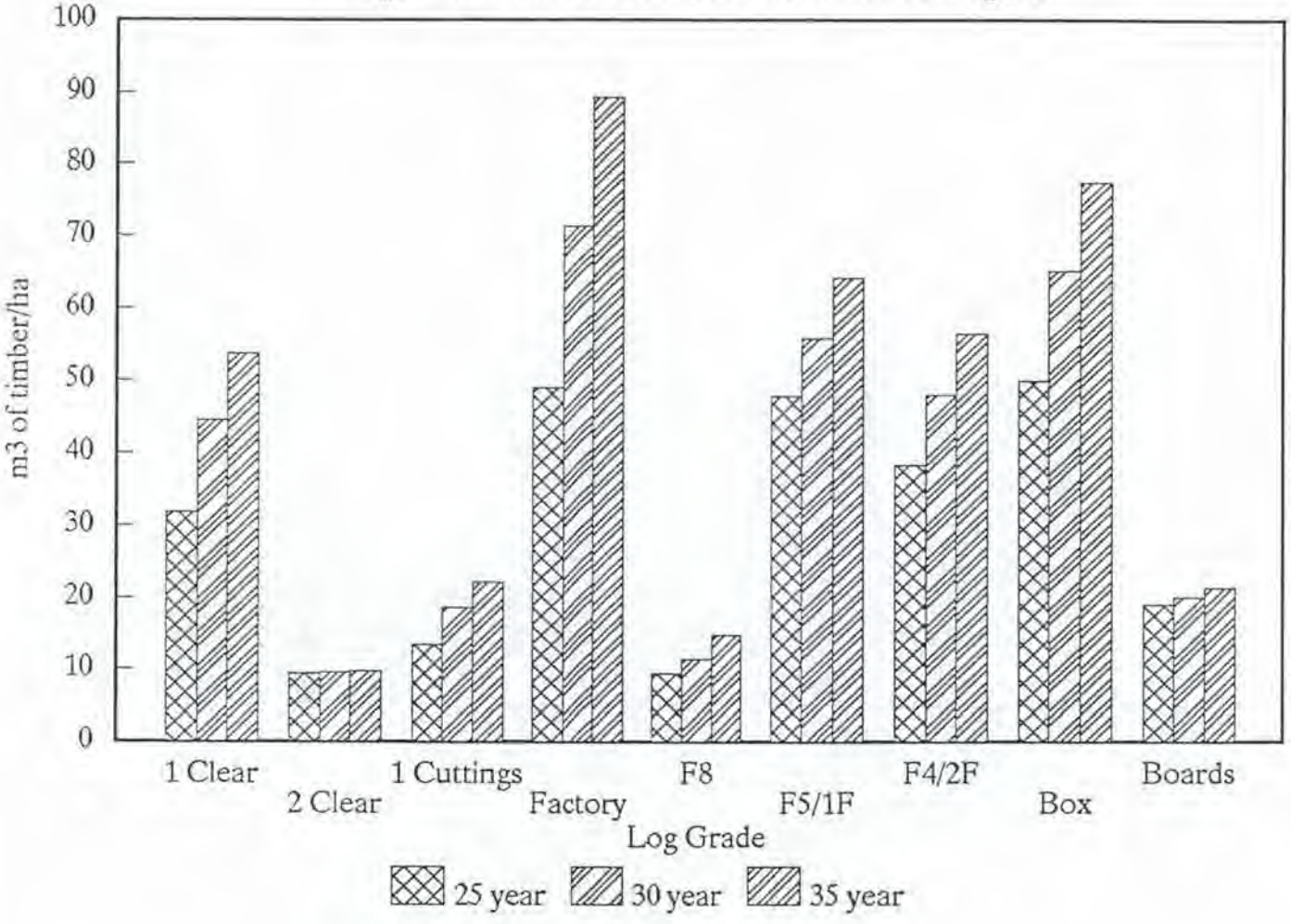


Figure 4 – Timber Production from Unpruned Regime

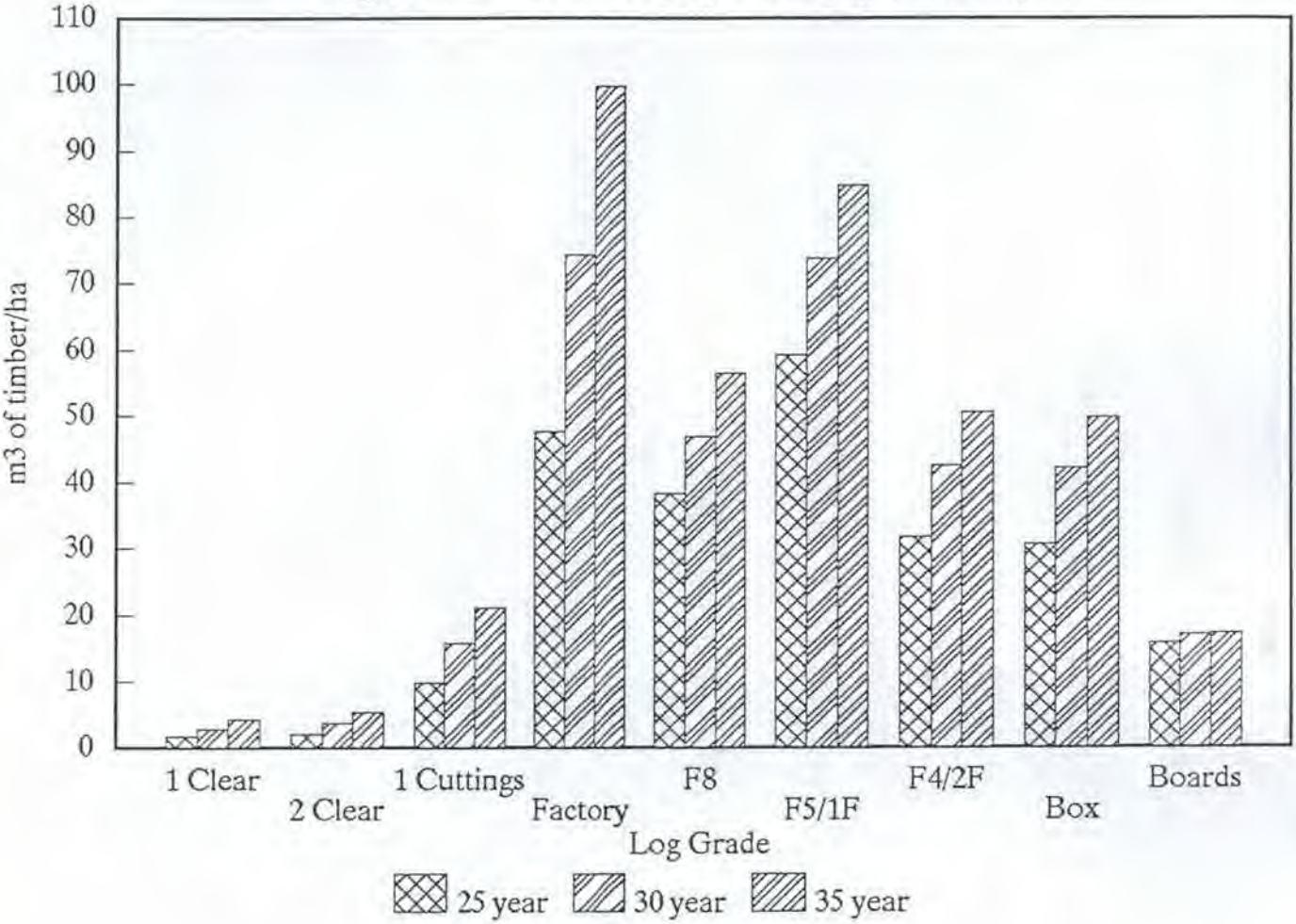


Figure 5 – Pruned Regime Grade Recoveries

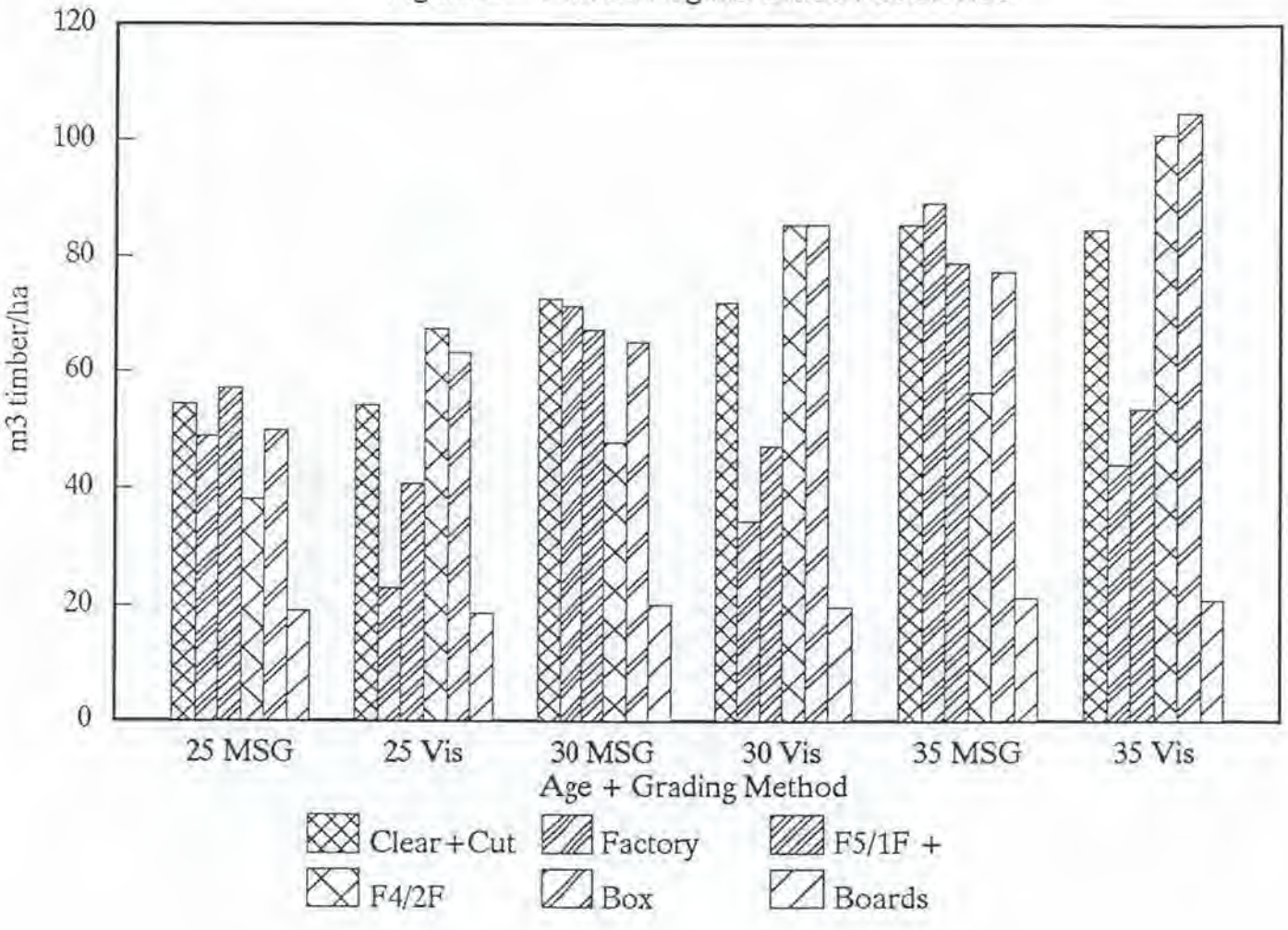


Figure 6 – Unpruned Regime Grade Recoveries

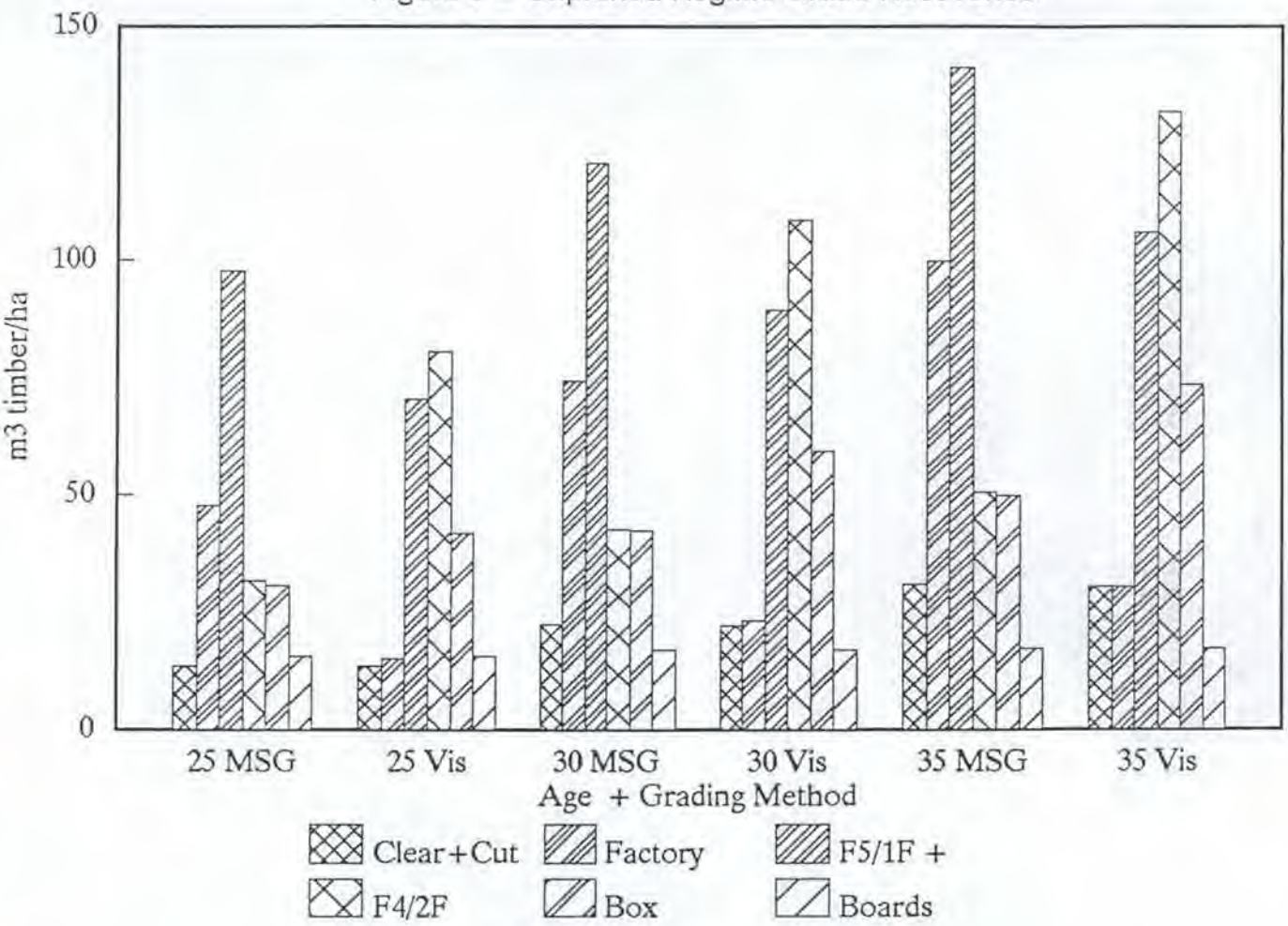


Figure 7 – Pruned Regime Residual Values
Comparision for two mills

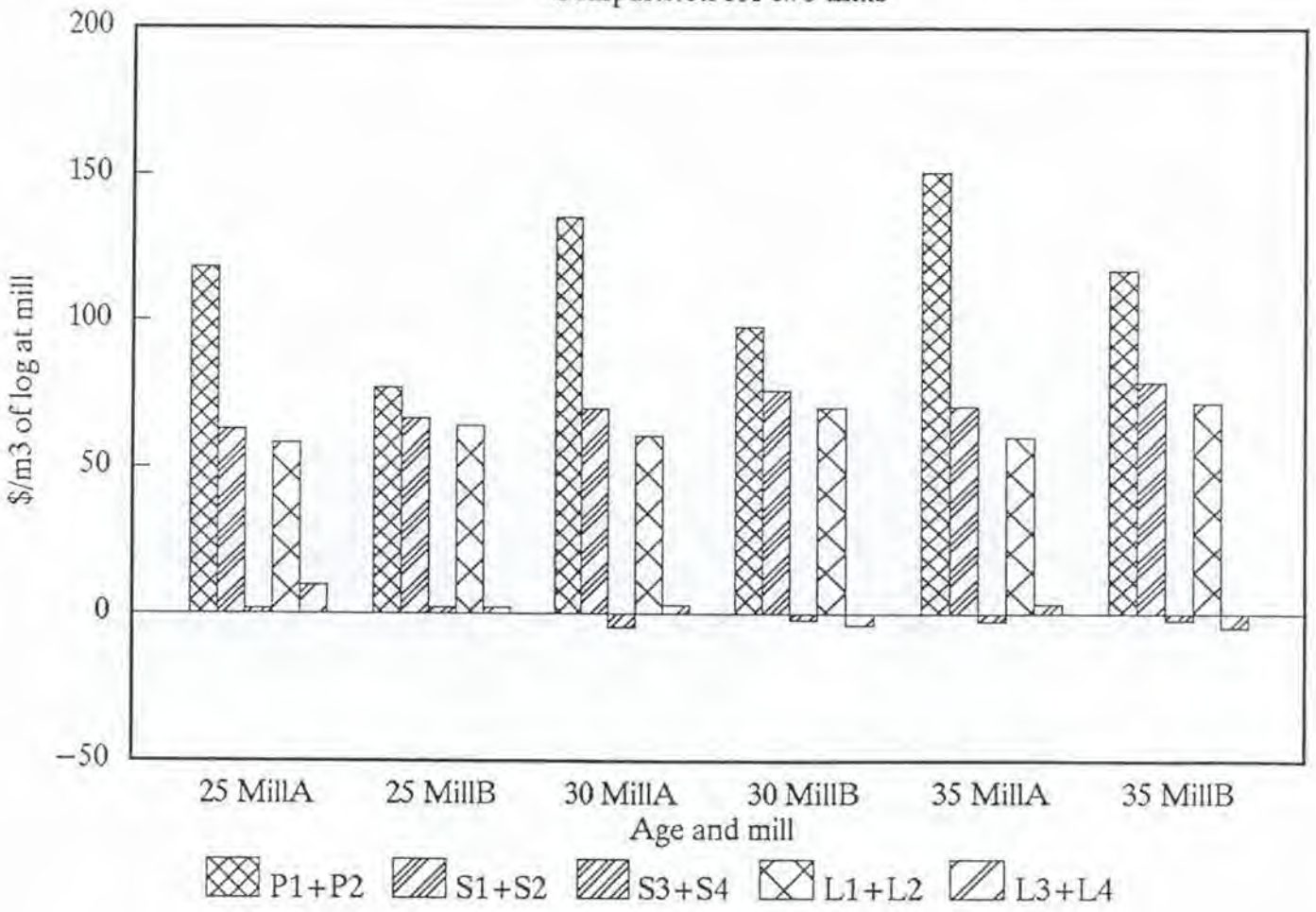
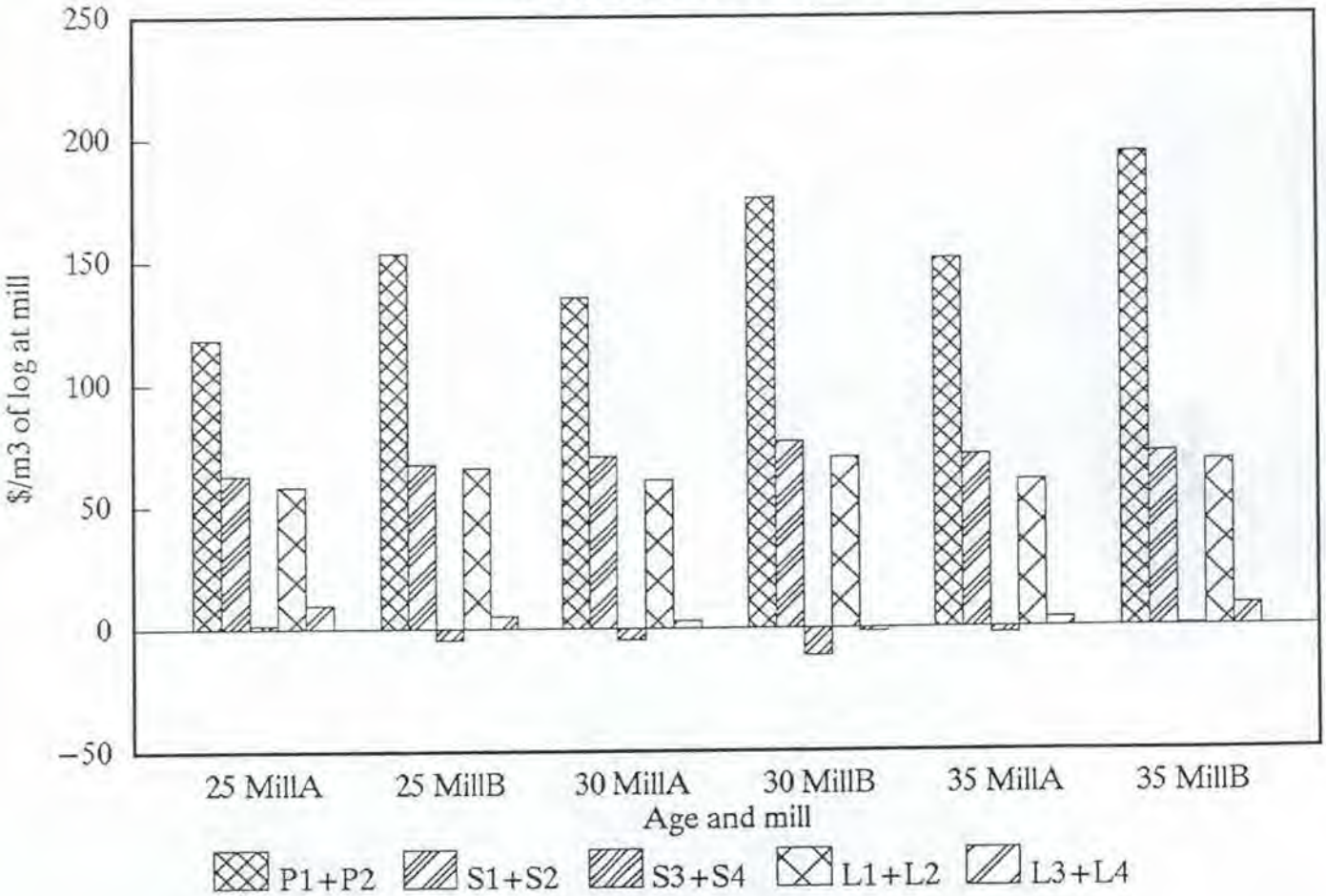


Figure 8 – Pruned Regime Residual Values
Comparision for two price lists



GROWTH RATE EFFECTS ON SOME JUVENILE WOOD PROPERTIES OF *PINUS CARIBAEA* VAR. *HONDURENSIS* STEMS SUBJECT TO HEAVY THINNING

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ABSTRACT

Comparisons were made between juvenile wood properties in a conventionally managed stand, maintained at a stocking of 900 stems/ha until age 11 years, and those in a trial which was heavily thinned to 500 stems/ha at age 5 years and maintained at 440 stems/ha over the comparison period. This latter trial material approximated the Queensland Forest Service's 'free growth' silvicultural prescription adopted in 1986 for Caribbean pine grown in north Queensland. Other trial material thinned to 240 stems/ha, 120 stems/ha and 60 stems/ha was also examined.

Mean basic density of the six growth rings (6 to 11) formed after the heavy thinning treatment, as well as mean whole core basic density were not significantly different in comparisons of the conventionally managed and 'free growth' sets of material.

Spiral grain and compression wood were higher in the growth rings formed after heavy thinning and tracheid length was slightly lower. However, these variations are probably not large enough to significantly affect timber utilisation.

Resin content was unaffected by growth rate, based on observations on the trial material thinned to 440 stems/ha, 240 stems/ha, 120 stems/ha and 60 stems/ha. However, a significant increase in resin content of the first two growth rings of the 60 stems/ha treatment could be due to earlier initiation of heartwood or an increased incidence of resin steaking in these widely spaced stems.

INTRODUCTION

The effect of growth rate on wood properties in many species has been widely reviewed in the literature in recent years. In the United States discussion has centred on the changes in wood properties encountered in timber harvested from old-growth, naturally-regenerated forests compared to that harvested from faster grown commercial forest plantations [1,2,3,4,5,6,7].

In Queensland, as in many other parts of Australia [8] and New Zealand [9,10,11], concerns have focussed on the development of silvicultural regimes designed to maintain plantation final crop trees in relatively free growth through their full rotation. Such silvicultural prescriptions, based on wide initial spacing and early thinning in advance of inter-tree competition, result in significantly faster average growth rates in the final crop trees. The concern of both foresters and wood technologists is that these significantly different growing conditions might adversely affect the wood quality of the trees.

The Queensland Forest Service adopted wide initial espacement planting regimes for *Pinus caribaea* Morelet var. *hondurensis* Barr. and Golf. in 1986 (details in Appendix 1) [12]. In north Queensland, Caribbean pine is now planted at 5.0 m wide inter-row spacings resulting in an initial stocking level of 665—740 stems/ha, which is reduced in a non-commercial thinning to 500 stems/ha at about age 3 years. This early thinning is designed to maintain the trees in 'free growth'; i.e. to delay the onset of inter-tree competition. A single commercial thinning at about age 16 years reduces the residual stocking from 500 stems/ha to the final crop stocking of 300 stems/ha. These final crop trees are then grown to a rotation age of 30 years before harvest. This regime is a significant departure from the previous convention which involved 3 m x 3 m initial spacing and several commercial thinnings before a final crop stocking level was achieved.

This paper reports the results of a study which examined wood properties in a 12-year-old trial of Caribbean pine grown in north Queensland. The trial included some plots which approximated the free growth silvicultural regime conditions as they were thinned to 500 stems/ha at age 5.5 years and 440 stems/ha at age 6.25 years. A range of its wood properties are compared to those of an adjacent stand which received more conventional silvicultural management, being maintained at 900 stems/ha until age nine years. Basic density, latewood percentage, compression wood percentage, resin content, spiral grain angle and tracheid length were assessed. Additionally, basic density, latewood percentage and resin content were measured in stands within the same trial, but which were thinned to the more extreme stocking levels of 240 stems/ha, 120 stems/ha and 60 stems/ha.

The objectives of the study were (i) to allow conclusions to be drawn as to the predicted effect of free growth silvicultural regimes on juvenile wood quality of stands grown under these regimes compared to those managed under the previous conventional regimes, (ii) to examine the effect of extreme thinning regimes on juvenile wood to determine if the resulting increases in growth rates were correlated to consequent changes in wood quality, and (iii) to assess fibre length and spiral grain angle variation in these stems to evaluate their potential to define the juvenile—mature wood boundary for them.

MATERIAL AND METHODS

The main material used for this study came from a cone production trial [13] planted at Cardwell (18°11'S) in north Queensland. This trial contains one treatment which approximates the free growth silvicultural regime (referred to hereafter as the 'free growth treatments'). An adjacent stand managed under the previous conventional regime (referred to hereafter as the 'conventionally managed stand') was used as a control for comparison with the free growth treatment. Stand histories for both this fast grown material and the conventionally managed stand are summarised in Table 1.

TABLE 1: STAND HISTORIES FOR ALL MATERIAL USED IN THIS STUDY

Event	STUDY MATERIAL					
	CONVENTIONALLY MANAGED STAND			FAST GROWTH TREATMENTS		
	Date	Age (years)	Residual Stocking (stems/ha)	Date	Age (years)	Residual Stocking (stems/ha)
Planted*	March 1973	-	1500	March 1974	-	1330
Thinnings						
- T1	May 1976	3.17	900	May 1977	3.17	1000
- T2	May 1984	11.25	600	Sept. 1979	5.5	500
- T3				June 1980†	6.25	440
						240
						120
						60
Wood sampled	November 1986	13.67	48 stems sampled	November 1986	12.67	No. of stems sampled
						440 ... 48
						240 ... 41
						120 ... 24
						60 ... 24

* Conventional stand planted at 3.0 m x 2.1 m spacing, fast growth experiment at 3.0 m x 2.4 m

† Cone production trial established by thinning to the four residual stocking levels indicated using a randomised complete block design with four replications.

Both the cone production trial and the conventionally managed stand were planted with seedlings raised from routine seed batches. Therefore they are of comparable genetic background.

As the boundary between juvenile and mature wood is regarded as occurring between 7 and 10 growth rings from the pith in most southern pines [3], the mean wood properties of the trees sampled are regarded as representative of juvenile wood values even though it is recognised that the outer 2 to 3 rings are probably transitional mature wood. The sampling height resulted in most samples containing 11 growth rings.

Field Sampling

All trees were chosen at random and sampled using increment borers. Cores were taken from the mid-whorl immediately below breast height, between 1.0 m and 1.2 m above ground level. Each sample was obtained as a single core, bored bark-to-bark through the pith and removed at right angles

to any lean or sweep in the tree. Twelve millimetre diameter increment cores were sampled from the routine stand and the 440 stems/ha plots. Five millimetre diameter increment cores were also obtained from the latter stands as well as from all other plots in the trial.

Laboratory Methods

All cores were subdivided at the boundary of the last formed latewood of the growth ring corresponding to the end of the growth season in which the trial was thinned. They cores were subdivided into four segments in the cone production trial stems and three segments in the conventionally managed stems as indicated in Table 2.

TABLE 2: NUMBER OF SEGMENTS INTO WHICH SAMPLES WERE SUB-DIVIDED AND THE NUMBER OF GROWTH RINGS CONTAINED IN EACH OF THESE SEGMENTS

Segment Number	FREE GROWTH REGIME		CONVENTIONAL REGIME	
	Age at thinning (or wood sampling)	Growth rings contained in segment	Age at thinning (or wood sampling)	Growth rings contained in segment
1	3 yrs 2 mths	0-2	3 yrs 2 mths	0-2
2	5 yrs 6 mths	3-4	11 yrs 2 mths	3-10
3	6 yrs 3 mths	5	13 yrs 8 mths	11-12
4	12 yrs 8 mths	6-11		
Total nominal ring count		11		12

Core segments were

- weighed green to determine unextracted volume
- freeze-dried to a pressure of 10^{-2} torr and a temperature of -50°C until stable weight was achieved
- weighed to determine pre-extraction freeze-dry weight
- extracted for 6 hours in a soxhlet apparatus using methanol as a solvent, followed by an 8 hour extraction using hot water
- oven-dried at 102°C for 16 hours until stable weight was achieved
- weighed to determine extracted oven-dry weight

Extracted basic density for each segment was measured as the ratio of extracted oven-dry weight to maximum unextracted saturated volume using the principles of Heinrichs and Lassen (14).

Latewood percentage was estimated by lineal measurement of latewood using a 10x eyepiece graticule. It was calculated as a proportion of diametral distance without volumetric weighting.

Prior to subdivision into segments, each 12 mm increment core was planed transversely to flat, approximately parallel, upper and lower surfaces. Final machined thickness was about seven millimetres.

To assess compression wood, a sector originating at the pith was drawn on the planed surface of each core from pith to cambium along each radius. The core was then placed on a light box, illuminated from below and the proportion of the sector affected by compression wood obtained by dot grid count. Results from the two radii were averaged to provide a mean compression wood percentage for each segment.

Grain angles were measured at the last formed latewood of each growth ring using the procedure described and illustrated by Hart and Harding [15] which is based on the method reported by Harris [16]. Grain angles in Caribbean pine frequently change direction from left to right handed angles, both within and between trees[17,18]. However, for the purposes of this study, the absolute reading of each grain angle was computed.

Mean tracheid length was measured as the mean of 50 tracheids. These tracheids were obtained from a macerated solution of the last-formed latewood of each growth ring with material from both radii combined. They were measured on a digitized measurement tablet mounted over a projection microscope as illustrated by Hart and Harding [15].

Resin content was estimated as follows:

$$\text{Resin \%} = \left(\frac{\text{Freeze-dried unextracted weight} - \text{Oven-dried extracted weight}}{\text{Oven-dried extracted weight}}\right) \times 100$$

RESULTS AND DISCUSSION

Basic Density and Latewood Percentage

Comparisons of basic density and latewood percentage results for the critical segment in the free growth treatment (i.e. following thinning to 500 stems/ha at age 5) versus the conventionally managed stand are presented in Table 3.

TABLE 3: MEAN BASIC DENSITY AND LATEWOOD PERCENTAGE COMPARISONS BETWEEN A CONVENTIONALLY MANAGED STAND (900 STEMS/HA) AND AN APPROXIMATE FREE GROWTH STAND (440 STEMS/HA)

Wood Property	Conventional Stand	Free Growth Stand	5% L.S.D. †
Mean basic density (kg/m^3)			
- growth rings 5-11 (F-G), 3-10 (C)	501	537	21.0 *
- whole core	448	459	17.5 N.S.
Latewood percentage			
- growth rings 5-11 (F-G), 3-10 (C)	31.5	33.3	3.7 N.S.
- whole core	21.6	19.7	2.2 N.S.

† 5% L.S.D. = Least square difference at P=0.05, * = Significantly different at P=0.05, N.S. = Not significantly different (at P=0.05)

Although these results are not directly comparable due to segmentation differences (growth rings 3-10 in the conventional stand versus 5-11 in the free growth treatment), they provide a comparison of practical value. They reveal small but non-significant differences in latewood percentages and whole core basic density. Although the basic density difference in this key segment comparison is statistically significant (at P=0.05), the mean value for the conventional stand is the lower one and it is likely to have been negatively biased due to the inclusion of growth rings three and four (wide, low density growth rings) in the segment.

The results suggest that faster growth rate in the period since heavy thinning in the free growth treatment has resulted in slightly higher mean density than the conventionally managed stand. This is also reflected in slightly higher latewood percentage, which is quite feasible as heavy summer rainfall during the period when latewood is formed is the normal rainfall pattern in north Queensland. If inter-tree competition significantly affects the amount of latewood formed in a season (which could realistically be hypothesised), removal of this competition, in combination with favourable rainfall, could result in increased latewood production and an increase in mean basic density.

Regression analysis was undertaken to examine the relationship between basic density, age and growth rate in these stems. As would be expected with the wide range of stocking levels in this trial, growth rate varied substantially. Mean diameters at breast height over bark of 26.4 cm, 29.3 cm, 33.0 cm and 35.8 cm for the stocking levels 440, 240, 120 and 60 stems/ha respectively. Both segment diameter increment (DI) in millimetres and segment age of the final growth ring in the segment (A) produced very highly significant (P=0.001) and positive regressions with mean segment basic density for combined data from all stocking levels. Nevertheless, neither relationship was strongly linear,

although age (r^2 = 0.39) accounted for over twice as much variation in basic density as diameter increment (r^2 = 0.16). These two relationships were:

(i) Mean segment basic density (kg/m^3) = 370.533 + 0.297 DI r^2 = 0.16

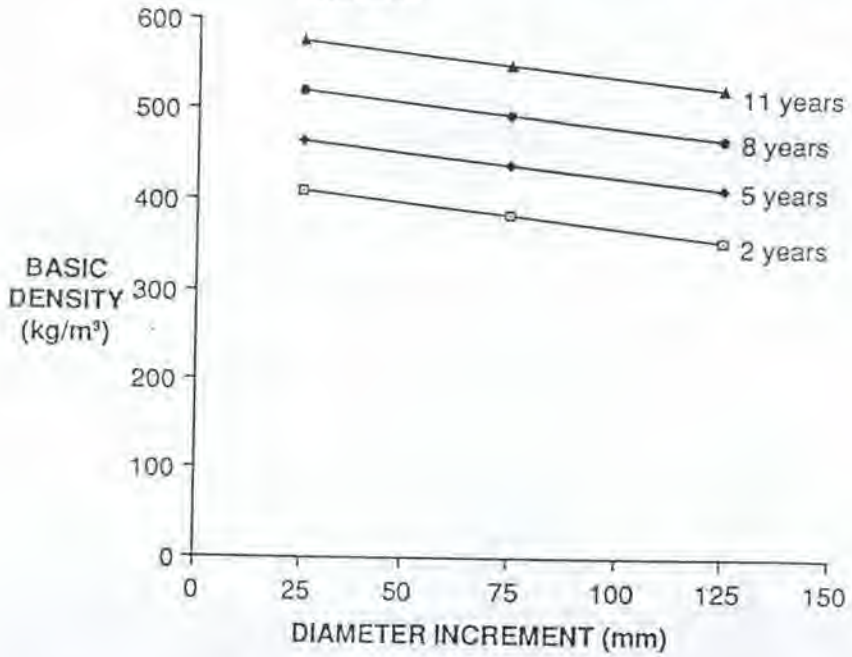
(ii) Mean segment basic density (kg/m^3) = 360.704 + 9.083 A r^2 = 0.39

When considered together in a multiple regression, the relationship (also significant, P = 0.001) between these three variables was:

Mean segment basic density = 387.111 - 0.549 DI + 18.478 A r^2 = 0.51

Thus, this two-variable regression was more strongly linear (51% of variation in basic density accounted for) than either of the variables alone, and predicts that juvenile wood basic density will tend to decrease with increasing growth rate (as measured by diameter increment) for any given age to 11 years. This point is illustrated in Figure 1.

FIGURE 1: VARIATION IN THE RELATIONSHIP OF MEAN JUVENILE WOOD BASIC DENSITY WITH GROWTH RATE (DIAMETER INCREMENT) AND AGE.



This relationship may at first seem to be at odds with the results in Table 3, which indicated an increase in mean density with faster growth. However, herein lies a classical confusion in interpreting the impact of rate of growth on mean basic density. Although mean density decreases with growth rate for a given segment of growth rings, the contribution of the mean density of any large segment to mean tree or whole core density obviously must increase with its expanding size. Consequently, if a

tree can be grown faster than the norm as it ages, the contribution to mean density of this larger volume of wood with slightly lower density (in the outer juvenile wood) can maintain and even increase mean juvenile wood density over that of a slower grown tree with a smaller band of slightly higher density outer wood. In terms of mean cross sectional density, a balance between optimised growth rate (i.e. volume production) and maintenance of mean density can be achieved.

This balance is best exemplified by comparing the results of two stems from the trial as presented in Table 4.

TABLE 4: COMPARISON OF TWO STEMS OF SIMILAR EARLY GROWTH AND DENSITY BUT MARKEDLY DIFFERENT GROWTH RATES IN THE OUTER JUVENILE WOOD

Growth rings contained in segment		SEGMENT DIAMETER (mm)		MEAN SEGMENT BASIC DENSITY (kg/m^3)	
		Tree 1 *	Tree 2 *	Tree 1	Tree 2
Segment 1	0-2	93.0	93.0	351	360
Segment 2	3-5	43.0	67.5	453	407
Segment 3	6-11	56.5	155.0	505	489
Whole core	0-11	192.5	315.5	420	432

* Tree 1 is from a 440 stems/ha plot and tree 2 from a 60 stems/ha plot

The similar growth and density in the first two growth rings of these two trees suggests that they are of comparable genotypic background. Also, the mean density of segments one and two combined (i.e. growth rings 0 to 5) was 383 kg/m^3 for tree 1 and 380 kg/m^3 for tree 2, further supporting this assumption about genetic background for basic density. Therefore, although tree 2 was larger (1.18 times the under bark diameter of tree 1) by the end of growth ring 5 which suggests some difference in growing conditions, one can assume that differences in density in the final segment (growth rings 6-11) reflect the effect of the thinning treatment which produced 2.74 times more diameter increment in tree 2 (60 stems/ha treatment) than in tree 1 (440 stems/ha treatment).

As can be seen in Table 4, the superior growth rate of tree 2 over segments two and three is reflected in lower basic densities. This would be predicted from the regression equations plotted in Figure 1. However, the mean whole core density (weighted by diameter increment) is higher for tree 2 reflecting the balance between increment and corresponding density, between the various segments which make up a complete cross section.

Whitmore and Leigel [19] also provide supporting evidence for this argument of 'wood quality balance' from a Caribbean pine spacing trial which was planted at four spacings and replicated at four sites, in Puerto Rico. When sampled at age 11.5 years to 13.6 years, the trend was for increasing density with increasing spacing. In fact, at three of the four sites, the closest spaced treatments (5 feet

square spacing) recorded the lowest density in the replication and the highest spaced treatment (14 feet square) recorded the highest density.

Other regressions of interest between mean basic density for growth rings 6 to 11, BD(6-11), for each treatment and diameter increment (DI) in millimetres are presented in Table 5.

TABLE 5: LINEAR REGRESSION RELATIONSHIPS BETWEEN MEAN BASIC DENSITY OF GROWTH RINGS 6 TO 11 FOR FOUR STOCKING LEVELS AND DIAMETER INCREMENT

Stocking Level	No. of Stems Sampled	REGRESSION EQUATION	r^2 and Degree of Significance†
440 stems/ha	96	BD (6-11) = 599.057 - 0.763 DI	0.05 **
240 stems/ha	41	BD (6-11) = 674.207 - 1.481 DI	0.35 ***
120 stems/ha	24	BD (6-11) = 688.527 - 1.273 DI	0.26 **
60 stems/ha	23	BD (6-11) = 720.755 - 1.545 DI	0.60 ***

† r^2 = correlation coefficient, ** = significant at P=0.05, *** = significant at P=0.001

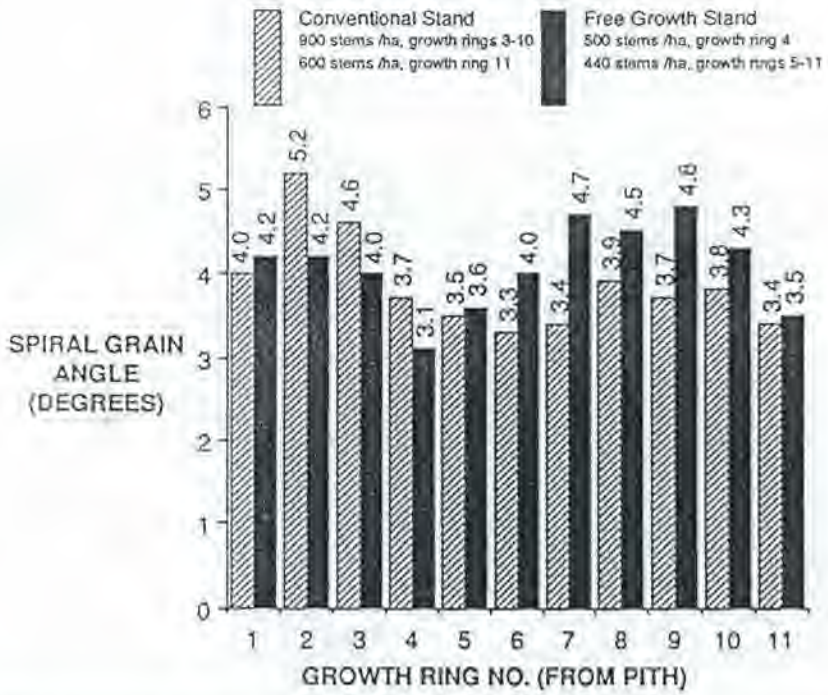
These regressions suggest that the strength of the linear relationship between growth rate and density increases with lower stocking levels. It is worth noting however that even at the maximum growth rate for growth rings 6 to 11 achieved by a tree in this trial, which was 197 mm in the 60 stems/ha treatment, the mean basic density of 370 kg/m^3 for this segment is still acceptable for structural applications of Caribbean pine. Australian Standard 2858-1986 (20) specifies a minimum basic density of 340 kg/m^3 for Caribbean pine used for structural purposes.

In summation, there is little in this trial to suggest that improved growth rate achieved by the application of a free growth silvicultural prescription has adversely affected the basic density of the juvenile wood zone in comparison to the juvenile wood of a more conventionally managed stand. Certainly there is evidence of a decrease in density with growth rate. However, the balance achieved between higher volumes of outer juvenile wood and total cross-sectional volume has resulted in a negligible change to mean basic density at breast height.

Spiral grain

Comparisons of the absolute values of the spiral grain angles of the first eleven growth rings in the conventionally managed stand and the plots approximating the free growth silvicultural prescription are illustrated in Figure 2.

FIGURE 2: MEAN SPIRAL GRAIN COMPARISONS IN THE FIRST ELEVEN GROWTH RINGS OF 48 TREES FROM A CONVENTIONALLY GROWN STAND AND FROM A STAND HEAVILY THINNED AT AGE FIVE TO MAINTAIN FREE GROWTH.



These results suggest that the faster growth rate of the free growth treatment from growth rings 6 to 11 is positively correlated to higher spiral grain angles in these growth rings. However, the only growth ring producing a statistically significant (P=0.05) result amongst these 6 rings was growth ring 7 where the difference between mean spiral grain angle in the two stands was 1.3 degrees. The segment means for growth rings 6 to 10 were 3.6 degrees and 4.4 degrees for conventional and free growth stands respectively and 3.8 degrees and 4.1 degrees respectively for the mean of all values (growth rings 1 to 11) — neither pair of means is significantly different (P=0.05).

Therefore the faster growth of the free growth treatment appears to be adversely associated with a small increase in spiral grain angle in the outer juvenile wood in those growth rings formed after the heavy thinning treatment.

In terms of identifying a juvenile—mature wood boundary for spiral grain in Caribbean pine, these results are not particularly helpful. Analysis of the results using sign to indicate left-handed and right-handed spiral rather than absolute values may be more useful in this regard. However, Caribbean pine spiral grain can show remarkable variation with alternating growth rings or groups of growth rings displaying spiral in one direction and then changing to the other[17,18] as well as very large

magnitudinal changes in grain angle in adjacent growth rings (14 degrees in adjacent rings in one tree)[17]. Also, Cown *et al.*[17] found many examples of Caribbean pine trees in Fiji which recorded quite low values in the first 8 to 10 growth rings only to display larger angles in growth rings 11 to 18, particularly at breast height. Nevertheless, Harding *et al.* [18] found mean spiral grain in a progeny trial planted on two sites was at a maximum at growth ring 3 and progressively decreased to growth ring 9 (for absolute values, as well as in analysis using sign to denote spirality direction). Therefore, it would seem that a juvenile core of high spiral grain angles is contained in the first 3 or 4 growth rings from the pith of Caribbean pine stems but that other factors, including fast growth rate, may be associated with relatively high spiral grain angles in growth rings as far as 18 growth rings away from the pith.

Compression wood percentage

Mean compression wood of the conventionally managed stand (4%) was significantly different (P = 0.05) from mean compression wood of the stems sampled in the free growth plots (6.6%). This is a somewhat surprising result given the higher residual stocking level in the conventional stand, which had 600 stems/ha when sampled, compared to 440 stems/ha in the free growth plots. One would expect that mean stem form and therefore compression wood incidence would be better in the more heavily thinned material. This result may suggest that greater exposure to wind at an earlier age in the free growth stand, perhaps in combination with faster growth rate, may be associated with higher compression wood incidence.

Nevertheless, at a practical level, differences in product performance during processing and utilisation due to this relatively small difference in mean compression wood incidence (whether statistically significant or not) are unlikely to be large.

Resin content

Comparisons of resin content yield as a percentage of extracted oven-dried wood weight are presented in Table 6.

TABLE 6: VARIATION IN PERCENTAGE RESIN CONTENT OF 12-YEAR-OLD CARIBBEAN PINE WITH VARIATION IN STOCKING LEVEL AND DISTANCE FROM PITH

STOCKING LEVEL (stems/ha)	SEGMENT NUMBER	GROWTH RINGS CONTAINED IN SEGMENT	RESIN CONTENT (%)
440	1	0-2	12.7
240	1	0-2	17.0
120	1	0-2	16.6
60	1	0-2	24.0
440	2	3-5	3.8
240	2	3-5	4.1
120	2	3-5	3.5
60	2	3-5	4.0
440	3	6-11	2.3
240	3	6-11	2.9
120	3	6-11	2.6
60	3	6-11	2.9

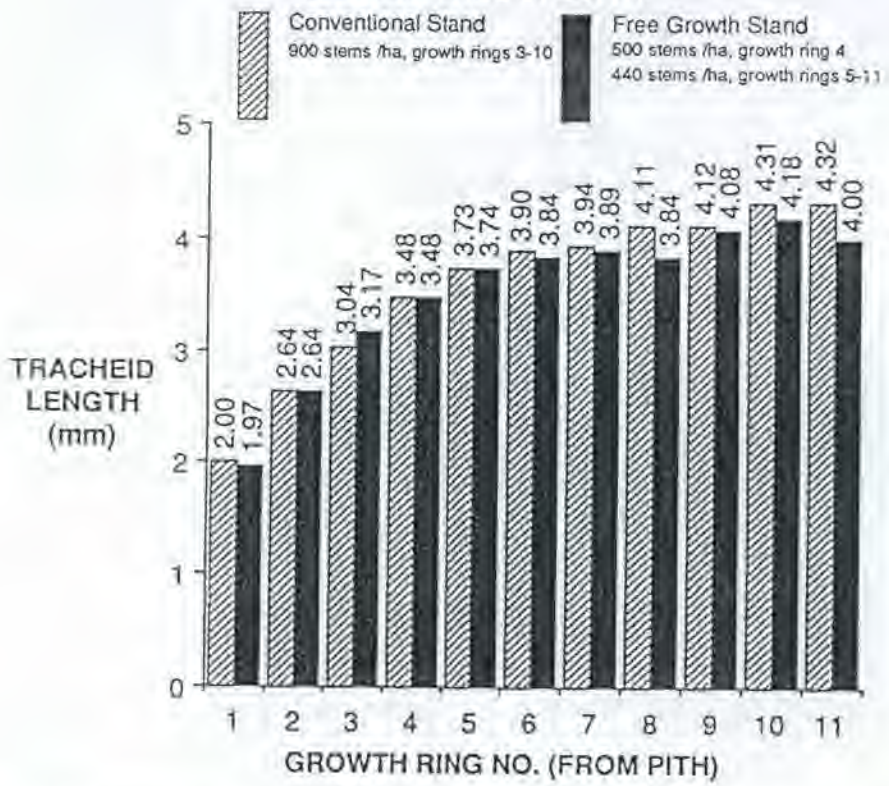
Table 6 reveals a distinct trend towards higher resin content in the inner growth rings of this 12-year-old Caribbean pine trial. The outer sapwood values of between 2.3% and 2.9% are in general agreement with Cown's [14] findings in Fijian-grown Caribbean pine. The higher resin content of growth rings one and two may be due to initiation of true heartwood or reflect the presence of resin streaks. Records of the presence of heatwood or resin streaks are unavailable. The result from the extreme treatment of 60 stems/ha stocking suggests that resin could be a potentially serious problem if stands were thinned to such low stockings early in their rotation. Therefore forest managers would be well advised to maintain their practice of clearfelling Caribbean pine stands which have been severely affected by windstorms, cyclones or other catastrophes, so that selective salvage operations do not result in such low residual stocking levels.

Regression analysis relating resin content to diameter increment generally produced non-significant equations with very low correlation coeficients. Exceptions were the 240 stems/ha plots/segment 2 ($P=0.001$, $r^2=0.26$), 120 stems/ha plots/segment 2 ($P=0.001$, $r^2=0.39$), 120 stems/ha plots/segment 3 ($P=0.001$, $r^2=0.49$) and 60 stems/ha plots/segment 3 ($P=0.01$, $r^2=0.32$). However, the inconsistent trend of these results between stocking levels and segments calls into question their reliability and utility for more general application.

Tracheid length

Mean tracheid length comparisons for the first eleven growth rings of the conventional stand and the free growth treatment are illustrated in Figure 3.

FIGURE 3: MEAN TRACHEID LENGTH COMPARISONS IN THE FIRST ELEVEN GROWTH RINGS OF 48 TREES FROM A CONVENTIONALLY GROWN STAND AND FROM A STAND HEAVILY THINNED AT AGE FIVE TO MAINTAIN FREE GROWTH.



It is clear that there is very little difference in mean ring tracheid length between the treatments. Nevertheless, the free growth treatment has produced shorter tracheids in growth rings 6 to 11, the growth rings laid down after the trial was heavily thinned. This decrease in mean fibre tracheid length in growth rings immediately following a heavy thinning is a commonly reported response to the faster growth rate induced by the thinning [3,5]. The only statistically significantly different (at P=0.05) results were for growth rings 8 and 11. The tracheid length means of growth rings 6 to 10 were 4.08 mm and 3.96 mm, and the means of growth rings 1 to 11 were 3.64 mm and 3.53 mm respectively for conventional versus free growth material (not significantly different at P=0.05 in both cases).

If we consider the juvenile—mature wood boundary for tracheid length from a purely practical viewpoint, it could be set at either growth rings 5 or 8 depending on whether 3.75 mm or 4.00 mm is regarded as a mature tracheid length. Certainly the rate of change in mean tracheid length with age diminishes rapidly from growth ring 5 onwards from the pith. If more mature wood data was available, the age of transition from juvenile to mature wood might be estimated at closer to 10 years. Loo *et al.* [21] determined that this age was 10.3 years in a study of 25-year-old Loblolly pine.

CONCLUSION

This study has provided a rare opportunity to assess the effects of a broad range of residual stocking levels on some of the juvenile wood properties of Caribbean pine.

The results suggest that differences between the juvenile wood quality of conventionally managed stands and those widely spaced (i.e. thinned early to 500 stems/ha residual stocking to maintain free growth conditions), are generally small and of little practical significance.

Mean basic density of the juvenile wood may even be increased by faster growth rate despite a clear negative correlation between basic density and growth rate. A balance between increased stem volume production and mean basic density can be achieved. Be this as it may, age is a greater determinant of basic density within the juvenile wood zone than growth rate.

Spiral grain angles seems to increase and tracheid length decreases with faster growth rate. No clear juvenile—mature wood growth ring boundary could be discerned for spiral grain in this study, but the rate of increase in tracheid length with age diminishes markedly from growth ring 5 onwards.

Compression wood incidence was higher in the more heavily thinned stand in this study and resin content was largely unaffected by treatment in the trial. Mean resin results suggest that heartwood or resin streaks were present in the central growth rings of the stems assessed for this study. Mean sapwood resin content was less than 3% in the outer sapwood but rose to about 4% in growth rings close to the pith and bordering the heartwood zone. Either a higher incidence of resin streaking, heartwood content or heartwood resin content seems to have resulted in significantly higher resin content in the inner two growth rings of the 60 stems/ha treatment.

Growth rate effects on juvenile wood properties of Caribbean pine stems subject to heavy thinning should be of little concern to forest managers and forest products processors unless increased volume production is used to justify decreasing rotation age. Juvenile wood is lower in quality than mature wood for most forest products processors and the proportion of juvenile wood in a tree stem decreases significantly with tree age.

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REFERENCES

1. North Carolina State University, College of Forest Resources 1984. Proceedings of the Symposium on "Utilization of the changing wood resource in the Southern United States" Raleigh N.C., June 12-14, 1984. 295 pp.

2. White, J.L. (Ed.) 1987. Conference proceedings, "Managing and marketing the changing timber resource", held in Fort Worth Texas, March 18-20, 1986. 122 pp.
3. Zobel, B.J. and van Buijtenen, J.P. 1989. Wood Variation - Its Causes and Control. Springer-Verlag, Berlin. 363 pp.
4. Zobel, B.J. and Talbert, J. 1984. Applied Forest Tree Improvement. John Wiley and Sons, New York. 505 pp.
5. Megraw, R.A. 1985. Wood Quality Factors in Loblolly Pine. Tappi Press, Tech. Park, Atlanta. 88 pp.
6. Zobel, B.J. 1981. Wood quality from fast grown plantations. Tappi 64(1): 71-74.
7. MacPeak, M.D., Burkart, L.F. and Weldon, D. 1990. Comparison of grade, yield, and mechanical properties of lumber produced from young fast-grown and older slow-grown planted slash pine. For. Prod. J. 40(1): 11-14.
8. Siemon, G.R., White, K.J. and Thomson, A.B. 1989. Sawmilling trial of agroforestry and conventionally-grown radiata pine. Report No. 8, Wood Utilisation Research Centre, W.A. Dept. of Cons. and Land Mgmt. 16 pp.
9. Sutton, W.R.J. 1984. New Zealand experience with radiata pine. H.R. MacMillan Lectureship in Forestry, University of British Columbia, February 23, 1984. 23 pp.
10. Harris, J. Maddern. 1981. Wood quality of radiata pine. Appita 35(3): 211-215.
11. Kininmonth, J.A. 1986. Wood from fast-grown, short-rotation trees. In proceedings of 18th IUFRO World Congress, Division 5 — Forest products, p. 425-435.
12. Hawkins, P.J. and Muir, J.D. 1987. Aspects of management of plantations in tropical and sub-tropical Queensland. Paper to Ninth Comm. For. Conf. 1968. Revised 1987 - G.M. Shea (Ed.) 71 pp.
13. Queensland Department of Forestry. 1985. Relationship between tree spacing and seed production in Honduras Caribbean pine. Research Results sheet No. 2, 1985 series, 1 pp.
14. Heinrichs, J.F. and Lassen, L.E. 1970. Improved techniques for determining the volume of irregularly shaped blocks. Forest Prod. J. 20: 24.
15. Hart, G.A. and Harding, K.J. 1989. Micro-computer assisted measurement of wood properties. Paper presented to IAWA/IUFRO 2nd Pacific Regional Wood Anatomy Conf., Los Banos, Philippines, October 15-20 1989, 10 pp.
16. Harris, J.M. 1984. Non-destructive assessment of spiral grain in standing trees. N.Z.J. For. Sci. 14: 395-399.
17. Cown, D.J., McConchie, D.L. and Young, G.D. 1981. Wood properties of *Pinus caribaea* var. *hondurensis* grown in Fiji. New Zealand Forest Service, Forest Research Institute, Wood Quality Report No. 39 (unpublished). 73pp.
18. Harding, K.J., Kanowski, P.J. and Woolaston, R.R. Preliminary genetic parameter estimates for some wood quality traits of *Pinus caribaea* var. *hondurensis* in Queensland, Australia. Silvae Genetica (In press, 1990).

19. Whitmore, J.L. and Liegel, L.H. 1980. Spacing trial of *Pinus caribaea* var. *hondurensis*. USDA For. Serv. Research Paper S0-162, Southern Forest Expt. Station, New Orleans, LA. 8 p.

20. Standards Association of Australia. 1986. Timber—Softwood—Visually Stress-Graded for Structural Purposes. Australian Standard 2858-1986.

21. Loo, J.A., Tauer, C.G. and McNew, R.W. 1985. Genetic variation in the time of transition from juvenile to mature wood in Loblolly pine (*Pinus taeda* L.). Silvae Genetica 34(1): 14-19.

APPENDIX 1

QUEENSLAND FOREST SERVICE SILVICULTURAL MANAGEMENT REGIMES FOR CARIBBEAN PINE*

INITIAL PLANTING ESPACEMENT

Zone† and planting stock type	Spacing (m) Between rows	Spacing (m) Along rows	Nominal stems per ha	To establish potentially merchantable stems per ha
Integrated zone				
— open root	4.5	2.1	1060	750
— tubed	4.5	2.4	925	750
Sawlog zone				
— open root	5.0	2.7	740	500
— tubed	5.0	3.0	665	500

STOCKING LEVELS AT THINNING STAGES

Stocking before thinning	Residual stocking after thinning stage T1	T2	T3
>1000	750	500	300
700-1000	500	300	
<700	300		

AGE OF THINNING† — FOR PRE-COMMERCIALLY THINNED STANDS

Integrated Zone			Sawlog Zone		
Age (years)	Stocking (stems/ha) Initial	Residual	Age (years)	Stocking (stems/ha) Initial	Residual
17	750	500	16	500	300
23	500	300	30	300	—
30	300	—			

* These regimes were implemented for routine practice in 1986.

† Zone: Integrated zone = south-east Queensland, T1 thinnings marketed as pulpwood
sawlog zone = north Queensland (Rockhampton north).

‡ Note: Rotation age = 30 years, Final crop (stems/ha) = 300.

VARIATION IN WOOD DENSITY OF *PINUS RADIATA* IN NSW

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ABSTRACT

Basic density was assessed in stems of mature *Pinus radiata* D. Don growing at 22 sites throughout NSW, and at an additional location in NSW in stems of 20-year-old trees grown on land formerly supporting pasture on the one hand and eucalypt forest on the other. Density, in all cases, was found to vary consistently and markedly within the stem, increasing in the centrifugal direction. Within-site variations between trees were generally about 20% while, across site, there was a significant tendency for density to be associated positively with rainfall in the summer months and negatively with growth factors (stem diameter, tree height, foliar phosphorus). There was no relationship with site temperature. Wood density was markedly higher in trees of the same diameter from sites which had previously grown eucalypts than in those from the pasture sites.

INTRODUCTION

Optimisation of land use is an essential part of plantation forest management. For this procedure to be effective, the probable limitations imposed by site itself must be available to managers. New Zealand investigations indicate that one of the properties which appears to be site determined is wood density. A marked association between *Pinus radiata* wood density and site temperature has been shown to exist[1][2], there being a 15-20% increase in density from the southernmost trees to the northernmost. These latter are growing at about the same latitude as those in southern NSW, and so most of the NSW plantations lie to the north of those in NZ. Climate and soils are also markedly different and so it would be unwise to extrapolate the NZ results to NSW.

The object of this paper is to examine the effect of different sites on the density of *P. radiata* wood derived from NSW plantations.

MATERIALS AND METHODS

Sites and Field Sampling

Principal Study

Twenty-two sites were selected in 1987, primarily in 1950-55 age classes in various State Forests, so as to cover the whole climatic and soil range in which plantations have been established in NSW[3]. They are located mainly either on the Great Dividing Range, or on its western slopes, from latitude 28° in the north to 37° in the south (Fig. 1) and mean annual rainfall across sites ranges from 860mm to 1835mm per annum. None of the sites were fertilised, even though a few were known to be phosphorus deficient. The soils are derived from sedimentary rocks (quartz sandstones, siltstones, metasediments of various types) on the one hand, and igneous rocks (rhyolite, granodiorite, basalt) on the other (Table 1). Specific site criteria required a slope of less than 5°, and a normal thinning history (two to four operations). Foliage samples were taken at each site in late winter-early spring and the nutrient levels determined[3]. These included nitrogen, phosphorus, aluminium, boron, calcium, iron, magnesium, manganese, potassium, sodium and zinc.

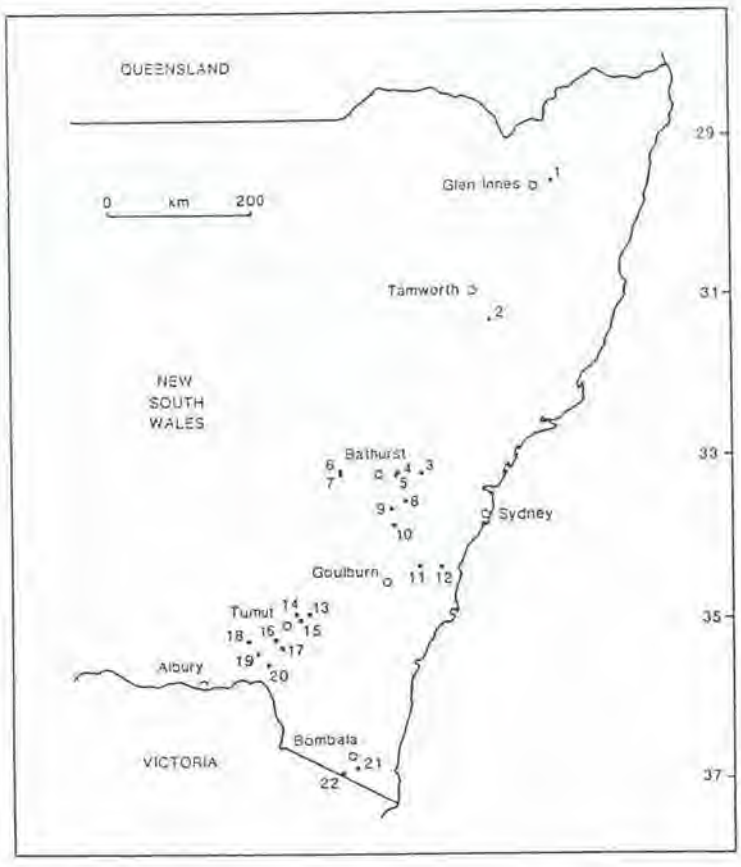

Figure 1. Location of the 22 sites in State Forests in eastern New South Wales where radiata pine wood samples were collected

Table 1. Site and stand characteristics

Site	Forest	Soil parent material	Stand age at felling (yr)	Tree diam. at 29 yr[a] (mm)	Tree ht. at 25 yr[b] (m)
1	Mount Mitchell	Acid volcanic	31	324	26.4
2	Nundle	Basalt	31	364	30.6
3	Newnes	Quartz sandstone	33	224	19.1
4	Sunny Corner	Siltstone	33	308	26.1
5	Sunny Corner	Rhyolite	33	311	26.4
6	Canobolas	Basalt	30	357	30.7
7	Canobolas	Trachyte	34	315	23.8
8	Jenolan	Siltstone	34	320	27.5
9	Vulcan	Granodiorite	31	346	26.6
10	Gurnang	Metasediments	34	306	24.1
11	Belanglo	Quartz sandstone	33	307	23.7
12	Gerrigaroo	Basalt over shale	31	386	28.3
13	Buccleuch	Metabasalt	49	357	29.2
14	Buccleuch	Granodiorite	37	305	26.5
15	Buccleuch	Basalt	33	377	28.3
16	Green Hills	Granodiorite	30	337	28.9
17	Bago	Granodiorite	30	358	28.7
18	Murraguldrie	Adamellite	50	314	22.2
19	Carabost	Metasediments	35	297	26.6
20	Mannus	Merasediments	30	291	25.8
21	Nalbaugh	Granodiorite	50	344	27.7
22	Bondi	Metasediments	49	270	27.4

[a] Mean breast height under bark diameter of final crop trees

[b] Mean height of final crop trees.

In each of the stands, 10 trees were selected at random, usually on a 200-m transect either up- or down-slope. These were felled and a diametrical section measuring about 40mm tangentially x 120mm axially was removed at each of four heights, approximately 0.4m above ground level (stump height) and three positions representing progressive decrements of eight rings from the stump. These were about 9, 18, and 26m above ground level. These samples were designated 1, 2, 3 and 4 in acropetal order. The three upper levels were taken midway between whorls. In addition, a sample was taken at 1.3m above ground level at breast height, so as to have some additional data at the level normally used in forestry for measurements.

Subsidiary Study

In addition to the 1950-55 age class sites, a subsidiary study was undertaken in the 1967 age class at Bago State Forest (Fig. 1), near Blowering Dam, that is in the southern section of the State and in a winter rainfall area. The object of this work was to compare

the properties of wood obtained from young forests which had been grown on land which had previously been under native forest with that which had been grown on land which had been previously under pasture. Two plots were established on sites which were adjacent to one another and which were indistinguishable in soil properties and aspect. Between 3 and 6 trees were selected in 20mm size class increments, commencing at 260mm up to the largest size class available, 420-440mm. A diametrical section was obtained from the butt of each log as in the main study.

All sections in both studies were oriented randomly unless they were obtained from an obviously eccentric stem, in which case the shortest axis was taken to minimise the incidence of compression wood. They were stored green in polyethylene for 2-7 days before laboratory analysis.

Laboratory Sampling

A strip 8x8mm was sawn from the centre of each diametrical section and split into four-ring segments. In this way seven blocks were obtained from the 28 rings for each of the radii at level 1 in the main study, five at level 2, three at level 3 and one at level 4. At breast height level, blocks were taken as for level 1, using the cambium as the reference point, the blocks adjacent to the pith containing, on the average, two rings.

In the subsidiary study, the same procedure was used, the single level samples from the trees normally yielding five four-ring blocks for each radius. Samples which did not yield five four-ring blocks were excluded from consideration because of the possibility that they came from trees which were refills and therefore younger than 20 years of age. The diameter of the tree under bark at the sampling point was obtained by measuring the diameter of the sampled section.

Blocks were extracted for 32 hours in two changes of boiling methanol and rinsed in a further change of this solvent at room temperature for 24 hours. Extracted basic density was determined using the maximum moisture content procedure[4] after the samples had been saturated by retention in boiling water for 24h and subsequently weighed oven dry. These extraction procedures typically removed about 2% of soluble material from the sapwood and 5% from the heartwood samples.

Analysis of Data

The mean value for opposite radii in each tree was calculated. The sixteen positions representing the various levels in the main study were allotted to three zones: inner wood (rings 1-8, positions 1, 2, 8, 9, 13, 14, 16), intermediate wood (rings 9-16, positions 3, 4, 10, 11, 15), and outer wood (rings 17-28, positions 5, 6, 7, 12) (Fig.2). Values found for inner, intermediate and outer wood were averaged to give an estimate of mean density, or an approximation of the overall density of the merchantable stem. These data were then subjected to two-way analysis of variance to apportion the variation in the data between

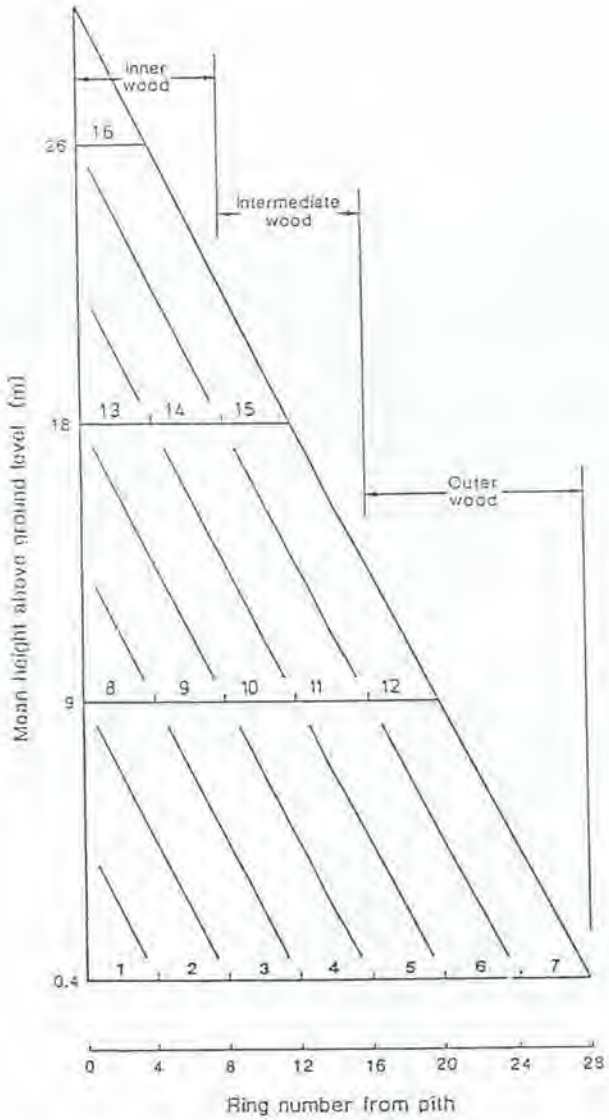

Figure 2. Location of the 16 within-stem sample positions. In acropetal order, the levels are as follows: 1, stump height; 2, 3 and 4, height of the tree 8, 16 and 24 years respectively; after reaching the stump level. The inner, intermediate and outer zones comprise samples 1-8, 9-16 and 17-28 rings from the pith respectively.

position and site, and zone and site. The data for equivalent rings in the breast height samples were included in the position x site analysis, but not in the zone x site. Standard procedures were used to test for homoscedacicity and normality of the data.

Associations between density and mean rainfall (total annual, summer, autumn, winter, spring), mean annual temperature, altitude, latitude, and foliar nutrients were examined by regression analysis. Similarly, correlations between density and growth characteristics were assessed. Stand height was estimated at age 25 years and diameter at breast height under bark for the trees at 29 years (see Table 1)[3].

The density data obtained in the subsidiary study were subjected to two-way analysis of variance to apportion the variation in data between site and position of sample in the stem, using the stem diameter as a co-variate. In addition to this, data for each sample position were compared with the sample log diameter for both sites separately by two-way analysis of variance.

RESULTS

Principal Study

Variation Within Sites

Within-stem density variation was similar for all trees. Density increased at each height level in the centrifugal direction. This increase was linear until about ring 14 (from 310kg m^{-3} to 410kg m^{-3} for breast height level) and curvilinear thereafter to ring 28 (from 410kg m^{-3} to 435kg m^{-3}) (Fig. 3). At comparable ring number from the pith, density was higher at butt level than at the other levels, although as the trees grew older the densities of the breast level samples closely approached those of the butt samples. The difference between the butt and the other levels for a comparable ring number was 20-40kg m^{-3}.

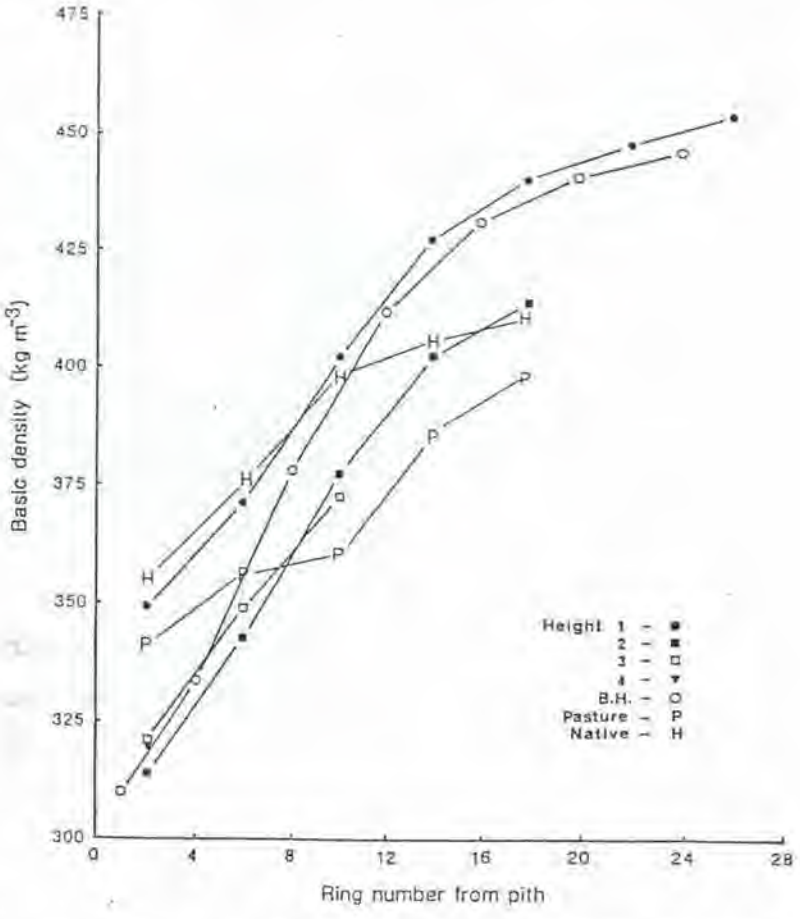

Figure 3. Mean wood density at various positions within stem for both the principal study and the subsidiary study

There was no discernible variation in density which could be related to tree position on slope. Differences in density between trees within sampling sites were generally about 20%.

Variation Between Sites

Density was significantly associated with site at each of the sampling positions and for each of the arbitrary zones, and for the estimated "mean".

Correlation analysis (Table 2) showed that there was a positive association between mean density and summer rainfall (coefficient of determination 29%) a negative association between density and winter rainfall (coefficient of determination 14%), and no association with annual, spring or autumn precipitation. There was no evidence of a correlation between density and mean annual temperature or altitude. Latitude accounted for about 10% of the mean density variation; but in the geographical context of the study, this could merely be a blunter way of expressing seasonal rainfall values. None of the nutritional factors, as expressed by the foliage analyses, appeared to be outside the adequacy range

Table 2. Correlations between wood density and site and stand characteristics

Independent variable(s)	Coefficient of determination (R^2) x 100			
	Inner wood	Intermediate wood	Outer wood	Mean
1 Summer rainfall	27+	28+	27+	29+
2 Autumn rainfall	0	0	0	0
3 Winter rainfall	19-	10-	15-	14-
4 Spring rainfall	3-	1-	1-	1-
5 Annual rainfall	0	0	0	0
6 Mean annual temperature	2+	0	1-	0
7 Altitude	1+	0	6+	2+
8 Latitude	11-	7-	12-	10-
9 Foliar phosphorus	26-	31-	16-	24-
10 Tree diameter, 29 years	26-	21-	25-	25-
11 Tree height, 25 years	24-	14-	15-	17-
1* and 10*	70	64	68	70
1.* 3, and 9	61	57	50	57
1.*, 3, 9, 10, and 11	72	67	69	70

Note: All correlations are based on mean values for 22 sites. Critical R^2 x 100 values for significance (P = 0.05, P = 0.01) one variable, 18 and 29; two variables, 19 and 30; three variables, 20 and 32; four variables, 21 and 33. A plus or a minus sign indicates that the variable is positively or negatively correlated with density.

* Variable with regression coefficient consistently significantly different from zero ($P < 0.05$).

required for *P. radiata*, except phosphorus. Eight of the sites returned foliage phosphorus values below the critical level of 1200 ppm, that is, their phosphorus status was inadequate. Six of these yielded trees with densities greater than the overall mean. This factor in fact accounted for 24% of the mean density. As it is well established that foliage phosphorus levels are highly correlated with tree growth below the critical level, it is not surprising to find that rate of growth, as expressed by either tree diameter at 29 yr, or tree height at 25 yr, was also strongly associated with mean density (coefficient of determination 25% and 17%, respectively). As can be seen in Table 2, the simplest and best correlation with mean density was found to be summer rainfall and tree diameter at age 29 years, the first making a strongly positive contribution to density and the second a negative one.

Subsidiary Study

As in the main study, density was highly significantly associated with position in stem (Fig. 3). Even more marked than this, however, was the very strong association of density with site, the wood growing on the site which was formerly a native eucalyptus site having a significantly higher density than that of the wood from the previous pasture sites. There was also a difference between the two sites in the relationship between density and diameter. The trees grown on the ex-hardwood site showed a significant tendency to produce wood of lower density with increasing diameter, whereas those grown on former pasture land yielded wood, the density of which was quite unrelated to tree growth.

DISCUSSION

In the principal study, the within-tree variation in density was found to be far greater than that associated with any site factor, and the tree to tree variations within site were also considerable (about 20%). In these respects, both were consistent with previous studies of *P. radiata* wood density. Also, the fact that there was a significant association between density and site concurs with the NZ findings that specific site differences exist[1][2]. However, the lack, in the present study, of a significant relationship between density and mean annual temperature which these workers found, suggests that this factor has no causal association with density at latitudes lower than those at which the NZ plantations are growing.

That about 70% of the inter-site differences can be explained using site associated factors other than mean annual temperature (Table 2) is noteworthy, particularly in view of the non-specific nature of some of the parameters. The positive and negative correlations of density with summer and winter rainfall closely parallel findings for slash pine (*Pinus elliottii* Engelm) in its native range[5]. It is probable that water availability at different times of the year influences the earlywood/latewood ratio in growth rings. Winter precipitation may lengthen the period of the spring shoot flush during which earlywood (low density tissue) is formed, while summer rainfall could maintain cambial activity further into the

growing season after the production of denser latewood has commenced[6][7]. Depending on when it occurs, precipitation in autumn or spring could favour either latewood or earlywood formations, which could account for the non-significant contributions of these seasons to the magnitude of wood density.

The strong negative relationship between growth factors associated with site and wood density is particularly interesting, and tends to confirm the findings[8] in the Gippsland region. The most precisely measured of these (diameter breast height under bark 29yr) gave the best relationship. It was closely followed by the estimated height (25yr). Under these circumstances it is not surprising to find that the most important primary cause for growth differences, after water availability, that is, phosphorus nutrition, accounted for a similar amount of the variation.

In the subsidiary study, the negative relationship between growth and density was significant but weak in the trees grown on former eucalypt forest sites, but completely absent in the trees grown on former pasture land. The most striking aspect of this study was the strong and unequivocal relationship between density and site, the previous pasture sites yielding wood with the lower density. The lack of any relationship between density and growth rate in these trees could be a reflection that some density minimum for the species has been reached in the culture conditions associated with these sites.

The practical outcome of this work is as follows:

(1) Within stem variations in density are considerable and predictable. Reasonably uniform material can be produced by segregating raw material according to formative age.

(2) Tree to tree variation is not site specific and is of limited significance. Any reduction in the extent of this would appear to require appropriate control over the genetics of planting stock.

(3) The higher density for a given growth rate found in the summer rainfall areas is not sufficient, in itself, to stimulate greater interest in growing *P. radiata* in such areas, although it should be a reasonably important factor when considering any such developments.

(4) The difference in average wood density in the two major pine growing Regions of Albury and Bathurst in NSW, is so small as to be of little significance.

(5) There appears to be a highly significant reduction in the density of the wood of trees which have been grown on land which was previously under pasture compared with that of trees grown on land which was formerly eucalypt forest.

(6) Wood from *P. radiata* grown on previous pasture sites does not appear to vary in density with growth rate.

REFERENCES

1. Harris, J.M. 1965). A survey of the wood density, tracheid length and latewood characteristics of radiata pine grown in New Zealand. NZ Forest Service Technical Paper No. 47.

2. Cown, D.J., and McConchie, D.L. 1983. Radiata pine wood properties survey (1977-1982). Forest Research Institute (Rotorua) Bulletin No. 50.

3. Wilkes, J. 1989. Variation in wood density of *Pinus radiata* in New South Wales, Australia. Canadian Journal Forest Research 19: 289-294.

4. Smith, D.M. 1954. Maximum moisture content method for determining specific gravity of small wood samples. US Forest Products Laboratory Report No. 2014.

5. Larson, P.R. 1957. Effect of environment on the percentage of summerwood and specific gravity of slash pine. Bulletin No. 63. Yale University School of Forestry.

6. Nicholls, J.W.P. and Wright, J.P. 1976. The effect of environmental factors on wood characteristics. 3. The influence of climatic and site on young *Pinus radiata* material. Canadian Journal Forestry Science 6: 113-121.

7. Wilkes, J. 1987. Review of the significance of variations in wood structure in the utilisation of *Pinus radiata*. Australian Forest Research 17: 215-232.

8. Turvey, N.D and Smethurst, P.J. 1985. Variations in wood density of *Pinus radiata* D. Don across soil types. Australian Forest Research 15: 43-49

RECYCLING - PROSPECTS AND PRACTICES

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ABSTRACT

Recycling of papermaking fibres is frequently presented as an obvious solution to a variety of environmental concerns. However, to achieve the ultimate aim of collecting and re-using all available papermaking fibre, a variety of factors must be taken into consideration. These range from the optimization of collecting systems to the environmental impact of fibre recovery processes. The present paper outlines the technical aspects of recycling processes and examines some possible waste management strategies.

INTRODUCTION

One of the major issues emerging from the current debate on the effective use of the forest resource is the use of recycled fibre in papermaking. Although the Division has not formulated a specific program of research into recycling as yet, we have accepted in principle that recycling is a subject where we might legitimately be expected to provide some input in the public interest. Accordingly, we have signified our intention to participate in the Standards Australia committee currently being formed to prepare Australian standards on recycling of paper. Meanwhile, we have been consulted by both the Australian and New South Wales Departments of Administrative Services as part of their reviews of possible Government action to promote recycling. We have also been consulted by the Australian Government Industry Commission (formerly the Industries Assistance Commission) and we subsequently prepared a submission for their Inquiry into paper recycling.

Before deciding the nature and extent of any future involvement in recycling, it seemed appropriate to examine the recycling situation as a whole. Such an examination might result in the identification of research opportunities and would certainly enable us to act more effectively in an advisory capacity. This presentation outlines some of the factors which should be considered in developing a strategy for obtaining maximum benefit from recycling.

RESOURCE MANAGEMENT

The paper industry in Australia has been using recycled fibre, particularly in the manufacture of packaging boards, for many years. It is somewhat ironic that in the past, the use of "waste paper" has been de-emphasized because of the perception that the products containing waste paper would be of inferior quality. Now, the use of recycled fibre is being vigorously promoted, but the extent to which recycling already occurs is frequently not recognized. In fact, 1987-88 statistics show that of the total consumption of pulp by paper manufacturers, 939,000 tonnes comes from local pulp producers, 276,000 tonnes from imports and 759,000 tonnes from recycled fibre. Thus, 38% of the total fibre used for paper manufacture in Australia came from recycled fibre. An alternative approach shows that 759,000 tonnes or 27.4% of the total consumption of paper in Australia is recycled. If we assume that 15% of the paper produced (e.g. tissues and the like) can never be recovered, we have about 1.6 million tonnes of potentially recyclable fibre still available.

These figures are somewhat outdated. Since 1988, there has been some increase in the use of selected waste for office papers, while the departure of Smorgon Paper and the expansion of the capacity of the Pratt group has led to a shift in the raw material for packaging grades, with a greater emphasis being placed on selected packaging waste rather than mixed household waste. Nevertheless, they agree quite closely with the Industry Commission estimate of 1.5 million tonnes of paper theoretically still available. It is estimated that at least half of this would be in the east coast capital cities and would be made up of 300,000 tonnes of packaging papers, 300,000 tonnes of printing and writing papers and 250,000 tonnes of newsprint.

In developing a strategy for maximizing the use of recycled fibre, we need to know how much of this 850,000 tonnes of paper is actually available for collection in a form suitable for recycling. The best recorded overall recovery rate of paper for recycling is approaching 60%, but there is little information on how this is distributed between the various product groups. Such information is essential for the development of a totally effective waste management system. Furthermore, two alternative scenarios should be considered, one for best possible utilization of the additional fibre still available and one for the best possible use of the total recycled fibre resource including the possibility of re-allocating some of the resource which is already being used.

Any strategy designed to increase the overall rate of recycling of papermaking fibres must be developed with a full appreciation of the consequences of its implementation. Reduced to the simplest terms, recycled fibre can be used either as a replacement for locally produced pulp with no increase in paper

production or to augment local pulp production with increased paper production providing either import replacement or an export capability. It is not within the province of this discussion to argue for or against changes in the pattern of pulp production within Australia. However, it should be noted that an option which maintains papermaking at its current level would necessarily involve a series of small installations (at each paper mill), each taking in selected waste of a quality appropriate to the grade of paper being produced at that mill. In theory, such a scheme would be relatively easy and cheap to implement, but its viability would depend on the availability of suitable raw material within an economic distance of the papermill site. This could pose significant problems for the Tasmanian mills. The alternative, to extend papermaking capacity, is clearly a more expensive undertaking. It would also require major upgrading of the present collection procedures, some assurance that the quality of the waste would remain constant, evaluation of the de-inked product and, finally, identification of a suitable grade of paper which could be both manufactured and marketed.

The viability of either option would be markedly improved if the quality of the waste paper available was upgraded. The current system of collecting selected waste from commercial and industrial premises could probably be extended to cover a wider area and smaller sources. This approach would be assisted, especially in the case of office waste and computer paper, if a centralized collection system was in operation. Facilities for the segregation of various types of household waste would also be beneficial - the present system tends to reduce quality to the least common denominator, rather dirty newsprint. There are also a number of more trivial factors which could be implemented, particularly at government establishments, to improve the recyclability of some grades of waste paper. For example, wherever possible, colourings and inks should be readily bleachable, preferably with peroxide. Where colour is required, blue should be preferred. Window-faced and self-sealing envelopes should be avoided as should self-adhesive labels. Papers made from synthetic fibres should be clearly identified so that they can be recycled in the plastics stream rather than contaminating the waste paper collection. In the light of these examples, the potential for improving the recycling quality of waste paper by a judicious choice of products should be extensively publicized.

USING RECYCLED FIBRE

Apart from a few specialty grades, there are very few types of paper where the fibre furnish cannot include some recycled fibre if the requisite quality is available. Possible exceptions are grades which require the highest possible strength

and cannot tolerate any reduction in fibre properties, especially fibre length. Current specifications for archival quality paper also prohibit the use of any recycled fibre but this prohibition is really only a safety measure to ensure that no lignified fibres are included. However, these are unusual situations. It is much more common to find that a given grade of paper can be produced from an appropriate type of recycled fibre, either alone or in admixture with virgin fibre, provided that sufficient of the appropriate fibre is available.

There are a number of ways in which recycled fibre can be reintroduced into a papermaking system. If there is a large market for a product and an adequate supply of suitable raw material, the best option is probably an integrated operation, similar to that in an integrated pulp and paper mill. Here the recycling system replaces the pulp mill, while additional pulp can be either imported or manufactured on site as appropriate. In the Australian context, this procedure is already in operation in the manufacture of packaging board grades and may also be appropriate for newsprint. It is doubtful whether there are many other grades of paper where local demand would be sufficient to warrant this approach. However, if an export market could be identified, the possibility of a project of this nature should be explored. A variant on this option which should be considered, if an export market is available but the supply of suitable waste paper is inadequate, is to combine a recycling operation with a complementary pulp mill using a fibre resource which may itself be inadequate to supply a conventional operation. Such a fibre resource might be a relatively small plantation, the products from farm and forestry operations or agricultural residues. Indeed, a combination of recycling and pulping of agricultural residues may minimize the problems often associated with the latter.

In countries with a large population and high population density, we find two distinct procedures which are used by commercial recyclers - organizations who process various waste streams and sell the recovered fibre to a paper mill.

Domestic refuse may be treated - often by municipal authorities - and the low grade fibre obtained may be used instead of groundwood. Although these schemes can recover fibre not accessible by other means, the fibre quality is inevitably poor and the overall result may be counter-productive where a major emphasis is being placed on the recycling of selected grades of waste paper. Commercial de-inking plants also provide a useful source of recycled fibre under certain circumstances. However, to be commercially successful, their product must be reasonably uniform in quality and this implies that an adequate quantity of selected waste is available. Any proposal to set up a de-inking plant designed to supply fibre to a paper manufacturer would require a careful investigation of the availability and uniformity of the incoming waste paper.

On the other hand, a small de-inking/fibre recovery plant attached to an existing pulp or paper mill can have several advantages. For example, if a pulp mill is digester capacity limited, good quality unbleached waste can be used to augment digester capacity or if the limitation is on bleach plant capacity, an appropriate grade of bleached waste can be used. Such a situation can readily arise. An imbalance in fibre supply and demand in any integrated mill following a paper machine rebuild or as a consequence of the closure of an outdated pulping line are typical examples.

Opportunities of this kind to increase the use of recycled fibre should be taken as they arise, but are not sufficiently frequent to play a useful part in any strategy to increase the use of recycled fibre. Perhaps a more obvious role for recycled fibre as a supplement to, or a substitute for, current virgin pulp usage is as a replacement for imported pulp. However, 80% of our imported pulp is derived from softwood and most paper and paperboard produced mainly from softwood chemical pulps is already being recycled.

Other uses for waste paper, outside mainstream recycling are also available. These include moulded fibre products and insulating materials. Even here the quality (and cleanliness) of the recycled paper can be important if the fibre product is to be used in the food or health industries. Further applications of this nature should be sought and may provide an outlet for the rejects from fibre fractionation. Nevertheless, it seems that the paper industry will continue to be the primary user of recycled fibre.

RECYCLING PROCESSES

THE RAW MATERIAL

Waste paper can be divided into a large number of categories. The Paper Stock Institute of America, even in 1974, listed 46 normal grades and an additional 26 specialty grades. However, for discussion purposes, a simpler classification scheme will suffice.

Mixed waste paper. This is the material obtained from household waste, collected by charitable and service organizations and from commercial premises where, for a variety of reasons, segregation of paper grades is not practised. It is generally considered to be the lowest usable quality of waste paper, firstly because it contains significant quantities of newsprint and similar products made from high-yield, low strength pulps and secondly because the variety of products present makes it difficult to select a process which will effectively remove all potential contaminants.

Selected waste paper - unbleached. This category covers a wide range of products, largely packaging grades, but also including items such as brown envelope papers, manila folder stock and the like. The quality of the fibre obtainable from packaging papers and paperboards varies considerably. At one end of the scale, we have items such as sack kraft and solid kraft linerboard, which are made from 100% chemical pulp, often largely derived from softwoods. At the opposite end come products such as the so-called "test" or "jute" liners where the principal fibre component is derived from mixed waste, with a cosmetic layer of higher quality pulp on the surface, constituting perhaps 10-20% of the total fibre in the product. The overall quality of selected packaging waste depends largely on the source and on the effectiveness with which the various types of product can be segregated.

Collection points range from manufacturers of packaging to retail outlets for the packed product.

Selected waste paper - bleached. This is primarily composed of printing and writing papers, although some packaging papers such as bleached bag kraft, solid bleached boxboards and milk carton stock may be present. The quality depends on the composition or the original furnish - many printing and writing grades contain bleached high-yield pulps, various quantities of mineral fillers and coatings and in some cases other contaminants introduced during processing. Quality is also affected by the nature and quantity of the inks present, which relates to either difficulty of removal or the effect if not completely removed.

Contaminants. Apart from the inevitable general rubbish which will be present in any recycling system (which may include anything), items arising from improper segregation practices during the collection of used packaging materials (the worst offender here is probably foamed polystyrene), and items used during the collection process (e.g. baling wire, plastics strapping), there are two kinds of contaminant which must be considered.

The first type, known in the UK as pernicious contraries and in the USA recycling industry classification a prohibitive materials, are usually introduced during printing and converting operations and are integral components of the finished product. They include functional coatings and laminations (plastics, foil, etc), certain resistant or intensely coloured inks (UV cured inks, fluorescent inks, etc), and specialty components (binding adhesives, self-seal adhesives, etc). The presence of such materials interferes with the ability of the product to be repulped for subsequent processing.

The second type of contaminant includes non-fibrous materials (fillers etc) incorporated during the papermaking process, together with those inks and other substances subsequently added which do not affect repulpability although they may well affect the yield of fibre from the process.

Fibre recovery. A wide range of alternatives are available, the choice depending on the nature of the raw material and the product required. These range from simple redispersion of the raw material to complete removal of all undesirable components to give a product virtually indistinguishable for virgin fibre.

The first step in any recycling process is to disperse the raw material in water, to the point where each fibre is separate from another. In some cases, simple mechanical agitation is sufficient to achieve this, while with other starting materials, it may be necessary to heat in the presence of appropriate chemicals. The chemicals most commonly used are caustic soda, soda ash, sodium hypochlorite, calcium hypochlorite, alum, acids and various wetting and penetrating agents. During the repulping stage, large items - rope, wire and general trash are removed by a junker fitted to the pulper. The slushed pulp is screened to remove incompletely dispersed paper and plastics sheet and then washed. It may also be centrifugally cleaned to get rid of small, heavy dirt particles or filling and coating pigments.

If the quality of the raw material is adequate (unprinted white cuttings, new brown bag waste) or if a low grade product is acceptable (inner plies of multi-ply liner), the product obtained above may be satisfactory. However, to obtain good quality recycled fibre from a typical source of waste paper, several other process stages are usually necessary, especially when the overall objective is to increase the amount of fibre being recycled.

De-inking processes are usually designed to break down the cured ink vehicle - the material which binds the pigment to the paper surface - in order to release the pigment and enable it to be removed by a physical process. The severity of the treatment required depends on the nature of the ink. At one extreme, the vehicles in radiation-cured inks cure to cross-linked polymers which are extremely resistant to the chemicals normally used for de-inking. Inks containing high-melting point thermoplastics can also be difficult to treat as can the toner used in plain paper copiers, which is similar in composition. Indeed, under some circumstances, paper printed with these recalcitrant inks are classified as prohibitive materials - defined as "materials which by their presence in excess of the amount specified will make the stock unusable as the grade specified". The amount specified is usually between zero and 2% in US standards. The actual de-inking process takes the output from

the pulping unit, where the appropriate chemicals have been added and the paper slushed for an appropriate time and temperature. Coarse contaminants are removed as outlined above and the mixture of dispersed fibre and small ink particles is then set to a special washer unit, a flotation cell or, after selective flocculation of the ink particles, to a hydrocyclone. The washer units - specially designed screens - are more efficient in removing filler particles and fibrous fines, but require more water for their operation.

An additional treatment step may be required to remove sticky contaminants which are likely to deposit on any surface if allowed to pass through into the paper machine circuit. Two systems are available. The contaminant particles may be dispersed by means of surfactants or extracted with an appropriate solvent, usually perchloroethylene. Solvent extraction offers some advantages because it is applicable in it simplest form to materials which require de-inking as well as the removal of bitumen, waxes and the like.

Coloured papers and papers printed with dye-based inks will require bleaching to give a white product. Some market pulp mills also produce a white pulp from unbleached packaging waste by incorporating a bleaching stage into the recycling process. Conventional bleaching chemicals - mainly hypochlorites - are used.

Having removed all unwanted extraneous material, the remaining pulp can be upgraded by fibre fractionation. By this means, fibre debris and excessively short fibres generated during the original papermaking operation and the recycling process can be removed. The degree of improvement obtainable depends on the fibre length distributing in the starting material, on the efficiency of separation obtained by the fractionator and on the criteria chosen for rejection / acceptance. Because of the wide variety of fibre blends used in various grades of paper, it is impossible to quantify the likely outcome of fibre classification in general terms. However, the process provides a valuable option in cases where fibre quality might otherwise be marginal for a proposed end use.

Effluents. Recycling seems to be perceived as a "pollution-free" process, but this is quite unrealistic. Even a relatively simple de-inking system may require 2% sodium hydroxide (on fibre basis) to aid in fibre dispersal and yields of 85% are not uncommon. This means that for every 100 tonnes of waste processed, 2 tonnes of sodium hydroxide or equivalent and 15 tonnes of rejected or dissolved material must be disposed of. As the effluent will be quite dilute, it is unlikely that a soda recovery system would be practical, except perhaps where there is a possibility of combining it with pulp mill effluent. Otherwise, disposal of the sodium component

could be a problem unless an ocean outfall was available - discharge to an inland waterway must be seen as a potential contributor to groundwater salinity. Soluble organic materials such as starch would require effluent treatment to reduce BOD, while insolubles could either be incinerated or used for landfill. Incineration could be difficult if the clay or other pigment content of the incoming waste was high. The possible presence of heavy metals in the system - derived from various ink components - should also be monitored. These could be concentrated to unacceptable levels in de-inking sludge. Other potential effluent components include surfactants (flotation and dispersion agents), polyphosphates (dispersion agent), and emulsified bitumen, waxes etc (components of waste paper). Where bleaching is necessary to give a white product or hypochlorite is used in the initial fibre dispersion the presence of organo-chlorines in the effluent must be monitored and appropriate effluent treatment installed.

OVERVIEW

Recycled papermaking fibres can be satisfactorily used as a component in most papers. Except in a few special cases, the paper so produced in comparable in performance to similar grades made entirely from virgin fibre.

The ideal use pattern for recycled fibre would be to compensate for the gradual deterioration in quality by using the fibre from a given paper grade as a component in a paper where the fibre quality requirement is minimally less than previously needed. In practice, the extent to which the ideal can be followed depends on the quality and quantity of each grade of waste available. This in turn, is influenced by market size and efficiency of collection and grade segregation and on the disposition of the waste and the production facility. In determining a practical system for optimizing the use of recycled fibre, a proper inventory of the potential wastepaper resource must be obtained. Such an inventory should provide sufficient information to permit the selection of suitable sites for both collection and processing of waste paper, together with the quantities of each grade of waste available at each point. The grade should be specified in more detail than the usual newsprint, packaging, printing and writing. Three classification systems are available, British, European and American, any of which will be satisfactory. Similar information should be obtained on collection systems already in place, for all end uses. A national scheme for the most effective development of waste paper as a fibre resource can then be developed.

In order to increase the collection and segregation of waste paper significantly, changes to the present system will be needed. To achieve a target whereby 50% of the Australian consumption of paper and paperboard is recycled,

the collection rate will need to be increased from the present figure of 46.2kg per capita to 84.5kg. There is little further benefit to be gained from random collections of mixed waste which is destined for use in packaging board grades. There is currently a surplus of this material in the market place. Thus, a waste management system capable of collecting an additional 600,000 tonnes of segregated waste paper will be needed. A considerable public education campaign will be required to ensure effective segregation of the various components of the waste paper stream.

The environmental impact of de-inking operations must also be carefully considered. Because recycling of papermaking fibres is generally perceived to be environmentally favourable, possible effluent disposal problems are often neglected. In fact, de-inking effluent is often high in BOD from dissolved starch. Furthermore, the starch and other polymers frequently behave as protective colloids, making the suspended solids very difficult to remove by conventional sedimentation techniques. When combined with the dissolved salts and the heavy metals, which are also likely to be present, the effluent from a de-inking plant could present a major problem. In particular, any proposal to site a de-inking plant where the effluent would be discharged to an inland waterway should be scrutinized very carefully indeed.

In addition to the purely technical aspects involved in increasing the recycling rate for paper products, some attention will need to be given to consumer perceptions of product quality. Until recently, the emphasis on recycling was rather towards whether a given product was recyclable, rather than whether it has been produced from recycled fibre. There is a perception that a product made from "waste paper" was inherently of lower quality. Consumers who consciously select products made from recycled fibre often feel that they are sacrificing some element of quality in exchange for an environmental benefit. It must be made clear that recycled fibre is not necessarily worse than virgin fibre. It may be the same, it may be different. In either case the quality of most products depends on the ability of the papermaker to adjust his blend of fibres so that the required properties are obtained. Hence, if the quality of the recycled fibre is adequate and constant, the quality of the product will also be adequate for the intended end use.

THE COMMONWEALTH GUIDELINES FOR NEW BLEACHED EUCALYPT KRAFT PULP MILLS

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ABSTRACT

In December 1989 the Commonwealth Government released a Pulp Mill and Industry Package which included a set of environmental guidelines for new bleached eucalypt kraft pulp mills. The reasons for these guidelines and their development are outlined. The application of these guidelines to a new kraft pulp mill in Australia and the research program associated with the guidelines are reviewed.

INTRODUCTION

The announcement by North Broken Hill and the Canadian company Noranda that they would participate in a joint venture to build a large kraft pulp mill in Northern Tasmania initiated a wide-ranging public debate about the environmental effects of the mill. The mill was to manufacture bleached kraft pulp, a large portion of which would be exported, from a wood resource consisting mainly of mature eucalypt woodchips. The capital cost of the mill would have been about $1000 million and the production of bleached pulp about 440,000 tonnes/year. The treated effluent from the mill would have been discharged through a pipeline into Bass Strait at a point near the township of Wesley Vale. The principal concern about the pulp mill was the effect on the marine environment of the chlorinated organics formed during bleaching of the pulp.

The Tasmanian Government has the primary responsibility for the regulation and monitoring of effluent from an industrial development such as a pulp mill in that State. A set of State Government guidelines was developed for the proposed Wesley Vale pulp mill and used as the basis for discussions with the joint developers. The Commonwealth Government was not involved in the early part of the proposed development but at a later stage Federal Cabinet was required to approve the project because of its foreign investment.

The Commonwealth Government expressed concern about some aspects of the Tasmanian Government's environmental regulations and at a meeting with company officials stated that Commonwealth approval was dependent on three conditions being met -

- The companies undertake oceanographic studies and a biological and chemical baseline study of the receiving water
- The companies meet superior guidelines and standards to be developed by the Commonwealth
- The companies agree to the development of an environmental plan to be monitored independently.

The second of these conditions was unacceptable to the companies because it would have involved them in an unspecified period of uncertainty while the guidelines were being developed and this would have resulted in the possibility of unacceptably high cancellation costs. The companies therefore withdrew their proposal to build the mill.

DEVELOPMENT OF THE COMMONWEALTH GUIDELINES

The first step in the development of guidelines was taken in May 1989 when the Commonwealth Government announced a policy which would ensure that new pulp mills built in Australia used the best available technology and environmental standards. CSIRO was requested to review relevant technical procedures in Sweden, Finland and Canada, and advise the Government on technical and environmental issues. The terms of reference included:

- become familiar with the latest technology in bleached kraft pulp mills
- collect and synthesise known information on toxicological effects on marine life

The review was conducted by an official delegation consisting of three CSIRO scientists, two Commonwealth Government representatives and three observers

from the pulp and paper industry. The delegation met with people from 30 organisations in Sweden, Finland and Canada. A comprehensive report (1) on the findings of the delegation was prepared and was the subject of a debate in the Senate. The most important conclusions of the report were:

- New mills using the best available technology economically achievable (BATEA) and efficiently operated should cause no significant acute (short term) toxicity.

- The possibility of some long term or chronic impacts remains an issue of some concern. Such impacts, if any, would be identified before irreversible damage took place provided that suitable environmental baseline studies were done before the mill commenced operation and an environmental monitoring program was maintained indefinitely to assess periodically the possible impacts of chronic toxicity.

The report also recommended that, because of possible long term environmental impacts of organochlorine compounds, it would be desirable to pursue a policy for the reduction and eventual elimination of organochlorines as technology permitted.

After considering the CSIRO report Federal Cabinet agreed that a set of guidelines should be developed for new bleached eucalypt kraft pulp mills. The guidelines were developed after extensive discussions involving Commonwealth and State authorities, conservation groups and the pulp and paper industry. The authors of the CSIRO report acted as researchers and principal advisors to the Commonwealth Departments involved in this procedure. The guidelines were examined by several engineering consultants to ensure they were achievable in practice. They were accepted by Federal Cabinet and released as part of Pulp Mill and Paper Industry Package (2) on 12th December 1989.

THE GUIDELINES

The guidelines are specifically for new bleached eucalypt kraft pulp mills discharging effluent into a marine environment.

They have the following key elements:

- The maximum emission levels for specified pollutants which may be discharged into the atmosphere or receiving waters are defined. The gaseous emissions which are regulated include particulates, oxides of nitrogen, reduced sulphur compounds, chlorine and chlorine compounds. The regulations for liquid emissions include traditional water quality parameters such as biochemical oxygen demand, total suspended solids, oil and grease, as well as parameters which are specific for bleached kraft pulp mills such as acute toxicity, dioxin and adsorbable organic halogens.

- The requirements for disposal of solid waste are outlined.

- Criteria for the determination of a suitable site
  - meteorological and topographical characteristics required to demonstrate that the proposed site can meet the ambient levels set for specified gaseous pollutants.

  - physical marine characteristics required to show that the dispersal of the liquid effluent at the proposed site is sufficient to meet the specified dilution criteria. A dilution of 200:1 must be achievable at all times at the edge of a mixing zone which is defined as a circular area of radius 500 metres centred on the outlet.

  - biological studies of the receiving waters.

- Baseline studies and monitoring
  - 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 will be reviewed on a regular basis (every five years) unless there are significant advances in BATEA or if unforeseen environmental impacts are observed which will necessitate revision of these guidelines.

They are more stringent than those set by the Tasmanian Government for the Wesley Vale mill in that emission levels are lower on some key parameters such as organochlorines, but the main differences are the comprehensive site suitability, baseline and monitoring programs.

CSIRO will receive all reports on the operation and monitoring of any mill approved under these guidelines and report to the Federal Government on the effectiveness of the implementation.

There will be negotiations with the States on joint Commonwealth/State assessment arrangements for future bleached eucalypt kraft pulp mills to ensure that there is a practical procedure for implementation of the guidelines.

RESEARCH PROGRAM

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

The research program will address several issues. There are a few specific areas of research which need to be completed before the guidelines become fully operative. These are well-defined (for example, the choice of micro-organisms appropriate to Australian waters for acute toxicity tests) and are not expected to delay implementation of the guidelines. On the other hand, the review procedures for these guidelines require that a comprehensive research program be undertaken to ensure that technological and environmental issues are kept under continual review.

The program will consist of projects in the following areas:

- Chemical composition of bleached eucalypt kraft mill (BEKM) effluent from mature and plantation eucalypts
- Processes for bleaching kraft pulps from mature and plantation eucalypts
- Alternative pulping and bleaching technologies
- Treatment of BEKM effluent

- Biological effects of BEKM effluents on single species
- Biological effects of BEKM effluents on marine populations and communities
- Effluent dispersion modelling

Management and funding of the program

CSIRO has been given the key role of managing the program, although it is intended that all persons with expertise whether in tertiary institutions, State or Commonwealth laboratories or in private industry will have the opportunity to contribute to the research funded by the program.

CSIRO best fits this role because of:

- the multidisciplinary requirements of this research;
- the need for the management of the program to be seen to be independent of vested interests; and,
- the expertise already developed in the course of the Commonwealth addressing these issues.

The research program will provide essential input to the State environmental protection agencies and some of its work could have spin-offs in other areas of environmental control. It will provide important information for the development of the pulp and paper industry and the protection of the fishing industry.

An Advisory Board chaired by the CSIRO and with membership from each of the Departments of Industry, Technology and Commerce, Primary Industries and Energy, and Arts, Sports, the Environment, Tourism and Territories, and the State and industry bodies which contribute funds, has been established. The Board will also include a community group representative. It will have the following roles:

- to be briefed fully on developments in technology and environmental impacts;

- to receive and consider all reports to the Commonwealth on performance and monitoring information from mills established under the Commonwealth guidelines;

- to contribute to determining the research program and its priorities;

- to advise on a program, to be undertaken by CSIRO as part of its management task, to keep the public informed on developments in the technology and environmental impacts of BEKMs; and,

- to make recommendations to the Ministers on updates to the Commonwealth's guidelines and EIA processes with regard to BEKMs.

A Technical Advisory Committee, chaired by the CSIRO manager of the Pulp Mill Research Program, has members from the relevant areas of CSIRO (oceanography, marine biology, pulp and paper technology), the pulp and paper industry, the fishing industry and a toxicologist.

The main function of the Technical Advisory Committee is to provide advice to the Board on all technical matters.

There is also a Public Awareness Committee, chaired by the CSIRO manager, which will have the role of ensuring that significant research advances, particularly those related to environmental protection, are given wide publicity.

Also, throughout the five year period of the research program a series of annual conferences will be necessary to ensure that the results and direction of the program are subject to ongoing technical scrutiny.

Two conferences, one of which has already been held, will be used to help formulate the research program. A Conference and Workshop on Toxicology and Monitoring was held in Melbourne in May of this year. An International Conference on Bleached Kraft Pulp Mills - Technical and Environmental Issues, will be held in February, 1991.

The guidelines and the associated research program will play a key role in the feasibility studies, approval and operation of a new kraft pulp mill in Australia. There are four locations in Australia where new kraft pulp mills have been considered - northern Tasmania, northern NSW, south-western WA and East Gippsland (Victoria). The successful establishment of any one of these mills would have a significant impact on the Australian pulp and paper industry and on the Australian economy.

REFERENCES

1. Pandry, C.F., Johannes, R.E. and Nelson, P.J., June 1989, Pulp mills: Modern technology and environmental protection. Report to Senator the Hon. John Button, Minister for Industry, Technology and Commerce.

2. Pulp Mill and Paper Industry Package, December 1989. Prepared by Departments of Industry, Technology and Commerce; Arts, Sport, the Environment, Tourism and Territories; and Primary Industries and Energy, with technical assistance from CSIRO.

REDISCOVERING THE EAST GIPPSLAND FOREST 6/3

- A summary of CSIRO investigations on the pulpwood quality of a prospective resource

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ABSTRACT

The East Gippsland forest area has the potential to supply woodchips from residual mature roundwood, sawmill offcuts and regrowth thinnings for the manufacture of pulp and paper products. The present work, undertaken during 1987-90 as part of a joint Victorian State Government/CSIRO research program, describes the composition and sampling of the prospective resource, the preparation of representative woodchip mixtures and the pulping of these mixtures by chemical and chemi-mechanical processes. The properties of bleached and unbleached pulps are presented and compared with results obtained from commercial woodchip mixtures from Central Gippsland, southern New South Wales and northern Tasmania.

INTRODUCTION

The Victoria Timber Industry Strategy of 1986 laid the foundations for long term, sustainable management of the State's native forests (1). An immediate reprecussion in East Gippsland was a reduction in the sawlog harvesting from about 350,000 m^3/year to the present rate of about 200,000 m^3/year. Concurrently, it was recognised that the future of the East Gippsland industry would increasingly lie with the regrowth rather than the old growth forests.

The management of regrowth eucalypt forests through thinning to promote future sawlog production was not an established practice in Victoria. Consequently, a study team with members from the DCFL Public Land Management and Forests Division, CSIRO and the Victorian Sawmillers Association was brought together in early 1986 to identify the research needs likely to be associated with regrowth thinning. The findings and recommendations of the study team were presented in October 1986 (2).

These recommendations were accepted by the State Government and, in 1987, a contract was signed with CSIRO to implement a collaborative research program. The research program, to be completed by 30th June 1990, was overseen by a Steering Committee with Government, Industry, Trade Union and Community Group representation. The day-to-day management of the investigation was the reponsibility of a Project Management Committee, comprised of senior research staff from the Department of Conservation and Environment (DCE) and CSIRO.

The specific components of the research work were allocated as shown in Table A.

TABLE A

Allocation of component projects in the East Gippsland investigation

DCE	CSIRO
(1) Resource assessment	(7) Harvesting/debarking in the forest (with DCE)
(2) Growth response to thinning	(8) Bark removal at the mill
(3) Flora/fauna characterisation	(9) Sawing and drying of regrowth
(4) Preliminary thinning trials	(10) Adhesion assessment
(5) Orbost Research Station	(11) Pulp/paper manufacture
(6) Fire protection (with CSIRO)	(12) Silvicultural systems (with DCE)
	(13) Production of Scrimber (with Scrimber International)

The largest component project undertaken by CSIRO was the evaluation of the prospective resource for the manufacture of pulp and paper products. More than twenty people at the Clayton Laboratory were directly involved in the the experimental work. A similar number of DCE personnel contributed to the provision of resource data and sample collection. In addition, we also gratefully acknowledge the generous help and co-operation received from the management and staff of Newmerella sawmill, Harris-Daishowa Pty Ltd, AMCOR Ltd and APPM in the use of their facilities and for the supply of reference materials.

Our methodology was based on previous experience gained from both the evaluation of other Australian timber resources and also the forests of Sarawak and Papua-New Guinea. The research proceeded in five stages :-

(1) Identifying the resource
(2) Preparing sampling plans and collecting the samples
(3) Reconstituting the samples into representative woodchip mixtures
(4) Pulping/bleaching/papermaking with the representative woodchip mixtures
(5) Evaluating the results and comparing them with previously known commercial woodchip mixtures

IDENTIFYING THE RESOURCE

The 300,000 ha East Gippsland Forest Management Area incorporates the sawlog supply areas of Cann River, Bendoc, Orbost and Nowa Nowa. The topography varies from coastal plains (generally south of the Princes Highway) to subdued foothills with slopes mainly less than 18° to the higher peaks forming the Dividing Range. The average annual rainfall is about 700 mm in the coastal districts, rising to above 1000 mm in the mountains (3).

The combination of rainfall and topography generates three major and a number of minor forest types. The major forest types are Coastal (CMS), Foothill (FMS) and Mountain (MMS) Mixed Species forests. The regrowth stands of potential interest originate either from wildfires or previous sawlogging operations and are distributed in scattered patches of 2 to 40 ha within the coastal and foothill forests (2).

Whilst the main emphasis of the East Gippsland investigation has been on the regrowth resource, it was recognised that the projected volume of regrowth roundwood (about 100,000 m^3/year) would only be a minor proportion of the total wood supply available to any pulp/paper mill. The main fibre source would be the 800,000 m^3/year of mature residual roundwood generated as a by-product of mature sawlog harvesting supplemented by 70-100,000 m^3/year of woodchips from sawmill offcuts. All three of these furnish components were separately examined and then recombined in their respective proportions to define the overall nature of the East Gippsland forest.

Sampling of residual wood resources

For efficient sampling of forest resources we need to know the species composition and the relative volume of wood in each forest type, i.e., we need a roundwood inventory of the area. This is used to determine the number of trees to be sampled from each species in each forest type, and also for the assemblage of representative chip mixtures. It is the resource composition, not the number of sample trees which determines the relative volumes of different kinds of wood in a chip mixture. Deta ls of the principles of sampling are given by Balodis, *et.al* (4)

Mature roundwood resource

The mature roundwood volumes for each Block of the East Gippsland Management Area were extracted from the DCE hardwood data base HARIS. The local DCE Officers from Orbost, Cann River, Bendoc and Nowa Nowa provided the approximate species composition by forest types of each Block in their area. Of the 104 Blocks in the management area, it is expected that 92, with a standing volume of 31.4 million cubic meters of mature roundwood, will be available for logging . The information on species was combined with the HARIS roundwood volume data to give species distribution for the major forest types (Table B).

TABLE B

Distribution of mature roundwood by species and forest types in East Gippsland

No.	Botanical name	Common name	All East Gippsland (vol.%)	CMS (%)	FMS (%)	MMS (%)
1*	*E.sieberi*	Silvertop Ash	34.94	55.1	45.3	7.2
2*	*E.obliqua*	Messmate Stringybark	15.61	2.8	12.9	28.4
3*	*E.globoidea*	White Stringybark	11.55	18.5	15.6	1.5
4*	*E.cypellocarpa*	Mountain Grey Gum	9.61	2.7	10.3	13.8
5*	*E.fastigata*	Cut Tail	8.28	-	2.4	21.7
6*	*E.radiata*	Narrow Leaf Peppermint	3.15	-	0.5	8.8
7*	*E.muellerana*	Yellow Stringybark	2.12	1.3	3.4	1.1
8*	*E.considenana*	Yertchuk	2.41	5.8	2.4	-
9*	*E.macrorhyncha*	Red Stringybark	1.28	1.5	1.6	0.8
10	*E.globulus*	Gippsland Blue Gum	1.30	0.4	2.2	0.8
11	*E.baxteri*	Brown Stringybark	1.87	3.8	2.0	0.2
12	*E.nitens*	Shining Gum	1.23	-	-	3.7
13	*E.dives*	Broadleaf Peppermint	1.02	-	-	3.0
14*	*E.botryoides*	Southern Mahogany	0.92	3.5	0.1	-
15	*E.delegatensis*	Alpine Ash	0.77	-	-	2.4
16	*E.rubida*	Candlebark	0.76	-	-	2.3
17	*E.viminalis*	Manna Gum	0.67	-	0.2	1.7
18	*E.regnans*	Mountain Ash	0.23	-	-	0.7
Representation of resource (%)			97.72	89.5	98.6	95.6
The following species were not sampled:-						
19	*E.mannifera*	Brittle Gum	0.57	-	-	1.7
20	*E.sideroxylon*	Red Ironbark	0.41	1.0	0.4	-
21	*E.gummifera*	Red Bloodwood	0.34	1.4	-	-
22	*E.polyanthemos*	Red Box	0.30	0.7	0.3	-
23	*E.elata*	River Peppermint	0.26	-	0.4	0.3
24	*Angophora floribunda*	Rough Barked Apple	0.16	0.7	-	-
25	*E.bosistoana*	Coast Grey Box	0.13	0.4	-	-
26	*E.agglomerata*	Blue Leaved Stringybark	0.09	0.4	-	-
27	*Acacia dealbata*	Silver Wattle	0.01	-	-	-
Total Standing Volume ($m^3 x 10^6$)			31.4	7.7	13.2	10.5

* *Representative mixtures were prepared for these species*

Only 13 of the 27 species contribute 1% or more to the total volume, whilst about 80% of the volume is contributed by the five major species.

Sampling plan

The sampling plan was designed to provide adequate material for the preparation of representative woodchip mixtures for the total resource, the forest types and 10 individual species. Nine species (see Table B) were excluded on the basis of being previously recognized as low quality pulpwood or because they were present in insignificant quantities.

The percentages of roundwood volume for species of commercial significance in the three forest types were used to determine the number of trees to be sampled from each species in each forest type. The number of sample trees ranged from 12 for *E.sieberi* to two for some of the minor species. From some species, such as *E.botryoides*, more trees were sampled than would be justified by its contribution to the total roundwood volume, because of the need to provide adequate representation for a species test.

Sampling procedure

A total of 85 mature roundwood trees were sampled from the four supply areas: Cann River (26), Bendoc (12), Orbost (30) and Nowa Nowa (17). The trees were sampled from widely separated, random locations in 40 different Blocks. If the tree at the chosen position had excessive and uncharacteristic defects, such severe fire damage, the next nearest tree of the required type was selected.

The sample trees ranged in diameter (dbhob) from 24 to 120 cm and in merchantable length from 8 to 55 m. The median tree had 60 cm diameter and stem length of 16 m. One sample billet (1.3 m long) was taken from each tree in a systematic way to represent different positions in the stem. For species from which 2 or 4 trees were sampled, the stem to crown point or 10 cm top diameter was halved and the samples taken alternatively from the midpoint of the butt and top half; for those with 3,6,9,or 12 sample trees the stem was divided in three equal lengths and sampled in rotation from the butt, middle and top log. The billets were debarked and chipped on a commercial chipper, then air dried and screened.

Preparation of representative woodchip mixtures

Preparation of representative mixtures followed a step-wise procedure. Firstly chips from the 85 trees were assembled to provide a representive sample of each species in each given forest type. At this stage it was assumed that each tree represents the same total volume so as to avoid a large tree from dominating a species mixture. The relative amount of chips included from a given tree was weighted to compensate for the relative size of the butt, middle and top log in a tree. The 85 samples were reduced to 31, representing seven species for CMS, 11 for FMS and 13 for MMS.

Chips from these mixtures were used to individually assemble test samples (600 g oven-dry equivalent) to represent forest types, species and the total mature roundwood resource. Since nine species were not sampled and not every species was sampled in each forest type, the major mixtures represent between 90 and 99% of the resources (see Table B).

Sampling of regrowth

Two regrowth samples were collected from East Gippsland. A reproducible sample of 30 year old *E.sieberi* from a limited area for chemi-mechanical pulping tests and a representative sample of mixed species for the assessment of wood quality of thinnings of CMS and FMS regrowth.

The *E.sieberi* sample for chemi-mechanical pulping was collected from small areas of adjoining stands. Nine trees from Pheasant Creek (60 ha) and three from Patrol Track (10 ha). In the general vicinity there are about 2000 ha of such regrowth. The sample trees ranged between 21 and 28 cm diameter (dbhob) and between 15 and 20 m in length to top diameter of 10 cm. If required, further sample trees can be collected from the same locations as the original samples.

Each stem was divided into three equal lengths to give a butt, middle and a top log. A 1.5 m long sample billet was taken from the midpoint of each log. Some of the 36 billets were chipped and used for imediate tests, others stored in a cool store at 4^{o}C for later use. The billets in the sub-samples were selected so that each tree and each position was equally represented.

A representative sample of CMS and FMS regrowth

It is more difficult to define a regrowth than a mature resource because it continuously changes with age. The current status of the regrowth resource of 44 blocks in the CMS and FMS forests is given by Radic (5), with roundwood accounting for nearly one million cubic metres. The species composition of the roundwood is set out in Table C.

TABLE C

Distribution of regrowth roundwood by species and ages class in CMS and FMS forests in East Gippsland

Species	Age class of regrowth* 47	52	57	62	67	72	77	Total
	(volume %)							
E.sieberi	0	1.0	7.4	10.2	28.2	8.2	0	55.0
E.globoidea and E.muellerana	0.1	2.8	2.7	3.3	8.3	0	0	17.2
E.macrorhyncha and E.baxteri	0	0	2.0	1.3	1.1	1.3	0	5.7
E.considenana	0	0	0	0	0	0.5	0	0.5
Gums (probably *E.cypellocarpa*)	0.1	0.8	0	0	0	0	0	0.9
E.obliqua	0	0.5	0.4	0	0	0	3.1	4.0
Unknown Stringybarks	0	0	1.0	0	12.5	0.3	0	13.8
Other	0	0	0.7	1.2	0	1.0	0	2.9
Total	0.2	5.1	14.2	16.0	50.1	11.3	3.1	100

* *Age class 47 corresponds to regrowth from 1945 to 1949, etc.*

For the design of a sampling plan it was assumed that the overall species composition will not change greatly in the near future by accepting the "average species mix" from Table C.

The unknown stringybarks (Table C) were assigned to the two stringybark groups. This lead to the following species distribution for regrowth and sampling intensity from each "species":- Sivertop Ash (55%, 12 trees), White and Yellow Stringybark (26%, 8), Red and Brown Stringybark (10%, 6), Messmate Stringybark (4%, 4) and gums (1%, 4). The 34 samples were to be taken from the 1960-69 age class in the 20-30 cm diameter (dbhob) class. The Block from which each sample tree was to be collected was selected prior to sampling. The selection was based on the volume of regrowth of the given species and age in the Block.

From each randomly selected sample tree a 1.5 m long sample billet was removed alternatively from the midpoint of the butt and top log. A total of 46 trees were sampled from 18 Blocks which ranged in diameter from 17-32 cm (dbhob) and length to 10 cm top diameter from 5-20 m. The median tree was 25 cm diameter with a 13 m merchantable length.

The billets were chipped on a commercial chipper, air dried and screened The species mixtures were prepared the weighting of samples from butt and top log in the ratio 5:3.

Sampling of sawmill off-cuts

From a survey of East Gippsland sawmills, off-cuts represent about one-third of the sawlog input. The proportion of off-cuts can be as high as 55% from D-grade logs (6). These residues are a significant resource of potential pulpwood which could annually yield 100,000 tonne/year of woodchips.

Samples of sawmill off-cut chips from the East Gippsland sawmills were collected during April and May 1988 by Harris-Daishowa Pty.Ltd (Aust.) staff at the Eden Mill. A total of 178 chip-trucks (each of 20 tonne capacity) were sampled. The sample represents the 18 East Gippsland sawmills which sell their chips for export. The sampling intensity was proportional to the size of the sawmill operation and ranged from 4 to 16 samples per mill.

The chips were air dried, combined for each sawmill and screened. The replicate test samples (600 g o.d.) of sawmill off-cut chips were individually prepared from the 18 sawmill chip samples. It was assumed that the volume of chips supplied from the different sawmills is proportional to the number of trucks sampled during the two month survey. The species composition of these chip samples could not be determined because the log sales dockets did not always list the species.

COMMERCIAL WOODCHIP SAMPLES

Four commercial chip samples were collected from plants using wood derived from areas adjacent to East Gippsland. The Australian Paper Manufacturers mill at Maryvale obtain their wood from central Victoria and the Harris-Daishowa Mill at Eden derive most of their wood from southern New South Wales. These resources are used commercially and provide reference materials of known characteristics against which the prospective East Gippsland resource can be compared.

Woodchip samples from APM Maryvale mill

At the Maryvale Mill, chips are segregated into four quality classes which are then blended for different products. The A and B grades represent the young and old wood from the mountain forests respectively whilst the C and D are the corresponding woods from foothill forests.

For the production of kraft pulp they use a mixture of A and D grade chips with some B grade. The exact composition varies with supplies, but in general it consists of about 50% A grade and more than 25% of D grade. The feedstock used for the manufacture of neutral sulphite semi-chemical (NSSC) pulp is a mixture composed of about 40% A grade, 25% B grade and 35% D grade woodchips.

A spot sample of fresh "A grade" chips was collected from their chip pile. The "Kraft feed" sample was taken from the conveyor belt above the batch digesters and the "NSSC mill feed" from the conveyor tunnel below the woodchip pile . None of the samples may be representative of the long term average quality of the Maryvale supplies. The "Kraft feed" chips had been stored for at least 3 months, which is longer than the normal storage period. All three chip samples were air-dried and screened.

Export woodchip sample from south-west New South Wales

A total of 100 commercial export woodchip samples were collected by Harris-Daishowa staff at the Eden Mill during the loading of two ships. Each sample was screened on a Rotex vibratory screen and each 10 consecutive samples were bulked to provide 10 intermediate mixtures.

The dry-matter content and relative basic density were determined for each intermediate mixture. The replicate test samples for pulping and other tests were individually assembled from these mixtures.

Since the samples represented 100,000 tonne (green) of chips, the reference sample could be regarded as representative of the April-May 1989 export woodchip quality from Eden.

Woodchip sample ex-APPM, Wesley Vale

The spot sample was of green, commercial run-of-mill mixed eucalypt woodchips from the north-west coastal region of Tasmania. The material was predominantly 25-40 year old regrowth, with *E.obliqua* the major species.

The woodchips were screened and stored in sealed plastic bags at 4^{o}C until required.

PULPING/BLEACHING/PAPERMAKING

Previous expressions of interest indicated that the majority of scenarios for pulp/paper manufacture in East Gippsland were likely to be based on a bleached kraft pulp mill. Most of our work was concerned with kraft pulping, although high yield chemi-mechanical (CMP), soda-AQ (soda-anthraquinone) and NSSC (neutral sulphite semi-chemical) pulping were also briefly investigated.

CEHD (chlorination-extraction-sodium hypochlorite-chlorine dioxide) bleaching was used to evaluate the relative ease of bleaching of the chemical pulps. Selected kraft pulp samples were oxygen bleached by an O(D1)(EO)(D2) (oxygen pretreatment-chlorine dioxide-oxygen extraction-chlorine dioxide) sequence to assess the effects of a more environmentally benign bleaching method.

The pulping, bleaching and paper making characteristics of the various woodchip samples will only be discussed here in abbreviated form. Comprehensive details of experimental methods and test results are given in references 7-12.

Kraft pulping

The individual mature roundwood species showed considerable variation in pulpwood quality. The best results, in terms of pulping chemicals consumption and screened pulp yields, were obtained with *E.fastigata* and *E.sieberi* whilst the stringybarked species gave the poorest results (Table D).

TABLE D

Kraft pulping of East Gippsland mature roundwood

Sample	Pulp Kappa no.	Active alkali (as % Na_2O)*	Screened pulp yield (%)*
Best			
E.fastigata	20.4	13.0	49.7
E.sieberi	19.1	16.0	48.7
Worst			
E.muellerana	20.0	17.0	41.7
E.globoidea	21.9	18.0	39.5

* *based on oven dry wood*

The regrowth roundwood, being younger material with a lower extractives content, gave pulps at higher yield and needed less pulping chemicals than the corresponding mature wood samples. The pulpwood ranking within the regrowth species was similar to that observed with the mature wood. *E.sieberi* regrowth was a more attractive pulpwood than any of the stringybarks (Table E).

TABLE E

Kraft pulping of East Gippsland regrowth species

Sample	Pulp Kappa no.	Active alkali (as % Na_2O)	Screened pulp yield (%)
Best			
E.sieberi	19.8	11.0	55.6
Worst			
E.obliqua	20.0	13.5	48.4

The furnish mixtures representing forest types, the total mature roundwood resource and overall combinations of mature roundwood, sawmill offcuts and regrowth roundwood corresponding to various potential pulp mill feedstocks reflected the properties of the constituent woodchips (Table F).

TABLE F

Kraft pulping of representative woodchip mixtures

Sample	Pulp Kappa no.	Active alkali (as % Na_2O)	Screened pulp yield (%)
Mature roundwood			
MMS forest	19.9	15.0	46.4
CMS forest	20.3	16.0	44.9
FMS forest	20.0	17.0	42.3
Total forest mix	19.4	17.0	42.6
Sawmill offcuts			
Composite mix	20.2	16.0	44.8
Regrowth roundwood			
Composite mix	21.2	11.5	53.7
Potential mill furnishes			
[89% mature roundwood + 11% sawmill offcuts]	21.4	16.0	43.9
[80% mature roundwood + 10% sawmill offcuts + 10% regrowth]	21.7	16.0	45.7
Reference samples			
"Eden export"	19.5	18.0	43.5
APM "A grade"	21.5	11.5	55.3
APM "Kraft feed"	22.0	13.0	50.6

The MMS forest produced woodchips giving a higher pulp yield with a lower pulping chemicals demand than were obtained from the other two forest areas. Since the higher quality mountain forests can only be harvested during summer, a decline in pulpwood quality will occur during winter as the MMS woodchips become unavailable. This might be ameliorated by increasing the rate of regrowth thinning from May to September. The beneficial effects of blending regrowth with mature wood were evident in the potential mill furnish containing 10% regrowth (corresponding to a prospective thinning rate of 100,000 m^3/year).

Comparison of the East Gippsland representative mixtures with the reference materials showed the East Gippsland mature wood (i.e. roundwood + sawmill offcuts) to be similar to the "Eden export" woodchips, despite the different species distribution in the southern New South Wales forest. Rather surprisingly, the East Gippsland composite regrowth mixture was only marginally inferior to the APM "A grade" mountain species regrowth, which is regarded as a premium pulpwood. The good result obtained with the APM "Kraft feed" mixture (containing about 50% "A grade" woodchips) further illustrated the gains to be made by the inclusion of young wood in a mature eucalypt furnish and added support to the proposal of establishing eucalypt plantations in East Gippsland to supplement the native forest resource (13).

Bleaching of kraft pulp

The three major components of the East Gippsland resource (mature roundwood, sawmill offcuts, regrowth roundwood) all had a similar response to CEHD bleaching to give pulps in the range of 84-85.7% ISO brightness (Table G). As a consequence, the ease of bleaching of the pulps from the potential mill furnishes was not affected by the amount of regrowth present.

The East Gippsland pulps were easier to bleach than the "Eden export" woodchip pulp and comparable to the pulps from the APM Maryvale woodchip samples.

Oxygen bleaching improved the brightness of the East Gippsland pulps by about 2 units relative to CEHD. Further treatment of the oxygen bleached pulp with hydrogen peroxide lifted the pulp brightness above the 88% ISO regarded as a minimum for export quality material. A penalty of oxygen bleaching was the loss of about one unit in bleached pulp yield when compared to CEHD.

TABLE G

CEHD bleaching of East Gippsland kraft pulps

Sample	Brightness (% ISO)	Bleached pulp yield (%)
Mature roundwood		
Total forest mix	84.0	40.5
Sawmill offcuts		
Composite mix	85.5	42.3
Regrowth roundwood		
Composite mix	84.7	50.9
Potential mill furnishes		
[89% mature roundwood + 11% sawmill offcuts]	85.5	41.2
[80% mature roundwood + 10% sawmill offcuts + 10% regrowth]	84.5	42.8
Reference samples		
"Eden export"	82.0	41.8
APM "A grade"	84.3	52.5
APM "Kraft feed"	84.7	47.4

Kraft pulp strengths

Rydholm and Gedda have suggested a tear index target of 9.2 and a tensile index of 49 as strength targets for a pulp furnish to be used in the manufacture of fine papers (14). All of the bleached kraft pulps from the East Gippsland representative mixtures, irrespective of bleaching method, met these proposed criteria when the strength properties were interpolated at 250 Csf. It seems unlikely that strength considerations would be a limiting factor in the acceptance of East Gippsland pulps, provided that any proposed bleaching process did not weaken the fibres more than the present methods.

Other pulping methods

Chemi-mechanical pulping

30-year-old East Gippsland *E.sieberi* regrowth was impregnated with sodium hydroxide solution and chemi-mechanically pulped using the Sunds Defibrator CD300 pilot plant at Clayton. The pulps were bleached with hydrogen peroxide and the results compared to those obtained with the Wesley Vale sample, where the material is chemi-mechanically pulped for inclusion in writing and printing papers.

The pulps from the *E.sieberi* woodchips were brighter and stronger but had lower opacity and light scattering coefficients than the corresponding pulps from the northern Tasmanian woodchips. Chemi-mechanical pulping of *E.sieberi* regrowth roundwood appeared to be a technically feasible option for East Gippsland, particularly if coated rather than uncoated grades of paper were to be the main products of the mill.

Soda-AQ pulping

Soda-AQ pulping needed a similar amount of active alkali and gave bleachable pulps of comparable screened yield to the kraft process. However, the soda-AQ pulps were more difficult to bleach and about 15% weaker in tearing strength than the corresponding kraft pulps. The soda-AQ process appeared to be better suited to a mill producing finished paper rather than export pulp.

NSSC pulping

An East Gippsland woodchip mixture representing the entire prospective resource gave poor results both in terms of pulp yield and pulp strength when compared to the APM "NSSC mill feed" woodchip mixture. NSSC pulping did not seem an attractive option for East Gippsland, particularly if the inherent difficulties of recycling NSSC pulping chemicals were also taken into account.

OVERVIEW

Our work has been part of a major multi-disciplinary effort which has transformed East Gippsland from the "terra incognito" of 1987 to a prospective resource for the future benefit of the entire community. It has demonstrated that our collective skills can be successfully interleaved to provide "a factual basis on which the State can decide the optimal use of the East Gippsland forest" and, hopefully, may serve as a pattern for similar collaborative investigations in the future.

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REFERENCES

(1) "Victoria Timber Industry Strategy - 9. Government Statement", Government Printer, Melbourne, (August 1986)

(2) "Management of eucalypt regrowth in East Gippsland", DCFL/CSIRO/VSA Report, Government Printer, Melbourne, (October 1986)

(3) Atlas of Victoria, Pages 28-30, Government Printer, Melbourne, (1982)

(4) "Sampling of East Gippsland Forest resources" V.Balodis, D.N.J.Menz, P.W.Geary,J.Radic 44th Appita Annual General Conference, Rotorua NZ (1990)

(5) Radic, Jan - DCE internal inventory report on regrowth (unpublished)

(6) Geary, Ann - Personal communication, DCE Orbost (1989)

DCE/CSIRO REPORTS - "MANAGEMENT OF EUCALYPT REGROWTH IN EAST GIPPSLAND"

(7) Technical Report No.1 - "Chemi-mechanical pulping of 30-year-old Silvertop Ash regrowth", C.P.Garland, N.G.Langfors, M.D.Williams, V.Balodis, A.McKenzie, H.Mamers, D.N.J.Menz (April 1989)

(8) Technical Report No.2 - "Kraft pulping of East Gippsland sawmill off-cuts", C.P.Garland, N.G.Langfors, V.Balodis, H.Mamers, D.N.J.Menz (April 1989)

(9) Technical Report No.3 - "Kraft pulping of 30-year-old regrowth and mature Silvertop Ash woodchip samples", N.G.Langfors, V.Balodis, C.P.Garland, H.Mamers, D.N.J.Menz (April 1989)

(10) Technical Report No.6 - "Kraft pulping of mature residual roundwood", D.N.J.Menz, C.P.Garland, N.G.Langfors, V.Balodis, H.Mamers, W.J.Chin (October 1989)

(11) Technical Report No.12 - "Kraft pulping of regrowth woodchips", H.Mamers, V.Balodis, C.P.Garland, N.G.Langfors, D.N.J.Menz (May 1990)

(12) Technical Report No.14 - "Pulpwood assessment of the total forest resource", V.Balodis, C.P.Garland, D.N.J.Menz, N.G.Langfors, H.Mamers (August 1990)

(13) "Prospectus - Registration of Expressions of Interest to undertake a Feasibility Study for the Development of a Pulp and Paper Mill in Victoria", February 1988, Department of Conservation, Forests and Lands, Melbourne

(14) "Quality and economy of pulps in fine paper production",Rydholm, S.A., Gedda, L.F., Paper Technology, 8, T61 (1967)

PROCESS ALTERNATIVES FOR CHEMICAL PULPING AND BLEACHING

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ABSTRACT

The kraft process remains the dominant process for chemical pulping because of its versatility and because it gives strong pulps. In spite of environmental pressures on the kraft process, improved technology is making it more acceptable and the number of installations is steadily increasing. In contrast, sulfite pulping is slowly declining. Current objectives in chemical pulping research are reduction in chlorine-containing organic compounds in effluents from bleach plants, elimination of reduced sulfur compounds formed in kraft cooking, and reduction in the capital costs of pulp mills. Developments in kraft pulping and bleaching towards achieving these objectives are outlined. Some novel pulping methods, mainly involving organic solvents, show considerable promise for commercialisation.

INTRODUCTION

Chemical processes for wood pulping are those in which the cellulose fibres are liberated from their encasing lignin-hemicellulose matrix by removal of the lignin. This is effected by digestion of woodchips with pulping liquors at elevated temperatures, whereby the lignin is solubilised. Because of the removal of wood substances in chemical pulping, the pulp yields are lower than those in mechanical pulping, usually between 40 and 50 per cent after bleaching. Two main types of pulping processes are practised, alkaline and sulfite. The dominant alkaline method is the kraft process, which uses a mixture of sodium hydroxide and sodium sulfide as the pulping chemicals. A much smaller number of mills using the soda and soda-anthraquinone processes, both non-sulfur methods, are in operation. Sulfite processes are based on sodium, calcium, ammonium or magnesium sulfites and operate at varying acidities.

The world-wide production of chemical pulp, about half of the paper industry's fibre source, is about 100 million tonnes annually. Kraft pulping accounts for about 85 per cent of this production and the proportion continues to increase,[1] while sulfite pulping is slowly declining.[2] The

advantages of the kraft process which gives it preëminence as a pulping technology are:

- the pulps are generally higher in strength than those from other processes
- it is suitable for all types of raw materials, including annual plants as well as softwoods and hardwoods
- the pulp quality is not very sensitive to pulping conditions, making quality control relatively easy
- a well-developed chemical recovery system is available.

However, the kraft process has the disadvantages of high capital costs, pulps which are generally more difficult to bleach than pulps from other processes, and unpleasant odours of reduced sulfur compounds which are formed as by-products. Because of this, there is considerable research interest in less capital-intensive alternatives to kraft pulping, particularly those which do not involve sulfur-containing compounds as pulping chemicals. Two approaches to kraft pulping alternatives are prominent, one based on alkaline systems and the other on organic solvents. Concurrently, there are continued efforts to improve the kraft pulping process.

DEVELOPMENTS IN ALKALINE PULPING PROCESSES

Kraft pulping and bleaching

In spite of the huge capital cost of new kraft mills that led to predictions some years ago that no more kraft mills would be built,[3] there has been a steady number of new mills installed, and many more have been proposed. Of considerable current concern are the potentially-harmful effects of effluents from kraft bleach plants. Unbleached kraft pulp is dark brown and is difficult to bleach to the high brightnesses required for bleached market pulp. Technology presently available requires the use of chlorine-containing chemicals to achieve these high brightnesses. The chlorinated effluents cannot be sent to the chemical recovery system; rather they are usually given some form of secondary treatment before being discharged to an outfall. The main objective in kraft mill developments in recent years has been to minimise the formation of chlorine-containing organic compounds during bleaching, and the ultimate objective would be to bleach the pulps without the use of chlorine-containing reagents.

Reduction of chlorine-containing organic compounds in kraft bleach plant effluents can be effected in three ways:

- extending the delignification in the pulping stage so that less lignin is required to be removed in the bleaching stage
- the use of oxygen delignification after the pulping stage

- new bleaching sequences that either minimise chlorine usage, e.g. by substituting chlorine dioxide for chlorine, or eliminate chlorine entirely.

Extended delignification Kinetic studies have shown that for kraft pulping, it is advantageous to have a high sulfidity in the early stages of the cook, an even application of the alkali charge throughout the cook so that the concentration of hydroxyl ions is levelled, and the dissolved lignin concentration low, especially at the end of the cook.[4] This allows more selective delignification, and the resulting pulps have lower lignin contents at a given viscosity. Some of the extended delignification conditions have been put into practice by three equipment manufacturers through modifications to their digesters.[5]

The Kamyr Modified Continuous Cooking (MCC) process[6] involves splitting the addition of kraft cooking liquor to a two-vessel digester; 55% is added together with the woodchips, 30% to the chips being sluiced from the impregnation vessel into the main cooking vessel, and the remaining 15% is applied countercurrently at the end of the cooking zone. This step-wise addition of cooking liquor ensures a more constant concentration of alkali throughout the cook, while countercurrent cooking at the end of the cooking zone greatly reduces the dissolved lignin concentration.

The Sunds process[7] uses a batch digester to achieve the same level of pulp quality and of energy usage as Kamyr continuous digesters. The cook is carried out in two stages with nine processing steps. A special feature of the process is the use of a cold blow-down of the digester contents, which gives stronger pulp. The system permits both energy savings and extended delignification.

The Beloit Rapid Displacement Heating (RDH) process[8] has primarily been designed to make a batch digester system competitive with a continuous digester in relation to energy usage and to product quality. The digester is charged with chips, filled with warm black liquor at 100°C, and pressurised. This liquor is displaced by a mixture of hot black liquor and white liquor preheated to 155°C. At the end of the cook, the hot black liquor is displaced by cool washer filtrate, and the cold delignified chip mass is blown down with compressed air.

Oxygen delignification Unbleached pulps can be further delignified by treatment with oxygen under alkaline conditions before entering the bleach plant. As the effluents from the oxygen delignification do not contain chlorine residues, they may be treated in the mill's recovery circuit. The discovery that magnesium compounds protect cellulose against excessive degradation during oxygen delignification[9] led to the first mill installation in 1970, and there are now more than 50 plants in operation worldwide.[10] Oxygen delignification can be carried out in systems of either medium or high stock concentrations; the more favourable option is often specific to economics and technical needs at a particular site.

Improvements to the selectivity of lignin removal in oxygen delignification by various pretreatments, mostly under acidic conditions, have been developed.[11] The Prenox process, in which the pulp is treated with nitrogen dioxide and oxygen, offers the possibility of lowering the Kappa number by 3-6 units after oxygen delignification without severe strength losses in the pulp.[12] The method has been tested on a pilot plant scale, and awaits full commercial implementation. Hydrogen peroxide and oxygen has also been used as an acidic pretreatment before an oxygen delignification stage.[13]

Bleaching modifications The formation of chlorine-containing organic materials during bleaching can be decreased by substituting other chemicals for elemental chlorine as bleaching reagents.[14] Examples of this strategy are the substitution of chlorine dioxide for chlorine, oxidative alkaline extraction with oxygen and/or hydrogen peroxide, and the use of ozone instead of chlorine. More efficient washing of the unbleached pulp (brownstock washing) is also advantageous, as dissolved black liquor components are particularly susceptible to chlorination.

The presence of chlorinated organic compounds in the effluents from the bleaching of kraft pulp with chlorine and chlorine dioxide is reduced linearly with a decreased consumption of elemental chlorine in the bleaching reagents.[15] Treatment of the pulps with mixtures of chlorine and chlorine dioxide showed that, at 50% substitution of chlorine by chlorine dioxide, the total amounts of chlorinated phenolics in the effluents were decreased, although the amounts of dichlorinated phenols increased.[16]

Many kraft mill bleach plants now include oxygen in the first alkali extraction stage to increase the delignification, a technique known as oxidative extraction. The advantage of this approach has been to reduce chemical consumption in the initial chlorination stage and also downstream in the chlorine dioxide stage.[17] Other oxidants such as hydrogen peroxide are sometimes added to the oxidative extraction stage for an additional effect.

Recent attention has been given to the use of ozone as a reagent for bleaching kraft pulps. Ozone is a very powerful oxidant, and its use for bleaching must be carefully controlled to avoid degradation of the pulp fibres leading to a loss of strength. Bleaching sequences involving ozone have given high brightness kraft pulps of acceptable strengths without the use of chlorine-containing compounds.[18] A full sized ozone bleaching stage is currently under construction in the USA.

Soda-anthraquinone pulping

A number of pulp mills throughout the world are applying the soda-anthraquinone (AQ) process to the pulping of hardwoods.[19] Soda-AQ pulping has the advantage of no use of sulfur-containing compounds as pulping chemicals, and gives less environmental load and enables the operation of

simpler recovery systems, for example the Direct Alkali Recovery System (DARS) process,[20] than those used for kraft pulping. In addition, a soda-AQ mill coupled with new recovery technology would be more economic on a small scale than a kraft mill.

A disadvantage of the soda-AQ process is that the pulps have generally lower tearing strengths than kraft pulps, especially for softwoods, and research efforts are being directed towards addressing this problem.[21] AQ is also used in kraft pulping to accelerate the pulping process.

A further pulping method involving AQ is mini-sulfide-sulfite-anthraquinone (MSS-AQ) cooking, a combined sulfide-sulfite method developed in Sweden which gives high yield pulps with strength properties equal to those of kraft pulps.[22] Advantages of the method are pulp yields which can be up to 10% greater than those of kraft pulp, easier bleaching pulps and less odour during cooking than kraft pulping. However, chemical recovery from alkaline sulfite systems is difficult, and the method has not proceeded beyond the laboratory stage.

DEVELOPMENTS IN ORGANIC SOLVENT PULPING

The possibility of pulping with organic solvents was first raised when Kleinert proposed the use of ethanol as a delignifying solvent in 1931.[23] Sporadic interest since that time has led to various pilot scale trials, and today some methods are close to commercialisation.[24] Organic solvent pulping developments are driven by the quest for mills which are more economic on a small scale than kraft pulp mills, the possibility of lower emissions of air and stream pollutants, and the potential of gaining value from by-product lignins and hemicelluloses. The operation and chemical recovery of organic solvent processes are, at least in principle, often simple, and allow the isolation of by-product lignin and hemicelluloses. However, the assumption that chemical recovery from organic solvent processes is easy must be treated with caution, as a recent study showed that the manufacturing costs of solvent pulps can be as high as those of kraft pulps.[25] Compared to kraft pulping, there are no emissions of volatile sulfur compounds, and the pulps can be easier to bleach without the need for chlorine-containing reagents.

Attractive as it may seem, organic solvent pulping has several drawbacks. Unlike conventional chemical pulps which can be washed readily with water, solvent pulps when washed with water tend to reprecipitate lignin on the fibres. Because of the volatility of most organic solvents, digestion pressures are high and there are inherent explosion and fire hazards. In contrast to kraft pulping, organic solvent pulping is sensitive to wood species and is most suited to hardwoods. The resulting pulp is generally lower in strength than kraft pulp, especially for softwoods, and cannot be regarded as a kraft pulp replacement. The processes which are

evolving can be seen as auxiliary methods for adding incremental capacity to existing mills or perhaps eventually as suitable for smaller scale operation.

Organic solvent pulping methods are catalysed by either acids or alkalis. In the former case, these methods can be operated without addition of an acid, being autocatalysed by the acetic acid liberated from the wood hemicelluloses. In such cases, the pulping temperatures are in the range 185-200°C, although the temperatures and pressures may be lowered by addition of acid to the pulping liquors. Alkali-catalysed pulping gives higher strength pulps but more complex systems are required for chemical recovery.

Acid-catalysed processes

The original "organosolv" pulping scheme of Kleinert has been recently developed as the Alcell process,[26] which has been operating on a 30 tonne/day scale in New Brunswick, Canada since 1989. The process uses batch digestion with 50% aqueous ethanol and for hardwood chips is carried out at 190-200°C. The spent liquor is diluted with water thereby precipitating the lignin, and the dissolved sugars can be obtained as a syrup after concentration of the filtrate. These fractions are available for chemical conversion.

The strengths of pulps from the Alcell process are reported to be equal to those of kraft pulp made from the same raw material.[27] The advantages of the process compared to the kraft process are lower capital costs due to a simpler recovery process, opportunity for smaller scale operation in areas of limited forest resources, lower production costs, by-product beneficiation and smaller environmental impact.

A three-stage method (the MILOX process) in which a formic acid digestion is sandwiched between two peroxyformic acid stages gives pulps which are easily bleached with peroxide to high brightnesses.[28] The method is more suited to birchwood than pine, and the strength properties and opacities of the birch peroxyformic acid pulps are close to those of kraft pulps. Pilot plant studies on the method will shortly be carried out.

Other acid-catalysed pulping methods which have been tested, often on a pilot scale, include "ester" pulping using approximately equal amounts of ethyl acetate, acetic acid and water,[29] and "phenol" pulping with aqueous phenol and an acid catalyst.[30] In the latter scheme, a phenol mixture obtained by pyrolysis of the lignin in the spent liquor may be used as the pulping agent. Many other acid-catalysed organic media have been considered for pulping, and recent studies have used acetic acid ("acetosolv" pulping), acetone, tetrahydrofurfuryl alcohol, and other alcohols.[24] A variety of acid catalysts have been proposed, including Lewis acids and salts of various metals.[31] Although the inclusion of acids in the pulping liquors permits pulping at lower temperatures, it can lead to pulps with lower strengths.

Alkali-catalysed processes

The MD Organocell pulping system is a hybrid process which combines an acidic with an alkaline organic solvent stage.[32] Softwood chips are reacted with aqueous methanol at 195°C in a continuous digester, and after removal of 20% of the lignin the chips are digested with sodium hydroxide in methanol at 170°C. The pulps have strengths which approach those of kraft pulps, and are easier to bleach than kraft pulps but still require chlorine dioxide as a bleaching reagent. Recovery of methanol is by distillation, while the sodium hydroxide and a lignin by-product can be obtained by electrolysis. The MD Organocell process with support from the West German government has already been demonstrated on a pilot scale, and a commercial scale plant with a continuous Kamyr digester for pulping mostly spruce is currently under construction. There are no kraft mills in West Germany, and the industry has been actively seeking alternatives to kraft pulping for a number of years.

A second alkali-catalysed organic solvent process, the alkaline sulfite anthraquinone methanol (ASAM) process, is under development in West Germany.[33] With judicious use of all four pulping components (and water), the system is able to pulp all commercial German woods including the resinous pines to give pulps with higher yields than and with properties similar to kraft pulps. Although chemical recovery is more difficult than for the kraft process, the pulps are easy to bleach without chlorine-containing compounds. A pilot plant has been successfully operated since 1989,[34] and the process awaits full commercial implementation.

DEVELOPMENTS IN BLEACHING

The major factor influencing developments in bleaching chemical pulps is the pressure to reduce the amounts of chlorinated organic compounds emitted from the bleach plants. This has been exemplified by the concern over the small amounts of chlorinated "dioxins" produced during bleaching, and has prompted measures to minimise the amounts formed.[35] Tighter process control of existing bleach plants and improved pulp washing have already resulted in lower emissions of chlorinated organic compounds.

Alternative bleaching reagents to chlorine-containing chemicals are the family of reagents which include oxygen, hydrogen peroxide and ozone. Use of oxygen in delignification of unbleached pulp and in alkali extraction is rapidly increasing, as is the use of hydrogen peroxide.[36] Ozone shows considerable promise as a bleaching agent and will probably assume an important rôle worldwide if the commercial facility at present under construction in the USA is successful.

Another approach to the replacement of chlorine in bleaching is the use of wood-degrading micoörganisms or their associated enzyme systems for delignification. This has the advantage of reaction under ambient conditions with no reagent residues, but long reaction times are required and enzyme costs are relatively high. White rot fungal strains have been effective in removing lignin from hardwood kraft pulps,[37] while hemicellulase enzymes were found to be more effective for lignin removal during bleaching than ligninases.[38] Biological treatments in future bleaching processes have potential for improvement.

CONCLUDING REMARKS

In spite of the high capital costs involved, new kraft mills will continue to be built. Modification of kraft pulping and bleaching technology has generally kept pace with the environmental constraints to the process. However, new pulping technologies which give pulps which are easier to bleach without chlorine-containing reagents and with acceptable papermaking strengths, while reducing the capital costs for new mills, could become alternatives to kraft mills.

REFERENCES

1. Männistö, H. 1980. Restrictions imposed by environment impact and energy problems. Proceedings of the EUCEPA Symposium, Delignification Methods of the Future, Helsinki, Finland, 2-5 June, 1980, Vol. I, No. 1.

2. Anon. 1990. The sulfite sector: ever smaller, ever more specialized. Tappi J., 73(6), 226.

3. Anon. 1976. Where's pulping headed? A review of the state of the art. Pulp and Paper, 50(August), 78.

4. Hartler, N. 1978. Extended delignification in kraft cooking - a new concept. Sven. Papperstidn, 81(15), 483.

5. Heimburger, S. A., Blevins, D. S., Bostwick, J. H. and Donnini, G. P. 1988. Kraft mill bleach plant effluents: recent developments aimed at decreasing their environmental impact, part 1. Tappi J., 71(10), 51.

6. Stromberg, B. 1987 Modified continuous cooking – an update. 1987 Pulping Conference Proceedings, TAPPI Press, Atlanta, 453.

7. Sjodin, L. and Petterson, B. 1986. A status report on the kraft cold blow batch cooking technique. 1986 Pulping Conference Proceedings, TAPPI Press, Atlanta, 633.

8. Andrews, E. K. 1989. RDH kraft pulping to extend delignification, decrease effluent, and improve productivity and pulp properties. Tappi J., 72(11), 55.

9. Samuelson, H. O. and Noreus, S. E. O. 1970. Process for treating cellulosic material. Ger. Patent 2,022,866.

10. Tench, L. and Harper, S. 1987. Oxygen-bleaching practices and benefits: an overview. Tappi J., 70(11), 55.

11. Fossum, G. and Marklund, A. 1988. Pretreatment of kraft pulp is the key to easy final bleaching. Tappi J., 71(11), 79.

12. Simonson, O., Lindström, L-Å. and Marklund, A. 1987. The Prenox process - experiences from a pilot plant installation. Tappi J., 70(8), 73.

13. Süss, H. U. and Hemling, O. 1987. Acidic hydrogen peroxide/oxygen treatment of kraft pulp prior to oxygen delignification. Das Papier, 41(10), 546.

14. Heimburger, S. A., Blevins, D. S., Bostwick, J. H. and Donnini, G. P. 1988. Kraft mill bleach plant effluents: recent developments aimed at decreasing their environmental impact, part 2. Tappi J., 71(11), 69.

15. Axegård, P. 1989. Improvement of bleach plant effluent by cutting back on Cl_2. Pulp Pap. Can., 90(5), T183.

16. Earl, P. F. and Reeve, D. W. 1990. Chlorinated organic matter in bleached chemical pulp production. Part 6: chlorinated compounds in effluents. Tappi J., 73(1), 179.

17. Reeve, D. W. 1984. E_o installations survey. Tappi J., 67(4), 143.

18. Liebergott, N., van Lietrop, B., Garner, B. C. and Kubes, G. J. 1983. Bleaching a softwood kraft pulp without chlorine compounds. 1983 Pulping Conference Proceedings, TAPPI Press, Atlanta, 323.

19. Kutney, G. W. 1987. Worldwide use of anthraquinone for pulping continues to expand. Pulp and Paper, 61(3), 73.

20. Covey, G. H., Maddern, K. N., Stoddart, B. A. and Scukovic, J. 1988. The leaching of sodium ferrite in 'DARS'. Appita J., 41(1), 22.

21. Nelson, P. J. and Irvine, G. M. 1989. Two-stage soda-AQ:kraft-AQ pulping of radiata pine wood. Appita J., 42(4), 271.

22. Dahlbom, J., Olm, L. and Teder, A. 1990. The characteristics of MSS-AQ pulping - a new pulping process. Tappi J. 73(3), 257.

23. Kleinert, T. N. and Tayenthal, K. 1931. Cellulose and other products from fibrous vegetable materials. U. S. Patent 3,585,104.

24. Aziz, S. and Sarkanen, K. 1989. Organosolv pulping - a review. Tappi J., 72(3), 169.

25. Muurinen, E. and Sohlo, J. 1988. Recovery of chemicals from organosolv woodpulping processes. Cellucon '88 Japan, an International Symposium on Cellulosics and Wood, Kyoto, Japan. Paper XIV-9.

26. Aziz, S. and Lora, J. 1985. Organosolv pulping: a versatile approach to wood refining. Tappi J., 68(8), 94.

27. Dillén, S. 1990. Canada invests in new pulp processes. Scand. Pulp Paper Mag., (3), 44.

28. Poppius, K., Sundquist, J. and Wartiovaara, I. 1989. Chemical pulping of birch and pine chips by the three-stage peroxyformic acid method. Cellucon '88 Japan, an International Symposium on Cellulosics and Wood, Kyoto, Japan. Paper XIV-11.

29. Young, R. A. 1989. Ester pulping: a status report. Tappi J., 72(4), 195.

30. Schweers, W. H. 1974. Phenol pulping - a potential sulfur-free papermaking process. Chemtech, 4(8), 490.

31. Paszner, L. and Cho, H. J. 1989. Organosolv pulping: acidic catalysis options and their effect on fiber quality and delignification. Tappi J., 72(2), 135.

32. Dahlmann, G. and Schroeter, M. C. 1990. The organocell process - pulping with the environment in mind. Tappi J., 73(4), 237.

33. Kordsachia, O., Reipschläger, B. and Patt, R. 1990. ASAM pulping of birch wood and chlorine free pulp bleaching. Pap. Puu, 72(1), 44.

34. Anon. 1990. Pilot ASAM plant - harbinger of a German pulp industry. Paper Technol., 31(8), 36.

35. Voss, R. H., Luthe, C. E., Fleming, B. I., Berry, R. M. and Allen, L. H. 1988. Some new insights into the origins of dioxins formed during chemical pulp bleaching. Pulp Paper Canada, 89(12), T401.

36. Robitaille, M. A. 1988. Hydrogen peroxide: a versatile bleaching agent. Pulp Paper Canada, 89(12), T411.

37. Paice, M. G., Jurasek, L., Ho, C., Bourbonnais, R. and Archibald, F. 1989. Direct biological bleaching of hardwood kraft pulp with the fungus *Coriolus versicolor*. Tappi J., 71(5), 217.

38. Viikari, L., Ranua, M., Kantelinen, A., Linko, M. and Sundquist, J. 1987. Application of enzymes in bleaching. Fourth International Symposium on Wood and Pulping Chemistry, Paris, France, April 27-30, 1987, Vol 1, 151.

HIGH-YIELD MECHANICAL PULP - WHAT'S IN IT FOR US?

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ABSTRACT

High-yield mechanical pulps can be substituted for chemical pulps in many paper furnishes. This has both economic and environmental benefits. High-yield mechanical pulps are manufactured by mechanical means and have yields up to 96 per cent, while chemical pulps are processed chemically and yield about 50 per cent fibre. There are many types of mechanical and chemical pulps and these are discussed. Fibre morphology is important in deciding which pulps to select when blending mechanical and chemical pulps for a particular end use. One of the main disadvantages of using high-yield mechanical pulps in high quality paper furnishes is the problem of brightness reversion or yellowing. This is due to the high lignin content remaining on the fibres. If this problem is solved it will expand the use of mechanical pulps enormously. There are many advantages however, including lower wood harvest requirements, lower capital and production costs, paper property reinforcement and opacity benefits to name a few. The selection of the components in the paper furnish should be based on the end product performance criteria. An export market for high-yield mechanical pulps, particularly CMP and CTMP based on plantation and regrowth eucalypt is available. All we need is the opportunity.

INTRODUCTION

There are two main types of pulp - chemical and mechanical. The type we choose depends primarily on the end product required. There are other factors to take into account, such as the wood resource available, whether it is hardwood or softwood, the strength properties required, and the wood handling and process economics. In many paper furnishes there is a blend of chemical and mechanical pulps in order to obtain the desired paper characteristics. Where possible, it is economically advantageous to substitute a proportion of high-yield mechanical pulp for chemical pulp in a paper furnish. This proportion depends on the end product.

The main objective of this paper is to show that high-yield mechanical pulps can be substituted for chemical pulps in paper furnishes. Topics of discussion will include: the difference between chemical and mechanical pulps and the relative advantages and disadvantages of each; the difference in fibre morphology between

hardwoods and softwoods, and the importance of each in a paper furnish; and the blending of chemical and mechanical pulps to achieve a particular end product.

The use of mechanical pulps can enhance and reinforce the properties of the end product as well as improving the economics. The environmental consequence of this will be discussed in terms of lower wood harvest requirements.

WHAT ARE MECHANICAL PULPS?

Mechanical Pulps

Mechanical pulps are produced by mechanical treatment of wood or other raw material to produce fibres ranging in yield from 85 - 96 per cent, as opposed to chemical pulping where the lignin and hemicelluloses in the wood are dissolved chemically to yield about 50 per cent fibres.

There is a large range of mechanical pulps that can be manufactured, and these are commonly called alphabet pulps for obvious reasons (Table 1). Stoneground (GW) pulps are produced by pressing billets of wood against the abrasive surface of a large rotating cylindrical stone. This produces a large proportion of fines, which can be used to advantage in some paper furnishes to improve optical properties. Refiner mechanical pulp (RMP) is produced by atmospheric refining of untreated wood. Most of the alphabet pulps are produced by utilizing steam and/or chemicals somewhere in their manufacturing process.
For example, in thermo-mechanical pulp (TMP), where the wood is refined under steam pressurized conditions. This allows the lignin to soften and fibre separation occurs more easily than for RMP, which improves strength properties with less fibre damage. The yield for these two processes is greater than 95 per cent. Mild chemical treatment of the wood prior to atmospheric refining (CMP) or pressurized refining (CTMP) improves the strength properties even further, and there are more whole fibres produced with less fines (Table 2), less extractives and generally a higher pulp brightness. There is very little lignin removed with this chemical treatment and a yield of greater than 85 per cent is obtained from hardwoods and more than 90 per cent from softwoods.

Table 1. Types of Mechanical Pulps (1).

Abbrev.	Process	Definition
GW	Stone Groundwood	*Groundwood produced by atmospheric grinding of logs with a conventional stone grinder, commonly called groundwood pulp*
PGW	Pressurised Stone Groundwood	*Groundwood produced by pressurised grinding (above 100°C) of logs with a conventional stone grinder.*
RMP	Refiner Mechanical Pulping	*Atmospheric refining of untreated woodchips*
TRMP	Thermorefiner Mechanical Pulping	*Pressurised presteaming of woodchips (above 100°C) followed by atmospheric refining.*
TMP	Thermomechanical Pulping	*Pressurised presteaming (normally 2-3 mins. between 100-135°C) and refining followed by atmospheric secondary refining.*
PTMP	Tandem or Pressure Thermomechanical Pulping	*Similar to TMP except that both primary and secondary refining stages are pressurized (above 100°C). Tandem refers to an arrangement of refiners*
PRMP	Pressure Refined Mechanical Pulping	*Atmospheric refining of untreated woodchips followed by pressurised secondary refining (above 100°).*
CMP	Chemi-Mechanical Pulping	*Atmospheric refining of chemically pretreated woodchips to produce pulp yields above 80%.*
CTMP	Chemi-Thermomechanical Pulping	*Pressurised presteaming and refining (above 100°C) of chemically treated woodchips followed by atmospheric secondary refining. The chemical can be added to the woodchips either prior to or during the pressurised presteaming to produce pulp yields greater than 90%.*
CRMP	Chemi-Refiner Mechanical Pulping	*Atmospheric refining of chemically pretreated woodchips to produce yields greater than 90%.*
TMCP	Thermomechanical Chemi-Pulping	*Pressurised refining (above 100°C) followed by chemical treatment of fibres before or after subsequent refining stages. The OPCO process developed by Ontario Paper Co. falls into this class using sodium sulfite to treat the fibres.*

Fibre Length Distribution.

Table 2 shows how the pretreatment conditions for softwoods influences the fibre length distribution.

Table 2. Fibre Length Distribution of Some High-Yield Pulps (2).

PULP	CTMP	GW	TMP	SBK
Long fibre % (>30#)	55-65	20-25	40-50	80-85
Intermediate % (30-200#)	20-25	35-45	25-35	10-15
Fines % (<200#)	15-25	30-40	22-28	3-7

Three mechanical processes are compared with a chemical process softwood (bleached kraft (SBK)). The effect the chemical has on the process is shown quite clearly. The long fibre fraction increases considerably when chemical and/or steam is used, whereas the fibre damage, indicated by the amount of fines, decreases. The optical properties of paper, such as opacity and scattering coefficient are improved as the fines content increases so obviously there are trade-offs to consider when formulating a paper furnish. The long fibre content of CTMP makes it ideal for fluff pulp, tissue and packaging grades.

WHAT ARE THE MAIN ADVANTAGES AND DISADVANTAGES OF MECHANICAL PULPS?

A list of the main advantages and disadvantages of mechanical and chemical pulps is shown in Table 3. The main advantage of mechanical pulps is their high yield. This means that compared to chemical pulping, about half as many trees are required per tonne of pulp. However a major disadvantage with mechanical pulping is the high amount of electrical energy needed for manufacture. For example, to produce a tonne of TMP from *P. radiata* to a Canadian standard freeness of about 150 mL, 2500 kWh are required, compared to about 100 kWh for a chemical pulping operation.

One of the main disadvantages of paper made from mechanical pulp compared to paper made from chemical pulp is its lower strength. In Figure 1 the tear-tensile relationships are shown for paper made from mechanical and chemical

Table 3. Advantages and Disadvantages of Mechanical and Sulphate Pulps.

	MECHANICAL	CHEMICAL (SULPHATE)
ADVANTAGES	. High-yield, up to 97% . Fibres stiffer . Can bleach with non-toxic hydrogen-peroxide . Lower capital costs . Loss chemicals required . Lower pollution load	. High strength . Can bleach to very high brightness . Negligible brightness reversion . Can be used for most wood resources both hardwood and softwood
DISADVANTAGES	. High energy use . BOD recovery systems necessary . Lower strength . Difficult to attain very high brightness . Brightness reversion problems . More sensitive to type of wood	. Low yield, ~ 50% . Foul odours emitted . Sophisticated chemical recovery plants needed . Very high capital cost of new plant . Chlorine or Chlorine dioxide bleaching

pulps. UBS is unbleached sulphite pulp. It can be seen that the tearing strength of the SBK (softwood bleached kraft) at a given tensile strength is considerably higher compared to the other pulps. This is indicative of the long and strong fibres of SBK. Although UBS has a high long fibre content, the tearing strength is low because of the processing conditions.

However, the relationship between light scattering coefficient and tensile index (Figure 2) shows that scattering is higher for paper from pulps that have not been manufactured from chemically treated wood. This results from a higher fines content for these pulps (see Table 2). In other words, these pulps have a larger number of reflecting surfaces, which leads to a higher opacity, an extremely important property, particularly in printing and writing papers.

Another disadvantage of mechanical pulps is the brightness reversion effect on ageing. An example of this is when a newspaper is left in the sun for a period of time. It yellows! The brightness reversion problem and its consequences will be discussed in more detail later in this paper.

MORPHOLOGY OF SOFTWOOD AND HARDWOODS

Fibre morphology is very important in determining the pulp quality characteristics of a raw material.

Figure 1. Tear-Tensile Relationship For Some Mechanical & Chemical Pulps (3).

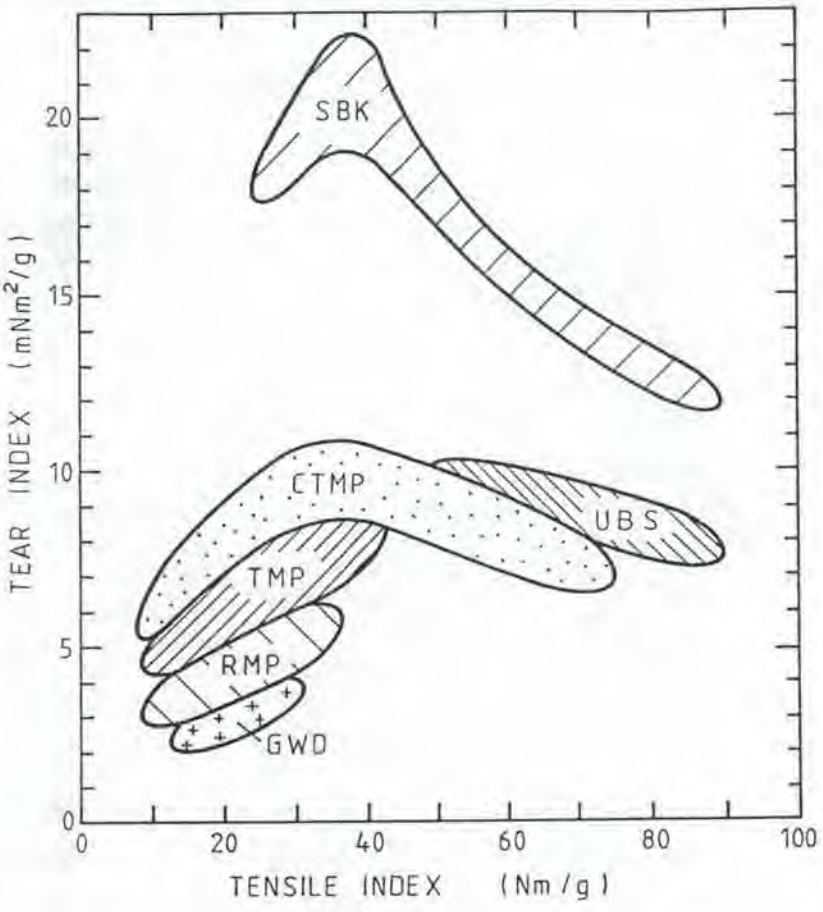
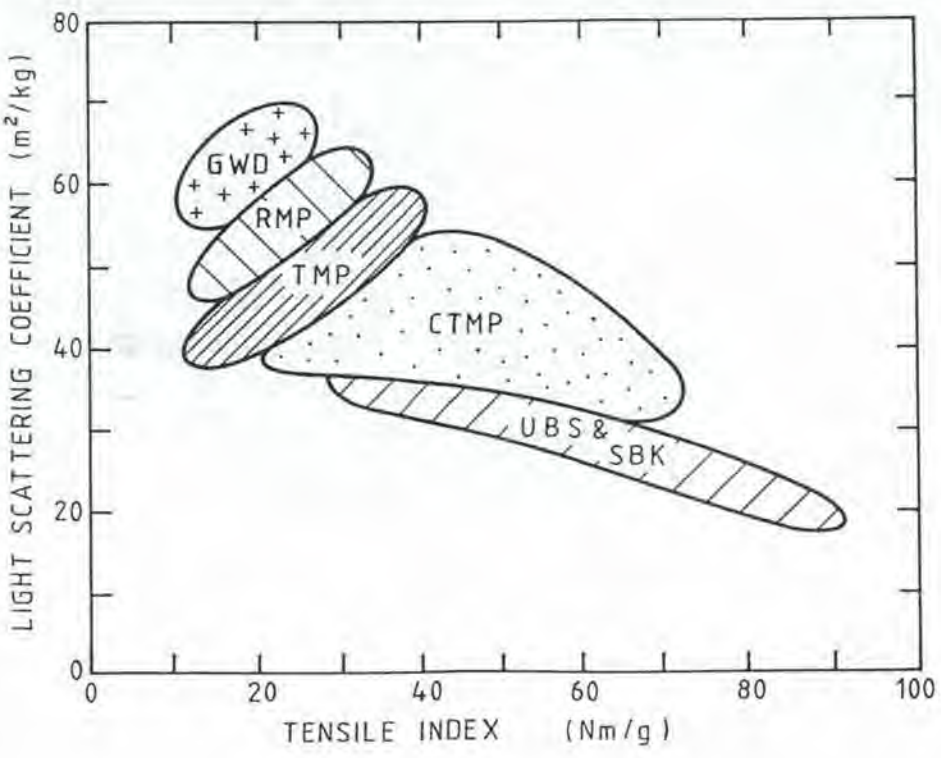


Figure 2. Light Scattering - Tensile Relationship for Some Mechanical and Chemical Pulps (3).



Hardwoods generally have a more complex physical structure compared to softwoods, and contain libriform and parenchyma cells as well as having a high weight proportion of short but large-diameter vessel elements. Softwoods consist of essentially one type of fibre, the tracheid, which generally ranges in length from about 3 to 4 mm. In the pulping and papermaking industry a tracheid is usually referred to as a fibre. Hardwoods have fibres of about 1 to 1.5 mm in length. There are other differences between softwoods and hardwoods such as fibre wall thickness and fibre diameter. The diameter of softwood fibres is much greater than for hardwoods and so are the lumens or hollow centres of the fibres. For many hardwoods the lumen is very small, resulting from a thick fibre wall. Hardwood species with this characteristic are not well suited for papermaking and during mechanical pulping, require very high amounts of energy to reduce the wood into individual fibres.

There is also a difference in chemical composition between softwoods and hardwoods with the latter having lower lignin contents and correspondingly higher levels of cellulose and hemicellulose. Furthermore, the distribution of lignin within the middle lamella and into the cell wall differs between softwoods and hardwoods. In softwoods the concentration of lignin in the cell wall is higher than for hardwoods. This restricts alkali swelling of the fibre to a greater extent than for hardwoods, which implies that a different approach is necessary to optimize quality in high-yield pulping of softwoods and hardwoods.

SHOULD WE USE HARDWOODS OR SOFTWOODS FOR PAPER?

The choice of whether we use a hardwood or a softwood in a paper furnish depends mainly on the end products required, which means that tailor made furnishes predominate.

The fibre components in a pulp furnish for a particular end product can be selected on the basis of a combination of the desirable properties of both hardwoods and softwoods. Higgins (4), has given some advantages and disadvantages of hardwood pulps for papermaking compared to softwood pulps. The advantages include: better formation because of the shorter fibre length; better surface properties because of finer fibres; more favourable strength-opacity relationships because of the greater number of fibres per given area; rapid beating response; lower flow resistance;, easier delignification due primarily to the lower lignin content in hardwoods (about 22 per cent) compared to softwoods (about 29 per cent). Disadvantages include: lower tearing strength and folding endurance because of a shorter fibre length; lower wet web strength, which is important in running high-speed paper machines; high drainage resistance; a tendency for vessel picking,

which may be a problem in printing papers; also some extractive related problems particularly for over-mature pulpwood.

BLEACHING AND BRIGHTNESS

When pulps have been manufactured, they generally require some brightening because of the requirements of the end product. A lot of these products are bleached to a high brightness because of consumer demands and pressures. Generally the concept of consumer perception is that the whiter it is, the cleaner it is, and based on this it is a better product. However, why do we need such highly bleached products? If we can get rid of these consumer ideas, we would go a long way in reducing not only manufacturing costs, but also in helping to alleviate environmental problems.

Bleaching of chemical pulps is generally achieved by a sequential treatment with bleaching agents such as chlorine, chlorine dioxide, oxygen, hydrogen peroxide and caustic soda. However, because toxic organochlorines may be formed as by-products of the various processes, bleaching techniques are under review and alternative methods are being researched.

Bleaching of mechanical pulps is generally carried out using alkaline hydrogen peroxide as the main chemical agent. The advantage with this type of bleaching is that there are no organochlorines formed. However, because of the high level of lignin remaining in the mechanical pulps, the paper made from these pulps undergoes brightness or colour reversion. i.e. the colour redevelops on ageing. This does not happen to the same degree in chemical pulping where brightness permanence is achieved.

There is a limiting factor therefore, on the use of mechanical pulps in certain applications, particularly in various grades of printing papers. Much effort has been made, but so far no universal economical method has been found which converts a high-yield pulp into a product with a brightness stability comparable to that of a bleached chemical pulp (5).

High-yield mechanical pulps can be bleached to brightness levels of over 80 per cent ISO. With brightnesses this high, one would expect that CTMP and TMP could be used in furnishes such as writings and high grade publication papers for books. However, because of their propensity to yellow, these pulps are restricted mainly to short life products such as newsprint. It has been suggested by Cockram (6), that if the time taken for brightness reversion to occur was increased from 3 months to 3 years, the potential consumption of CTMP would be increased from 0.6 to 2.2 million tonnes. If the technical problem of brightness reversion was solved, this would be an enormous breakthrough, and would not only enlarge worldwide

production of high-yield pulps for replacement of chemical pulps, but would also have a significant impact on the environment by reducing the number of trees required for pulping.

BLENDING OF MECHANICAL AND CHEMICAL PULPS.

Blending of mechanical and chemical pulps is important to achieve the functional characteristics required for the end product. At one end of the spectrum for example, 100 per cent unbleached softwood chemical pulp is used for sack paper, while at the other end, newsprint can be made from 100 per cent softwood TMP. High quality printing papers require a strong, bright, age-resistant pulp, therefore a hardwood chemical pulp with a small amount of mechanical pulp would suit. In printing papers, addition of mechanical pulps as replacement for chemical (kraft) pulps improves some of the printing characteristics, particularly opacity. There is also an increase in surface strength, and there are gains in dimensional stability, stiffness and bulk. In fine papers, bleached CTMP can be used to replace a significant amount of bleached kraft pulp provided a high brightness (> 80 per cent) is not required (7).

In tissue and towelling products, absorbency is the most important property. Softness, strength, appearance, bulk and brightness are also important for the consumer. All products may differ by varying degrees but, for high quality tissue products, bleached chemical pulps are normally used. There is a major disadvantage however, and that is low bulk. High-yield pulps such as CTMP can be used in tissue and fluff products by up to 50 per cent to increase bulk without adverse effect on the network strength (7). High bulk translates to higher roll diameter and greater absorbancy, and as tissue is sold by volume, a higher bulk is economically favoured.

The term fluff pulp applies to fibres which have been separated by mechanical means from dry pulp for application in dry-formed non-woven webs or pads in the household or sanitary fields (8). High-yield pulps such as TMP and CTMP are extensively used in the manufacture of fluff products. More recently there has been some competition from superabsorbents such as polyacrylates which can reduce the amount of fluff pulp in a disposable nappy by about 30 per cent. Synthetic fibres like polyethylene also compete, although they are significantly more expensive. However, because of the reduction in core weight, the price of the product is reduced.

Supercalendered (SC) magazine printing papers for gravure and offset applications are made form a mixture of chemical and mechanical pulps (up to 75 per cent) and fillers (up to 25 per cent or more). High-yield pulps need to have a

low drainage rate and a large fines content, as long and stiff fibres may 'stick out' of the surface and be detrimental to the surface smoothness. These high-yield pulps may replace the chemical pulp component by up to 15 per cent.

Light-weight coated (LWC) paper production has increased markedly over the last few years as 'junk mail' and low quality magazine papers flourish. The paper furnish is made up of 50-60 per cent bleached mechanical pulp, 5-10 percent filler and the remainder is chemical pulp. Machine runnability is the greatest concern with this product and therefore the base paper must be of high quality with low shive content and low drainage (CSF ~ 50mL). The high-yield component is predominantly a short fibred CTMP.

High-yield mechanical pulps are widely used for packaging board furnishes, mainly because of their fibre stiffness. The bulky nature of mechanical pulp in the middle ply or back ply of multi layered board gives a structure of high bulk and stiffness whilst still maintaining a lower grammage. In food packaging, contamination can occur by migration of compounds from the board material to the foodstuff. This can be a major problem in liquid food packs such as milk, juices and wine. This food board has been traditionally made with bleached chemical pulps, and while there are no taste or odour problems, the general stiffness of the network is inferior. The use of CTMP as the middle ply in these products serves to improve stiffness and bulk and thereby reduce grammage and associated costs. There are no taste or odour problems associated with CTMP as there can be for TMP used for this application.

An example of the economic advantage in using high-yield pulps to replace chemical pulps, is to be found at Iggesund, a company in Sweden which supplies high quality packaging board. They have developed a centre ply of a multiply board that is much stiffer due to the increased component of CTMP. The stiffness at a given grammage has improved by 35-40 per cent compared to the Company's original board based on solid bleached kraft (9). This development permits a 10-15 per cent reduction in weight due to the CTMP's bulk advantage, a definite economic plus.

WHAT'S IN IT FOR US?

A major challenge facing us now and in the future is to maximize the use of high-yield mechanical pulps, and to increase their market penetration. We can do this by improving the quality of these pulps, thereby facilitating an increase in the replacement of chemical pulp in a paper furnish. There are two ways we can do this. As mentioned earlier, if the problem of brightness reversion is solved, the

prospects for an expansion of high-yield pulp produciton are enormous. The other way is to improve the strength and optical properties of high-yield pulps.

There is a huge incentive for Australia to tackle these challenges, because not only can we reduce the wood harvest requirement, but also the quantity of imported chemical pulp. For example, for every 1000 oven dry tonnes of chemical pulp replaced by high-yield pulp, the industry saves about $400,000, i.e. if 2000 o.d. tonnes of wood produces about 1000 o.d. tonnes of chemical pulp, and if replaced by 1000 o.d. tonnes of high-yield pulp, then the saving is 1000 times the difference between the $ cost of chemical and high-yield pulp i.e. 1000 x $400 = $400,000. At the same time, the wood harvest requirement is reduced by 1000 o.d. tonnes, and at about 1.5 o.d. tonnes per tree (eucalypt), about 670 trees are saved.

Alternatively, we can make a further saving in Australia's balance of payments if the substituted pulp is imported. In other words, if 1000 o.d. tonnes of imported chemical pulp is replaced by 1000 o.d. tonnes of high-yield pulp, the balance of payments improves by $1 million i.e. 1000 o.d. tonnes at $1000/tonne is $1 M. This is at the expense of 1000 o.d. tonnes of local forest resource instead of 2000 o.d. tonnes of wood from overseas countries.

FINAL COMMENTS

In this paper, I have shown that high-yield mechanical pulps can be substituted for chemical pulps in many applications. Fibre morphology is important in determining which type of fibre to use to achieve a particular property, and it was shown that pulp furnishes can be tailor made to suit the function of the end product.

Before the components of a paper furnish are selected, it is important to firstly consider the end use of the final product. The components may then be chosen on the basis of the performance expectation of the end product. It is product performance that determines its selling potential.

In some products there is a limitation on the amount of high-yield mechanical pulp that can be used in high quality paper because of brightness reversion. This is a problem that if solved will be a major breakthrough and will expand the mechanical pulp market considerably.

What's in it for us then? There is a potential for a local and export pulp market in Australia to manufacture CMP and CTMP from plantation or regrowth eucalypts. The capital and operating costs are lower than for chemical pulp manufacture and there are economic and environmental benefits of high-yield mechanical pulps as partial replacement for chemical pulps.

We have the forest resources. We have the technology. All we need now is the opportunity.

REFERENCES

1. Williams Max D., 1985. CSIRO, Industry and High-Yield Pulping - A Common Link. CSIRO Div. of Chem. and Wood Tech. Research Review 1985 p. 35-49.

2. Croon, I. 1989. High-Yield Pulping in the Future. 6th Sunds Defibrator Technical Seminar, Quebec, Canada, Oct. 20, 1989.

3. Höglund, H., Fredriksson, B., Erikson, I. 1977. Chemithermomechanical pulp in newsprint furnishes. IMPC 1977, Helsinfors 5:53.

4. Higgins, H.G. 1969. The Long and the Short of Papermaking. The Australian Timber Journal. Vol 35 No. 1. Feb 1969.

5. Gellerstedt, G. 1989. Light Induced Yellowing of High Lignin Content Pulps. 6th Sunds Defibrator Technical Seminar, Quebec, Canada, Oct. 20, 1989.

6. Cockram, R. 1989. CTMP in Fine Papers. Internal Mechanical Pulping Conference Proceedings, Helsinki, 1989.

7. Breck, D.H. and Styan, G.E. 1985. High Quality, High-Yield Pulps: The Pulps of the Future. Pulp and Paper Canada 86:3 (1985).

8. Nordman, L. 1987. Utilization of Mechanical Pulps. Pulp and Paper Manufacture. Vol. 2 Mechanical Pulping. TAPPI-CPPA, Canada, 1987.

9. Engman, C. 1989. Iggesund's Experience of CTMP in High-Quality Packaging Board. Pulp and Paper Canada 90:9 (1989).

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FOREST PRODUCTS RESEARCH CONFERENCE COMMITTEES

23rd FOREST PRODUCTS RESEARCH CONFERENCE

OPENING ADDRESS BY DR W. HEWERTSON,

CHIEF, CSIRO DIVISION OF FORESTRY & FOREST PRODUCTS

I would like to congratulate the Organising Committee for the work they have done so far in organising this 23rd Forest Products Research Conference. The Committee under the Chairmanship of Dr John Thornton, CSIRO Division of Forestry and Forest Products; Noel Clark of the same Division; Harold Brietinger, CSIRO Division of Building, Construction and Engineering and Bill Keating - formerly of CSIRO has done a fantastic job. Having glanced through the program two points are quite obvious. Firstly, that this is a meeting for researchers to tell researchers preliminary results of their work. I was impressed with the level that we have returned to in terms of the fundamental approach where we are concerned with research in the early stages. The second thing that impressed me was the breadth of the presentations where the number of organisations represented, including research organisations in companies, has increased considerably.

A number of innovations that we have tried previously we have carried on at this meeting. This is the second time we have involved people from the forestry background and forestry research in the conference. The first occasion was a great success. The other thing we have carried on from the previous conference is the poster session which has allowed us to introduce projects that are very early in their genesis.

Since the last meeting we have seen huge changes in the nature and perception of the community into our research. The whole question of sustainability, the whole question of the balance between production and the environment has stepped up. We all owe it to society and to our professions to make sure that that debate on that balance is carried out

in a logical sort of way. I would urge you all to make sure that the community as a whole is appreciative of the way the research is done, the implication it has for society and what it can do to this balance on how we live and how we use the world in which we live.

Since the last meeting I believe the import/export balance has improved to Australia's favour but we are still net importers of forest products to the extent of around 2 billion dollars. The great feature of this industry and the research we are doing in supporting it is that compared with wheat or wool, or any other rural industry, the extent of added value is quite incredible. The added value is many, many times the value of the raw material on which you base all your research. Yesterday, there was a great play on the front of 'The Australian' about the little bit of added value in the wool industry which one would have thought would have been a major value adding industry - it never has been and it is only starting to look as though to might be. It only adds about 8% value whereas this industry adds many hundreds of percentages, not only in high quality furniture but also in such things as bleached kraft paper.

The import dollar and the export dollar for some reason have always seemed to have a different value to the man in the street. I don't know why that is but when one looks at the balance of payments import substitution is every bit as valuable as exports. In fact, an import substitution market, a local market, is much easier to sustain in an economic climate such as the one that we have at the moment.

There are two major issues on which we should be concentrating. Firstly, greater efficiency in the conversion of the raw material as produced by the forest, whether they be native or plantation. That will allow us to cope with the massive reduction in the resource base there has been in the country since the last conference. The industry has a splendid record of utilising resources in a way where the last year's residues are next year's products and I think all of you can play a hand in that. The second point is one that CSIRO introduced at the last conference, viz, the advantages of growing for end use. That has started to show itself in some of the Conference papers.

I would like to welcome all our interstate visitors and our international visitors, particularly that we have six visitors from New

Zealand, Dr Joe Mauldin from the United States and Dr Kunio Tsunoda from Japan, welcome to you all.

Turning now to our Keynote Address. We have a long history of having distinguished speakers to open our Conference and this year we welcome Dr Peter Ellyard. He has just returned from Western Australia after the All Australian Timber Congress where he gave an exciting Opening Address. He has been concerned with the vital issues of the economics and ecology of a sustainable future. Many of you would have read his excellent paper presented to the Institute of Foresters at a meeting in Leura in September 1989. So he is not only interested in the area he has made a professional contribution to it.

Peter Ellyard was born in Wagga and obtained his first academic qualification from the University of Sydney in Agriculture. He continued his work in research and took an MSc and later PhD at Cornell University. He has held very senior positions in State Government, Federal Government and International Government. He now comes to us as Director of the Commission for the Future and holds the position of Chairman of the South Australian Council, Technological Change. I cannot imagine anyone more qualified to give this address at this time - Peter Ellyard.

23rd FOREST PRODUCTS RESEARCH CONFERENCE

KEYNOTE ADDRESS BY DR PETER ELLYARD, DIRECTOR, COMMISSION FOR THE FUTURE

19 November 1990

FUTURES FOR AUSTRALIA

I would like to quote three of my favourite sayings which together express my own views about looking at the future.

The Commission for the Future (CFF), has a motto. This motto is "The Future is not some place we are going to, but one we are creating. The paths to it are not found but made, and the making of those pathways changes both the maker and the destination."

The other two sayings are as follows:

"One cannot create a future which one cannot imagine", and

"Those who do not live in the future today, will live in the past tomorrow."

Most of us contemplate the future by standing in the present and looking forward. People often wonder what the future will bring, without putting themselves in the position of actually trying to realise a future which they might want. The second quote indicates that we must be visionary. If we do not know where we want to go, any road will do. The third quote reminds us that we are in rapidly changing times, and that unless we are visionary, we will be swept aside by events beyond our control. Our only protection in these rapidly changing times is to live with at least one foot in the future.

We can have three kinds of Future: I call them the 3 P's

- the possible future;
- the probable future;
- the preferable future.

We in the CFF are passionate believers in the third of these.

It means that we all must become vision driven in the 1990s if we want to make preferable futures happen. To many Australians a visionary is a "nut" or at least highly suspect.

The 1990s promises to be the most exciting decade of the 20th Century. Some time ago I took some time out to examine some newspapers of the 1890s. They were full of articles about the nature of the coming 20th Century. I believe that we are now entering a similar period of "end of century thinking". For most of this century we have allowed our thinking to extend to the year 2000 as a suitable horizon for the future, thinking that contemplation beyond this mark is not terribly relevant. With this mark less than 10 years away we now have a lot of catching up to do in our thinking.

The CFF in the next couple of weeks will launch a new magazine "21C" (21st Century), jointly with ABC Television. This will be a quarterly commercial magazine through which we hope to guide and stimulate creative "end of century thinking" in Australia and use it to create preferable rather than probable futures. In it there will be many pages of visions of a preferable Australia written by prominent Australians - Visions of a Preferred Future. In addition our advertising is based on corporations describing their own preferred futures. We are trying to encourage them to be "vision driven" also. It is important to remember that in the 1890s despite the fact that the biggest boom and bust in Australian history occurred, visionary thinking helped create the new Commonwealth of Australia on the first day of the 20th century. People at that time did not look inward and tighten their belts. They allowed vision to ride over the top and ultimately steer the social and political future of the country. Similarly it is no accident that President Gorbachev and Chancellor Kohl are both predicting a unified Europe from the Atlantic to the Urals by the end of the 20th century.

I believe that we will be privileged to live through the 1990s. It is likely to be the most exciting decade of the century. However, there are some very important actions that we must take if we are to utilise the 1990s for our long-term benefit.

This new set of circumstances is due to changes occurring both in Australia and globally, changes which are certain to continue in the 1990s. It is important, however, that we look beyond the 1990s, and into the 21st century. We need to consider most of all what we would like the 21st century to look like for us, and to plan a preferred early 21st century. Then we will be able to chart an intelligent course through the 1990s. We need to do this in order to create a few <u>self-fulfilling prophecies</u> for ourselves.

These are pieces of a preferred future. Two quite "utopian" prophecies which have been fulfilled in the last few decades are the prophecy by President Kennedy to put a human on the moon, and the goal enunciated by the World Health Organisation and others to rid the world of smallpox. Without the original vision,

these goals would not have been achieved. We need to do more of the same in Australia.

Australia needs to address three large issues in the 1990s. While, of course, there are others of great importance, it is these three which I believe are the most critical ones. Each of these challenges is reflected in the new program of the CFF.

The first of the issues relates to the economic reconstruction of Australia. We all know about the terrible situation about our balance of payments. We must produce more goods and services of much higher unit value, than in the past.

Australia's economic future will be dependent on whether we are able to marshal our impressive intellectual resources to produce new goods and services for which there are markets.

Most Australians are still of the view that wealth comes from beneath the ground or off the hoof, rather than from between the ears. Some of you will know that the Australia Council has recently held an "ideas summit" to address this issue, and this process will be repeated regularly from now on. The CFF also has had a program promoting the creation of a "brain based" economy. Many of the new products and services, which we need to create, will still be related to our traditional natural resource-based industries. Many will also be based on the three current global technological revolutions (information technology, biotechnology, and new materials technology) which have resulted in the world being deluged by new products and services based on them. We have been impressive contributors to these revolutions in terms of ideas. However, we have failed to produce many new goods and services based on them. We will also need to utilise our knowledge in the areas of Art, Science and Technology in order to achieve this.

We must also develop a culture which is much more creative, enterprising and innovative. This is a major task of the education system. The CFF has two new programs called Creative Futures and Enterprising Futures, in which we are attempting to address these problems. Australia needs to find ways of ensuring that Australian intellectual resources and property are better used to generate national wealth. At present, many knowledge-based startup enterprises are failing, and this is seen by some of us as some sort of "proof" that we should stay with the old ways. It doesn't seem to stop the Taiwanese or the Thais who are making more computers than we do. This is a matter that requires urgent attention.

The current economic reconstruction of Australia to me is still based on the assumption that our major wealth generation will continue to come from our natural resource based industries with only minimal value addition. We spend a fortune on documenting our geological resources and our soil resources which are the basis of our natural resource industries. However, we spend virtually no money on

documenting the quality and quantity of our intellectual resources, which will be the basis of our new wealth generating opportunities. Our economic future will be dependent on what we know both in terms of knowledge and skill.

The self-fulfilling prophecy we should seek is to create economic sustainability by the year 2000.To do this we need to make and export more knowledge based products and services and not continue to look to pay for imports on them by exporting "third world" type resource based products.

Earlier this month the Commission launched an occasional paper called "Rethinking Skilling for a Restructured Workplace" by Professor Bill Ford. This is part of the CFF's contribution to promoting the development of innovative, creative, and enterprising workplaces appropriate for the 21st century. Without this we will never achieve true economic sustainability.

The second great agenda area for Australia's attention is the ecological one. We need to achieve ecological sustainability probably by about the year 2010. The 1987 report of the World Commission on Environment and Development, Our Common Future, should be the basis of this effort. The CFF launched an Australian edition of this book in March. It included additional Australian material and a preface by the Prime Minister. The CFF also published an occasional paper relating to economic and ecological sustainability at that time.

In the next 20 years we need to create in Australia, sustainable agriculture, forestry, fisheries, manufacturing, tourism, and energy use. This is also a self-fulfilling prophecy we must make, and then we must use the 1990s to realise it. This will require the innovation of many new products and services which could find their way to world markets. It will also require major changes to the way we think and to what we do as individuals.

The CFF will be commencing a series of round tables in a couple of months to address in more detail the creation of an ecologically sustainable future. In fact this program is called Sustainable Futures. The greening of industries will be one of the biggest issues of the 1990s. Green industry consists of at least three components:

* The development of a new environmental management industry to provide products and services to create a sustainable future both in Australia and globally. We in Australia have one of the best potentials in the world for such an industry.

* The development of new products and services for an increasingly environmentally aware population. This includes sustainable packaging, longer lasting products, non-toxic alternatives to current toxic products, and the

production of food products which both promote health and ecological sustainability.

* The reorganisation of existing industry so that it performs in a more environmentally wise and responsible way.

The CFF is addressing all of these issues in its Sustainable Futures program. A green industry round table will occur shortly under CFF auspices. This will be the first of many which will focus on the means of achieving economic and ecological sustainability. The CFF has also established a working group of economists and ecologists which will examine the changes which are needed, in both economic theory and management, in order to help realise a sustainable world.

In my work for the United Nations I wrote a report called "Ecomission 2020".

"Ecomission 2020" proposes two policy frameworks for the achievement of Ecologically Sustainable Development (ESD). Both frameworks need to be further developed and Ecomission 2020 recommends that this process be completed by 1 March 1991.

The Problem Centred Approach and Framework (PCAF) focuses on the major global environmental issues, such as climate change, biodiversity loss, ozone depletion, acid rain, land degradation, etc. The UN system has identified nine issues and five subsidiary issues which need to be responded to at a global level.

All these issues are of critical importance in various parts of the Asia Pacific region. In some cases the environmental situation is continuing to rapidly worsen, because of development pressure driven in particular by population growth, poverty and the need for food security and fuelwood supplies. This situation can be likened to a critical medical situation before longer term healing can begin.

The PCAF is an environmental equivalent to the use of medical services to treat and then cure illness. Medical services can cure illness. However they cannot create genuine health. To achieve this a different approach is needed, one which considers the basic conditions which promote health, such as nutrition, a healthy lifestyle, and freedom from environmental hazards and containments. Sustainable development likewise will never be achieved by only attempting to cure environmental problems, important as these are in the short term. For this to occur the conditions which permit and support sustainable development must be created by another approach.

The Mission Directed Approach and Framework (MDAF) is designed to focus on the creation of the conditions which will promote the achievement of ESD by the year 2020 at the latest. Such an approach can be implemented once some of the critical situations caused by environmental degradation and deterioration have been eased or stabilised. This process begins with a definition of a mission (or vision) such as the establishment of ecologically sustainable rice growing, ecologically sustainable tourism in a particular environment, or the manufacture of ecologically sustainable packaging. The MDAF then seeks to implement a program to create these conditions and with it ESD in that particular sector.

In each case we need to design the ecologically sustainable alternative. We need to think about the products, services and technologies, the materials and use patterns, the marketing approaches, the government incentives or taxes needed to promote this alternative. This is the self-fulfilling prophecy, then we need to make it happen. The world needs these alternatives. We have a global problem with global markets for solutions to that problem. The creation of an ecologically sustainable world is the great economic opportunity and imperative of the 1990s.

In addition there needs to be a "greening" of key professional ranks, including engineers, designers, planners, and marketing specialists to ensure that they produce the products and services suitable for an ecologically sustainable world. This is a specific challenge for the education system.

We in Australia have an excellent opportunity to help solve the world's environmental problems and generate wealth for ourselves at the same time. As a person who has worked for 20 years in the environment and technology areas I know for a fact that Australia's intellectual resources and property in environmental management is world class. The tragedy is we do virtually nothing with it except use it to produce food, fibre and minerals. We could be selling expertise and technology to world markets and we could play a part disproportionate to our small size in helping to solve global environmental problems.

Ecomission 2020 suggests that the Asia Pacific region will need to use the problem centred approach until approximately the year 2000 in many parts of the region. After that time the mission directed approach can be implemented, while it can probably be introduced earlier in those parts of the region and countries where development pressure on resources is not causing a rapid deterioration of the environmental situation.

The third great agenda is that Australia must come to grips with its relationship with the Asia Pacific region. Australia is slowly becoming Asianised. However, we have no long term view about what kind of future relationship we would like with Asia and the Western Pacific. The CFF has introduced a new

program called "Asialink". We must decide on the kind of future relationship we would like to have with Asian and Pacific countries, define where we want to go in these relationships, and then set out to build that relationship. We must be able to effectively relate.

It is interesting to note how many recent Australian films and mini series have had an Asian connection. We have a "film links" component in Asialink to further encourage this. This is just one aspect of defining our future relations. If we don't, those relationships will be increasingly dominated by Asian countries who do live with one foot in the future and who are willing to think further ahead than we are. A failure to be sufficiently visionary could result in Australia becoming the "poor white trash of Asia".

All of these broad issues are being focused on in a series of CFF programs under the banner of "Planning for the 21st Century" (P21C). Two components for this program are "Visions for the 21st Century" (V21C), in which we are asking Australian's to write their scenarios for a desirable Australia in the year 2010. Another program is called "Round Tables for the 21st Century" (RT21C) in which we will examine the ways of achieving some of the goals that I have set out above. Among the groups we will be working with will be a group we are calling "Leaders of the 21st Century" (L21C).

I now want to go onto some global issues. The globe is undergoing astonishing changes. In the brief time I have available I would like to talk about just one or two of them. We are just beginning, in my view, a new era of "co-operative globalism". This is being created by the fact that political, economic, technological and ecological forces are all working together to bring it into being. The political agenda largely created by President Gorbachev is causing astonishing changes, undreamed of just five years ago. Not only has the cold war ended, but in the 1990s large scale disarmament is highly likely, thereby releasing large financial resources for other urgent tasks including eradication of illiteracy, dealing with third world debt, reconstructing food production, managing population, and dealing with large environmental problems.

New economic forces are leading to the creation of a united Western Europe. In 1992 and soon after, it will have common currency. A new economic region in our Asia/Pacific region is beginning to form. An international conference relating to this took place in Canberra three months ago. These processes are being driven by increased trade and interdependence. Meanwhile technology now allows 2 billion people to watch a single "live aid" rock concert. The whole globe can, and increasingly will, be focused on single events simultaneously. This is making the world smaller each year.

Finally, ecological forces are forcing us to cooperate. We need to co-operate to solve ecological problems of a dimension such as greenhouse effect, ozone depletion, acid rain, rainforest depletion and desertificaiton. In just 14 months an agreement to phase out ozone depleting substances has been achieved. By the mid 1990s we should have an international agreement relating to climate change. In the last year or so the primitive emotional fear is beginning to make us co-operate rather than fight wars. Fear has "changed sides", at least in some aspects, from that of the "baddies" to that of the "goodies". We can even say that the "greenhouse effect" is possibly a blessing in disguise, in that it is forcing us to plan 40 years ahead for the first time in our history, and it is forcing us into global co-operation.

While more primitive nationalism, and cultural and religious bigotry are still very strong in numerous areas of the world (e.g. the Soviet Union), I firmly believe that these combined forces will be ultimately too strong and will overcome these divisive forces. When the 21st Century begins in 10 years time we will be a long way down this track.

All the old nasty issues such as illiteracy, malnutrition, denial of human rights, and racial, cultural, religious, and gender intolerance are all still alive and well. However, there are many reasons why we should be more optimistic than we have been for a long time. The issue of cooperative globalism is an issue which must be urgently addressed including the development of a paradigm appropriate for cooperative globalism.

The second global issue I want to address is the issue of global technological change and the development of brain based economics in the first world. The three technological revolutions, I've already mentioned, could and most likely will be joined by others in the 1990s. These global changes are leading to the creation of brain based eoncomies in the first world, where creativity in the arts, science and technologies, is leading to the creation of new products and services at rates unimaginable 20 years ago.

Wealth is now dependent on education, and our basic knowledge and our skills, and on the methods we've developed to advance them further. Australia has been left behind, even though on a per capita basis we are a high knowledge and reasonably highly skilled society. Our terms of trade imbalance is due to the fact that we want more of these First World broad based products and services, but we are not making them ourselves for export. We are trying to pay for them with Third World natural based products. Our plight is very similar to third World countries who can't pay their way.

In a nutshell, it is our failure to innovate that is the major cause for our economic problems. We are exporting basically the same items as twenty years ago.

Meanwhile, the profile of our imports has changed dramatically. What we are importing are high value technology-based products, and other products of human brain power. We are an inventive nation, for we have many creative people. However, we are not innovative; we are not turning these inventions into wealth-generating products and services. We must deal with this problem by developing a more creative, enterprising and innovative culture at home. Our predicament is not only due to what we have failed to do at home. It is also due to the fact that others, including newly industrialised countries such as Korea, Taiwan and Singapore, are investing in this brain power and skill to develop new brain based economies. Even though we are restructuring, others are restructuring also, and often at a faster rate than us.

As my time is limited I now would like to begin to examine the implications of some of these issues for our education systems. The first issue is the development of cultures and systems of "lifelong learning" in the majority of the world's countries. This goal has been a UNESCO goal for some years. However, the concept is still neither understood nor being systematically implemented in Australia. Where it is happening, it is happening without a holistic vision to guide it. All Australian States and the Federal Government need to develop strategies to realise a national goal of lifelong learning. Now the rich countries recognise that their economic viability depends on building such systems. The CFF recently issued a report relating to "lifelong learning". It made clear that there were many reasons why we should have it. The most important of these are:

1) The need to maintain education for work throughout life. In many modern industries 50% of these skills are rendered technologically redundant every five years. Just to stay relevant we must renew 50% of our skills every 3-5 years.

ii) Technology itself is "blurring" (as Professor Bill Ford calls it) the demarcation between jobs. To maintain a robot for example one needs to know mechanics, hydrologics, pneumatics and electronics. Until recently these areas were all the responsibility of separate individuals. Technological change therefore means that we must be both more broadly skilled, and also continuously skilling.

iii) We need to ensure that all people have many opportunities to learn throughout life. A lifelong education system will have many more access points, and it will give people who initially "fail" in the education system,

second and third chances. The social justice implications of this are considerable.

Lifelong learning will also have profound implications for our primary and secondary system. They will be increasingly relieved of a need to provide sufficient education to prepare a person for a lifetime of work, retirement and leisure. They should be able to unburden their systems of much of their curriculum. Provided people want to learn, and have the tools to learn, they will be able to thrive in a rapidly changing world by being given opportunities to learn throughout life. I don't think that the implications of lifelong education are being addressed by most of the people running our primary and secondary education systems. I'd like to note in passing that the orderly division of life into the "three ages" of education, work and retirement, is also likely to become more blurred in the 1990s. For example, we already have the "University of the Third Age". Increasingly people are likely to work longer. However, they are also likely to retire from full time work earlier, and work part-time. Schools and education systems will also need to become exemplars of lifelong learning. No education system in the country provides anything like sufficient lifelong education to the teachers in that system. Education systems will have to practise what they preach.

The second educational issue is the development of "learner-driven learning". The new emphasis on education must be less on teaching, and more on learning. There is a big difference. Technology of course is increasing the opportunities for individually driven learner driven learning. I see no reason why this should not continue. We need to fundamentally address the issue of what the role of the "teacher" will be in an education system which is both lifelong and learner-driven.

The third issue I want to address is the issue of the broadening of learning. The OECD have introduced a concept of the "third education passport". The OECD Centre for Educational Research and Innovation (CERI), has proposed that education should consist of "three passports". The first of these is the "academic" passport, the traditional role of education, which most of all provides the tools for lifelong learning. The second passport is the "vocational" passport. This has dominated the educational agenda, rather too much, in my view, since the early 1970s. However it is here to stay. The third educational passport is based on the acquisition of skills by active learning, by doing, rather than listening. Therefore it relates to the issue of "teaching" and "learning" which I have just mentioned. Colin Ball, who first described these three passports for CERI describes the enterprising person as:

> "An enterprising individual has a positive, flexible and adaptable disposition towards change, seeing it as normal, and as an opportunity rather than a problem. To see change in this way, an enterprising individual has a security born of self-confidence, and is at ease when dealing with insecurity, risks, difficulty and the unknown. An enterprising individual has the capacity to initiate ideas ... develop them, and see them through into action in a determined manner. An enterprising individual is able, even anxious, to take responsibility and is an effective communicator, negotiator, influencer, planner, and organiser. An enterprising individual is active, confident, and purposeful, not passive, uncertain and dependent ...".

Being enterprising involves thinking, planning, co-operating, communicating, organising, problem solving, and monitoring. How many of us have ever been given the chance to develop these capabilities in our formal education? Yet we also recognise that these are critical for success in life. These capabilities will empower anybody to have an economically and socially more fulfilling life. A society full of such people will be innovative, creative and economically vigorous, and will rapidly develop a brain based economy, if it is also combined with life long learning and learner driven learning. The enterprise passport needs to become as important as the other two passports in our education systems. Technology can play a major role in helping to create a more enterprising culture. The CFF has released a manual on enterprising skills, "Use Your Initiative" as part of it's Enterprising Futures Program.

A critical ingredient which needs to be promoted in our education systems, as necessary for the 21st Century is "learning to care". This should be part of the paradigm for cooperative globalism. this was a major issue at a UNESCO Conference in Beijing which I attended. Learning to care has many facets including:

Caring for oneself, including one's health

Caring for others

Caring for other species

Caring for a habitable earth.

Caring is likely to become a major focus for education in the 1990s and there will be a major shift towards emphasising greater caring and nurturing.

As we enter the 1990s it is clear that we have become a much less caring society in the 1980s. The spectacular financial crash of 1987 followed by the bankruptcy of some of the paper millionaires of the greedy, yuppie 1980s and the

crisis generated for the bankers who loaned them money - is somehow a fitting end to this decade of "greed is good". I believe that caring and globalism will reinforce themselves in the 1990s, although population growth and urban growth, food security are likely to cause big problems in some third world countries, thereby threatening the development of such a climate of opinion in some places. How about the thought that 40% of Australians will be vegetarian by 2010? How much of the new age thinking and values will become mainstream? A fundamental "caring" theme in education will address a large number of the issues which I am talking about.

A senior executive from the Carnegie Foundation listed a few shifts of emphasis in the education system as likely in the 1990s.

- A change from education for conformity, to education to promote creativity and innovativeness.
- A change from promoting competitiveness, to promoting cooperativeness.
- A change from a natural or parochial viewpoint and loyalty, to that of a global viewpoint and loyalty.
- A change from emphasising the private benefits from learning, to emphasising the public benefits of learning. We need to develop a sense of service and to stress community benefit and the advancement of public good.

This address is about "staying ahead". To me this means living in the future, as an anticipator, vision maker, and creator of the future, rather than a reactor to events initiated only by others. Australia has for most of its history regarded "visionaries" as a highly suspect individual, even a "nut". We are paying a high price for this lack of vision.

The world is passing us by. We still export basically the same major "big ticket" items as we did 20 years ago. No other so-called first world country has this dubious distinction. Conservative forces tell us when we try to change and fail that we are paying for trying to change. I would like market researchers to become a major part of the effort to build a vision driven 1990s and early 21st century in Australia - to ensure that we live in the future today so we avoid living in the past tomorrow. I'd like you to play a major role in creating a much more future oriented Australia capable of making appropriate prophecies and then fulfilling them, to realise preferred futures. The CFF's promotion of "preferred futures" and "vision driven planning" needs your assistance.

REPORT OF THE AUSTRALASIAN WOOD PRESERVATION COMMITTEE

23rd Forest Products Research Conference

H. GREAVES, CHAIRMAN

Since the 22nd Forest Products Research Conference the Committee, now known as the Australasian Wood Preservation Committee (AWPC), has met on five occasions: 6-10 April 1987 at the Forest Research Institute, Rotorua, New Zealand; 21-24 March 1988 at the NSW Forestry Commission, Sydney; 28-29 November 1988 at the Indooroopilly laboratory of the Queensland Forest Service, Brisbane; 4-6 September 1989 at the Forest Research Institute, Lae, PNG; and 31 July to 1 August 1990 at the Highett laboratory of CSIRO Division of Forestry & Forest Products, Melbourne.

The Brisbane meeting marked the end of the formal sessions held jointly with technical members of the preservation industry. As forewarned in my report to the 22nd Forest Products Research Conference these sessions, known as the Joint Wood Preservation Committee meetings (JWPC), were no longer the two-way flow of information concerned with research, technical, and commercial aspects affecting the preservation industry's operations. The idea, which was conceived at the 1971 Forest Products Research Conference was probably unique in the preservation world in representing an interface between the researchers and the industry. Sadly, the industry's perspective on R&D has changed such that their need for this interface is not now seen as a necessity; technical competence has apparently been replaced by economic prowess and the JWPC appears to have little relevance to today's industry. It is hoped that this may change, especially as environmental pressures mount and the industry has to develop more acceptable chemicals and processes. Recruitment of personnel with technical abilities may thus become necessary and the JWPC again a relevant interface.

Current membership of the AWPC is drawn from CSIRO Division of Forestry and Forest Products (Greaves); Forestry Commission of New South Wales, Wood Technology & Forest Research Division (Gardner); Queensland Forest Service, Division of Technical Services (Norton); New Zealand Forest Service, Forest Research Institute (Hedley); Papua New Guinea Department of Forests, Forest Research Institute, (Konabe); Ministry of Forestry, Fiji (Bulai). From this membership it will be seen that the AWPC has extended its sphere of activity. The Committee, however, is concerned that even broader representation should be sought particularly from the Australian laboratories with preservation R&D interests. Accordingly, it is recommended that the WA Conservation & Land Management Department be invited to join the AWPC.

The Brisbane meeting in November 1988 marked Rex Johnstone's last attendance. His contribution to both WPC/AWPC and JWPC over the years was greatly appreciated. On behalf of both the WPC/AWPC and JWPC, his former Committee colleagues, and the Forest products Research Conference, I would like to record our appreciation for his excellent services and wish him well in his retirement. Liam Leightley (QFS) also left the Committee in this period, and his place is now taken by Jack Norton.

The topic headings set up in 1979 as a framework for our sessions have continued to guide the work activities. The table attached to this report summarises the major agenda items of the five meetings.

Preservative formulation and testing work continued to occupy a high proportion of Committee time. Antisapstain chemicals received a deal of attention, together with metal soaps, notably copper naphthenate. Emulsion formulations were discussed, with special reference to modifications to CCAs by the addition of waxes and oils. As noted in my last report to the 22nd Forest Products Research Conference, a great deal of attention, world-wide, is being focussed on developing emulsion-based preservatives, particularly CCA-oil emulsions. It would appear that Australian research leads the field in this innovative chemistry. Diffusion treatment processes received Committee attention with the vapour boron and thickened boron treatments developed in New Zealand

prominent on our agenda. Field testing has always played a prominent part in preservation R&D, and items covering above-ground tests, natural durability, antisapstain treatments, and termiticidal efficacy testing were discussed at the AWPC meetings.

The dominant work of the committee was associated with revising AS 1604 with particular reference to industry/consumer interests, the NSW Timber Marketing Act (TMA), the Queensland Timber Utilisation and Marketing Act (TUMA) and trans-Tasman unification. By way of example, I am including in this report a reminder of the now-agreed six defined hazard classes:

Hazard Level Selection Guide

Hazard level number	Exposure	Specific service conditions	Biological hazard	Typical uses
H1	Inside above ground	Completely protected from the weather and well ventilated and protected from termites	Insects other than termites (i.e. lyctid or anobiid)	Framing, flooring, furniture, interior joinery
H2	Inside above ground	Partially protected from wetting. Nil to slight leaching	Borer, termite and/or moderate decay	Framing, flooring, etc. used in dry or damp situations
H3	Outside above ground	Subject to periodic moderate wetting and leaching	Moderate decay and/or borers and termites	Weatherboard fascia, window joinery, exterior framing and decking
H4	Outside in ground contact	Subject to severe wetting and leaching	Severe decay, borers and termites	Fencing, greenhouses, pergolas and landscaping timbers
H5	Outside in ground contact or in fresh water	Subject to extreme wetting and leaching and/or where the critical use requires a higher degree of protection	Very severe decay, borers and termites	Retaining walls, piling, house stumps, building poles, cooling tower fill
H6	Marine water exposure	Subject to prolonged immersion in sea water	Marine wood borers and decay	Boats hulls, marine piles, jetty cross bracing, landing steps, etc.

In addition to agreeing on common hazard categories, the Committee has greatly assisted the work of Standards Australia, Committee TM/6, in providing guidance on preservative retentions and penetration requirements for the substantially re-cast and long-awaited AS 1604 revision. The figures, while not necessarily being taken directly from any one set of data, were arrived at within Committee, and take into account CSIRO laboratory bioassays, QDF and FCNSW field work, FRI data and overseas experience. In this context, the preservation industry has made significant contributions both within JWPC and in the TM/6 Committee. Indeed, most of the JWPC work was concerned with standards, State Acts, etc., and the table of agenda topics shows that in this area the industry representatives brought forward as many items for Committee consideration as did the research members.

It is interesting that agenda items associated with environmental and safety aspects of the industry have become more prominent in the past two years. Such matters are receiving considerable attention overseas, witness the International Research Group on Wood Preservation special symposium in Cannes, February 1990 "The Challenge - Safety and Environment". I believe we will see more discussion in the future within AWPC, and perhaps the industry will again join us for this important aspect.

In concluding this report, it is clear that 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). Although the interval between meetings is now longer it would seem that AWPC still has a significant role to play, and the Committee should continue to function. It is hoped that the research base, so essential to the work of the Committee, is not eroded by current pressures to deliver *ad hoc* results for short term problem solving.

H. Greaves
Chairman

Summary of agenda items discussed at AWPC meetings

Topic	Rotorua Apr 1987		Sydney Mar 1988		Brisbane Nov 1988		Lae Sept 1989	Melbourne Jul 1990	Total
	AWPC	JWPC	AWPC	JWPC	AWPC	JWPC	AWPC	AWPC	
Preservatives	4	6	4	3	3	1	3	3	27
Treatment Processes	7	6	3	2	3	0	1	2	24
Remedial Treatments	1	0	0	0	1	0	1	3	6
Biodeterioration	3	4	5	4	3	1	1	0	21
Field Testing	6	5	5	3	11	3	6	5	44
Laboratory Testing	2	1	3	0	6	4	2	1	19
Commodities									
Posts	0	0	0	0	0	0	0	0	0
Poles & Piles	4	3	2	2	0	0	0	1	12
Sleepers	2	2	1	1	0	0	0	0	6
Building Timbers	2	1	2	2	1	1	0	0	9
Panel Products	0	0	0	0	0	0	1	0	1
Quality Control, Standards, Legislation	6	8	2	6	5	6	5	4	42
Environmental Plant Hygiene, Safety	0	0	0	2	1	3	4	2	12
Information	6	4	1	0	2	2	3	0	18
Miscellaneous	1	0	0	3	2	1	0	1	8
Total	44	40	28	28	38	22	27	22	249

Report of the Joint Timber Seasoning Committee to the 23rd Forest Products Research Conference for the period November 1986 to November 1990.

The objectives of the J.T.S.C. as redefined at a meeting in February 1985 are:

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. Summarize 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 objectives have been most appropriate over the past four years and although a further review may be desirable, it is felt that the committee has been successful in its goal to be the national advisory body on timber seasoning.

Of considerable value to the J.T.S.C. has been the seasoning group formed and funded by the Australian Timber Research Institute (ATRI) in 1984. Several JTSC members are also members of this group, whose main aim is to develop a more complete understanding of the timber drying process, through the application of mathematical modelling. Emeritus Professor A Oliver, from the University of Tasmania, who led the development of this concept, has been an inspiration to all within the group, and now that ATRI has wound up, it is hoped that the J.T.S.C. will be able to ensure that this valuable modelling research is continued.

Membership

Current committee members are listed on the last page of this report.

The membership covers all major industry sectors and the various research bodies, in particular:-

- State Forest Service Laboratories
- CSIRO Division of Forestry and Forest Products
- Timber Industry Associations
- Timber Industry representation through individuals responsible for drying activities of representative companies

Members who have retired since the 21st Conference are:-

Mr. R. Adams
Mr. F.J. Christensen
Mr. P. Reed
Mr. J. Carson
Mr C. Hogarth

Meetings

The format for committee meetings has been for each member to present a short report or discussion paper on recent research activities and results, and to provide information on new kiln installations, etc. Other business is also discussed and items for action between meetings are identified.

Six meetings have been held since the 22nd conference as follows:

21 November 1986 at CSIRO, Clayton
A representative from the Forest Research Institute attended this meeting and a resolution was passed to invite the F.R.I. to permanent membership. This move has been to the considerable benefit to all concerned.

Other resolutions of note were:

- for nominated members from each State to liaise with their respective Timber Industry Training Councils to encourage and assist with the development of seasoning training courses.
- for a listing of moisture meters and suppliers to be compiled.
- for the variation in equilibrium moisture content within individual States to be examined.

16 July 1987 at Q.F.S., Gympie
It has been the practice of the J.T.S.C. to combine a field inspection with every second or third meeting. Inspections of timber seasoning plants in S.E. Queensland as follows, were organised to coincide with this meeting:

- Qld Forest Service, research facilities and solar kiln in Brisbane

- High temperature pine kilns operated by Queensland Stud Mills, Narangba; CSR Softwoods, Caboolture; Hyne and Son, Tuan and Melawondi.

17 February 1988 at CSIRO, Clayton
This meeting was held to coincide with a series of seasoning workshops for industry, which were organised by J.T.S.C., with assistance from ATRI and the various State Timber Industry Councils. Funding was provided by the National Industry Extension Service (NIES), to assist with travel expenses for Prof. E. Wengert, a wood technology extension specialist in timber seasoning from the Virginia Polytechnic and State University, U.S.A., who accepted our invitation to be the guest speaker at each of the workshops.

Workshops were held in five states as follows:

Queensland	— Gympie
New South Wales	— Grafton
Victoria	— Clayton
South Australia	— Mt. Gambier
Western Australia	— Perth

A workshop planned for Tasmania was cancelled because Prof. Wengert had to return to America due to sudden illness in his family. In fact he was not able to be present for the Mt. Gambier or Perth workshops either. None-the-less all workshops were considered to be most successful and a total of 241 people representing 78 separate companies attended.

The general procedure involved:

- Prof. Wengert's presentation on the hardwood timber industry in the eastern USA and how his extension service operates, with examples of how profit is increased by concentrating on improving techniques instead of cutting costs.
- Presentation on current local, seasoning research.
- Presentation of the DRYWOOD computer model of the timber seasoning process, developed by Prof. Oliver with assistance from the Tasmanian Timber Promotion Board and the ATRI Seasoning Group.

Those attending included company managers, production managers and kiln operators and the workshops provided an opportune focus on improving the standard of seasoning throughout Australia.

The J.T.S.C. meeting was held after the Melbourne Workshop. Items of note were:

- A timber seasoning course developed for the Queensland Timber Industry Training Council had been presented on four separate occasions and the course was being adapted for use in the other States.
- A comprehensive listing of available moisture meters with appropriate commentary on each unit was provided to members.
- The efficiency of any timber seasoning operation can not be evaluated unless accurate records of the costs of individual tasks are known. Prof. Wengert had demonstrated a computer program which he developed to record seasoning costs and it was suggested that this be adapted for distribution in Australia.

3 November 1988 at University of Tasmania, Hobart
Field inspections were made of the timber seasoning operations at Risby Forest Industries and Kemp and Denning Pty Ltd, both in Hobart. The laboratory kilns operated by the Tasmanian Timber Promotion Board at the University of Tasmania were also inspected.

An issue discussed at the end of the committee meeting was the much needed revision of AS1080-1 "Methods of Test for Timber — Moisture Content". Some years previously, J.T.S.C. had written to Standards Australia to initiate a revision, but due to staff changes within Standards the action had lapsed and it was resolved to make a further approach on the matter. Consideration was also given to assessing the potential for incorporating information in relevant standards on the variation in equilibrium moisture content within different regions in Australia.

22 June 1989 at NSW Forestry Commission, Pennant Hills
An item of interest following the customary presentation of reports on research, etc., was the progress being made with seasoning training in each State:

- The Victorian Timber Industry Council had decided to instal kilns for training purposes at the Creswick sawmilling training centre.
- Meetings similar to the Dry Kiln Clubs in U.S.A. had been initiated in Tasmania to encourage kiln operators and supervisors of various companies to get together to exchange information and discuss problems, etc. This concept was proving most successful and was to be commenced in Victoria.
- Timber seasoning courses organised by the various State ITC's were expanding.

While the J.T.S.C. had no direct involvement in any of the above, individual members had been responsible for much of the impetus required to get these projects going.

12 and 13 February 1990 N.Z. Forest Research Institute, Rotorua
This meeting was combined with a Seasoning Research Workshop, inspection of the F.R.I. laboratories and a tour of the sawmilling and timber seasoning operations in Central North Island.

The research workshop provided an opportunity for research workers from the University of Canterbury and the F.R.I. to give input to the group. It also provided more time for the presentation and discussion of technical papers, which is often the item to suffer in normal J.T.S.C. meetings. The industry tour was of particular value to the Australian contingent. Operations inspected were:

Prolog, Rotorua	— High temperature and conventional kilns and a steaming cylinder
Tasman Lumber, Taupo	— Direct gas fired H.T. kilns and a Drymax dehumidifier.
Carter Holt Harvey, Taupo	— RF/Vacuum kiln and an Entec high temperature/vapour boron treatment kiln.
Tasman Lumber, Kawerau	— Conventional kilns using DRYSPEC.
Mt. Maunganui Wharf	— Export of logs and timber.
Aitkens, Mt. Maunganui	— Direct gas fired H.T. kiln.

A Forest Industries Exhibition at Rotorua also coincided with the meeting and this provided an excellent opportunity to view various items of seasoning and sawmilling equipment.

Items of note discussed at the meeting were:

- Revision of AS 1080.1 "Methods of Test for Timber — Moisture Content". Standards Australia had requested that J.T.S.C form the revision committee and a draft prepared by D. Gough and J. Hartley was discussed and appropriate amendment were made.

- Kiln design and performance. Concern was raised that the performance of some recently constructed kilns in both Australia and New Zealand was in many respects quite poor, when attention to the established principles of kiln design would have ensured a much more satisfactory outcome. Considerable expertise is available within J.T.S.C membership and it was resolved that an article on the subject be prepared for publication.

- The desirability of inviting Mr. J Carson to return to the J.T.S.C in his capacity as Technical Director for NAFI.

The past four years have been quite productive for the J.T.S.C. Not all issues raised have been taken to their completion but significant progress has been made in many areas, particularly in the training of kiln operators and the revision of AS 1080.1.

The exchange of technical information in the relatively informal atmosphere of meetings still remains a most important function of the J.T.S.C. In these days when public funding for research is becoming tighter and the public and private sectors' regard for research appears in general to be declining, rather than improving, it is even more important for research workers to be able to discuss projects with their peers and to ensure that duplication of effort does not occur.

The ATRI and the RPRI, which have now been wound up, provided research workers in seasoning (and other fields) not only with encouragement, but also with funding for certain projects. NAFI, which of course has much wider responsibilities than research, has unfortunately been unable to provide either of these needs. Although not for the want of trying on the part of NAFI, the establishment of a Forest Industries Research Fund, has so far not reached any conclusion.

Prior to the 1986 Conference, the J.T.S.C had established a formal link with the Forest Products Research Advisory Panel (FPRAP). This provided the committee with access to the Standing Committee on Forestry. However, the National Forest Products Research Advisory Panel (NFPRAP) which, it appears was set up under NAFI to replace FPRAP, has yet to become fully operational and that link is no longer effective.

As mentioned, the J.T.S.C has still been quite productive during this period and seasoning research is still being undertaken. The most important computer modelling work has also been progressing, but members know that much more needs to be done and we certainly need the assurance that a sound basis has been instituted for the funding of long term investment research.

D.K. GOUGH
19/11/90

JOINT TIMBER SEASONING COMMITTEE MEMBERS

Mr. D.K. Gough, (Chairman)
Queensland Forest Service,
Timber Research & Extension Branch

Mr. R.L. Northway, (Secretary)
CSIRO, Division of Forestry and Forest Products

Mr. W.J. Atyeo
Woods and Forests Department,
South Australia
Operations Research Branch, R & D Division

Mr. J. Dunstan
Dunstan Drying Consultancy

Dr. P. Evans
ANU, Department of Forestry

Mr. G. Hall
Bunning Forest Products Pty Ltd

Mr. J.N. Hartley
Forestry Commission of NSW,
Wood Technology & Forest Research Division

Mr. R.L. Hyne
Hyne and Son Pty Ltd

Mr.H. Kippo
Timber Industry Consultant

Mr. A.V. Jaeger
Kemp & Denning Timbers

Mr. J. Ilic/Mr. A. Rozsa
CSIRO, Division of Forestry and Forest Products

Mr. W. Miller
Forest Research Institute,
New Zealand

Mr. R. McKimm
Department of Conservation Forests and Lands,
Victoria

Mr. S. Bolden
Radiata Pine Research Institute

Mr. R. Mills
Tasmanian Timber Promotion Board

Mr. R.D. Schaffner
Timber Drying Technology Pty Ltd

Mr. P. Shedley
Department of Conservation and Land Management,
Western Australia

FIRE RESEARCH COMMITTEE

Report by

R.H. Leicester
(November 1990)

1. Notable Events Since 1986

Since the last Forest Products Research Conference in 1986, there has been considerable activity related to the use of timber in construction where fire resistance is a consideration. These included four international Conferences in which considerable data on the fire resistance of timber construction was presented, publication of AS 1720.4, the extensive study on fire safety by the Warren Centre Task Force, and the appointment of Bob Appleton as the full time fire officer for NAFI. A listing of the more notable events is as follows;

- 1988 International Conference on Timber Engineering (Seattle, Sept. 1988)
- 1989 Pacific Timber Engineering Conference (Auckland, Sept. 1989)
- 1990 International Timber Engineering Conference (Tokyo, Oct. 1990)
- Warren Centre Project 'Fire Safety and Engineering' (Australia, completed 1989)
- Conference on Fire Engineering for Building Structures and Safety. Institution of Engineers, Australia (Melbourne, Aug. 1989)
- Publication of AS 1720.4 – Timber Structures. Part 4: Fire-Resistance of Structural Timber Members (Standards Australia, 1990)
- Appointment of a full time officer on fire technology (Bob Appleton) by NAFI.
- Visit to Australia by a Canadian mission on fire safety regulations
- Publication of Building Code of Australia

2. Risk Assessment

In building regulations, both in Australia and overseas, there has been a discrimination against timber on the basis of its combustible nature. Arguments against this discrimination have never been successful; the only hope of reversing the situation has been in the development and acceptance of risk models for designing systems for specified performance targets. In recent years there has been a glimmer of hope in this regard with the development of three major project proposals based on risk modelling. These are as follows;

(i) Standards Australia draft design Code on Fire Safety Systems

(ii) AUBRCC project on non-combustibility and fire resistance levels

(iii) BRR/AUBRCC project on the development of performance based codes

In addition NAFI has commenced a project to obtain acceptance of timber for 3–storey residential buildings. It will be based on risk modelling and undertaken by the National Research Council of Canada.

3. Early Fire Hazard

Difficulties are being experienced due to the requirement that timber linings for public buildings need to pass early fire hazard ratings as measured by AS 1530. Variability in the results of tests and failure to meet regulatory requirements are factors.

Fire retardant systems are no longer controlled by State marketing acts, and the time is opportune for the formation of an industry based quality control scheme. Paint-on systems are prohibited by the BCA and major hurdles would need to be overcome to obtain their acceptance.

Currently CSIRO (DBCE) and WTFRD are conducting full scale corridor tests which include timber as a lining material. There is a high probability that the results will be accepted by the BCA.

4. Structural Performance

The standard AS 1720.4 has been accepted by regulatory authorities, but more test data is required before it can be applied to complete wall and floor assemblies. Currently NAFI is collecting such data from both local and overseas sources.

WTFRD have undertaken charring tests on eight species and UNSWIT have tested loaded glulam beams under fire conditions. Moves are being made to promote the use of LVL in the roofs of tilt-up wall reinforced concrete construction; timber does not expand during a fire and hence, unlike steel, it does not push walls out of position.

5. Bushfires

During the past few years the public discussion on bushfires has become increasingly informed. It is now appreciated that ember attack is the basic threat, and there is no longer an unfair discrimination against the use of timber. Relevant building standards are not yet completed; however significant technical progress has been made in the classification of the hazard (both for houses and bridges), particularly by CSIRO (DBCE).

6. Future of the Fire Research Committee

With the increased activity on fire research related to timber construction, and with the appointment by NAFI of a full time fire officer, it is timely to reconsider the role of the fire research committee. Currently discussions are in progress to reorganise or replace this committee so that we have a more effective forum for planning future activities related to building regulations associated with the effects of fire on timber. It is suggested that both research and industry personnel will be represented on this committee.

POSTER INDEX

Poster Number	Title	Author(s) and Affiliation(s)
1	Characterisation of Phenolic Resins by Nuclear Magnetic Resonance Spectroscopy (NMR)	M. Reilly P.J. Collins Y. Yazaki (CSIRO DFFP)
2	Characterisation of Phenolic Resins by Gel Permeation Chromatography	S.D. Terrill P.J. Collins Y. Yazaki (CSIRO DFFP)
3	Reducing Surface Checking of Brush Box by PVC Wrapping	A. McNaught (Qld For. Ser.)
4	Efficacy of Selected Knot Sealers on Three Painted Softwood Timbers	M.L. Cause (Qld For. Ser.)
5	Performance of Four Timber Species as Exposed Timber Decking	M.L. Cause (Qld For. Ser.)
6	The Evaluation of above Ground Durabilities for a Range of Timbers and Sites in Eastern Australia	M.L. Cause (Qld For. Ser.)
7	Micro Computer Assisted Measurement of Wood Properties	G.A. Hart K.J. Harding (Qld For. Ser.)
8	Investigations on the Weathering of Chemically-Labelled Modified Wood by Scanning Electron Microscope/Energy Dispersive X-Ray Analysis	D. Plackett (FRI N.Z.)
9	Wood Density, Fibre Properties and Growing Conditions in Radiata Pine	B.J. Myers T.E. Craig R. Evans M.L. Benson (CSIRO DFFP)

10	The Effect of 12 Years Weathering on the Properties of Treated and Untreated Radiata Pine Plywood	J. McLaughlan (FRI N.Z.)
11	Thickened Boron Treatment - "DIFFUSOL"	P. Vinden (FRI N.Z.) J. Drysdale M. Spence (Hickson Tim.Prod.)
12	Vapour Boron Treatment of Solid Wood	P. Vinden R. Burton T. Bergervoet (FRI N.Z.)
13	Recent Data From CSIRO Field Tests of Natural Durability and Preservative Efficacy	J.W. Creffield G.C. Johnson N. Nguyen J.D. Thornton (CSIRO DFFP)
14	Identification of Sludges, Spots, Stickies by Fourier Transform Infrared (FTIR) Spectroscopy	A.J. Michell (CSIRO DFFP)
15	Structural Properties of Timber with Reference to Grading	W. Joe (For. Comm. NSW)
16	Inoculation of Sassafras (*Atherosperma moschatum* Labill.) Trees with Stain Fungi	M. Line (Tas. Univ.) M. Jessup T.J. Wardlaw (For. Comm. Tas)
17	Leaching of CCA Salts from Freshly Treated Timber	B. Atyeo A. Cameron (Woods and For.) B. Ellis (Koopers-Hickson)
18	Australian Furniture Research & Development Institute Ltd: Research Projects	B. Ozarska (AFRDI)

19	Emulsions - The Key to the Future	J. Goode J.B. Watkins (CSIRO/Koppers)
20	Plywood and Veneer Research at the NSW Division of Wood Technology and Forest Research	J. Wade

THE POSTER SESSION

WAS WELL ATTENDED

NUCLEAR MAGNETIC RESONANCE SPECTROSCOPY OF PHENOLIC RESINS

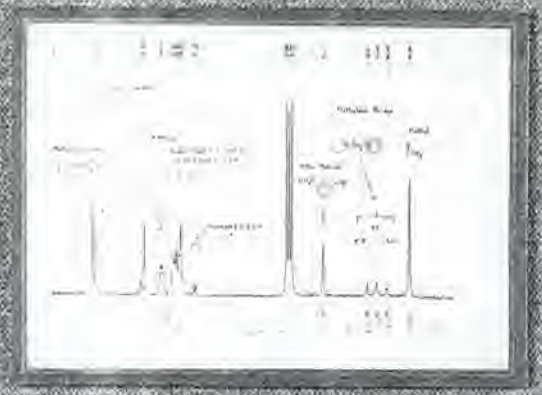


Fig.1 Quantitative C-13 NMR spectrum of a phenolic resin

Nuclear magnetic resonance (NMR) spectroscopy can provide valuable information on the chemical structure of phenol formaldehyde (PF) resins. Due to the high natural abundance of ^{1}H (99.98%) an analysis of PF resins using ^{1}H-NMR provides reproducible and quantitative data in a short time. Unfortunately, because of the polymeric nature of the resins ^{1}H-NMR yields signals that are broad, lacking in fine detail, and overlap to a degree. In contrast, far more detail and information can be obtained, both structurally and quantitatively from the ^{13}C-NMR of acetylated derivatives of PF resins. In spite of the low natural abundance of ^{13}C (1.108%), the need to suppress the Nuclear Overhauser Effect, and the requirement to acetylate the PF resins for NMR analysis, the authors have found both ^{13}C- and ^{1}H-NMR in conjunction with GPC (see related poster), to be invaluable tools in the characterisation of PF resins.

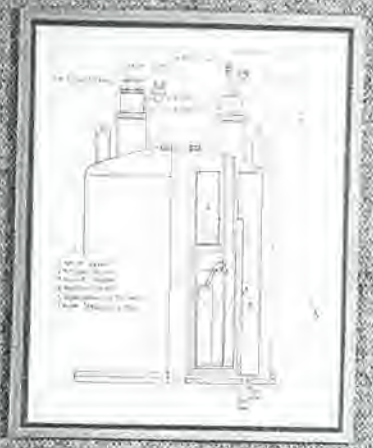


Fig.3 Bruker AM-100 Superconducting Magnet Arrangement

Fig.2 Quantitative H-1 NMR spectrum of a phenolic resin

ANALYSIS OF RESINS A AND B BY QUANTITATIVE NMR SPECTROSCOPY

	RESIN A	RESIN B
% acetylated	50.8	47.6
benzylic:methylene	1.00:1.00	1.00:1.00
degree of substitution	6.478	6.37
degree of polymerisation	1.22	1.03
molar ratio (F:P)	1.20:1	2.17:1

Fig.4 Bruker AM-100 NMR spectrometer

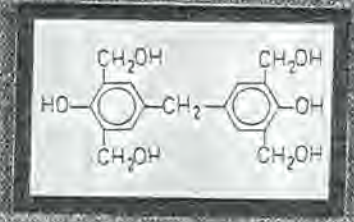


Fig.5 General Resol Structure

M.J. REILLY , P.J. COLLINS , Y. YAZAKI

POSTER NO. 1

CHARACTERISATION OF PHENOLIC RESINS BY NUCLEAR MAGNETIC RESONANCE SPECTROSCOPY (NMR)

Mary Reilly, P.J. Collins and Y. Yazaki

The increasing environmental and ecological concerns about log harvesting and the diminishing availability of large diameter logs of high quality, is leading to an increase in the production of reconstituted wood products. The manufacture of products such as plywood, particle board and laminated timber relies on wood adhesives, among which phenol-formaldehyde (PF) resins are known to provide high quality, strong and durable bonds.

PF resins are synthesized by reacting phenol and formaldehyde under heat and either acidic or alkaline conditions. Australian resin manufacturers and users have generally characterised resins by measurement of viscosity, Ph, total solids, gelation time, and free formaldehyde content. However, it has been found the commercial resins, which were characterized as "similar" can give very different gluebond quality. Therefore, a method was needed to further characterise PF resins.

Nuclear magnetic resonance (NMR) spectroscopy can provide extremely valuable information on the chemical structure of compounds. Due to the high natural abundance of ^{1}H (99-98%), an analysis of phenolic resins using proton magnetic resonance (^{1}H NMR) provides reproducible and quantitative data in a short time. However, since some peaks overlap, quantitative data are not sufficiently accurate to define chemical structure. On the other hand, due to the greater chemical shift range, carbon-13 (^{13}C) NMR can produce well resolved peaks so that more accurate qualitative and quantitative information can be readily obtained. A disadvantage is the long experimental times required because of the low natural abundance of ^{13}C (1.1%).

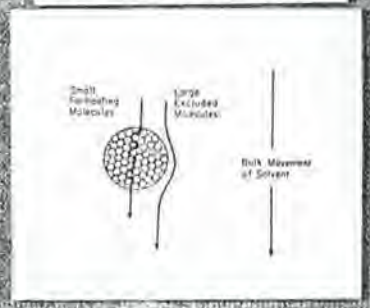
This poster paper illustrates how well phenolic resins can be characterised by NMR, particularly ^{13}C-NMR, and how a combination of ^{1}H NMR and ^{13}C NMR can be used.

GEL PERMEATION CHROMATOGRAPHY

OF PHENOLIC RESINS

VISCOSITY

PHENOL FORMALDEHYDE CONDENSATION



GEL PERMEATION MECHANISM

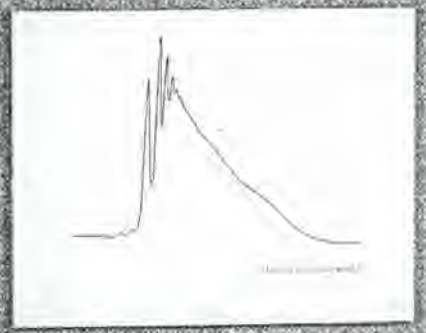
PHENOL FORMALDEHYDE (PF) BASED ADHESIVES ARE USED IN PRODUCTION OF PLYWOOD, PARTICLEBOARD AND LAMINATED VENEER LUMBER ETC. WHERE STRENGTH AND EXTERIOR DURABILITY IS REQUIRED.

COMMERCIAL PF RESINS ARE TAILORED BY CONTROLLED CONDENSATION OF PHENOL WITH FORMALDEHYDE TO YIELD VISCOSITY, GELATION TIME AND STORAGE STABILITY CONSISTENT WITH DEMONSTRATED ADHESION PERFORMANCE.

GEL PERMEATION CHROMATOGRAPHY (GPC) PROVIDES A MOLECULAR WEIGHT DISTRIBUTION (MWD) WHICH CAN CHARACTERIZE A PF RESIN AND THE CORRESPONDING END PROPERTIES IMPORTANT IN WOOD ADHESION.

GELATION TIME

MOBILE PHASE FLOW PATH



NARROW MWD $\bar{M}_W$=4,000

BROAD MWD $\bar{M}_W$=20,000

S.D.TERRILL ,P.J.COLLINS AND Y.YAZAKI

POSTER NO. 2

CHARACTERIZATION OF PHENOLIC RESINS BY GEL PERMEATION CHROMATOGRAPHY

S.D. Terrill, P.J. Collins and Y. Yazaki

Phenol-formaldehyde (PF) based adhesive systems are used to produce strong, durable and value-added end products, such as plywood. The Australian market for plywood is worth up to $125M and demand for phenolic resins increases annually by 1,000 tonne, valued at $2.5M.

PF resins, produced by condensation and polymerization of phenol with formaldehyde must possess appropriate viscosity, gelation time, stability and compatibility for them to perform in commercial systems.

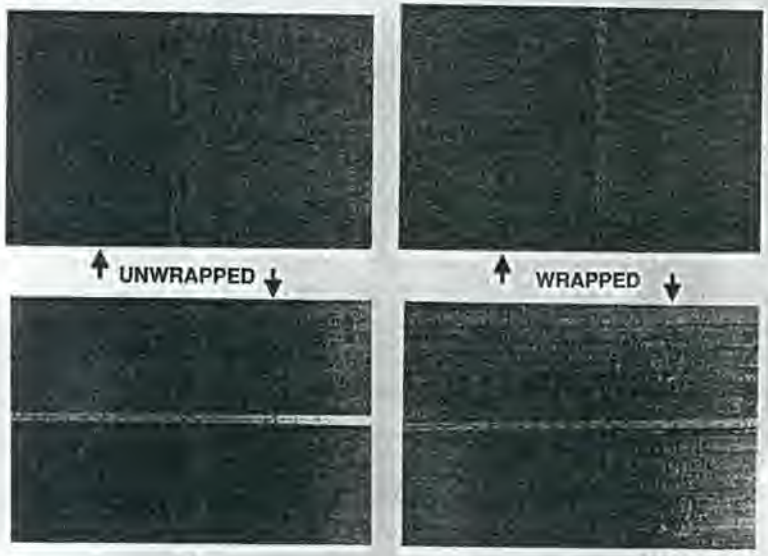
It has been established by CSIRO that most bond failures are due to over-penetration or dryout of adhesives in the glueline. Over-penetration is related to excessive flow and dryout insufficient flow of adhesive. Adhesive flow is affected by many factors including characteristics of wood substrates such as anatomical features, extractives and wood moisture content as well as glue formulations and gluing conditions, e.g. glue spread, assembly time, etc. However, the most important influence on adhesive flow is believed to be the molecular weight distributions of the phenolic resins.

Gel Permeation (or Size-Exclusion) Chromatography is especially useful in providing quantitative and comparative molecular weight distribution data.

This poster presentation illustrates that Gel Permeation Chromatography can be extremely powerful in phenolic resin characterization and has the potential for predicting resin flow behaviour, on the basis of molecular weight distribution.

REDUCING SURFACE CHECKING OF BRUSH BOX BY PVC WRAPPING

Brush Box (Lophostemon confertus), like many other Australian hardwoods, is prone to surface checking during air drying. These checks are caused by high levels of tension stress near the surface of the wood induced by steep moisture content gradients which initiate very early in the drying process soon after sawing. Some checking has been acceptable when forest hardwoods have been applied to traditional uses, but if they are to be used as high value cabinet timbers, all checking must be eliminated. This can be achieved by wrapping the timber with a single layer of thin, semi-permeable PVC film. The film is glued to the surface using a modified PVA glue. This process, originally developed by the Tasmanian Timber Promotion Board, has been commericialized by Bunnings Forest Products in W.A. for jarrah drying. The wrapping system works equally well with Queensland hardwoods that are prone to surface checking.



Brush box slabs of nominal section 450 x 45 mm were docked to produce two 1.8 m long pieces from each, one of which was wrapped using the PVA / PVC wrapping system and the other being the unwrapped control. The wrapped and unwrapped pairs were included in a pack for air drying in Brisbane, commencing in September 1988.

AFTER 4 WEEKS EXPOSURE

The unwrapped slabs developed severe surface checking in the backsawn regions. Checks were typically 0.7 to 1.5 mm wide. The wrapped slabs by contrast had no checking whatsoever, even around grain deviations caused by knots.

AFTER 20 WEEKS EXPOSURE

Surface checks in the unwrapped slabs were no longer clearly visible, as they had closed up in response to the shrinkage of the core of the section. However, docking of slabs showed that checks penetrated to a depth of about 25% of slab thickness. The wrapped slabs did not contain any surface or internal checks.

DRYING TIME

The wrapped brushbox slabs in this trial took approximately 25% longer to reach 25% moisture content than the unwrapped controls. It is expected that further trials using a slightly more permeable film will yield results similar to that obtained with jarrah, where drying time of wrapped timber is about 10% to 15% longer than for unwrapped timber.

The extra cost of production attributable to longer drying times and the cost of wrapping should be more than offset by improvements in volume and and grade recovery. The high selling prices obtained for "cabinet grade" jarrah has also allowed companies to maintain existing sales revenue levels with reduced log volume intake.

AFTER KILN DRYING

After air drying, both wrapped and unwrapped slabs were dried to 10% moisture content in a solar kiln. The surface checks in the unwrapped sample (top) are clearly visible.

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Queensland Forest Service

POSTER NO. 3

REDUCING SURFACE CHECKING OF BRUSH BOX BY PVC WRAPPING

A. McNaught

Brush box (*Lophostemon confertus*), like many other Australian hardwoods, is prone to surface checking during air drying. These checks are caused by high levels of tension stress near the surface of the wood induced by steep moisture content gradients which initiate very early in the drying process soon after sawing. Some checking has been acceptable when forest hardwoods have been applied to traditional uses, but if they are to be used as high value cabinet timbers, all checking must be eliminated. This can be achieved by wrapping the timber with a thin, semi-permeable PVC film. The film is glued to the surface using a modified PVA glue. This process, originally developed by the Tasmanian Timber Promotion Board has been commercialised by Bunnings Forest products in WA for jarrah drying. The wrapping system works equally well with Queensland hardwoods that are prone to surface checking.

Trials have shown surface checks in uncoated 40 mm thick boards develop rapidly even in mild air drying conditions. Checks reach maximum width after approximately 4 weeks but by 20 weeks they are closed tightly enough to be invisible on rough sawn timber.

No checking developed in wrapped timber, even around areas of grain distortion. Wrapped timber took 25% longer to air dry to 25% moisture content.

PVC wrapping provides opportunities for sawmillers to enter the high value seasoned product market at relatively low capital cost and without extremely skilled seasoning staff. As markets develop, most companies would dispense with wrapping and use carefully designed kilns for predrying.

EVALUATION OF SELECTED KNOT SEALERS ON THREE PAINTED SOFTWOOD TIMBERS

The Queensland Forest Service and T.R.A.D.A.C. installed a cooperative trial in February 1990 to investigate the effectiveness of four knot seal coatings for the control of knot bleed in three species of softwood with different seasoning, preservation treatment, and paint finish systems.

TEST UNITS

Species tested were hoop pine (*Araucaria cunninghamii*), slash pine (*Pinus elliottii* var. *elliottii*), and white cypress pine (*Callitris glaucophylla*). The test units were docked from routine industry stocks of knotty lining or cladding material, and were solid timber 'tiles' approximately 100 mm x 150 mm, containing a single knot or knot cluster with surrounding clear wood. Each source board had its moisture content checked by the oven-dry weight method. Knot sealers were applied evenly to the entire knot surface area and immediate surrounds, and allowed to dry overnight. Acrylic and alkyd paint systems (primer, undercoat, and white topcoat) were subsequently applied following manufacturer's recommendations.

The 550 test units in the trial were attached to a wall in a 'protected exterior' situation, with exposure to good light but only occasional direct rain wetting. Additionally, the test units were installed in a full randomised format to even out any possible 'local' environmental effects over the 20 m² exposure area.

RESULTS

Knot sealer efficacy was gauged by a present/absent record of paint discoloration from knot bleed. Data collection was undertaken after 3 months and 6 months exposure. The colour chart indicates relative performance of the four sealers and a control. Each cell position in the chart had four replications in the trial.

Estanol 7008
This two-part mix was the best performer in preventing knot bleed. It was effective in all situations, regardless of timber species, acrylic or alkyd paint systems, or moisture status of the wood.

Shellac
Shellac was effective in preventing bleed in white cypress pine, regardless of acrylic or alkyd paint systems, or moisture status of the wood. Shellac was also effective on seasoned timber finished with the alkyd paint system (slash, CCA treated slash, and CCA treated hoop).

With the exception of cypress, shellac was poor in preventing bleed on timber finished with acrylic paint.

Stain Seal
Stain seal was effective in preventing bleed in white cypress pine, regardless of acrylic or alkyd paint systems, or moisture status of the wood. Stain seal was also effective on seasoned CCA treated hoop finished with the alkyd paint system, but was variable with other seasoned timbers.

With the exception of cypress, stain seal was poor in preventing bleed on timbers finished with acrylic paint.

Silvasheen
Silvasheen (silverfrost type) was only effective in preventing bleed on seasoned white cypress pine finished with an alkyd paint system. Silvasheen was variable or poor at preventing knot bleed in all other combinations tested.

SEALER TYPE	CYPRESS				SLASH				CCA SLASH				HOOP				CCA HOOP			
	Acrylic		Alkyd		Acrylic		Alkyd		Acrylic		Alkyd		Acrylic		Alkyd		Acrylic		Alkyd	
	Seasoned	Unseasoned	Seasoned	Unseasoned	Seasoned	Unseasoned	Seasoned	Unseasoned	Seasoned	Unseasoned	Seasoned	Unseasoned	Seasoned	Unseasoned	Seasoned	Unseasoned	Seasoned	Unseasoned	Seasoned	Unseasoned
1 CONTROL																				
2 SILVASHEEN						not tested		not tested												
3 SHELLAC																				
4 STAIN SEAL																				
5 7008 ESTAPOL																				

poor
variable
good

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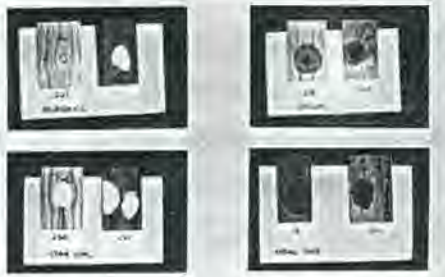

The four knot seal coatings were applied on the knot and immediate surrounds and allowed to dry overnight before test units were painted with acrylic or alkyd paint systems.

Examples of bleed through the finish coating to test units three months after commencement of the trial.

POSTER NO. 4

EFFICACY OF SELECTED KNOT SEALERS ON THREE PAINTED SOFTWOOD TIMBERS

M.L. Cause

The Queensland Forest Service and T.R.A.D.A.C. installed a cooperative trial in February 1990 to investigate the effectiveness of four knot seal coatings in controlling knot bleed in three species of softwood with different seasoning, preservation treatment, and paint finish systems.

Species tested were hoop pine (*Araucaria cunninghamii*), slash pine (*Pinus elliottii* var. *elliottii*), and white cypress pine (*Callitris glaucophylla*). Test units were solid timber 'tiles' approximately 100 mm x 150 mm, containing a single knot or knot cluster with surrounding clear wood. All test units were docked from routine industry stocks of knotty lining or cladding material, and each source board had its moisture content checked by oven-dry weight method. Knot sealers were applied evenly to the entire knot surface area and immediate surrounds, and allowed to dry overnight. Primer and paint finishes were subsequently applied following manufacturer's recommendations.

The 550 test units in the trial were attached to a wall in a 'protected exterior' situation, featuring good light but only occasional direct rain wetting. Additionally, the test units were installed in a full randomised format to even out any possible 'local' environmental effects over the 20 m^2 exposure area.

The major interest in knot sealer efficacy is a presence/absence record of paint discoloration from knot bleed. Data collection was undertaken after 3 months and 6 months exposure. Results were assessed using log linear analysis of contingency tables containing frequency (count) data for presence of discoloration.

PERFORMANCE OF FOUR TIMBER SPECIES AS EXPOSED TIMBER DECKING

The Queensland Forest Service and T.R.A.D.A.C. installed a cooperative trial in January 1987 to investigate the decking performance of white cypress pine, CCA treated slash pine, CCA treated hoop pine, and brush box.

TEST UNITS

Decking panels were constructed with standard industry profile decking boards fixed over joists at 450 mm centres, with each test panel being approximately 1.1 m x 0.6 m in area. A total of 96 deck panels were constructed. All species (72 panels) were installed in an open sunny location while a further 24 panels of one species (white cypress pine) were installed at a nearby well-shaded location. Several factors were incorporated in the test panels, as follows:-

joist seal	—	copper preservative emulsion present; absent (all species)
gap size	—	3 mm; 6 mm (all species)
finish	—	paint; stain; nil control (all species)
board orientation	—	heartwood up; down (cypress only)
nail type	—	annular shank; plain shank (CCA slash only).

ASSESSMENT

To assess the trial, individual boards were allocated separate numerical scores for measured performance in surface checking, end splitting, cupping, nail proudness, knots, splinters and decay. Subsequently, these parameter scores for each of the nine individual boards in a deck panel were aggregated to produce a simple panel performance score, with larger scores indicating better performance than lower ones.

RESULTS

Statistical analysis of trial results after 24 months and 36 months exposure, has demonstrated a number of significant factors influencing deck performance.

Panels finished with acrylic decking paint performed best in physical appearance of all species, having less surface checking, raised knots and splinters than other finishes. However, following three years exposure, this finish was associated with significant decay in cypress sapwood and some surface decay in brush box heartwood.

Panels finished with a combination of one coat all round of water repellent followed by two coats of oil-based stain performed best against decay. Brush box heartwood showed no decay with this finish, while cypress sapwood decay was substantially reduced. Decking board orientation was also significant in cypress, with less sapwood decay occurring when boards were fixed with heartwood side uppermost.

Nail type used was significant in CCA treated slash decking, with annular shank nails having significantly less proudness after two years exposure than plain shank nails.

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Decking panels were installed in sets of three, with paint, stain, and nil finish.

Cypress pine sapwood decay in acrylic paint finished decking following three years exposure.

Surface heartwood decay in acrylic paint finished brush box decking following three years exposure.

Nail proudness after two years in CCA treated slash pine decking was significantly worse in plain shank nails (above) than in annular shank nails (below).

POSTER NO. 5

PERFORMANCE OF FOUR TIMBER SPECIES AS EXPOSED TIMBER DECKING

M.L. Cause

The Queensland Forest Service and T.R.A.D.A.C. installed a cooperative trial in January 1987 to investigate the decking performance of white cypress pine, CCA slash pine, CCA hoop pine, and brush box.

Decking panels were constructed with full-size industry standard decking boards fixed over joists at 450 mm centres, with each test panel being approximately 1.1 m x 0.6 m in area. A total of 96 deck panels were constructed. 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. A number of factors were incorporated in the test panels, and these were as follows:

joist seal	-	copper preservative emulsion present; absent (all species)
gap size	-	3 mm; 6 mm (all species)
finish	-	paint; stain; nil control (all species)
board orientation	-	heartwood up; down (cypress only)
nail type	-	annular shank; plan shank (CCA slash only)

To assess the trial, individual boards were allocated separate numerical scores for measured performance in surface checking, end splitting, cupping, nail proudness, knots, splinters, and decay. Subsequently these parameter scores for each of the nine individual boards in a deck panel were summed to produce a simple panel performance score, with larger scores indicating better performance than lower ones.

Following three years exposure, statistical analysis of trial results has demonstrated a number of significant factors influencing deck performance. The finish system used has a major impact on performance for all species. Additionally, board orientation and sun exposure were significant in cypress pine, while nail type was significant in slash pine decking.

THE EVALUATION OF ABOVE GROUND DURABILITIES FOR A RANGE OF TIMBERS AND SITES IN EASTERN AUSTRALIA

SITES

The Queensland Forest Service has established a comprehensive trial to determine the 'above-ground' durability of 39 local and imported timber species at 11 sites in eastern Australia. The exposure test sites represent a range of climatic environments. The main site is at Beerburrum near Brisbane, and other reference sites are Innisfail, Townsville, Mackay, Rockhampton, Toowoomba, Dalby, Mt Isa, Sydney, Canberra and Melbourne.

TEST UNITS

The trial employs simulated joinery units i.e. 35 mm x 35 mm cross section mortise and tenon L-joints exposed above ground in the weather in a rack frame designed to provide a high decay hazard. There are 9 reference species at all sites, with a further 30 species configurations at the main site at Beerburrum. Two treatments (painted and unpainted) are included in the trial, and each L-joint test at each site has 24 replications. In total, 6192 L-joints were prepared and set out in the field in 1987. Support for the trial has included the retention of matched laboratory pieces from every individual L-joint, and provision for setting out a second batch of reference L-joints after an appropriate period.

ASSESSMENTS

Eight assessments will be made over the 20-25 years duration of the trial. Assessment involves a visual decay inspection of all replications in the field, together with a destructive laboratory check of a smaller number (3 replicates) for presence of Basidiomycete fungi. Monitoring of climate data is being undertaken at all sites, and the relationship between climate indices and decay scores will be examined. The first full field inspection of the trial is being completed in 1990, following 3 years of field exposure.

REFERENCE SPECIES (all sites)

Trade name	Botanical name	Type of timber
radiata pine	*Pinus radiata*	unreated sapwood
white cypress pine	*Callitris glaucophylla*	unreated sapwood
Douglas fir	*Pseudotsuga menziesii*	fast growth heartwood Nth America
northern silky oak	*Cardwellia sublimis*	
brush box	*Lophostemon confertus*	outer heartwood
western red cedar	*Thuja plicata*	slow growth heartwood Nth America
spotted gum	*Eucalyptus maculata*	
grey ironbark	*Eucalyptus drepanophylla*	
radiata pine	*Pinus radiata*	CCA treated sapwood above-ground

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OTHER SPECIES (Beerburrum site only)

Softwoods

Trade name	Botanical name	Type of timber
black cypress pine	*Callitris endlicheri*	sapwood and heartwood native
Caribbean pine	*Pinus caribaea*	heartwood plantation
Douglas fir	*Pseudotsuga menziesii*	slow growth heartwood Nth America
hoop pine	*Araucaria cunninghamii*	heartwood native
hoop pine	*Araucaria cunninghamii*	heartwood plantation
radiata pine	*Pinus radiata*	heartwood plantation
slash pine	*Pinus elliottii*	heartwood plantation
white cypress pine	*Callitris glaucophylla*	heartwood native

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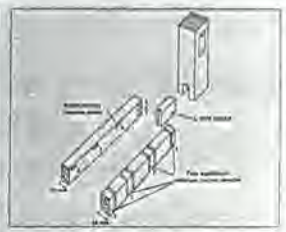
Hardwoods

Trade name	Botanical name	Type of timber
alpine ash	*Eucalyptus delegatensis*	
blackbutt	*Eucalyptus pilularis*	mature inner heartwood
blackbutt	*Eucalyptus pilularis*	mature outer heartwood
blackbutt	*Eucalyptus pilularis*	regrowth heartwood
brush box	*Lophostemon confertus*	inner heartwood
flindall silky oak	*Neorites kevediana*	
forest red gum	*Eucalyptus tereticornis*	
Johnstone River hardwood	*Backhousia bancroftii*	
kamarere	*Eucalyptus deglupta*	
kapur	*Dryobalanops* spp.	
light red meranti	*Shorea* spp.	
messmate	*Eucalyptus obliqua*	
mountain ash	*Eucalyptus regnans*	
Queensland maple	*Flindersia brayleyana*	
red balau	*Shorea* spp.	
red mahogany	*Eucalyptus resinifera*	
rose alder	*Caldcluvia paniculosa*	
rose gum	*Eucalyptus grandis*	
spotted gum	*Eucalyptus citriodora*	
spotted gum	*Eucalyptus henryi*	
Sydney blue gum	*Eucalyptus saligna*	
white Eungella satinash	*Syzygium* sp.	

Field data collection using a Husky microsystem.

Removing L-joints for destructive laboratory sampling.



Method of conversion of an L-joint mock for destructive laboratory sampling.

POSTER NO. 6

THE EVALUATION OF ABOVE GROUND DURABILITIES FOR A RANGE OF TIMBERS AND SITES IN EASTERN AUSTRALIA

M.L. Cause

The Queensland Forest Service has established a comprehensive trial to determine the 'above-ground' durability of 39 local and imported timber species at 11 sites in eastern Australia. The exposure test sites generally represent a range of climatic environments. The main site is a Beerburrum near Brisbane, and other reference sites are Innisfail, Townsville, Mackay, Rockhampton, Toowoomba, Dalby, Mt Isa, Sydney, Canberra and Melbourne.

This trial employs simulated joinery units i.e. 35 mm x 35 mm cross section mortise and tenon L-joints exposed above ground in the weather in a rack frame designed to provide a high decay hazard. There are 9 reference species at all sites, with a further 30 species configurations at the main site at Beerburrum. Two treatments (painted and unpainted) are included in the trial, and each L-joint test at each site has 24 replications. In total, 6192 L-joints were prepared and set out in the field in 1987.

Support for the trial has included the retention of matched pieces from every individual L-joint, and provision for setting out a second batch of reference L-joints after an appropriate period. Monitoring of climate data is being undertaken at all sites, and the relationship between climate indices and decay scores will be examined.

Eight assessments will be made over the 20-25 years duration of the trial. Assessment involves a visual decay inspection of all replications in the field, together with a destructive laboratory check of a smaller number (3 replicates) for presence of Basidiomycete fungi. The first full field inspection of the trial is currently being completed in 1990 (3 years exposure), however 3 replicates were removed from all sites in 1988 (1 year exposure) to provide early failure and Basidiomycete colonisation data.

MICROCOMPUTER ASSISTED MEASUREMENT OF WOOD PROPERTIES

The system illustrated is a microcomputer based wood properties assessment network developed by the Queensland Forest Service. It comprises four IBM PC/AT compatible workstations networked into a MIPS 1000 minicomputer which acts as the file server for this network.

The four workstations are:

A. Video Camera – for image processing and analysis
B. Analytical Balance
C. Graphics Tablet – mounted over a projection microscope
D. Linear Traversing Stage

The system can be used for data acquisition when measuring:

- Latewood percent, heartwood and reaction wood incidence (workstation A)
- Density, moisture content and extractives content (workstation B)
- Fibre dimensions, spiral grain angle and stem cross-sectional area features such as heartwood, reaction wood and resin defects (workstation C), and
- radial growth ring increments, earlywood / latewood percentages and other distance measurements (workstation D).

PROJECTED IMAGE MEASUREMENT

SPIRAL GRAIN

Graphics Tablet

FIBRE LENGTH

Sample Types:
Segmented Core Sample (Spiral Grain)
Macerated fibre pulp solution (Fibre Length)

DIGITAL IMAGE PROCESSING

CCD Video Camera

LATEWOOD
COMPRESSION WOOD

Sample Types:
Core or Disc

Video Monitor

WEIGHING WORKSTATION

All devices are networked to a MIPS 1000 minicomputer

LINEAR TRAVERSING

BASIC DENSITY
MOISTURE CONTENTS
RESIN CONTENT

Sample Types:
Whole cores
Segmented Cores
Wedges
Strips
Blocks

Core Sample

AREA MEASUREMENT

Photocopies are attached to a graphics tablet where areas are traced with a computer cursor.

COMPRESSION WOOD %
HEARTWOOD %
RESIN DEFECT %

Standing Tree

Stem Cross-section (Disc)

Stem Disc samples are photocopied for Area Analysis

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For futher information, please contact:
GARY HART and KEVIN HARDING
Wood Structure Laboratory
Queensland Forest Service
Phone: (07) 877 0767 Fax: (07) 371 2217

POSTER NO. 7

MICROCOMPUTER ASSISTED MEASUREMENT OF WOOD PROPERTIES

G.A. Hart and K.J. Harding

The system illustrated is a microcomputer based wood properties assessment network developed by the Queensland Forest Service. It comprises four IBM PC/AT compatible workstations networked into a MIPS 1000 minicomputer which acts as the file server for this network.

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- Latewood per cent, heartwood and reaction wood incidence (workstation A)
- Density, moisture content and extractives content (workstation B)
- Fibre dimensions, spiral grain angle and stem cross-sectional area features such as heartwood, reaction wood and resin defects (workstation C), and
- Radial growth ring increments, earlywood/latewood percentages and other distance measurements (workstation D).

SEM/EDX ANALYSIS OF CHEMICALLY MODIFIED WOOD

Evidence suggests that modified (acetylated) wood has better dimensional and ultra-violet (UV) stability than unmodified wood. An improved understanding of wood stabilisation through chemical modification is desirable, and is being sought at the Forest Research Institute in New Zealand.

ABSTRACT

Radiata pine sapwood, chloroacetylated to increasing weight gains, were examined using scanning electron microscopy/energy dispersive x-ray analysis (SEM/EDX). Relative chlorine concentrations in the middle lamella increased with increasing weight gain suggesting that chloroacetylation of the wood cell wall was DIFFUSION-CONTROLLED under the given conditions.

METHOD

Small samples of radiata pine sapwood were placed in a solution of chloroacetic anhydride in refluxing xylene for various time periods to achieve sample weight gains of 4.3, 10.2 and 27.7%. The samples were then air-dried to allow evaporation of xylene and examined by SEM/EDX to obtain information on relative chlorine concentrations in regions of the wood cell wall.

RESULTS X-RAY MAPS FROM SEM/EDX ANALYSIS

0 Weight Percentage Gain, Unmodified wood

Little or no chlorination in middle lamella.

4.3 WPG Chloroacetylated wood

SPOT ANALYSIS AT SELECTED SITES IN WOOD CELL WALL (confirms relativity of concentration to weight gain)

10.2 WPG Chloroacetylated wood

27.7 WPG Chloroacetylated wood

Relative chlorine concentrations in middle lamella increased with higher weight gain.

CONCLUSIONS & FUTURE WORK

The results suggest that the attachment of chloroacetic reaction sites in the cell wall was governed by diffusion of the reactant. Further work should involve chloroacetylation after vacuum impregnation of samples to determine the rate of reaction of the anhydride with the various cell wall regions. The technique will also be used to examine weathering of chemically modified radiata pine.

D. R. Cronshaw,
Forest Research Institute,
Rotorua New Zealand

POSTER NO. 8

INVESTIGATIONS ON THE WEATHERING OF CHEMICALLY-LABELLED MODIFIED WOOD BY SCANNING ELECTRON MICROSCOPY/ENERGY DISPERSIVE X-RAY ANALYSIS

D. Plackett

Chemical modification of wood (e.g., acetylation) has been shown to improve the dimensional stability, durability, and colour stability of wood products. Changes in the modified wood during weathering can potentially be investigated by using chemically labelled wood-modifying agents and examining the material using scanning electron microscopy (SEM) coupled with energy-dispersive x-ray analysis (EDXA). It is hoped that this method will provide a better understanding of the weathering process in modified wood and lead to improvements in wood modification treatments.

WOOD DENSITY, FIBRE PROPERTIES AND GROWING CONDITIONS IN RADIATA PINE

OBJECTIVES

To determine if silvicultural practices that promote rapid growth in radiata pine plantations result in lower quality wood, specifically lower density wood.

METHODS

Five variations of water and nutrient regimes were applied to an 11 year old plantation from 1983 to 1987:

C - Control;
F - complete solid fertiliser in spring 1983 at the rate of 400 kg N ha^{-1};
I - irrigated regularly to maintain soil water near field capacity;
IF - combination of I and F;
IL - I plus weekly addition of macro- and monthly addition of micro-nutrients.

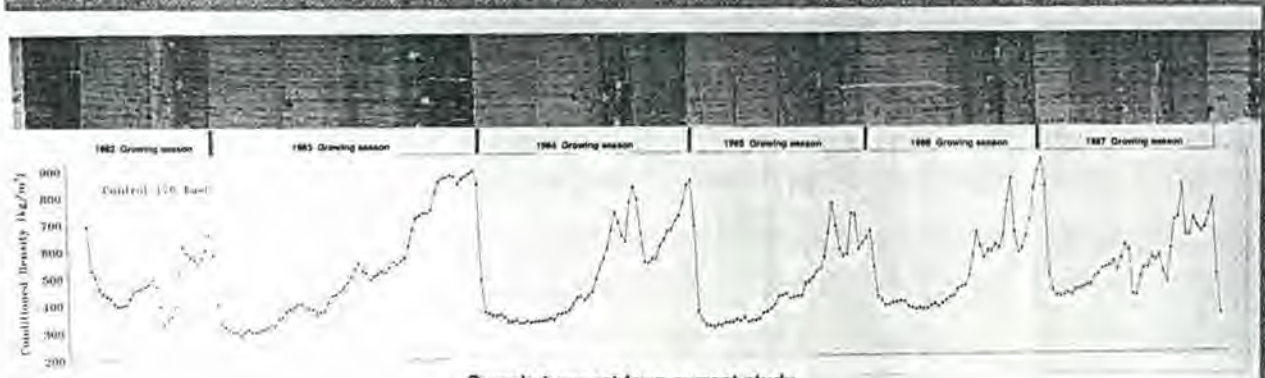
Wood of the 1986-87 growth ring was analysed in detail by:

- *5-micron thick cross sections used to estimate proportion of earlywood and latewood volume occupied by cell walls (density);*
- *radial wood cores used to measure proportion of annual ring composed of earlywood and latewood.*

RESULTS

1. *All treatments were more dense than Control except for the fastest growing treatment, IL, which was slightly less dense in both earlywood and latewood.*
2. *Latewood was about 1.7 x more dense than earlywood on all treatments.*
3. *Trees on all irrigated treatments had 3-5 x greater proportion of latewood than non-irrigated trees.*
4. *As a result of 2 and 3 above, the average ring density of even the fastest growing treatment, IL, was equivalent to Control.*
5. *Trees on all irrigated treatments produced 2-3x greater mass of cell wall than Control.*

1986-1987 Growth Ring



Sample transect from current study

CONCLUSIONS

Average wood density of radiata pine was not reduced as a result of irrigation and fertiliser regimes that increased stemwood growth rates by up to 3x.

Removal of water stress in late summer and early autumn, significantly increased the proportion of denser latewood produced.

Brian J. Myers, Ian E. Craig, Robert Evans and Marisa L. Bonaiti
CSIRO, Division of Forestry and Forest Products

POSTER NO. 9

WOOD DENSITY, FIBRE PROPERTIES AND GROWING CONDITIONS IN RADIATA PINE

B.J. Myers, I.E. Craig, R. Evans and L. Benson

Relationships between field growing conditions, wood density and fibre properties is not well understood. Wood sections from trees grown in an irrigation-fertilisation experiment in an 11-15 year old radiata pine plantation near Canberra are being used to study the effects of water availability, growth rate and nutrient supply on a range of wood and fibre properties. Irrigation and fertilisation treatments, accentuated by marked annual differences in amount and distribution of rainfall over the 4 year experiment, resulted in a 3-fold range in growth rates between treatments/years (18.4-56.8 m^3h^{-1}). Stem diameter and crown growth, soil water content, tree water stress and foliage nutrient content were measured every fortnight and meteorological conditions were monitored hourly.

Preliminary results of wood density analysis and future directions of the study are presented. Initial density analyses were based on: (1) microscopic measurement of the proportion of earlywood and latewood in the 1986-87 ring at breast height; and (2) the proportion of the cross-sectional area of earlywood and latewood that consisted of cell walls, as measured on photomicrographs of 2-micron thick cross-sections.

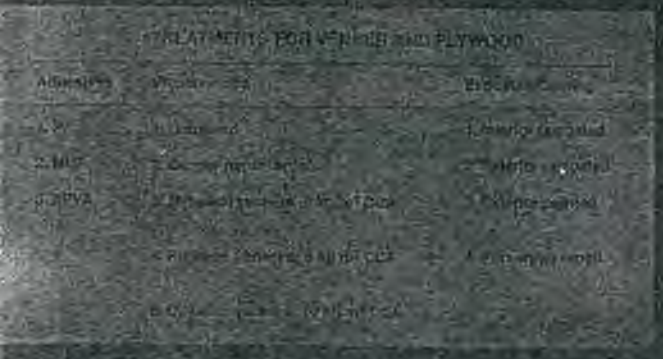
Latewood was about 1.7 times more dense than earlywood on all treatments. Both earlywood and latewood were most dense in trees growing with adequate water but very low nutrient levels. The proportion of latewood in irrigated trees (with and without fertiliser) was 3 to 5 times greater than that in non-irrigated ones, suggesting that the biggest effect of adequate soil water on wood density was the continued growth made possible in the latter part of the growing season when the denser latewood was being formed. Most treatments caused an increase in average ring density relative to control trees. However, the fastest growing trees, which received irrigation plus regular applications of liquid fertiliser (simulated effluent), contained less dense earlywood and latewood than did the control trees, but since this treatment greatly increased the proportion of latewood, the average ring density was similar to that of the controls.

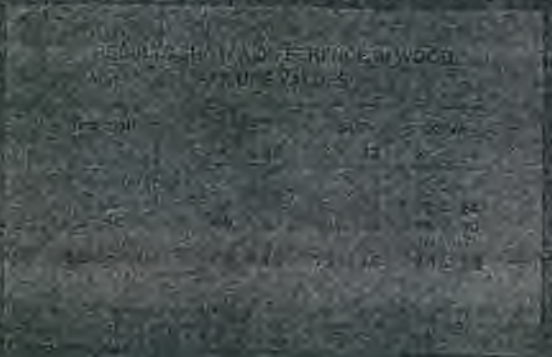
Current studies aim to relate wood and fibre properties (such as fibre length and coarseness, cell size, cell wall thickness, density, resin content and presence of compression wood) to field growing conditions for discrete and identifiable segments of the growing season during which the cells were laid down. This will be achieved by using diameter growth data from fortnightly-measured dendrometer bands to scale x-ray densitometer traces of breast-height 2 millimeter thick radial wood transects and photomicrographs of adjacent 2 micron-thick transects. A sample transect is presented.

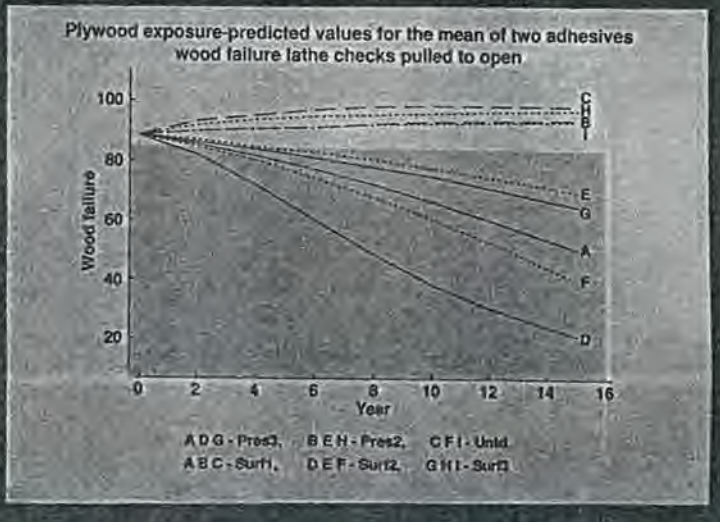
Weathering Effects on Ra

Effect of 12 years' Weathering on Treate

...ped in 1976 to monitor ...performance of plywood panels ... which the individual veneers were treated with a CCA-type preservative prior to ...





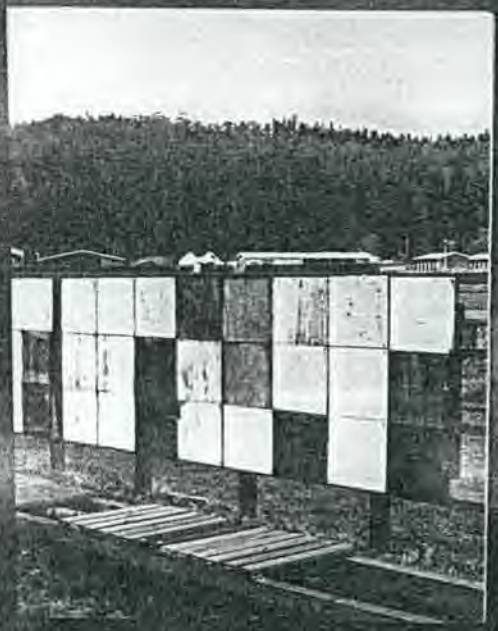


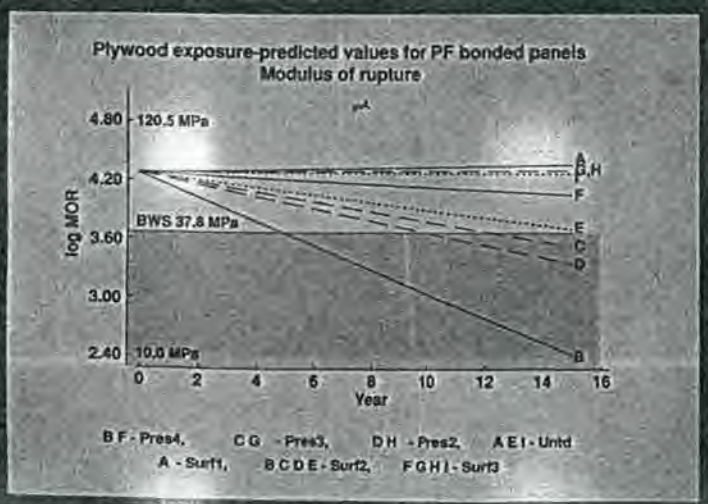
Treatment Effects on Wood Failure:
- no difference between XPVA and PF panels
- decline in 5kg/m³ treatment even for indoor panels
- painting was effective in protecting glueline of untreated panels

›n Radiata Pine Plywood

on Treated and Untreated Plywood

J. M. McLaugh
Forest Resea
New Zealand





Treatment Effects in Modulus of Rupture:
- MOR reduced more than MOE on exposure
- basic working stress not able to be met for some treatment combinations
- PF panels gave higher average value than XPVA after weathering

anels

POSTER NO. 10

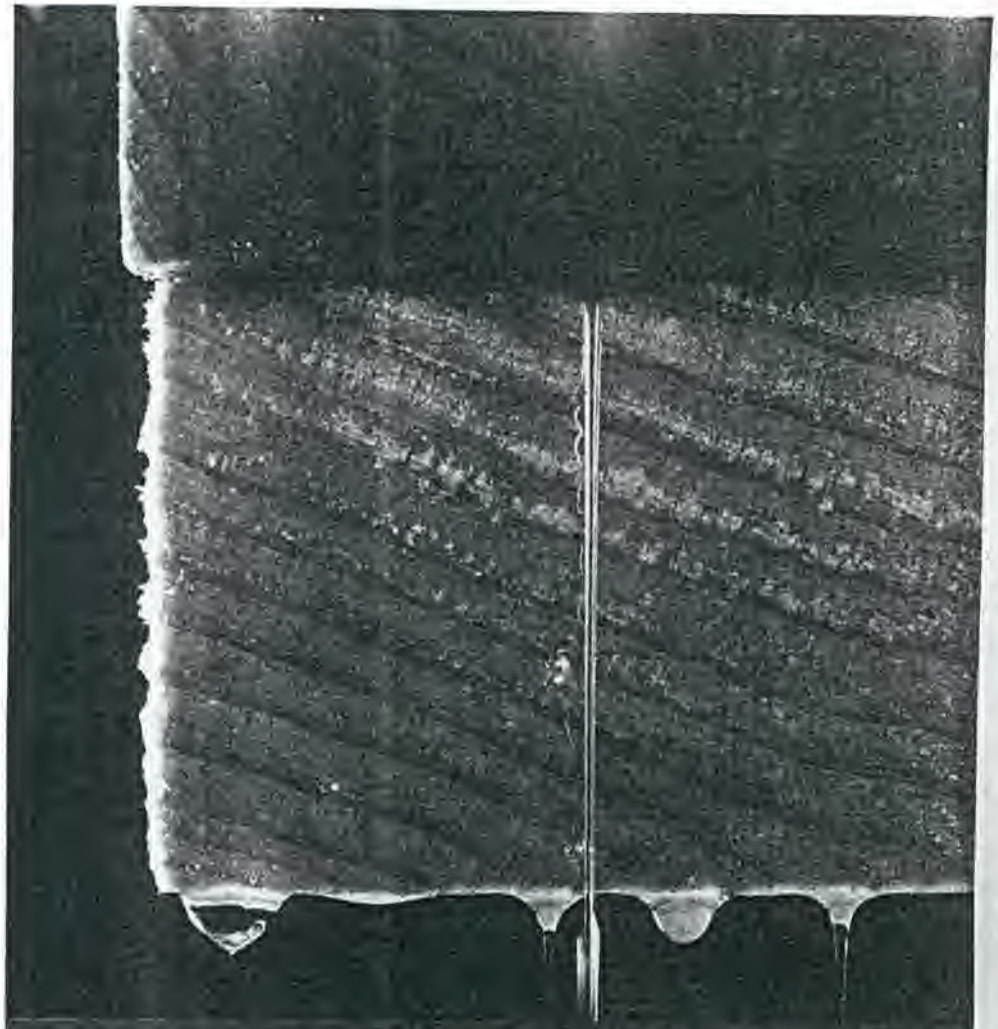
EFFECT OF 12 YEARS WEATHERING ON THE PROPERTIES OF TREATED AND UNTREATED RADIATA PINE PLYWOOD

J. McLaughlan

An exterior exposure trial was established in 1976 to monitor the performance of plywood panels in which the individual veneers were treated with a CCA type preservative prior to panel lay-up. Today, this type of treatment is no longer in favour and also the formulation of the salt solutions and adhesives have changed. The results, however, are still considered to be relevant particularly with the new building industry controls that place emphasis on performance and also with the expansion of other composite product types into uses that require preservative treatment of the furnish prior to consolidation in a hotpress.

3-ply panels of 9.6 mm thick radiata pine plywood were erected vertically on a test face with a North-South aspect in Rotorua. The trial include three adhesive types: pf, xpva and muf; 5 preservative treatments: momentary immersion of green veneers in tanalith NCA solution to give salt retentions of 5 and 10 kg/m^3, pressure treatment of dry veneers to 6 kg/m^3 (pf panels only), copper napthanate coating of the finished panel and an untreated control; and 4 surface/exposure treatments: interior stacked, exterior uncoated, exterior painted and exterior painted plus a water repellant. Panels were tested initially and then after 1,2,4 and 12 years of exposure.

Regression models were used to investigate the effect of various treatment combinations. The uncoated MUF panels had failed completely after 12 years and delaminations occurred in panels of the other adhesive types with one failure occurring for the 10 kg/m^3 treated pf bonded panel. Uncoated panels with CCA treatment generally fared less well than either the untreated or the copper napthanate panels. Assessment of serviceability after 12 years was difficult because of the differences in wood failure values obtained from the tension shear test and the chisel test.



Thickened boron "Diffusol"

- a new approach to a traditional wood treatment

Forest Research Institute,
Rotorua, New Zealand

Thickened boron "Diffusol"™ – *a new approach to a traditional wood treatment*

By P. Vinden, J.A. Drysdale, M. Spence

About 50 timber preservation plants in New Zealand adopted "Diffusol"™ treatment in its first 18 months of release on the market. The high solution viscosity and low surface tension of the formulation have improved productivity and timber quality.

In 1985 FRI implemented a research programme with the objective of improving boron treatment and, in particular, accelerating the diffusion process. In a joint project with Koppers/Hickson Timber Protection (N.Z.) Ltd, a thickened boron treatment was developed for which world-wide patent applications have been lodged.

Commercial trials were undertaken before launching the new product. The variables tested included:

- the effects of temperature,
- tight banding versus loose banding of packets,
- the influence of solution viscosity and concentration,
- anti-sapstain chemical performance,
- treatability of machined timber compared to rough-sawn,
- solution spray characteristics,
- treatment times for thickened solution compared to traditional boron solutions,
- within — and between — charge retention variability.

These tests were followed by more exhaustive commercial trials conducted over a 6 month period at a single commercial installation. Hickson Timber Preservatives (N.Z.) Ltd has since packaged the technology to streamline the process.

Higher uptakes can be achieved with thickened boron compared to unthickened boron solution. This facilitates the treatment of gauged timber rather than rough-sawn timber, the use of lower solution concentrations, and the use of cold application rather than a heated bath. Preservative retention analyses highlight very low variation between pieces when treated with thickened solutions and up to 25% saving in time to achieve the core loading specified by the Timber Preservation Council.

Large stockpiles of boron-treated timber are stacked under cover to allow time for the preservative chemical to diffuse.

Koppers/Hickson has packaged preservative handling technology to provide turn-key solution storage, and automatic mixing, filtering, and waste removal. The boron preservative, "Diffusol"™ — which includes an anti-sapstain chemical — is delivered in liquid form by tanker, or in a bulk bin or drum to the storage tank to avoid mixing of powders at the plant.

The full advantages of the development include:

- more even uptake and distribution of preservative on and within the timber;
- faster diffusion times;
- the treatment of gauged timber (through improved uptake);
- savings in energy costs (heating of boron solutions no longer necessary and no burner maintenance);
- addition of anti-sapstain chemical — an integral component of formulation — gives improved sapstain and mould control during diffusion storage;
- the treatment of surface-dry timber overcoming the hydrophobic properties of surface-dry timber;
- delivered as liquid — no bags to dispose of; no chemical dust from emptying bags;
- thermal degradation of anti-sapstain chemical is minimised as solution is used at ambient temperature;
- the treatment of high-resin-content species, e.g., *Pinus elliottii*, is made easier;
- chemical degradation of treatment solution by wood sap is minimised;
- reduced aerosol effect during stacking;
- the cost of drying to produce powdered formulations is eliminated.

Trademark of Hickson International PLC.

POSTER NO. 11

THICKENED BORON TREATMENT - "DIFFUSOL"

P. Vinden, J. Drysdale and M. Spence

Traditional boron treatment in New Zealand has involved momentary immersion or tunnel spraying of freshly sawn green timber, followed by 8-10 weeks' storage under cover to allow diffusion. The Forest Research Institute, Rotorua in association with Hickson Timber Preservatives (NZ) Ltd has developed a thickened boron treatment "Diffusol"™. This formulation provides higher uptake of preservative, which facilitates the treatment of gauged timber rather than rough-sawn timber, the use of lower solution concentrations, and the use of cold application rather than a heated bath. Preservative retention analyses highlight very low variation between pieces when treated with thickened solutions and up to 25% saving in time to achieved treatment specification. Extensive experimental trials started in May 1988 and by the beginning of August 1990 there were about 50 boron treatment plants in New Zealand enjoying the benefits of this new product.

VAPOUR BORON

The treatment of solid wood

Forest Research institute,
Rotorua, New Zealand

VAPOUR BORON — The Treatment of Solid Wood

By Peter Vinden, Russell Burton, Tony Bergerhoff, Khurram Nasheri, and David Page
Ministry of Forestry, Forest Research Institute - Rotorua, New Zealand

SUMMARY
Vapour boron is a new process for boron treatment of wood and composite products. It was developed as part of a cooperative research programme between the Forest Research Institute (New Zealand) and Imperial College (United Kingdom).

The process utilises a gaseous form of boron to effect treatment. Providing the product is primarily dried, deep and even boron distribution can be achieved through the wood.

LABORATORY WORK

SCALE-UP

ADVANTAGES OF VAPOUR BORON TREATMENT

The whole process is a gas in gas operation. Vapour boron treatment is combined with kiln drying so that wood is dried, treated and steam conditioned in the same vessel. The whole operation is continuous, there is no need to restack the wood between any of the steps. The plant layout is given schematically in Figure 2.

Implications of the process include:

1. Very rapid treatment
The treatment for [illegible] exposure to the gas to the total depth of the wood is just one minute. For a deep treatment process, from start to finish, is approximately an hour.

2. An even distribution of boron through the wood
The vapour action is uniformly applied. By the gas it that an even deposition of bond acid is achieved. Even loadings on the outer edges of the wood are maintained (avoided).

3 The entire process is automated
The Vapour Boron process is an integral part of kiln [illegible] and is controlled in a similar manner.

The means:
No additional handling
reduced manual involvement
Assured consistency between operations
Ideal for quality control purposes

4. Maximise use of plant
One vessel can carry out three operations
Drying
Steam conditioning
Treatment

5. A very clean process
Only the exact amount of preservative required to effect treatment is used. Spillage and excess chemical handling is eliminated.

6. Production time to output needs
The entire process is very rapid. That is dried and treated wood ready for shipping to the customer can be produced in under 30 hours. Implication of this are:

No more quessing market demand in three months time.
Reduced storage of wood.
Reduced working capital tied up in value added products.

7. End use advantages
Potential advantages in the use of dry treated framing such as stability, lightness and speeding up construction time.

8. Cost
Process cost is competitive with any other process to produce dry boron treated wood.

COMMERCIAL TRIALS

POSTER NO. 12

VAPOUR BORON TREATMENT OF SOLID WOOD

P. Vinden, R. Burton and T. Bergervoet

The vapour boron process has been developed through a number of stages over a period of approximately 5 years:

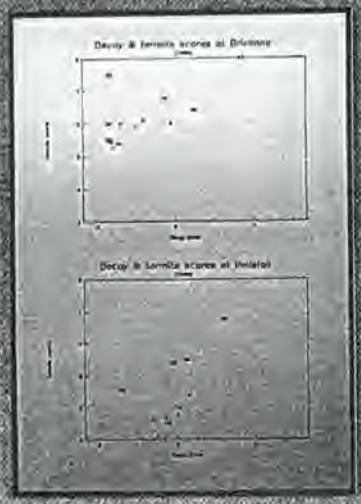
- Initial laboratory studies of interaction of candidate chemicals and wood.
- Laboratory studies of combined drying and preservative treatment.
- Pilot scale drying and vapour treatment.
- Commercial trials.

The benefits of integrated drying and preservative treatment include:

- Processing time from green timber to dried and treated of less than 30 hours (as opposed to 8-10 weeks for conventional treatment).
- A single vessel operation reducing labour and handling costs.
- One control system for both drying and treating stages.
- Ability to adjust the drying process to meet stringent preservation requirements.
- Use of a drying method which has demonstrated benefits for strength and reduced warp in producing structural timber.

21 YEAR RESULTS FOR THE CSIRO IN-GROUND NATURAL DURABILITY TESTS

GRAPHS OF MEAN DECAY RATING VERSUS MEAN TERMITE RATING



SOURCE OF STAKES

- Butt log of mature trees
- outer heartwood only

RATING SYSTEM

8 = completely sound

0 = failed

3 = unserviceable

JAMES W. CREFFIELD,
GARY C. JOHNSON,
NAM-KY NGUYEN AND
JOHN D. THORNTON

CONDITION OF PRESERVATIVE - TREATED PINUS RADIATA STAKES AFTER 25 YEARS EXPOSURE

DECAY IN PRINTED TIMBERS EXPOSED ABOVEGROUND

MODEL OF TEST FRAME PRIOR TO PAINTING

POSTER NO. 13

RECENT DATA FROM CSIRO FIELD TESTS OF NATURAL DURABILITY AND PRESERVATIVE EFFICACY

J.W. Creffield, G.C. Johnson, Nam-ky Nguyen and J.D. Thornton

This poster will present recent results of 3 tests:

1. 21 year in-ground natural durability data, for each of four sites, graphed (as condition against termites v condition against decay, for all those timber species still surviving in a serviceable condition).

2. 9 year (3 separate exposures of 3 years each) above-ground data, for four different climate types, of painted and unpainted panels, tabulated and grouped statistically according to decay resistance.

3. 25 year in-ground preservative performance, for each of 3 sites, for oil-borne water-borne and dip treatments, in sawn hardwood and round hardwood and sawn pine. Tabulated, mean scores and standard deviations (not statistically analysed).

Identification of Sludges, Spots, Stickies by Fourier Transform Infrared (FTIR) Spectroscopy

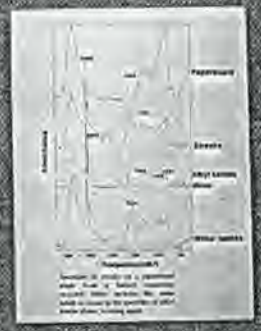
by
A J Michell

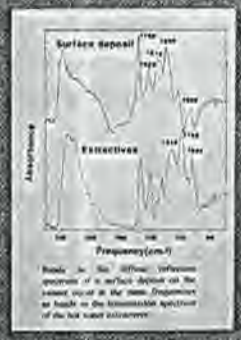
Unwanted solid residues are the bane of many industrial processes. The first step in overcoming these problems is often to determine the nature of the deposit.

One technique which is very useful for this is infrared spectroscopy since a substance's infrared spectrum has the same distinctiveness as a fingerprint. Moreover, unlike many other techniques, it works well with insoluble solid samples. Where the deposit is a mixture of substances the resultant spectrum will be the sum of the spectra of the individual components.

Infrared spectroscopy is not a new technique but recent advances have greatly increased its sensitivity and allowed low energy sampling techniques such as diffuse reflectance to be used.

Examples are given here of its use to examine the state of the chromium in CCA sludges, the nature of a deposit causing bonding difficulties with a veneer, the nature of a sludge formed by a foamed adhesive and the cause of streaks on paperboard made from recycled fibres.





POSTER NO. 14

IDENTIFICATION OF SLUDGES, SPOTS, STICKIES BY FOURIER TRANSFORM INFRARED (FTIR) SPECTROSCOPY

A.J. Michell

Unwanted solid residues are the bane of many industrial processes. Examples which come readily to mind in the forest products industry include: sludges in preservation liquors or in adhesives, spots in paperboards from contaminants in recycled pulps, deposits on papermaking machinery and in paper from insolubilised extraneous wood components, deposits on wood surfaces from the migration of extractives. The first step in overcoming these problems is often to determine the nature of the deposit.

One technique which is very useful for this is infrared spectroscopy since a substance's infrared spectrum has the same distinctiveness as a fingerprint. Moreover, unlike many other techniques, it works well with insoluble solid samples. Where the deposit is a mixture of substances the resultant spectrum will be the sum of the spectra of the individual components. The usefulness of the spectrum in enabling the components to be identified will depend on the degree of overlap of bands in the component spectra.

Infrared spectroscopy is not a new technique but its previous major disadvantage, its lack of sensitivity, has now been overcome by the combined application of interferometry and Fourier transform techniques using digital computers.

The purpose of this poster is to show the method's wide application through examples of work taken from recent projects in our laboratory.

STRUCTURAL PROPERTIES OF TIMBER WITH REFERENCE TO GRADING

Lateral view of the up-grading mechanical testing machine and dust extractor for timber specimens.

ABSTRACT

An extensive study was undertaken to critically evaluate the mechanical properties of timber scantlings with particular reference to visual grading. Three major species of Australian hardwoods from regrowth forests of NSW - blackbutt, spotted gum and brownbarrel, were tested to destruction in bending in both seasoned and unseasoned conditions.

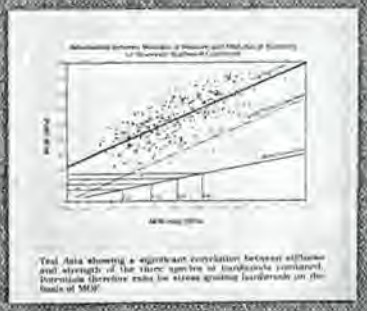
The study found that the current visual grading rules for hardwoods were more than adequate for bending strength but not for stiffness. The mean stiffness values for the higher grade material (structural grade No. 1) were, in particular, lower than the values given in the Timber Structures Code AS1720-88 Part 1. In practice, stiffness would govern the design of most engineering structures loaded in bending, and therefore this should be considered in grading. A significant correlation between stiffness and strength of the three hardwoods combined showed that there is potential for mechanical grading as is currently done for some softwoods. Investigations have also shown that the use of ultrasonics provided a good indication of stiffness and thus could be used in conjunction with visual grading.

Ultrasonic test recorded with portico.

Graph showing that the frequency of ultrasonic vibration and the length of material that would produce natural vibration are directly related.

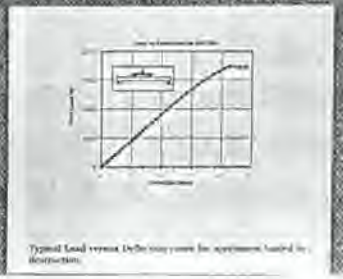
Specimen specimen showing the effect of sloping grain on the failure mode.

Derivation of Basic Working Stress is based on the lower 5th-percentile test value of the reference population.



Test data showing a significant correlation between stiffness and strength of the three species of hardwoods combined. Therefore grades for stress grading hardwoods on the basis of MOE.

Specimen undergoing the effect of a knot on the failure mode.



Typical Load versus Deflection curve for specimens tested to destruction.

Bill Ire, Research Officer
Forestry Commission NSW
Wood Technology and Forest Research Division

POSTER NO. 15

STRUCTURAL PROPERTIES OF TIMBER WITH REFERENCE TO GRADING

W. Joe

An extensive study was made on the in-grade properties of three major Australian hardwood species of sawn timber - blackbutt, spotted gum and brown barrel. Scantlings sampled from regrowth forests of NSW were tested in bending in both seasoned and unseasoned conditions. The test method was biased such that the worst visual defect was located in the middle region of the test span and on the tension side. Visual stress grading was done in accordance to AS 2082-79.

The study found that the current visual rules for hardwoods were overly conservative for bending strength but not for stiffness. In nearly all cases with the exception of seasoned spotted gum from the south coast, strength (MOR) exceeded the values given in AS 1720-88 for a given species-grade combination. Stiffness was adequate except for the higher grade material (Structural Grade No. 1) where MOE was lower than that required for the grade. In general the tests showed that bending strength was high relative to MOE for inclusion into a particular grade. Preliminary investigations to address this problem has shown that the use of ultrasonics has some potential in predicting the MOE. Work is presently continuing with the aim of improving the grading efficiency.

Inoculation of sassafras (Atherosperma moschatum Labill) with stain fungi.

An increment corer was used to bore a 6 mm hole into clear sassafras heartwood followed by inoculation with 1 mL of spore suspension (10^6 mL^{-1}) and sealing with a wooden plug.

"Black-heart" is a dark, fungal staining of the otherwise pale heartwood of sassafras, highly valued by the woodcraft and furniture industries. It occurs naturally, but only in a few prescribed areas, so demand often exceeds supply.

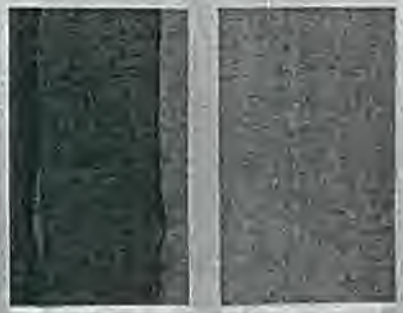
Fungi have been isolated from freshly cut black-heart sassafras sampled from 11 localities in south-eastern Tasmania. The fungi included more *Alternaria alternata*, *Cladosporium cladosporioides*, *Sclerostagonospora*, and several *Penicillium* species including *P. echinulatum*. These fungi were inoculated into stain-free sassafras to test their ability to induce staining.

Twelve months following inoculation, selected trees were felled to determine the extent of staining. Large variability in the extent of staining was apparent, with only *P. echinulatum* showing significant spread. Gel electrophoresis of enzyme patterns proved the fungus reisolated from stained regions was identical to the original inoculum.

More extensive inoculations are to be established in the near future to assess the development of stain intensity and pattern.

Longitudinal spread from the wood *Penicillium* were clear in excess of 1 m for *P. echinulatum*. Lateral spread was more restricted.

Two of the fungi isolated, *Cladosporium cladosporioides* (left) and *Penicillium echinulatum* (right).



Natural black-heart (left) and clear (right) sassafras (veneers kindly supplied by Australian Veneers, Boyer, Tasmania).

Induced stain of sassafras (12 months following fungal inoculation) – the end result (notwithstanding by Russell Hoffman, Mt. Nelson, Tasmania).

Martin Linz, University of Tasmania, Churchill Ave, Sandy Bay, Tasmania

Tim Wardlaw, Forestry Commission, 199 Macquarie St, Hobart, Tasmania

Murray Jessup, Forestry Commission, 199 Macquarie St, Hobart, Tasmania

POSTER NO. 16

INOCULATION OF SASSAFRAS (*ATHEROSPERMA MOSCHATUM* LABILL.) TREES WITH STAIN FUNGI

M. Line, M. Jessup and T.J. Wardlaw

"Black-heart", a wood staining in sassafras (usually associated with crown damage), is highly valued by the wood-craft industry of Tasmania. Black-heart is less abundant than sassafras with clear, unstained wood and demand may exceed supply. A joint study is being conducted by the Forestry Commission of Tasmania and the University of Tasmania to isolate and identify the fungi associated with black-heart, and to determine their ability to induce staining in stain-free trees following inoculation with the isolates in pure culture.

Freshly-cut black-heart sassafras from 11 localities in south-eastern Tasmania yielded: *Alternaria alternata, Cladosporium cladosporiodes, Gliomastix* sp. and various *Pencillium* species including *P. echinulatum* from stained regions of wood samples. The presence of fungi was invariably associated with sizeable bacterial and yeast populations, up to 5×10^7 cell g^{-1} dry weight of wood. The role of the bacteria and yeasts in the staining process has not been examined.

In February 1989, nine sassafras trees, free of staining, growing in mixed eucalypt/rainforest were inoculated by boring into the heartwood with a 6 mm diameter increment corer at intervals up the trunk, introducing a suspension of fungal spores (approximately 10^9 spores/core), one isolate/core, and plugging with wooden dowel. Four trees were felled and dissected in January 1990 and the remainder in July 1990 after they had been killed by a bushfire in March 1990. Staining around inoculation holes progressed only a short distance (2-3 mm) in the sapwood, in contrast to rapid vertical spread in the heartwood (up to 1 m from the point of inoculation). Tangential spread was restricted (at 300 mm from one inoculation point the tangential spread of the stain column was 35 mm) while radial spread corresponded with the depth of the inoculation hole. The staining induced by the inoculations tended to be paler than in black-heart.

One isolate, *P. echinulatum*, dominated the fungi reisolated from the stained regions, being the only fungus reisolated at significant distances from the point of inoculation. This isolate was shown to be identical to the inoculated strain by pectic zymograms following gel electrophoresis.

A further trial of fungal inoculations was established in July 1990 using a mixed suspension of *P. echinulatum, Cladosporium cladosporoides* and *Alternaria alternata* inoculated at four equidistant radial points at the same height into 20 trees. These trees will be dissected at intervals to monitor the rate of spread of staining and the colour development in the stained regions.

LEACHING OF CCA SALTS FROM FRESHLY TREATED TIMBER

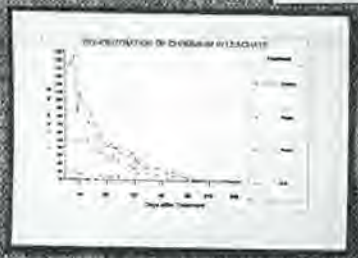
woods forests

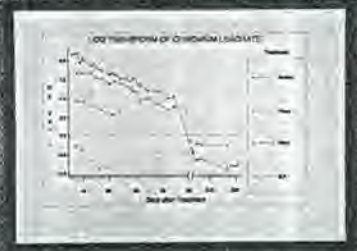
PROJECT OBJECTIVE

TO DETERMINE THE FIXATION TIME OF CCA TREATED ROUNDWOOD BY EXPOSURE TO SIMULATED RAIN-WATER LEACHING.

FIXATION WAS MONITORED BY MEASURING THE CONCENTRATION OF CCA COMPONENTS IN THE LEACHATE.

THE EFFECT ON FIXATION TIME OF THREE ACCELERATION TREATMENTS WAS STUDIED.





COPPER

CONTROL: THE LONG-TERM [CU] WAS REACHED 42 DAYS AFTER TREATMENT.

PRESS. STEAMED: FIXATION OF CU WAS COMPLETE 14 – 17 DAYS AFTER TREATMENT.

DRY PROCESS: THE [CU] IN THE LEACHATE WAS STILL FALLING 49 DAYS AFTER TREATMENT. THE LONG-TERM LEVEL IS NOT YET KNOWN.

ARSENIC

CONTROL: THE LONG-TERM [AS] WAS NOT REACHED 44 DAYS AFTER TREATMENT.

PRESS. STEAMED: FIXATION OF AS WAS VIRTUALLY COMPLETE 18 DAYS AFTER TREATMENT.

DRY PROCESS: FIXATION RATE SIMILAR TO CONTROL.

BILL ATYEO, ANDREW CAMERON — WOODS AND FORESTS DEPT. S.A.
BRETT ELLIS — KOPPERS HICKSON PTY LTD

POSTER NO. 17

LEACHING OF CCA SALTS FROM FRESHLY TREATED TIMBER

B. Atyeo, A. Cameron and B. Ellis

Current South Australian regulations regarding environmental protection practices during treatment with copper chrome arsenic salts (CCA) specify that freshly treated timber must be held on a bunded catchment pad for a minimum of 72 hours after treatment. However, recent work (McNamara, W., IRG/WP 3504) indicates that at temperatures below 20°C, the fixation time of CCA exceeds this. If treated timber is removed from the drip pad before the completion of fixation, there is the potential for soil and water contamination if the treated wood is exposed to rainfall.

The present investigation was undertaken to determine the effect of heat treatment on reducing the fixation time for CCA treated, radiata pine timber under winter conditions in Mount Gambier, South Australia. The effect on the fixation rate of high and low temperature steaming was investigated.

Low temperature steaming treatments significantly increased the rate of fixation as assessed by leachate concentration of all elements. High temperature steaming further increased the rate of fixation. However, the low temperature steaming treatment, and presumably the high temperature steaming treatment, caused a large amount of CCA solution to be exuded from the timber during steaming.

Leachate tests will be repeated on timber treated using a Modified Bethell ('Dry') Process, in an attempt to further improve the rate of fixation and eliminate exudation during post-treatment heating.

AUSTRALIAN FURNITURE RESEARCH & DEVELOPMENT INSTITUTE LTD

RESEARCH PROJECTS

PROJECT 1 : THE SUITABILITY OF NATIVE TIMBERS FOR FURNITURE MANUFACTURE

1.1 Studies of the properties of Tasmanian minor species

1.2 The use of River Redgum (*Eucalyptus Camaldulensis*) in furniture manufacture

1.3 The suitability of Hoop Pine (*Araucaria Cunninghamii*) for furniture

PROJECT 2 : THE PERFORMANCE OF FURNITURE AND FURNITURE COMPONENTS IN CHANGING CONDITIONS OF ENVIRONMENT

Testing facility : Environment room

Testing parameters : see graph 1

Graph 1 Testing parameters in the environment room

PROJECT 3 : TESTING FURNITURE AND FURNITURE COMPONENTS

Development of standards and test methods for testing of strength and durability, and assessment of quality and workmanship

Fig. 1 Fatigue test of chair

Fig. 2 Testing the strength of domestic seats

Fig. 3 Testing the resistance of seat and backrest

Fig. 4 Testing the resistance of a recliner to load

PROJECT 4 : THE STRENGTH DESIGN OF FURNITURE

4.1 Computer design of furniture frame

4.2 Stress analysis of frame and carcase furniture

Fig.1 The distribution of internal forces in the case furniture under the standard load H

PROJECT 5 : IMPROVING DRYING METHODS FOR THE PRODUCTION OF APPEARANCE GRADE TIMBER

5.1 Acoustic emission

5.2 Computer based mathematical modelling
- Oriwood
- Kilnsched

5.3 Fundamental research in conjunction with University of Tasmania

5.4 Experimental kiln runs

5.5 Mill trials

5.6 Kiln programme testing

Contact : Project Mills - Research Scientist

Graph 2 Acoustic emission from quarter sawn Tasmanian Oak

University of Tasmania experimental research kiln

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POSTER NO. 18

AUSTRALIAN FURNITURE RESEARCH AND DEVELOPMENT INSTITUTE LTD: RESEARCH PROJECTS

B. Ozarska

1. The suitability of native timbers for furniture manufacture

1.1 Studies of the properties of Tasmanian Minor Species
1.2 The use of River Red Gum in furniture manufacture
1.3 The suitability of Hoop Pine for furniture manufacture

(short description of the project)

2. The performance of furniture and furniture components in changing conditions of environment

(short description, 1 graph)

3. Testing furniture and furniture components

(short description, 4 photographs)

4. Strength design of furniture:

4.1 Stress analysis of frame and carcase furniture
4.2 Computer design of furniture frames

(short description, 3 graphs)

5. Improving drying methods for furniture timber

(short description, 1 photograph, 1 graph)

PIGMENT EMULSIFIED CREOSOTE (PEC) — A CLEANER ALTERNATIVE

PEC is a wood preservative consisting of —
- High temperature creosote
- Water
- Pigment
- Emulsifier
- Anti-settlement additive
- Stabiliser
- Emulsion structure modifying agents

Benefits of using PEC based on pilot plant study —
- Dry surface after a short period
- Marked reduction in creosote exudation
- Aesthetically pleasing surface
- Significant energy savings — treatment temperature at 50°C instead of 100°C
- Vapour emissions and odour are minimised
- The emulsion is non-flammable

Future research Programmes —
- PEC of various colours for industrial and domestic applications
- Improving the biological efficacy with the addition of specific toxicants
- Modifications of the basic formulation, tailored for specific end-users
- PEC to combat fire retardancy

POLES TREATED WITH PEC BROWN

RAILWAY SLEEPERS TREATED WITH PEC BROWN

POLES TREATED WITH PEC WHITE

POLE IN SERVICE TREATED WITH PEC BROWN

CCA-OIL EMULSIONS

HYCON 16 ... treated Eucalypt Cracknell 7 months after treatment

7.11.90 : HYCON 16 WR/ON EMULSION

POSTER NO. 19

EMULSIONS - THE KEY TO THE FUTURE

J.H. Goode and J.B. Watkins

PEC - A CLEANER ALTERNATIVE

PEC, or pigment emulsified creosote, represents a new generation of environmentally acceptable preservatives. These novel emulsions have been jointly developed in a collaborative venture between CSIRO and KOPPERS Australia.

PEC is an emulsion of approximately 70% conventional high temperature creosote and 30% water together with a sophisticated micronised pigment dispersed throughout the formulation. It is the brain-child of Mr John Watkins.

The pigment plays the role of minimising creosote movement once impregnated into the timber. The fine particles are distributed throughout the wood cells where they show a tendency to coat the lumina, thereby inhibiting the mobile creosote phase. The result is clean, oil-free, dry surfaces on commodities impregnated with PEC. The emulsion does not deteriorate in the presence of contaminants, and can be applied by vacuum pressure impregnation, by brush and spray.

Test results from bioassays and field tests show that PEC performs as well as conventional creosote but without the vapour emission or creosote exudation.

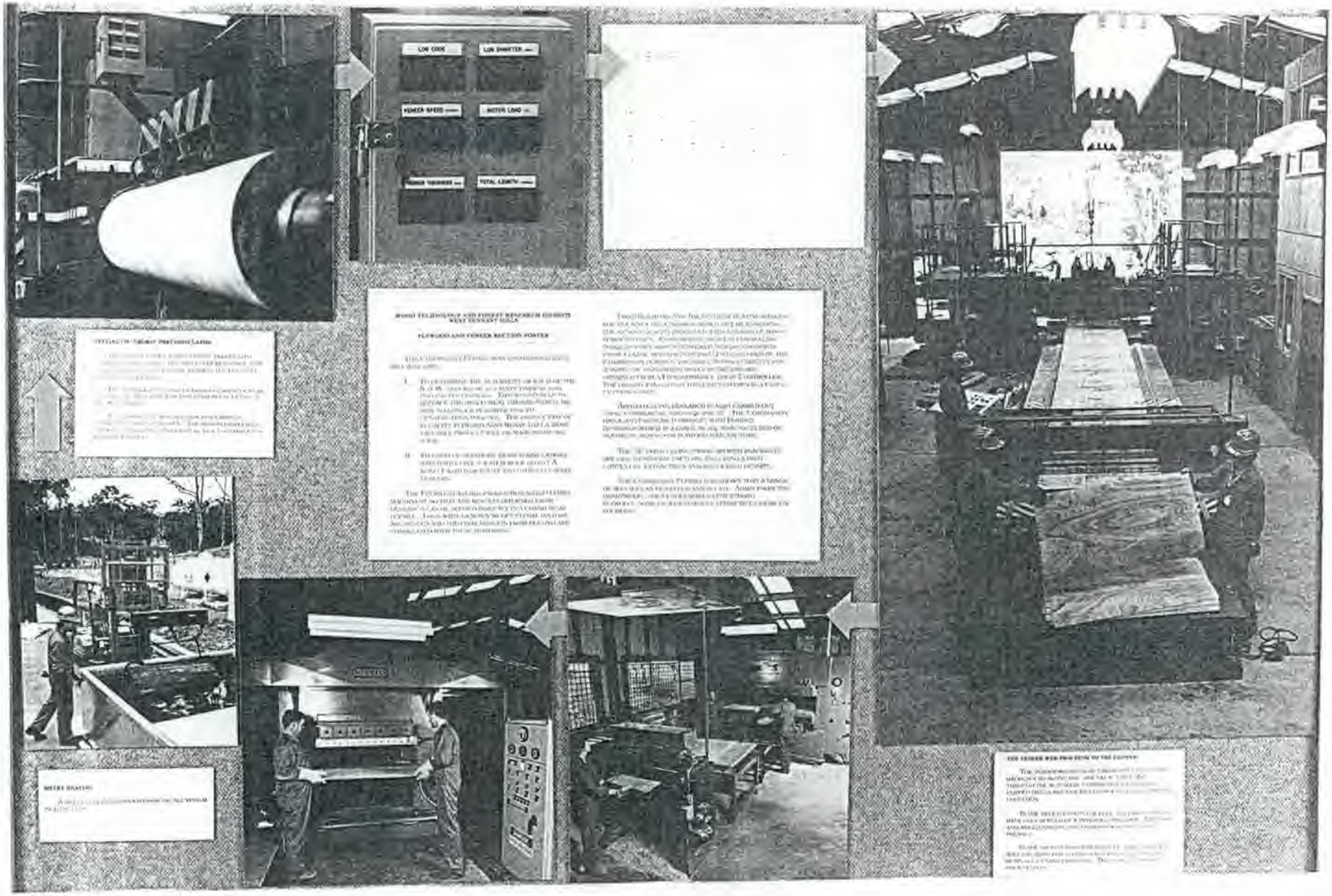
CCA/OIL EMULSIONS - LOCKED-IN PRESERVATIVES

Each year in Australia more than 3500 tonnes of water-borne copper-chrome-arsenate (CCA) preservatives are used to treat a range of timber products. CCA treatment is not as effective in stabilising and water-proofing wood as some other treatments (for example light organic solvents (LOSPs)). However the clean and nonhazardous treatment provides excellent protection against biological degradation. The ability of the chemicals in CCA to fix within wood cells means that very little preservative is lost during the service life of the timber.

Incorporating oil into CCA preservatives to produce an emulsion would provide the treated timber with better dimensional stability and general weathering resistance.

A stable and fine emulsion has been developed. At this stage the emulsion consists of nominally 5-20% oil phase and 95-80% water phase. The CCA concentration can vary between 2% and 12% based upon total emulsion.

Pilot plant trials of 300-500 kg batches of this emulsion suggest that emulsion retention (sapwood volume) is in the range 400-800 kg/m^3, giving CCA retentions significantly higher than the Australian standards for softwoods and hardwoods.


LOG CODE
LOG DIAMETER
VENEER SPEED
MOTOR LOAD
TOTAL LENGTH

POSTER NO. 20

PLYWOOD AND VENEER RESEARCH AT THE NSW DIVISION OF WOOD TECHNOLOGY AND FOREST RESEARCH

J. Wade

The Commission Plymill was established with two main aims:

1. To determine the suitability of each of the NSW species of eucalypt timbers for peeling into veneer. This would help to replace the rainforest timbers which are now no longer available due to conservation policies. The production of eucalypt plywood also means that a more valuable product will be made from the logs.

2. To develop synthetic resin formulations which will give a waterproof bond ("A Bond") with blackbutt and other eucalypt veneers.

The Plymill features production-sized plymill machinery so that the results obtained from research can be applied directly in a commercial plymill. Logs with a known silvicultural history are peeled and the final results from peeling are correlated with these histories.

Investigations into the optimum heating ranges for eucalypt billets are carried out by assessing the veneer quality produced with a series of wood temperatures. Comparative results for peeling torques for various temperatures are obtained from a lathe monitor/controller developed by the Commission in which the drive motor currents for a series of diminishing billet diameters are obtained from a programmable logic controller.

Applied gluing research is also carried out using commercial sized equipment. The Commission has a joint research product with Borden Australia which is a large-scale manufacturer of synthetic resins for plywood manufacture.

The "A Bond" gluing problems with Blackbutt are due to several factors, including a high content of extractives and also a high density.

The Plymill has shown that a range of species can be peeled and glued. Apart from the heartwood, the veneer makes very strong plywood, some of which has an attractive figure on polishing.

23rd FOREST PRODUCTS RESEARCH CONFERENCE

Session Summary - Session 1 - Biodegradation and Chemical Treatments

The six papers presented in this section covered a wide range of topics including the development and assessment of new chemical treatments, a review of current chemicals and timber resources and the increasing influence of environmental considerations in preservation matters.

Jack Norton's paper discussed the impact on the timber preservation industry of the public attitude towards the use of environmentally hazardous chemicals. He stated there were environmental advantages in using CCA treated timber - particularly the utilization of arsenic by-products from metal refining industries and more effective utilisation of our timber resources. He also outlined the problems of disposing of sludge from treatment plants, and treated timber and machining residues from treated timber. Queensland regulations related to treatment plant design and waste disposal were discussed. Norton concluded that the future of timber preservation depends largely on the timber preservation industry operating, and being seen to be operating, in an environmentally responsible manner.

David Gardner's paper on fire retardants examined the efficacy of fire retardants when they were applied as surface coatings or by impregnation. Their efficacy was demonstrated by testing by several small-scale test methods and one full-scale test method. It was shown that the perceived effect of fire retardants on the fire performance of forest products can sometimes vary according to the test method selected, particularly when smoke release was being measured. Gardner's data showed that the fire retardant applied as a surface coating was as effective as the retardant applied by impregnation.

Karl Schmalzl's paper on chemical modification of wood surfaces also focussed on evaluation methodologies. Schmalzl used weight loss data and zero span tensile strength loss data to determine the protection afforded to thin veneers by four novel candidate surface applied chemicals.

The several years that are required to produce efficacy data using the traditional exposure technique was reduced to 35 days using these techniques. Schmalzl used FTIR analysis to demonstrate that delignification is the major process induced by weathering and that materials that protect the surface of wood form stable complexes with lignin.

Graham Siemon reviewed some of the preservation research that had been undertaken in Western Australia over the last 60 years. The research included field trails of fence posts and dowelled two piece sleepers. Laboratory testing to determine the inground durability and lyctus susceptibility of regrowth eucalypts and the effect of sapstaining and CCA treatment on the strength of radiata pine poles was also reported. The purpose of most of the reported research was to compare the properties and performance of regrowth material with that of mature material. Most of the research is in progress and the results should provide valuable information on the current and future timber resources that will be available in Western Australia.

The theme of effective utilisation was continued by Kevin McCarthy who addressed the question of detecting and treating defects in wooden poles. Wooden poles represent an investment of approximately $15 billion to the Australian community. There is also a major annual outlay on their inspection and maintenance. McCarthy outlined the biological hazards faced by poles in service and discussed the various techniques available to detect defects that result from attack by fungi and insects. The techniques ranged in complexity from a hammer and auger to computerised tomography using radioactive sources. It seems likely that pole inspections in the future will be based upon a range of techniques rather than a single method., The vital question of groundline maintenance was also discussed with preference being expressed for systems employing diffusing chemicals. Diffusing chemicals are more likely to achieve

control of biological agents than non-diffusing chemicals. They will have the added advantage of greater acceptance on environmental grounds because they are retained on the surface or within the poles and are hence less likely to contaminate the adjacent areas than chemicals that are added to the soil around poles. The development and use of effective inspection and maintenance procedures are critical if the optimal utilisation of our wooden pole population is to be achieved.

The final paper was presented by John Watkins. He gave an insight into the complex world of emulsions and described some of the emulsion types that had been used in the development of emulsified creosotes. Watkins strongly supported the use of emulsion based organic preservatives rather than those based on organic solvents because the environmental impact of the emulsified preservatives will be less. The emulsified preservatives may release their solvent to the atmosphere during service, but as this is only water, it must be preferable to the organic solvents that would be released by the organic solvent based preservatives. It is certainly an argument worthy of very serious consideration by the preservation industry in the current climate of environmental awareness. One of Watkins' aims with this presentation was to show that emulsions are not too complicated or too difficult for our industry and its chemists to understand and to produce.

While all six papers may have seemed entirely separate, there were at least two themes, one or both of which were common to most of them. The environmental aspects of timber preservation were either addressed directly or were an implied consideration in most of the papers. It is difficult to argue with Norton's claim that the future of the timber preservation industry depends largely on the industry being clean and safe. It is apparent that environmental matters are being received with much greater interest by the preservation industry and the development of an environmentally acceptable industry is treated as a high priority goal. The second theme that was common to many of the papers was the need for relevant and effective test methods to determine the condition of forest products and the risks posed by them or the preservation chemicals contained on or within them during their service life. The development of

relevant test methods to predict condition and service performance is critical if the goal of optimal use of forest products is to be achieved.

W.D. Gardner

Session Chairman

22 November 1990

23rd FOREST PRODUCTS RESEARCH CONFERENCE

Session Summary - Session 2 - Structural Applications

The papers presented during this session addressed a number of key issues concerning structural reliability and more importantly the reliability of complete structures. Issues discussed included:-

- the need, direction and priority of future in-grade testing with emphasis being directed towards manufactured/fabricated components and building systems
- an urgent need to redress the apparent lack of structural reliability of hardwood glulam with particular emphasis (as pointed out by Dr Bob Milner) directed towards finger joints
- the need to further develop and calibrate the model of Bob Leicester and John Barnacle to provide a much needed basis for reliably predicting the durability of structural timber applications for both members and their connections.

Further discussions in this area highlighted the need for much greater co-operation between engineers and wood scientists to progress the concept of introducing a reliability approach to "design for durability". This hopefully will occur and will lead to a world first - that is, a Standard Code of Practice for Durability Design.

In addition to these items, Denis Grant's review of machine grading systems and associated quality control and Ted Lhuede's review of bolted connections have provided Industry with a basis for pursuing future research and testing in these field.s

The excellent review of NZ structural research by Hank Bier has shown the value of close co-operation between industry and research facilities with much of its worth being demonstrated as being driven by market forces, particularly in the areas of full scale shear wall and manufactured products testing.

In conclusion, the need for a much greater effort in structural applications research has been demonstrated to ensure Industry can maintain existing and develop new markets and this work must recognise both the political and environmental climate and pressure we now all face.

C. MacKenzie

Session Chairman

22 November 1990

23rd FOREST PRODUCTS RESEARCH CONFERENCE

Session Summary - Session 3 - Primary Conversion, Drying and Utilisation

The lead paper by Professor Ian Ferguson, 'Industry Requirements for Future Research' set the scene for the session and although it did not directly provide answers it threw out a number of challenges. The scenario of where wood products are heading and an overview of the industry sectors manufacturing these products was presented. He made some very interesting comments regarding the low R&D in certain industry sectors and noted particularly how slow industry has been in taking advantage of the taxation incentives for research. It could be that this is also a reflection on researchers and their inability to become more involved in technology transfer.

The next two papers related more to overall conversion. Graeme Siemon presented a fairly pragmatic paper on the opportunities and problems relating to the handling and sawing of regrowth eucalypts. The findings were presented in a way where they could be directly picked up by industry. Andrew Rozsa presented a broad overview of the findings of the sawing and drying project of the Young Eucalypt Program. He has presented in his findings the opportunities and the steps necessary for back- sawing for appearance products in an industry traditionally tied to quarter-sawing a mature, high quality resource.

The next group of papers all relate to the drying of wood. The first paper by Graeme Siemon outlined the work being carried out at the research centre at Harvey, W.A. and indicated how his Department will be able to meet the future needs of the industry. Richard Northway presented quite a different paper on the opportunities for modelling. In some ways it was a review paper showing how drying models may be used in training, research and industry. But he went further to demonstrate how one particular model can lead to quite considerable energy savings in high temperature drying. The

subsequent discussion period indicated how valuable and relevant the technique can be as a research tool.

The final paper 'Drying Developments in Australia' by Jamie Hartley and David Gough was a first-class review paper on the current state of the art in wood drying. On its own it would have served as an excellent lead paper and is deserving of close study by everyone with an interest in the topic.

In summary, several authors highlighted the question of how far researchers should go in the field of technology transfer in order to make available to industry the fruits of their research as documented in the conference papers.

Gary Waugh

Session Chairman

22 November 1990

23rd FOREST PRODUCTS RESEARCH CONFERENCE

Session Summary - Session 4 - Reconstituted Wood Products

The range of papers reflected the breadth of the topic Reconstituted Wood Products. There was, however, a common theme that permeated the session. Research into reconstituted wood products provides a basis for the forest products industry to produce high value and reliable products from lower value forest resources and waste products ranging from 'Activated Wood Pellet Carbon for Gold Extraction' in the work presented by Dr Fung to heavy equipment timber structures in the papers presented by Messrs Strofield and Hutchings or 'Bridgewood' and 'Laminated Veneer Lumber' LVL.

The importance of a basic understanding of adhesion and adhesives and the need to be able to control resin chemistry on a scientific basis to achieve reliability in bending was highlighted in the paper 'Molecular Designing of Wood Adhesives' by Dr Yazaki and Mr Collins. The relevance of this leaching edge research in providing a basis for the development and control of structured wood adhesives should not be under estimated. The reliability of many reconstituted wood products is indisputably tied to adhesive reliability. Industry's contribution in dollars and kind to this project is an excellent model for future industry involvement in research.

Dr Siemon's presentation on "Valwood^{R}' provided the conference with not only a summary of the Valwood development but also a model for applied basic research. The market survey established industry's needs prior to commencing the project gave a total forest resource to marketplace approach to the project.

The presentation by Mr K. McDowell summarising the development of 'Stressed Skin Panel Floor Systems' was again leading edge research. The philosophy of utilising the flooring as a stressed skin and building bearers and joists in line to lower the floor profile all provide improved structural performance, economics and

reliability. It will provide industry with a system that will allow it to regain flooring market share.

The session showed that considerable research effort was ongoing in 'Reconstituted Wood Products' outside of the traditional forest products laboratories, in tertiary institutes and in the private sector. This research effort is, however, and must continue to be, underpinned by a research component in basic research in the traditional government funded laboratories. It may be that future forest products conferences will need to be opened somewhat to allow a greater input by private sector forest products research.

K.J. Lyngcoln

Session Chairman

22 November 1990

Forest Products Research Conference 1990

SESSION 5 - GROWTH FOR END USE

Session summary - A.G. Brown

The five papers to this session, complimented by posters, provide an informative sample of research on wood properties and quality as affected by options available to forest managers.

Two report the outcome of major collaborative projects -

- Paper 5/5 is an account of portion of the Young Eucalypt Program, which has examined the management of valuable dense young stands of the ash eucalypts. It is the only report to this Session which deals with naturally-regenerated or seeded forests. A full report of the whole study will shortly be published as a book.

- Paper 5/1 summarised much New Zealand research on the relationship between the silvicultural treatment of radiata pine and sawmilling characteristics of the resulting logs. The research has been brought together and made readily accessible to managers - of both forests and sawmills - through computer-based models.

Two other papers provide accounts of studies of important properties which are essential if models of the type described in Paper 5/1 are to be soundly based -

- Paper 5/4 described variation in the density of wood of radiata pine grown in New South Wales. Whereas a relationship between density and site temperature has been considered significant in New Zealand, the site-to-site variation in NSW is better accounted for by rainfall in the summer months, tree diameter and height at specific age, and the phosphorus content of the foliage.

- Paper 5/3 reported a study of the impact of heavy thinning on the density and other properties of the wood of Caribbean pine, a species of which rapidly-increasing volumes will become available in Queensland in the next decade. Whereas heavy thinning or irrigation of pines grown in southern Australia may

increase wood density (e.g. by permitting more growth in summer months when latewood is being formed), Caribbean pine was not significantly affected by thinning.

The remaining paper, 5/2, reported early but promising results in breeding eucalypts for pulp production by a specific chemical process. By selecting parent trees using an index incorporating economic weights, and made available by CSIRO, pulp yield was shown to deserve great attention in a breeding program. Pulp yield not only determines how much wood is required to obtain a nominated quantity of pulp, but may also determine how much pulp can be obtained from a pulp mill of nominated wood intake, and is thus rather more important in breeding than growth rate.

As rotations in plantations decrease in length and the management of portions of native forests approaches that of plantations, understanding relationships between silviculture and wood and log properties will become of increasing importance. I hope that this session has contributed to that understanding.

23rd FOREST PRODUCTS RESEARCH CONFERENCE

Session Summary - Session 6 - Optimal Use of Fibre Resources

The six papers presented in this session covered two important aspects of the work of the Fibres and Chemicals Program of the Division. The two papers presented by P.J. Nelson and H. Mamers reported on work carried out on behalf of Government Departments. The remainder cover topics which are perceived to be of public concern and where CSIRO might be expected to provide expert advice.

The first paper, "Recycling - Prospect and Practices" by A.W. McKenzie summarized information provided to an Industry Commission Inquiry, while amplifying certain aspects which need to be addressed to obtain maximum benefit from the recycled fibre resource. Factors of particular importance were a proper waste management with effective segregation of various paper grades, adequate realization that the recovery of recycled fibre can have a significant environment impact, the possible advantages of a joint-venture deinking/bleaching/fibre fractionation system and the identification of printing paper grades as the most likely application for recycled fibre.

"The Commonwealth Guidelines for New Bleached Eucalypt Kraft Pulp Mills", by P.J.Nelson described the historical background to the Commonwealth Government request that CSIRO review relevant overseas technology and advise the Government on technical and environmental issues. He outlined the concept of "Best Available Technology Economically Achievable" (BATEA) and indicated that mills using BATEA and efficiently operated should cause no significant short term toxicity if discharging into a marine environment. He then discussed the steps recommended to monitor long-term environmental effects and the research program to be implemented so that technological and environmental issues are kept under continual review.

G. Gartside reviewed the current position with respect to "Alternative Fibre Sources", both agricultural residues and specialty fibre crops. He pointed out that fibres such as cotton linters, which have unique properties, will always be required for specialty products. However, where the fibres are chemical and morphologically similar to wood fibres, the disadvantages associated with collection, handling, processing and end-use properties generally mean that such materials only provide a viable alternative in countries which are deficient in wood resources.

In "Rediscovering the East Gippsland Forest", H. Mamers and V. Balodis reported on the pulpwood evaluation component of a joint Victorian Government/CSIRO research program aimed at evaluating the resource as part of the Government's Victorian Timber Industry Strategy. The work undertaken involved identification of the resource, preparing a sampling plan, collecting wood samples and converting them into sample mixtures representative of the forest types found in the area under study and preparing and evaluating pulps prepared from the various woodchip mixtures. The results provide a factual basis for future Government decision on the optimal use of the East Gippsland forest.

A.F.A.Wallis presented a review of current chemical pulping and bleaching practice which indicated that the kraft process is still the preferred option for chemical pulping. He outlined new developments in kraft pulping and bleaching aimed at the elimination of reduced sulfur compounds and the reduction of chlorine-containing organic materials in mill effluents. Alternative pulping processes, including some involving the use of organic solvents, were also discussed and their potential benefits and commercial possibilities considered.

A similar review, "High-Yield Mechanical Pulp - What's in it for us", by M.D. Williams, outlined the possible benefits to be obtained by substituting high-yield pulps for chemical pulps. These include lower wood consumption, lower capital and production costs and improved opacity. Disadvantages are lower mechanical strength and loss of brightness on aging. It has been estimated that if the time for brightness reversion to occur was increased from 3 months to 3

years, potential consumption of CTMP would be increased form 0.6 to 2.2 million tonnes. A solution to the brightness reversion problem could provide the impetus for a major export industry based on eucalypt CMP or CTMP.

The attendance at this session suggested that the pulp and paper industry does not regard the Conference as important for their interests, while those involved in solid wood and panel products were not interested in what they regarded as peripheral topics. Future Conference committee's might consider obtaining opinions form sponsoring organizations about the type of contributions they consider appropriate.

A.W. McKenzie

Session Chairman

22 November 1990

23rd FOREST PRODUCTS RESEARCH CONFERENCE

LIST OF DELEGATES

ATYEO, Bill	SA Woods & Forests Dept
BALODIS, Bill	CSIRO DFFP
BARNACLE, John	CSIRO DFFP
BEEL, Martin	WA Forest Products Assoc.
BIER, Hank	NZ Forest Research Institute
BOLDEN, Stephen	Radiata Pine Assoc.
BREITINGER, Harold	CSIRO DBCE
BROWN, Alan	CSIRO DFFP
CARSON, John	National Assoc Forest Industries
CAUSE, Myron	Qld Dept Forestry
CHIN, Charles	CSIRO DFFP
CLARK, Noel	CSIRO DFFP
COLLEY, Dick	Forestry Commission of NSW
COLLINS, Peter	CSIRO DFFP
COOKSON, Laurie	CSIRO DFFP
COSTOLLOE, John	SECV
COUTTS, Bob	CSIRO DFFP
COWN, Geoff	NZ Forest Research Institute
CREFFIELD, Jim	CSIRO DFFP
DEAN, Geoff	APPM
DUNNINGHAM, Elizabeth	NZ Forest Research Institute
ELLYARD, Peter	Commission for the Future
FERGUSON, Ian	Melbourne University
FRENCH, John	CSIRO DFFP
FRICK, Tony	Royal Melb Inst Technology
FUNG, Paul	CSIRO DFFP
GARDNER, David	Forestry Commission of NSW
GARTSIDE, Geoff	CSIRO DFFP
GOODE, Jenny	Koppers/CSIRO
GOUGH, David	Qld Dept Forestry
GRANT, Denis	Forestry Commission of NSW
GREAVES, Harry	CSIRO DFFP
HALL, Scott	CSIRO DFFP
HARDING, Kevin	Qld Dept Forestry
HARTLEY, Jamie	Forestry Commission of NSW
HEWERTSON, Warren	CSIRO DFFP
HIGGINS, Huntly	CSIRO DFFP
HILLIS, Ted	CSIRO DFFP
HOWICK, Doug	CSIRO DFFP
HUTCHINGS, Bruce	Consultant
ILIC, Jugo	CSIRO DFFP
IRVINE, Geoff	CSIRO DFFP
JOE, Bill	Forestry Commission of NSW
JOHNSON, Gary	CSIRO DFFP

KEATING, Bill	Conference Secretary
KERRUISH, Bill	CSIRO DFFP
LEICESTER, Bob	CSIRO DBCE
LHUEDE, Ted	CSIRO DBCE
LLEWELLYN, Peter	SA Timber Development Assoc
LYNGCOLN, Kevin	Plywood Assoc of Australia
MacKENZIE, Colin	TRADAC
MAMERS, Heikki	CSIRO DFFP
MAULDIN, Joe	USDA Forest Service
McARTHUR, David	CSIRO DFFP
McCARTHY, Kevin	CSIRO DFFP
McDOWALL, Mick	Plywood Assoc of Australia
McKENZIE, Alex	CSIRO DFFP
McLAUGHLAN, Jack	NZ Forest Research Institute
McNAMARA, Bob	CSIRO DBCE
McNAUGHT, Andy	Qld Dept Forestry
MICHELL, Tony	CSIRO DFFP
MILLER, Wayne	NZ Forest Research Institute
MILLS, Robert	Aust Furniture Res & Dev Institute
MILNER, Bob	Monash University
NELSON, Peter	CSIRO DFFP
NIKPOUR, Touba	CSIRO DFFP
NORTHWAY, Richard	CSIRO DFFP
OZARSKA, Barbara	Aust Furniture Res & Dev Institute
PRESTWICH, David	Aust Hardwood Quality Council
RAWLINS, Bill	CSIRO DFFP
REILLY, Mary	CSIRO DFFP
ROZSA, Andrew	CSIRO DFFP
RUDLING, Ken	Southern Timber Treaters Group
SCHMALZL, Karl	CSIRO DFFP
SIEMON, Graeme	WA Conservation and Land Management
SIOUMIS, Tony	CSIRO DFFP
STROHFELDT, David	Hancock Bros
TERCELLI, Fabian	CSIRO DFFP
TERRILL, Stuart	CSIRO DFFP
THORNTON, John	CSIRO DFFP
TIGHE, Maureen	CSIRO DFFP
TSUNODA, Kunio	Kyoto University
VICKERS, Lloyd	CSIRO DFFP
VINDEN, Peter	NZ Forest Research Institute
WADE, John	Forestry Commission of NSW
WALLIS, Adrian	CSIRO DFFP
WATKINS, John	Koppers/CSIRO
WAUGH, Gary	CSIRO DFFP
WEARNE, Ross	CSIRO DFFP
WILLIAMS, Max	CSIRO DFFP
YAZAKI, Yoshi	CSIRO DFFP
YOUNG, Fran	CSIRO DBCE
YURITTA, John	CSIRO DFFP

EMULSIONS - THE KEY TO THE FUTURE

J.B. Watkins and J.H. Goode

ABSTRACT

An overview of emulsion science, emulsions, emulsion chemistry and emulsion processing and control is discussed. An increasing need to research, develop and apply emulsions to existing (and in many cases wasteful, polluting and energy consuming) technologies, for obvious benefits to planet, resource and user is exemplified in some developments utilized in the preservation of timber commodities.

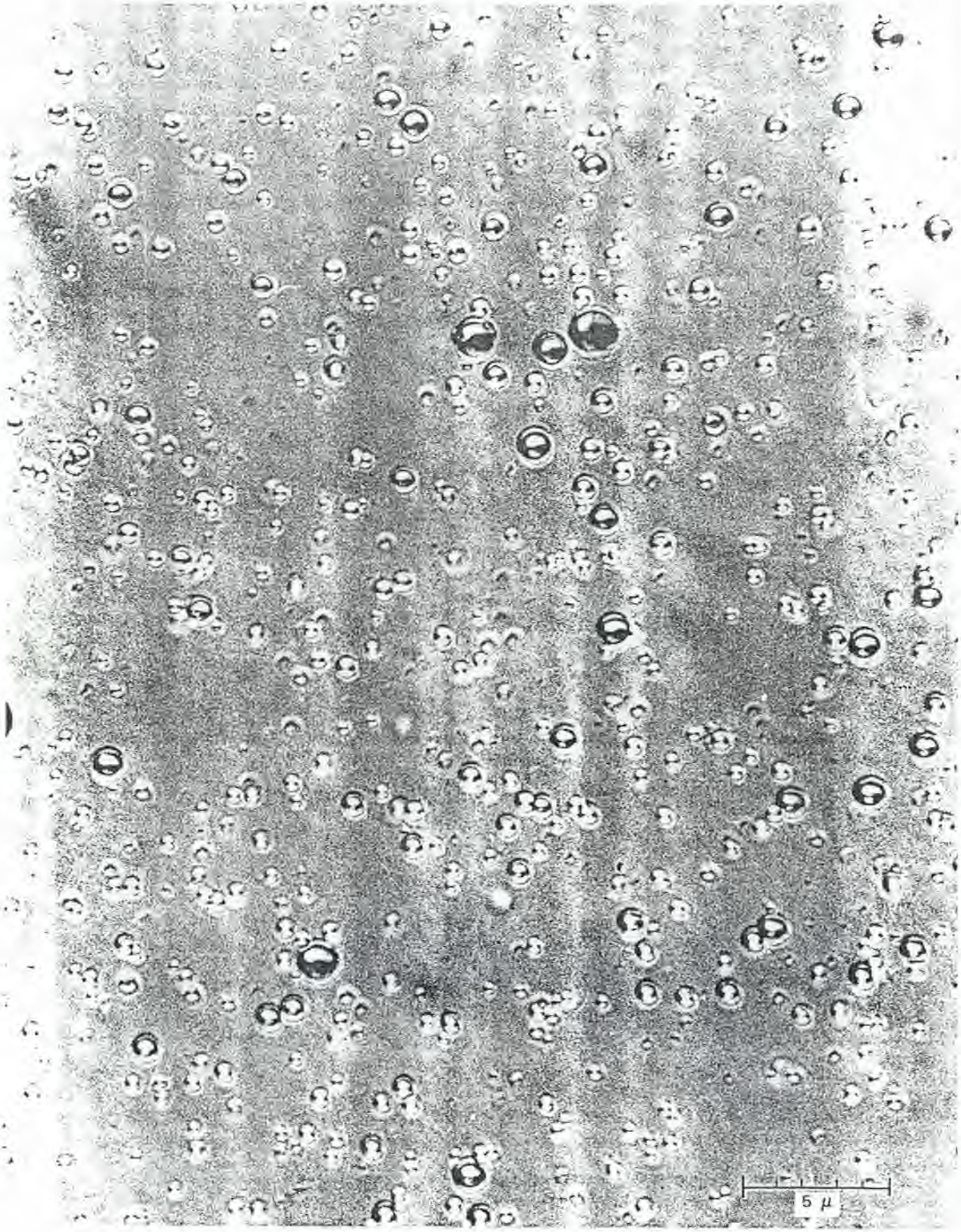
INTRODUCTION

If there is to be a future, especially relating to forests as they benefit human and animal kind in the widest sense, then not only must their resources be managed wisely, wasteage stopped, but the insidious attack upon their very existence by so many and varied forms of pollution must be thwarted. As one of mother nature's most dedicated apostles, David Suzuki, warns us, unless we make significant changes in attitude and practice by the turn of this century, it will be too late, especially for future generations.

Mother nature provided us with the universal solvent, water. Emulsion technology provides the mechanisms by which means, water can be adapted for use in systems which depend largely upon derivatives of petroleum, coal or synthetic organic fluids. Gases can be utilised in the manufacture of foams and emulsions. However, in the context of this discussion, the term emulsion will refer to liquids only.

Emulsions

Emulsions in one form or another had been used long before knowledge of emulsions in a defined sense, existed. Thus, when emulsions began to emerge as a useful (or nuisance) product, their theory grew just as haphazardly. And as scientific principle and practice began to be applied to their understanding and production so too, the definition of the term "emulsion" became wide and varied.



CATIONIC EMULSION OF HYDROCARBON IN WATER

For the purpose of this discussion I propose the definition put forward by Paul Becher[1]: "An emulsion is a heterogeneous system, consisting of at least one immiscible liquid intimately dispersed in another in the form of droplets, whose diameters, in general, exceed 0.1 μ. Such systems possess a minimal stability, which may be accentuated by such additives as surface-active agents, finely divided solids etc."

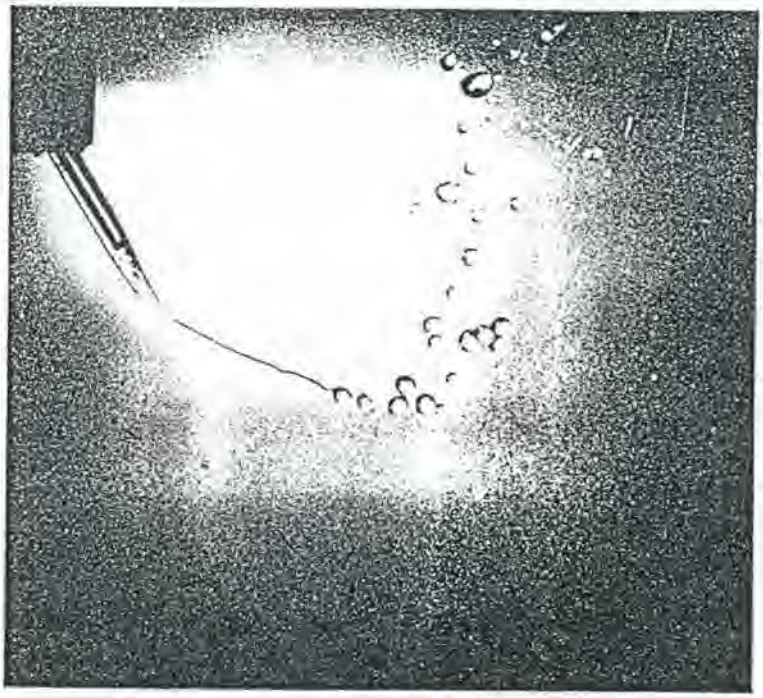
However, to this definition I would add the words, which may confer stability and/or impart special properties to the emulsion as it is ultimately used. The significance of this wider definition will become obvious during discussion of examples of applied emulsion technology in the wood preservation industry today.

By its very nature an emulsion is unstable. The degree of stability or instability depends upon many factors both within the emulsion and without. The physical chemistry inherent in the emulsion, conferred upon it by such things as the nature of the immiscible liquids, surface-active agents ("emulsifiers") used to aid in the formation of the emulsion, the ratio of the major components and additives, presence of solids, addition of stabilizers, the charge on the droplets and the method of production of the emulsion. Even the order of addition, of the components, temperature of manufacture, the energy involved in and imparted during manufacture, equipment utilized, physical chemistry involved, storage and of course the use to which the emulsion will be put - or factors which led to the formation of an unwanted emulsion - will determine the stability of the final product.

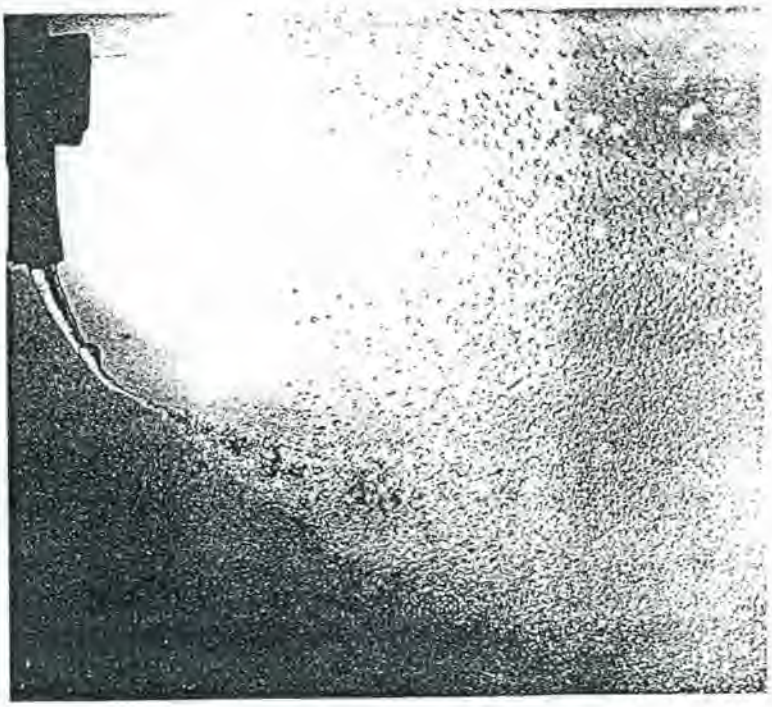
The very many and diverse uses to which emulsions will be put, dictate the degree of stability which must be built into the emulsion. The stability and performance of the emulsion is due largely to the skill and "feel" of the formulator, the emulsion chemist; and still considered by many as an art. The final products may be a skin cream, paint, road material, polish, wood preservative, herbicide, food, cutting oil, wax suspension, fuel, coal slurry, medicinal injection.

Terminology of Emulsions

In order to discuss emulsions further it is necessary to understand the terminology which has evolved. Basically, one liquid is dispersed within another. One liquid is almost always water and the other an oil. The liquid in which the second liquid is dispersed is termed the continuous phase, sometimes, external phase. The dispersed liquid is termed disperse phase, sometimes, internal phase. Either phase can be complicated further, by chemical and/or physical modification and one or both phases can contain a separate



Breakup in a liquid jet at velocities below the critical. *Courtesy: Prof. E. G. Richardson and Journal of Colloid Science.*



Breakup in a liquid jet at velocities above the critical. *Courtesy: Prof. E. G. Richardson and Journal of Colloid Science.*

additional dispersion of a liquid or suspension of solids within the droplets, the continuous phase or at the interface of the two immiscible liquids i.e. surrounding the droplets - or both.

To complicate matters even further, since in most emulsions, oil and water constitute the two immiscible liquids, then depending upon the volume of each, the emulsion can exist, in the main as two distinct types. One type, in which water makes up the continuous phase and in which oil is dispersed, is termed oil-in-water usually expressed as O in W. The other type, which comprises oil as the continuous phase, in which water is dispersed, is termed water-in-oil, expressed W in O. There can exist, more complicated emulsions which may exhibit very complex structure and behaviour such as liquid crystal phenomena, but such emulsions are beyond the scope of this paper. One further important point which must be borne in mind is that even in a relatively simple formulation, dual phase emulsions can exist. In other words droplets can exist within droplets in either W/O or O/W emulsions. Such emulsions are complex and exhibit complex behaviour. These emulsions are best exemplified by the range and complexity of photographic emulsions. They perform a very complex role in that their very fine, homogeneous structure provides a means of applying a thin film evenly over the surface of a photographic plate or paper. Once broken, the remaining dry film constitutes a specially designed and very light sensitive surface. These emulsions enable the formulator to manipulate the chemistry inherent in the dry film, to fulfil the diverse needs of the photographer in black and white and especially colour photography.

Surfactants cover a very broad range of natural and synthetic chemicals which exhibit surface activity when dissolved or dispersed in a liquid and the term derives from surface active agent. These materials can be emulsion promoting, emulsion breaking and some special surfactants such as the fluorocarbons can achieve both effects in solution. Almost all emulsifying agents are surface active so that these terms are synonymous in the context of this discussion.

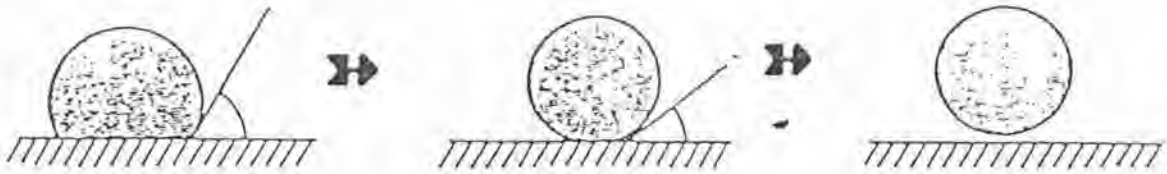
Some terms will become clearer when emulsion properties are elucidated. However, a surfactant is crucial in the formulation of an emulsion. Its primary purpose is to be compatible in one or both phases - more than one can be used, termed Co-surfactant - and thus modify surface tension of one or both phases. Simply, the surface tension of a liquid is a measure of its ability to wet a surface and the lower the surface tension the better the wetting properties. Ultimately the right surfactant will lead to lowered

Adhesion

Very often the cause of damage to a bituminous road surface can be attributed to adhesion failure. Water has the ability to strip bitumen from stone, and once this process has started, it is accelerated by the traffic.

By studying the contact angle between bitumen and stone in the presence of water, information on the stripping tendency can be obtained.

By applying a drop of bitumen to an even stone surface and covering it with water, the contact angle between bitumen and stone can be observed. The pictures below show how bitumen is stripped off a stone.



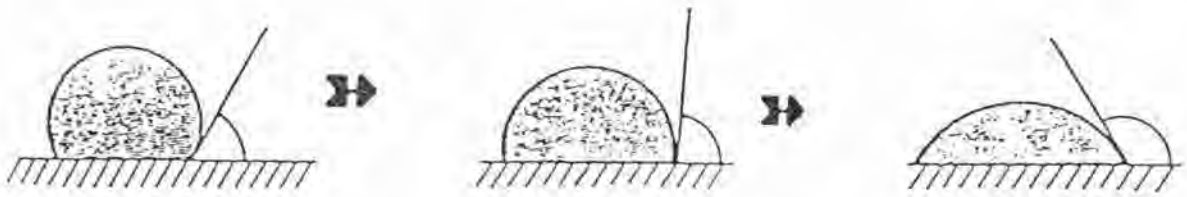
At the time of immersion the contact angle is smaller than 90°.

The water has started to lift the bitumen drop and the contact angle has decreased.

The stage is reached where the contact angle is 0 and the bitumen has begun to lose contact with the stone surface.

The speed of this process depends on the temperature, the type of stone and the viscosity and the composition of the bitumen.

If a surface active compound is added to the bitumen, the process proceeds in the opposite direction, as shown below.



At the time of immersion the contact angle is smaller than 90°.

The contact angle increases and reaches 90°.

The bitumen drop spreads on the stone surface and the contact angle increases.

Active Adhesion

Active adhesion implies that the binder cannot be stripped off the stone by water and the binder is able to cover wet stone surfaces.

Passive Adhesion

Passive adhesion implies that the binder is able to retain on dry stone surfaces or very slowly strip off by influence of water.

interfacial tension and reduce cohesion of the continuous phase, hamper coalescence of the disperse phase and thus confer a degree of stability to the emulsion.

A stabilizer is a compound which may or may not be surface active. However, a stabilizer usually works in conjunction with the surfactant to increase stability chemically, physically or electrically. It may also modify the structure of the emulsion by thickening the water phase or changing the density of one of the phases (reduce the difference) or modify the viscosity of the continuous phase. An insoluble dispersed stabilizer can assist the droplets to form and remain small and well dispersed by distributing around the interface and provide protection for the droplet film.

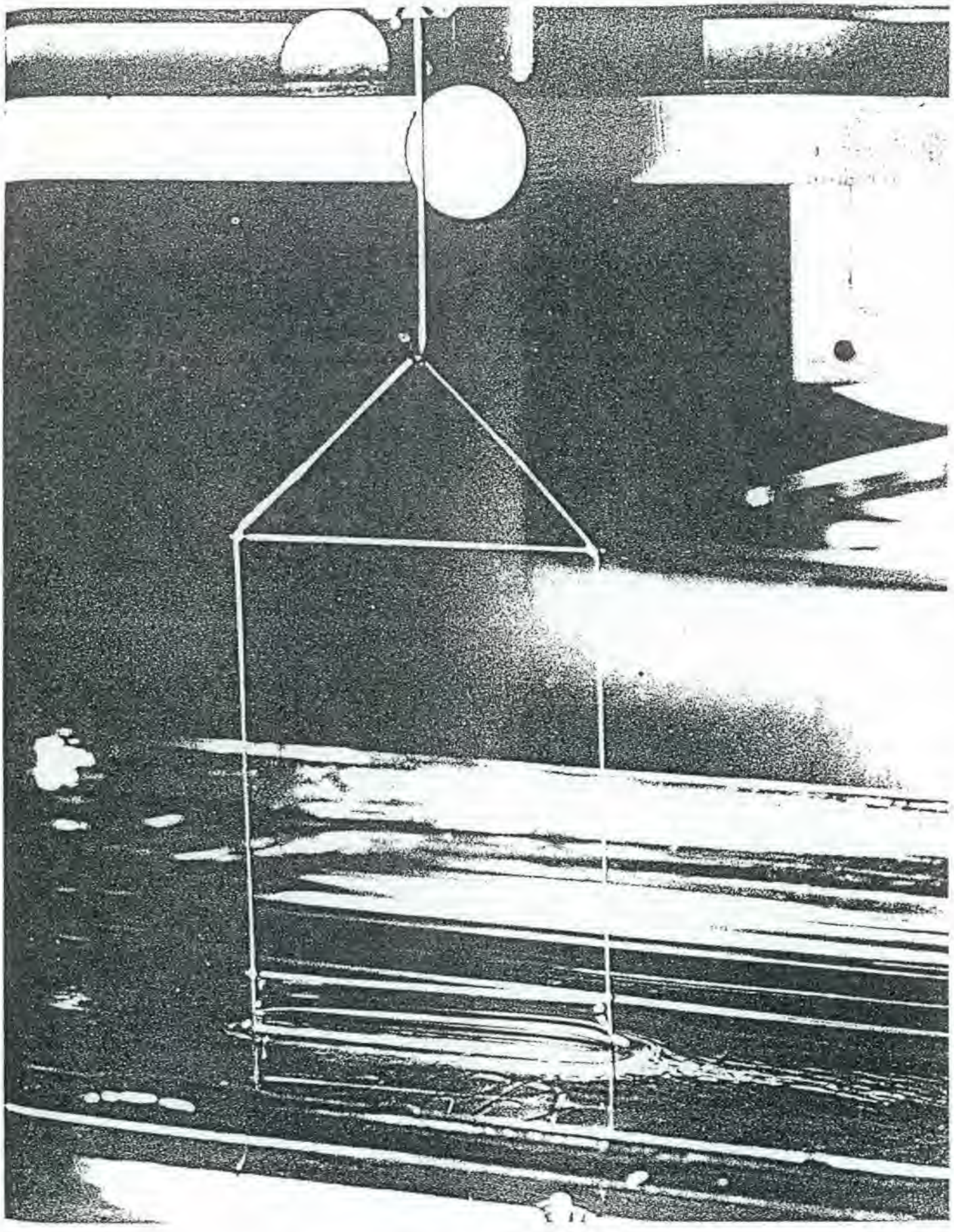
Additives generally relate to compounds dissolved in one or both phases for a special purpose such as changing pH, providing toxicity, or medicinal efficacy, promoting film formation, adhesion, lubrication, colour etc.

When an emulsion breaks, its ultimate goal, the two phases separate and one or both may evaporate leaving a film, deposit, chemically active surface, electrical charge or lack of it (antistatic formulations), precipitate, colour (paint), bitumen or tar (roads) etc. An emulsion can be formulated to break quickly or have stability built in to prevent premature breaking. With a spontaneous or undesirable emulsion such as may form in oil storage tanks or oil wells, every attempt will be made in an effort to break this emulsion quickly and completely to recover one (or both) phase.

Finally, a very important term encountered is inversion. This describes the fascinating phenomenon which occurs when say an O/W emulsion becomes W/O or *vice-a-versa*. Inversion can be deliberately brought about or will occur spontaneously. There is a phase-volume relationship which will influence whether the emulsion is O/W or W/O and above a (much debated) critical value ratio of about .74 inversion will occur so that the higher ratio phase becomes the continuous phase. So many factors can influence inversion such as temperature, pressure, shear, contamination, surface and interfacial tension changes and of course the nature of the surfactant(s) and the emulsion ionisation.

Emulsion Properties

Again a science in its own right. So, a very brief note on the more important properties which of course can highlight problems in a nuisance emulsion or dictate the limitations in manufacture and utilization of the finished emulsion.



MEASURE OF SURFACE ACTIVITY

Particles or globule size will be influenced by the chemistry, physical chemistry, nature of the phases, emulsion type, surfactants chosen, stability (inter-related) and method of processing; ageing too, plays a role.

The shape of the fluid particle will ultimately be governed by the laws of thermodynamics. The most thermodynamically stable energy of configuration in an emulsified droplet is spherical. This shape minimises surface area and thus the surface energy of the globule. The smaller the globule the more stable the emulsion.

The type and amount of emulsifying agent must provide sufficient thermodynamic energy to maintain the dispersion of the globules in the continuous phase. The way in which a surfactant works is to orient at the interface of the globule-continuous phase so that the oil soluble part remains in the oil and the water soluble part protrudes into the water. The surfactant molecule which modifies one or more boundary tensions, is composed of a long chain compound containing a small, oil soluble "head" and a large water soluble "tail" (or *vice-versa*). The term hydrophilic is used for the water-loving group(s) and hydrophobic is used for the oil-loving group(s). Thus the HLB value, sometimes useful in formulating emulsions, refers to the hydrophile-lipophile balance peculiar to many types of surfactants. This value can influence whether the emulsion will be O/W or W/O and whether a surfactant is worth trying when initial formulation work commences. (Further elucidation can be followed through in the references).

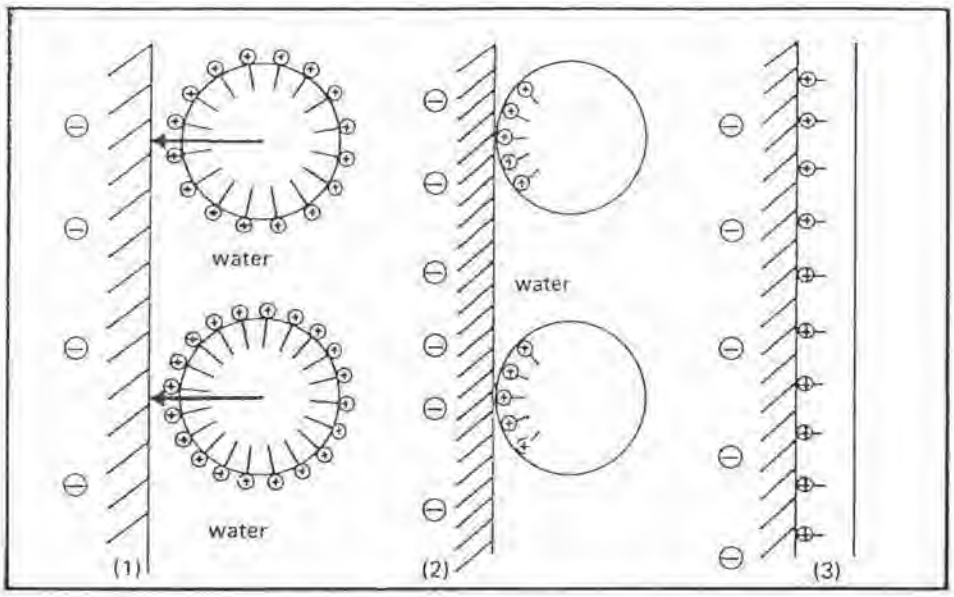
Surface tension is a critical parameter and will influence stability of the emulsion, its ability to wet a substrate and mechanism of breaking. The lower the value (determined by many methods) the better the emulsion. The surfactant choice and its successful use is critical to this value usually expressed as m Newtons per square metre.

Interfacial tension is very important and will determine stability, droplet size, behaviour of the emulsion in use. This property is very difficult to determine, but plays a significant role at the droplet-continuous phase boundary. Co-surfactants and intuition combined with formulation skills, most important.

Rheological behaviour of the emulsion, even its simple apparent viscosity can be as important as stability and globule size and distribution. This property, only now receiving the scientific study it deserves, is probably the most important single property of a

In general, a stable emulsion can only break by evaporation of the continuous phase.

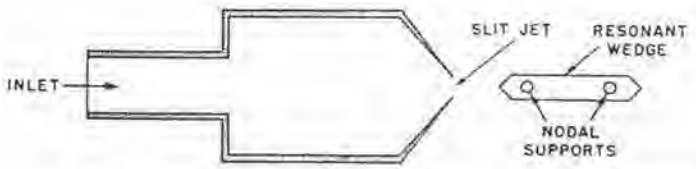
In the special case of a cationic emulsion in the presence of an electronegative surface, another phenomenon predominates :



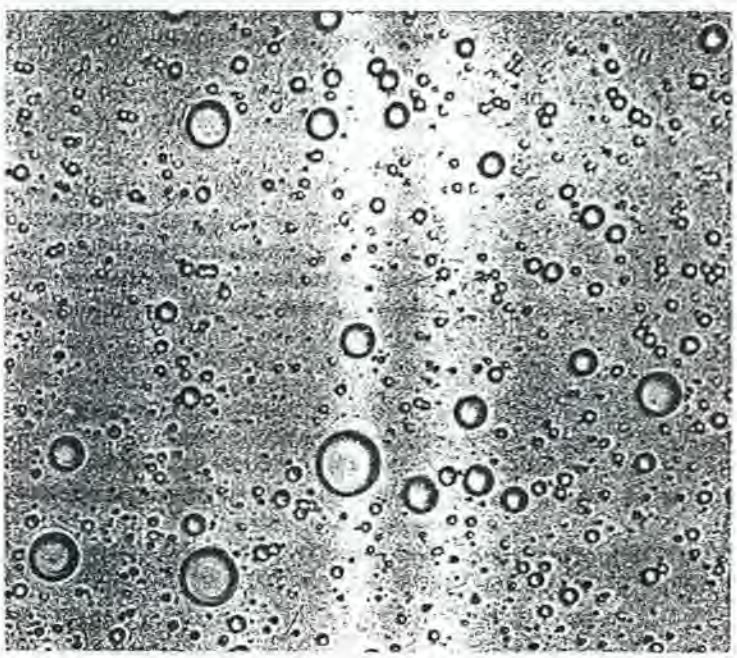
(1) : The positively charged globules migrate to the electronegative metal.

(2) : The globules make contact with the metal, and the amine cations tend towards it.

(3) : The globules coalesce, the positively charged cations ensuring, through their hydrocarbon chains, strong adhesion of the organic film to the electronegative surface.



Schematic diagram of a Pohlman whistle. The nodal supports of the blade are separated by a distance equal to half the wave-length of the characteristic vibration of the system.



PHOTOMICROGRAPH OF AN OIL-IN-WATER EMULSION
This is a polish, magnified 1100 times, using bright field. Range of sizes of particles and agglomeration are evident. (From *Dow Corning Corporation, Midland, Michigan*)

successful emulsion. This property determines not only matrix behaviour upon standing, but, above all, flow characteristics in the final product. Too complex to discuss here, but best exemplified in following cases. Imagine a toothpaste which liquified too soon or too much, a margarine too stiff to spread, an ointment which ran off the skin, a cream which would not thicken, a paint which would not brush out, or brushed out, not break quickly, a bitumen emulsion which would not flow or spread evenly or lower its viscosity with heating. These are but a minute sampling of emulsions which depend upon their formulated rheology for their efficacy.

Other properties too numerous to discuss in detail are, for example, electrolytes, pH, inadequate dispersion, surfactant type(s), stabilizer(s) and mode of action, colour, consistency, temperature effects, phase-volume ratios, phase-volume relationships, solids dispersions, iso-electric point of solids, solids stabilization, phase chemistry, phase modification, microscopic nature, electric charge phenomena, forces acting upon globules, particles, pressure effects.

Emulsion Categories

There are four main categories:-

Anionic
Non-ionic
Cationic
Amphoteric

The nature of the emulsion will depend upon its use and the chemistry-physical chemistry inherent in the emulsion as a result of its components and their formulation together with the skill of the formulator. The two most important parameters manipulated to bring about the final outcome are pH and surfactant type.

The type of emulsion to be made will be dictated by its proposed use.

Anionic Surfactants

An anionic surfactant will ionise in solution to yield a large negatively charged ion (anion) and a small positively charged ion. Typically, the chemical structure of the four main dategories are, sulphates, alkyl sulphonic acids and their salts, carboxylic acids and

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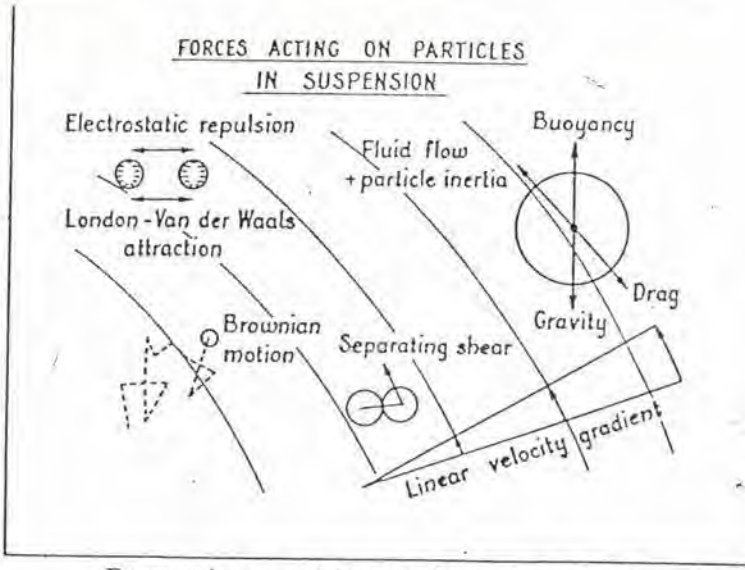
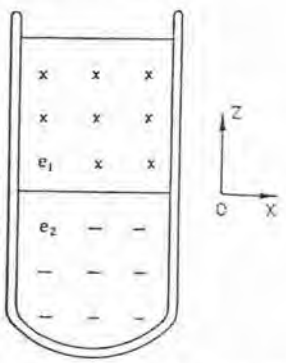
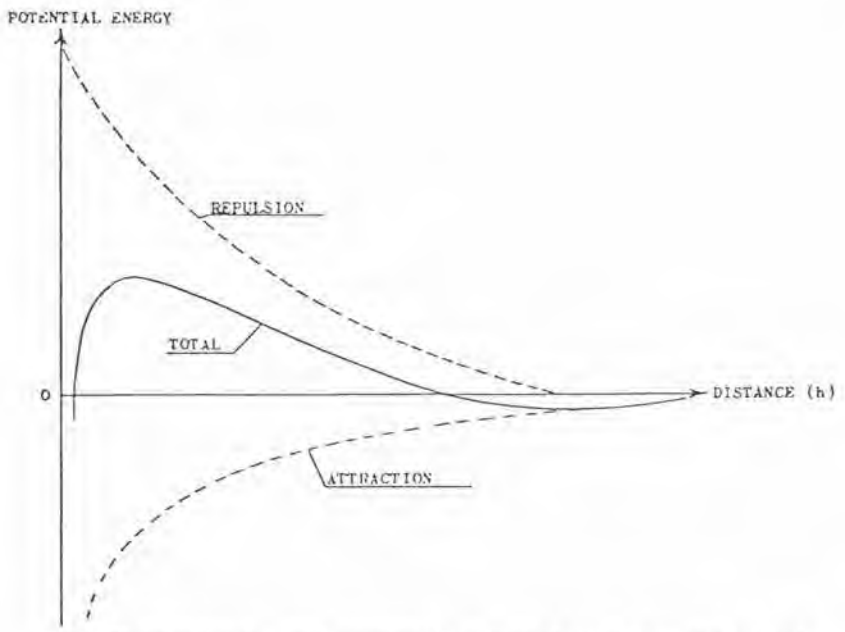


Forces acting on and between the particles of a suspension i
laminar flow.

Emulsion rheology



Simple arrangement for producing emulsions.



Showing how interaction energy depends on distance between dispersed particles.

their salts and alkylaryl sulphonic acids and their salts and miscellaneous or synthesised compounds.

Na^+ Alkyl Sulphate $^-$

Pigment Emulsified Creosote (PEC)

This wood preservative composition developed by CSIRO, in collaboration with Koppers Australia Pty Ltd and the State Electricity Commission of Victoria,has been patented world wide. It has been successfully commercialised in Australia and Indonesia. Serious expressions of interest in the technology have been received from the U.K., Japan, USA, Canada, Germany and Brazil.

PEC is a super stable high temperature creosote emulsion. This emulsion comprises approximately 30 per cent water, 65 per cent HTC (AS1143), 4.0 per cent pre-dispersed, micronised and coated titanium dioxide, structuring agents, primary emulsifier and stabilizer. The pigment is a very sophisticated, all-phase, micronised pigment (particles less than one micron) which distributes in both the oil and water phases, predominantly around the droplets. The emulsion is W/O and is anionic. PEC is a unique anionic emulsion and demonstrates the potential inherent in this technology. The emulsion is processed through a Dispax Reactor®. The charge on the droplets is negative and once the emulsion breaks within the structure of the pressure treated commodity, only the water evaporates. The creosote is permanently "locked" within the timber microstructure by the complex action of the pigment particles which have been deposited, uncoalesced, in the vessels. The creosote distributes in the vessels and fibres, however, the surface of the treated commodity dries and during the hottest weather no creosote exudes from the surface of the timber. Vapour is almost undetectable.

Further evidence for the value of this application of emulsion technology has been discovered in the work of Associate Professor Tunan Fang during a collaborative study with the Rheology Group under Dr Carlos Tiu at Monash University. The flow of the emulsion within the vessels (hardwoods) and rays (softwoods) under pressure, is apparently much more complex than it is for either water-borne preservatives or oil-borne preservatives respectively. Over the years, observations and results of some limited research, indicated that the same uptake of oil could be achieved with PEC vacuum-pressure impregnation at 60°C as was achieved with creosote alone at treating temperatures

exceeding 100°C. The surprising aspect was that thirty percent more, total liquid - the aqueous phase of the PEC - was impregnated into the timber structure at this much lower temperature. Professor Fang has found that the viscosity of the emulsion decreases uniformly with increase in temperature up to 60°C. As the temperature increases beyond 60°C the viscosity of the emulsion changes little up to 98°C. The ramifications for energy savings and wear and tear on equipment (normally operating above 100°C) are enormous.

Most timber species exhibit a negative charge on their surfaces. The PEC being an anionic emulsion, therefore, encounters no impedance to flow. And the iso-electric point of the pigment particles, (pH 6.2 for titanium dioxide), is exceeded by the pH of the emulsion (pH 9 for PEC) so that the particles do not sediment, do not block pores, do not coalesce or filter out during pressure treatment and thus deposit within the structure where they cause the unique drying effect. Neither is the emulsion affected by pressure, temperature, shear, etc.

Nonionic Surfactants

A nonionic surfactant will not ionise in solution. Most importantly, non ionic surfactants are compatible with anionic and cationic surfactants. Their effectiveness is almost independent of hard water or the pH of the solution or emulsion in which they are used. (This property alone opens up "Pandora's box of potentials" for the wood preservative/preservation researcher). The nonionic surfactants can be classified as

Alkyl Polyethoxy

These surfactant compounds have alkoxy ether, alkoxy ester, or amide linkages to the solubilising groups. Condensation with propylene oxide has resulted in a wide variety of nonionic surfactants. The surface-active properties of the molecule can be altered by the amount and type of alkoxy compound reacted. These materials can be water soluble, water dispersible or oil soluble which makes them very versatile, individually or in combination.

PROCCA and HYCON

These emulsions represent a number of very exciting developments based upon the copper-chromium-arsenic preservatives usually referred to as CCA (Tanalith® Boliden® Wolman® etc.).

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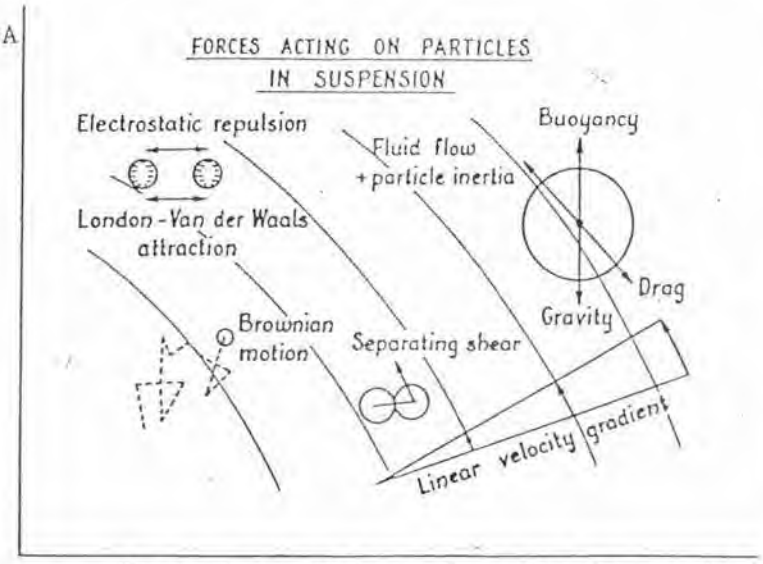
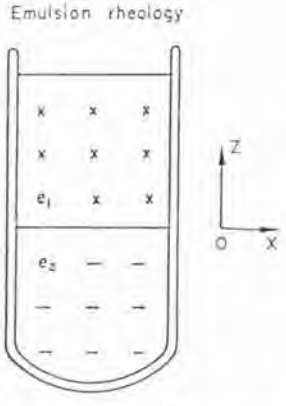
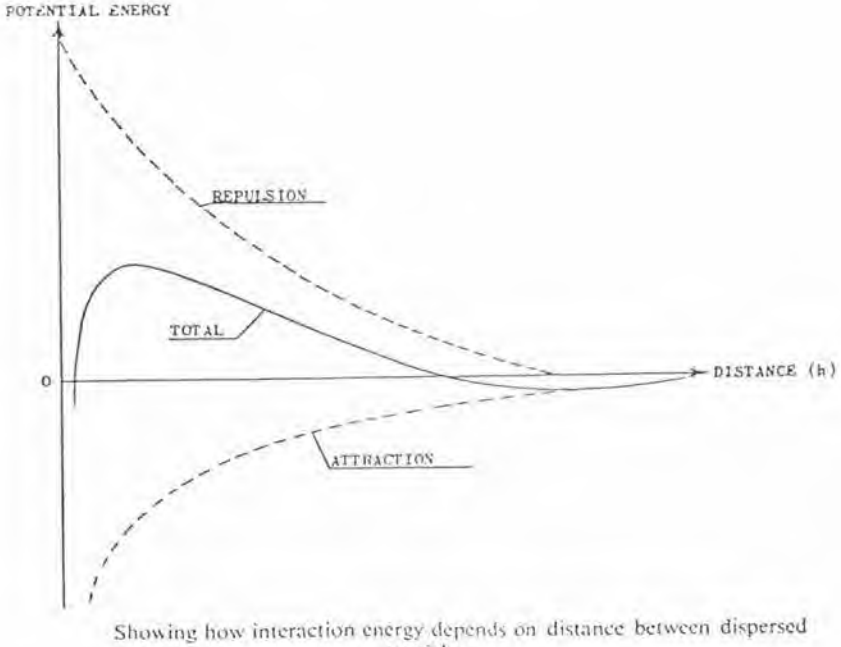


Forces acting on and between the particles of a suspension in laminar flow.



Simple arrangement for producing emulsions.



Showing how interaction energy depends on distance between dispersed particles.

CCA has long been known for its excellent wood preserving properties. However, it suffers some drawbacks evidenced during weathering by cracking, checking, warping, embrittlement and discolouration. PROCCA is an oil-in-water emulsion comprising CCA aqueous phase and a high boiling petroleum oil which can be emulsified in the CCA to any level as required by the end user. The oil which is limited in type only by availability, economy or specified end-use, can be incorporated at up to 5 per cent where the timber, especially *Pinus radiata*, is to be utilized in cladding, decking, architectural finishes. Or it can be incorporated up to 35 per cent for severe in-ground uses such as fence posts, vineyard timbers, bridge timbers etc. The timber, so treated by the various VPI processes, dries very quickly, retains an aesthetically pleasing oiled-surface appearance which highlights the grain, even in rounds, obviates salt migration to the surface and exhibits far superior weathering characteristics over conventional CCA treated timbers. Evidence from field testing, bio-assays and accelerated field simulators after some five years indicates reduced "after-glow", a sysnergistic effect leading to enhanced termiticidal efficacy (several species including *Mastotermes darwiniensis*) dimensional stability, absence of leaching of toxic elements or oil, vastly improved weathering characteristics and durability. Some testing has indicated a unique fire-retardancy effect confirmed by the emulsion treatment. The incredible versatility of the emulsion system (two-phases) opens the way to capitalise upon this property, confer fire-retardancy and put timber back into the forefront of construction and building industry world-wide.

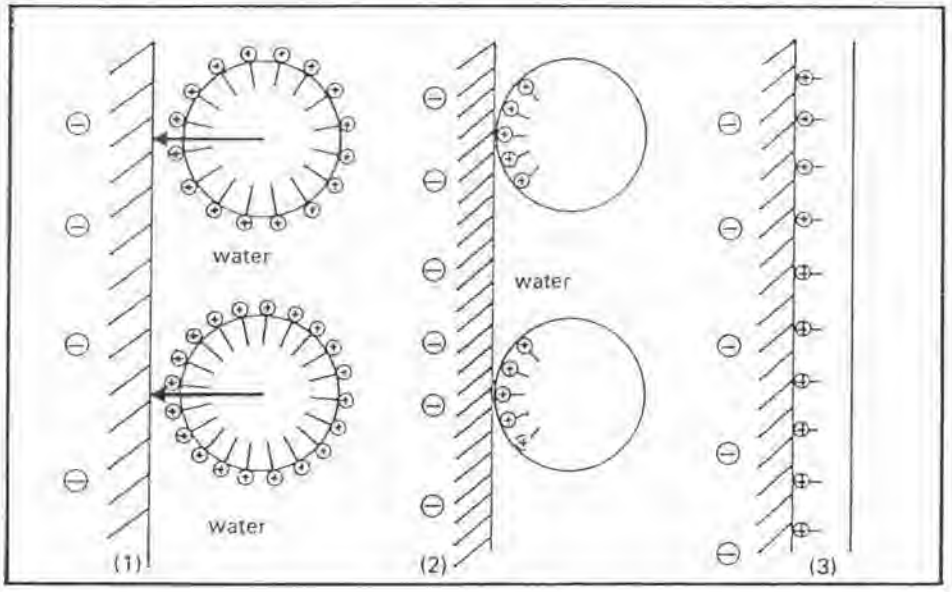
HYCON

Each new development simply points the way to so much more that is possible. HYCON is a very real breakthrough which not only provides the means of varying the oil content, but varying the CCA content to an unprecedented level. Its use to date has resulted in both hardwoods and softwoods being VPI to highlevels of CCA and oil during very short, full-cell schedules and re-drying in hours, undercover or field exposed. Surface temperatures as high as 57°C have caused no bleeding at all and to date, dimensional stability has been exceptional. Emulsion stability is also exceptional, especially considering the hostile nature of the oil's "host".

Processing of the PROCCA and HYCON emulsions is very simple. However, the chemistry can not be discussed since patents are pending world-wide and the latest developments have enormous ramifications for wood preservation, modification, architectural enhancement and above all, much wider and more diverse utilization of timber as such and in composites.

In general, a stable emulsion can only break by evaporation of the continuous phase.

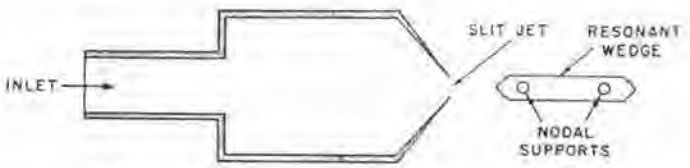
In the special case of a cationic emulsion in the presence of an electronegative surface, another phenomenon predominates :



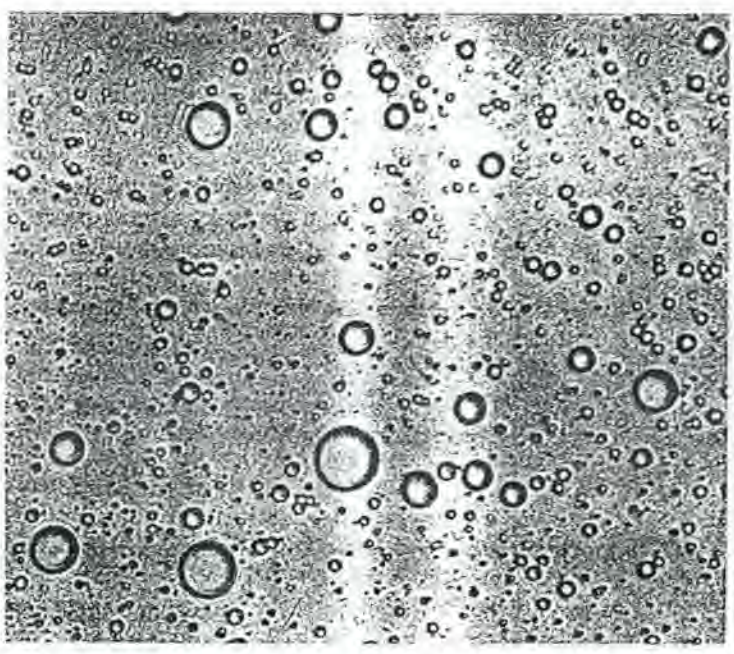
(1) : The positively charged globules migrate to the electronegative metal.

(2) : The globules make contact with the metal, and the amine cations tend towards it.

(3) : The globules coalesce, the positively charged cations ensuring, through their hydrocarbon chains, strong adhesion of the organic film to the electronegative surface.



Schematic diagram of a Pohlman whistle. The nodal supports of the blade are separated by a distance equal to half the wave-length of the characteristic vibration of the system.



PHOTOMICROGRAPH OF AN OIL-IN-WATER EMULSION
This is a polish, magnified 1100 times, using bright field. Range of sizes of particles and agglomeration are evident. (From *Dow Corning Corporation, Midland, Michigan*)

Cationic Surfactants

These surfactants will ionise to form a large positively charged ion and a small negatively charged ion. They are far more complex in their manipulation and use, however, chemically they provide the means by which very difficult, complex and in some cases chemically antagonistic compounds can be emulsified to form a safe, extremely useful and/or unique product. This group can be represented

Ethoxylated diamine $^{+}$ Cl^{-}

Their exceptional properties which can be manipulated in emulsions can be characterised by the following attributes:

(i) They are electrically attracted to, and bound by, surfaces with a negative charge, e.g. cellulose, proteins, wool, silk and hair

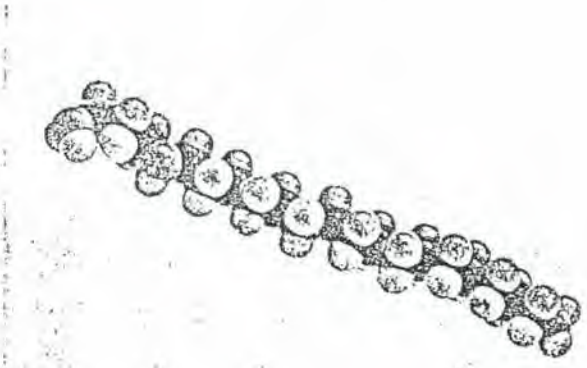
(ii) They give a soft feel to textiles, hair and skin

(iii) They have a high degree of bactericidal and fungicidal action

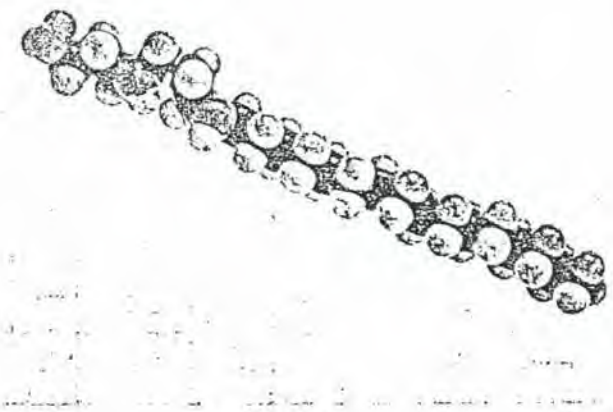
The surfactants comprise, primary, secondary or tertiary amine salts, quaternary ammonium compounds and a diverse range of miscellaneous compounds. Mixing cationics extends their versatility.

PECCA PECAT and PECBUS

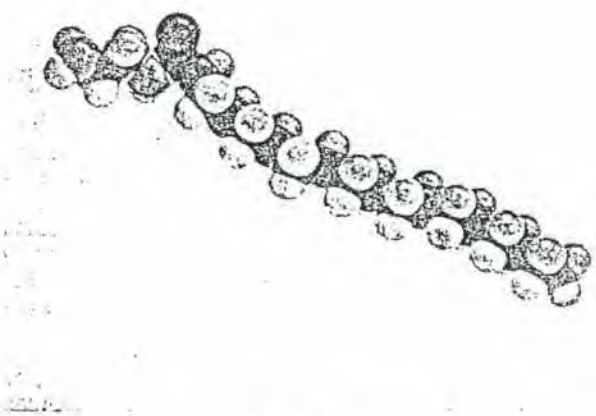
These emulsions all contain creosote. They are very sophisticated and unique emulsions. Their great potential lies in the fact that creosote is used, but is blended to varying degrees with other toxicants to achieve a very clean, dry, aesthetically pleasing finish without any evidence of creosote at all. Under normal circumstances creosote mixed with CCA will result in a dangerous, exothermic reaction. However, emulsion science has enabled creosote to be blended with CCA, resulting in a very safe and versatile preservative which exhibits unrivalled long-term efficacy in ground or in water. The emulsion chemistry permits of blending the CCA and creosote in any ratio which can be aimed at highly specific problems or utilized in very difficult situations where inspection or routine maintenance is difficult or impossible. And of course these emulsions can be pigmented for colour enhancement or surface treatments.



Diamine.

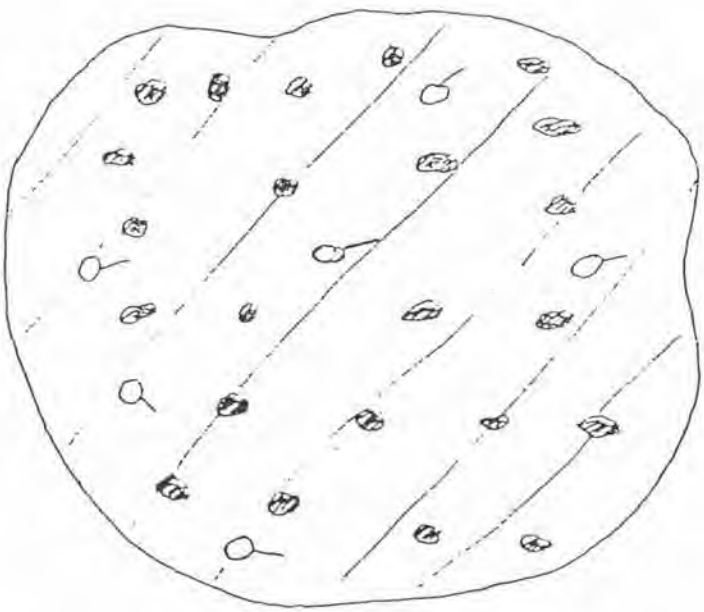


Triamine.

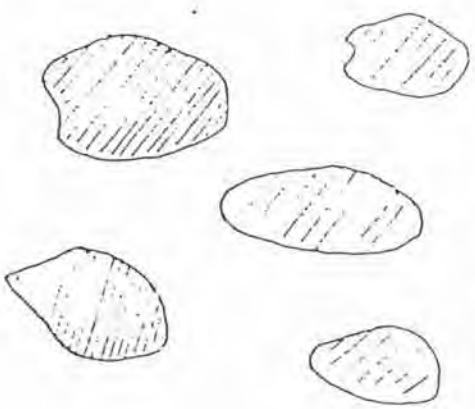


Amidoamine.

Schematic Explanation



Coal tar dispersion



Aggregate

a) Stabilized coal tar dispersion

b) Water phase

c) Surfactant

Hydrophobic tail

Hydrophillic tail

a) Hydrophobic surface

In the case of PECBUS another unique emulsion compounded the best of two toxicants. Creosote is fortified with BUSAN® concentrate to meet the hazard level encountered and emulsified at much lower levels of creosote. Its use resulted in creosote loadings above 100 kg/m^3 and yet the VPI poles dried quickly and soon weathered to a white surface resembling an untreated pole.

PECAT embodied a high creosote content emulsified with very carefully blended surfactant to produce a "gently" cationic version of PEC, both with and without CCA, the potential for which is obvious.

The chemistry involved in these cationic emulsions provides the basis of producing preservatives tailored to any environment, climate, atmosphere, hazard, utilizing toxicants otherwise immiscible, insoluble, expensive on their own at concentrations needed, and they have been successfully blended for excellent results with eight toxicants; the results of which have been reported elsewhere. Their versatility is almost limitless.

Amphoteric Surfactants

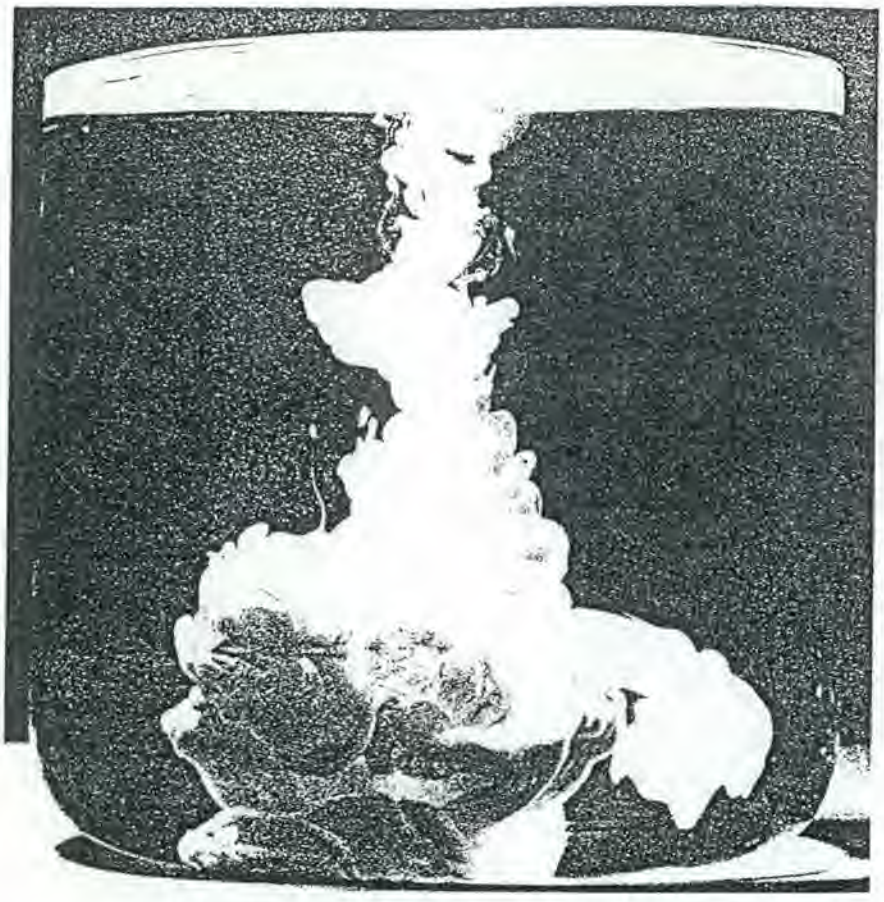
Sometimes termed ampholytic, these surfactants assume either an anionic or cationic ionisation in solution. Therefore, an amphoteric surfactant will ionise according to the pH of its solution or emulsion. (Under certain circumstances they can function as a nonionic surfactant - neutral solutions).

Amine $^+$ Carboxylate $^-$

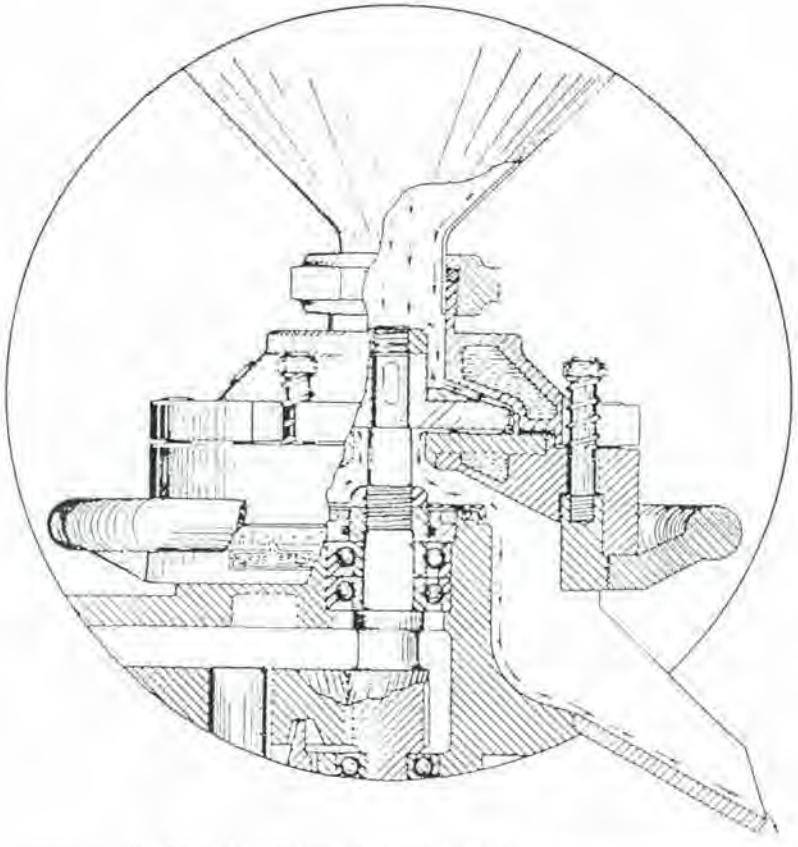
The main categories comprise:

(i) Amino and carboxy compounds
(ii) Amino and sulphuric esters
(iii) Amino and alkane sulphonic acids
(iv) Amino and aromatic sulphonic acids
(v) Substituted betaines e.g. N-dodecyl n:n-dimethyl betaine
(vi) Quaternary phosphono-ammonium compounds
(vii) Alkali salts of normal long-chain alkyl β amino propionic acid

Amphoteric surfactants represent diversity which would be limited only by the imagination and skill of the formulator. Used only to a limited extent in some highly specific preservative research, their utilization is best exemplified by typical uses which are



Spontaneous emulsification ("bloom") in an agricultural emulsion system. *Courtesy: Atlas Chemical Industries, Inc.*



The vertical colloid mill of Figure 7-21 shown in cross-section. *Courtesy: Tree Company & Manton Co.*

commonly, cleaners, degreasers, dish washing liquids, hair rinses, shampoos, hair straighteners, lotions, lubricants, polishes, skin cleanser to name but a few.

Naturally Occurring Surfactants

These are not used in wood preservative compositions. However, no general discussion would be complete without listing some of the more common compounds which are:

Alginates
Phospholipids and steroids
Lecithin
Sterols
Water soluble gums
Cellulose derivatives

Equipment, Process and Control

Together with "intuition" and chemistry, equipment constitutes the most vital link in formulating and producing emulsions. The variety of types and their principle of operation are numerous. No matter how good is the "feel", if the wrong type of equipment is chosen, the successful outcome of real innovation could be missed. Having some idea of the complexity of the emulsion required, the necessary stability and the physical chemistry of the perceived system - or that involved in its end-use - then the choice of equipment is narrowed somewhat. Potential apparatus should be tested in its supplier's laboratories, otherwise, if possible, in laboratories nominated by the supplier. In all of this, the one vital question often overlooked (sometimes with disastrous outcome) is, does this apparatus or pilot scale equipment have its industrial equivalent? In other words, can a successful formulation developed in the laboratory, be scaled up, even to large tonnage quantities as is the case with the wood preservative compositions discussed earlier.

Of course some emulsions require nothing more than simple hand mixing. Depending upon the skill of the formulator some formulations, concentrates can be prepared so that they emulsify spontaneously, when one phase is added to another. Micro-emulsions, outside the scope of this discussion, are often formulated to do just this.

Following upon simple mixing would come in-line eductors which produce turbulence to mix the phases, vortex mixers, venturi devices, pressure nozzles, vibrating

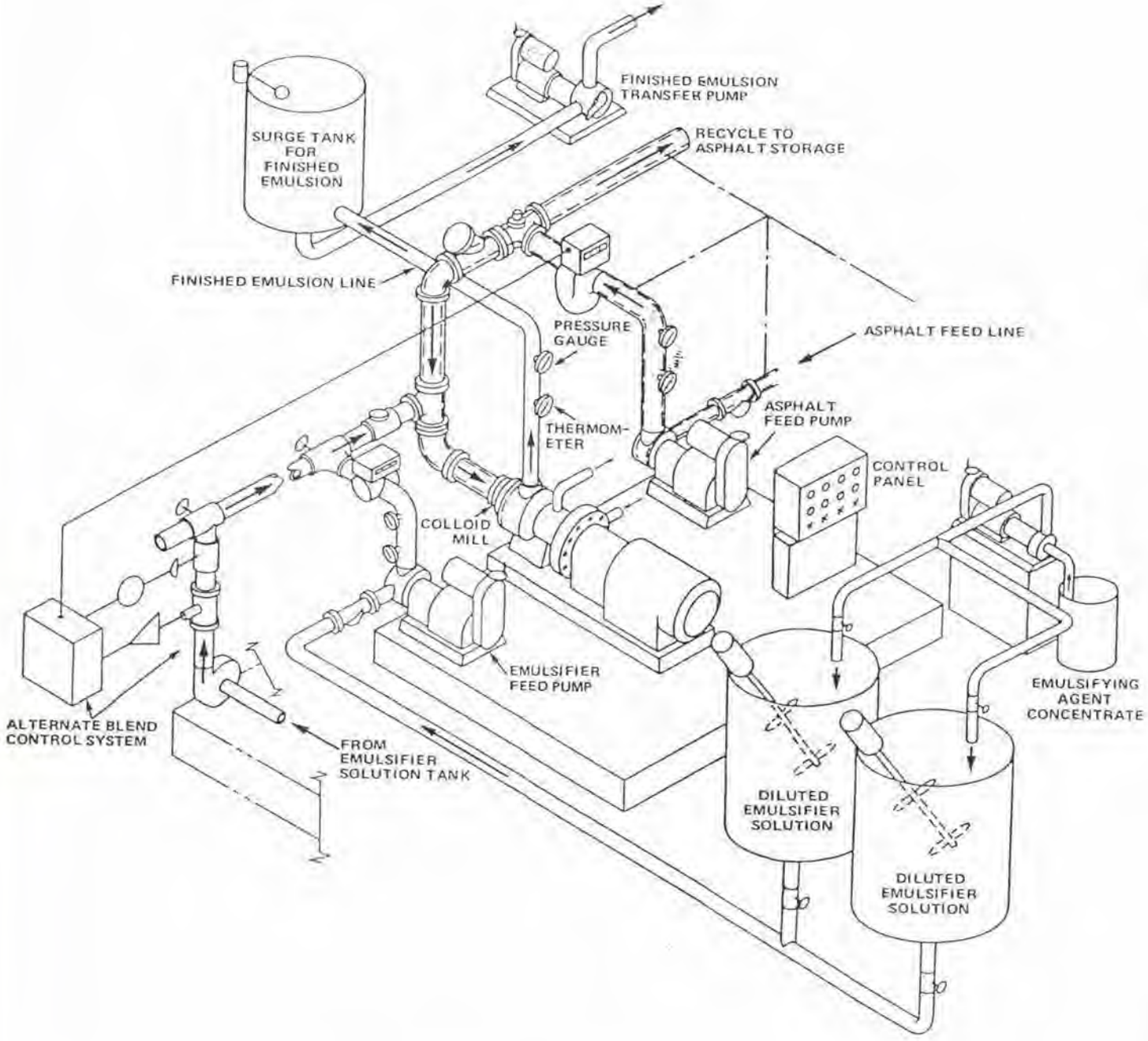
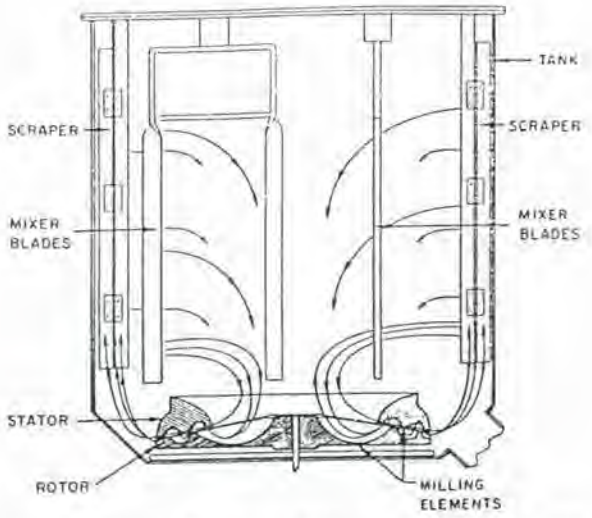
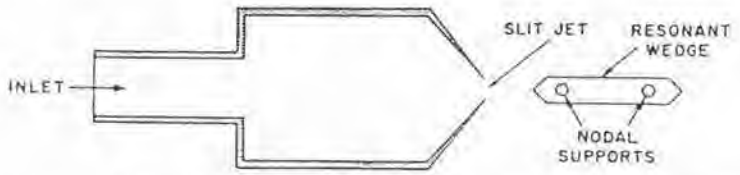


Diagram of an asphalt emulsion manufacturing plant.

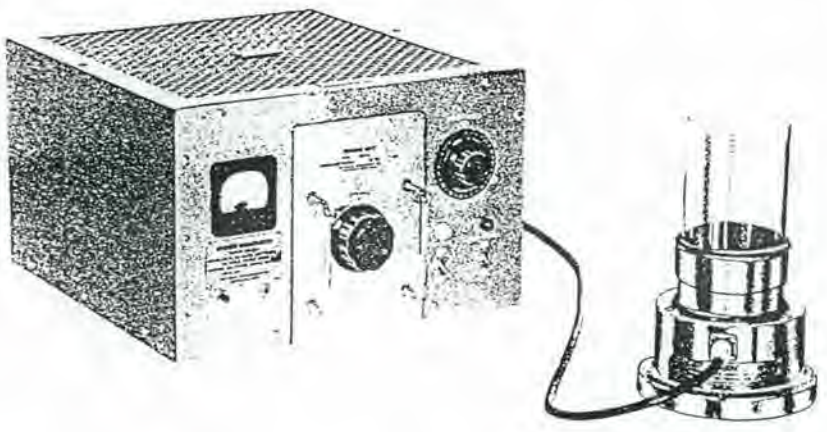
Courtesy Chemicolloid Laboratories, Inc.



Simple mixer. The walls of the vessel may be jacketed, and steam or refrigerants circulated to maintain constant temperature. *Courtesy: Abbé Engineering Co.*



Schematic diagram of a Pohlman whistle. The nodal supports of the blade are separated by a distance equal to half the wave-length of the characteristic vibration of the system.



A laboratory ultrasonic emulsator. This device is driven by a piezocrystal. *Courtesy: Brush Electric Co.*

reeds and the Pohlman whistle. High speed mixers designed to utilize a very wide variety of paddles, ribbons, impellors, combinations, sometimes complemented by vessel shapes with constrictions on their walls to produce simple shear, are widely used.

As complexity of the formulations, components and their chemistry increase, so does that of the apparatus types available increase and vary in design and throughput.

As the complexity of formulation increases, or the components become very difficult to emulsify and/or a high degree of stability must be embodied in the final product then colloid mills or ultra high shear, rotor-stator units must be used. These devices can usually be run to produce emulsions during addition of one hot phase into another or simultaneous addition of both phases hot or cold. And such units, sometimes referred to as "homogenisers", are utilized to produce very fine, or uniformly small globule, disperse phase emulsions.

Plant layout and design varies according to batch size, complexity, phase configuration and difficulty entailed in the emulsification of the two (or more phases) and its control can be simple batching manually, or very sophisticated automatic control.

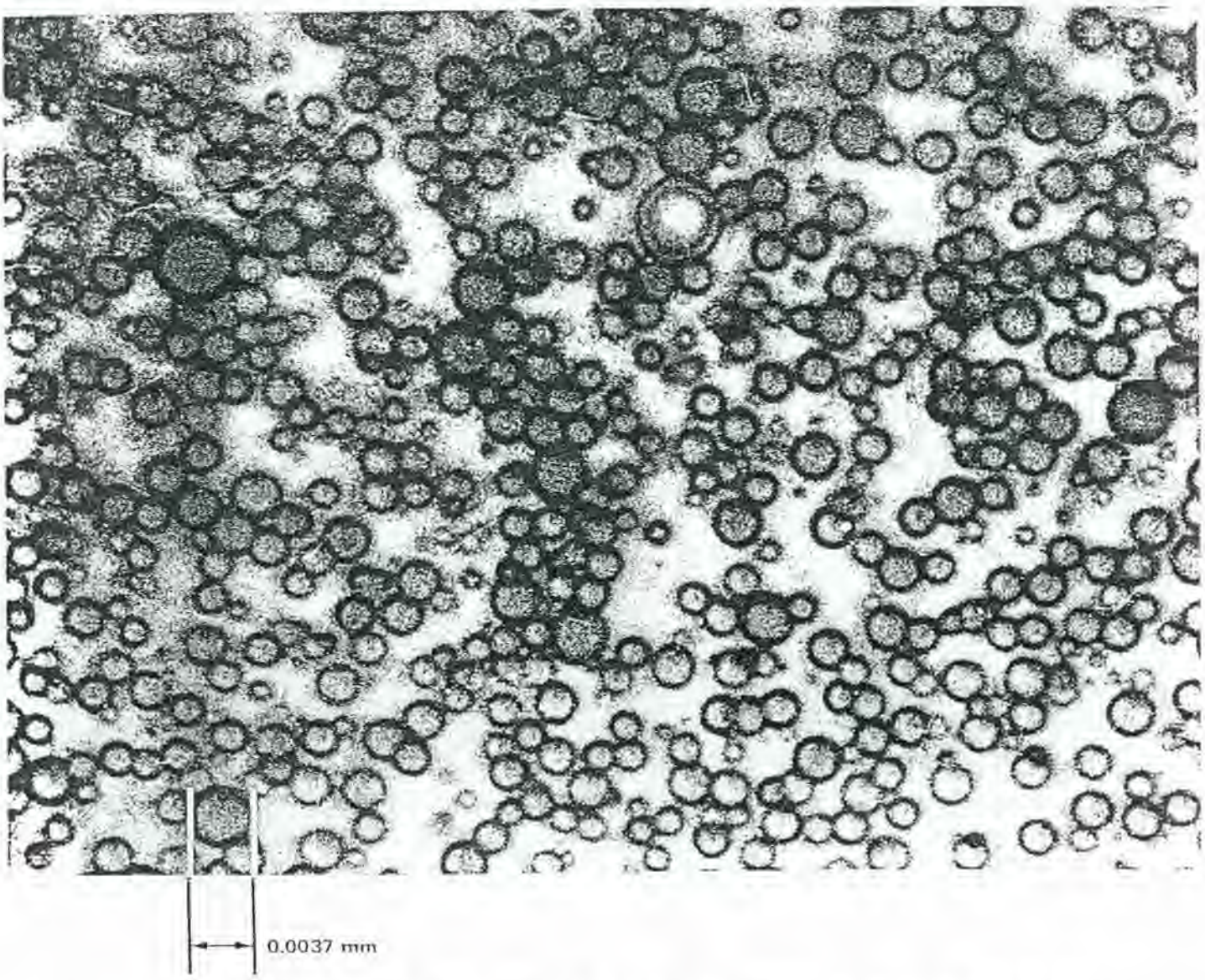
The raw materials for emulsions must be of a high quality. Above all, consistency of ingredients from batch to batch is vital. Therefore, it is not only necessary to instigate quality control during production and certainly of the final product, but each raw material must be certified or assured by the supplier and procedures agreed to so that regular or random checks may be carried out by the emulsion producer. Even the quality of the water must be high since some emulsions can be de-stabilized by hard water, mineral contamination, organic matter or sudden changes. Most emulsions are produced with a water phase softened by ion exchange units and these units can be set up for either anion exchange, cation exchange or both depending upon the nature and sensitivity of the final product. Again, lack of attention to raw material quality and water purity can cause the formulator to miss an otherwise successful emulsion.

The more stringent the quality control the less is the chance of failed batches, or emulsions which fail to perform or fail prematurely in use. The most useful tool which can be utilized by formulator and plant operators alike, is the microscope. Its routine use under standardised conditions, can very quickly signal a problem in emulsion production and use.

Asphalt particle size is a vital factor in making a stable emulsion. A microscopic photograph of a typical emulsion reveals the following average particle sizes:

Smaller than 0.001 mm (1μm)	28 percent
0.001–0.005 mm (1–5μm)	57 percent
0.005–0.010 mm (5–10μm)	15 percent

These microscopic-sized asphalt droplets are dispersed in water in the presence of the chemical surface-active emulsifier (surfactant). The surfactant causes a change in the surface tension at the contact area between the asphalt droplets and the surrounding water, and this permits the asphalt to remain in a suspended state. The particles, all having a similar electrical charge, repel each other, which also aids in their remaining in a suspended state. Figure II-2 is a photomicrograph showing the sizes and distribution of the asphalt particles.



Relative sizes and distribution of asphalt particles in an emulsion.

Courtesy Chevron U.S.A. Inc.

Coarsening of droplets, coalescence, phase separation, sedimentation or creaming can be identified and corrective measures commenced. The microscope, routinely used by plant operators in the vacuum-pressure impregnation timber treatment plants, is a very fast technique by which an emulsion's quality can be checked at any time. If the emulsion is found to be coarsening, more large droplets appearing, then further processing or re-circulation through the emulsifying unit can be instituted immediately. And of course in the case of an emulsion used indefinitely or with top-up, as is the case with PEC, PROCCA and HYCON, the bulk of the emulsion can be maintained with timer operated units.

The properties of the very diverse emulsions used in industry can not be discussed adequately here. Suffice it to say, that some properties are vital to all emulsions and these would include:

(i) Particle size and distribution, as determined by microscopy
(ii) Density - emulsion and phases
(iii) Surface Tension - emulsion and phases
(iv) pH
(v) Rheological Behaviour
(vi) Apparent Viscosity
(vii) Water Content
(viii) Oil Content
(ix) Solids Content
(x) Phase Configuration i.e. O/W or W/O
(xi) Temperature Stability

The above properties are self explanatory and their methods of test can be studied in the appropriate text books or National Standards. The more specialised properties sometimes necessary to test for, such as Zeta-Potential, Inter-facial tension, Conductivity, etc., are without the scope of this paper, but explained in books dealing with emulsion science and technology.

Finally, the emulsion producer and/or user is sometimes confronted with "creaming", separation of phases and concentrated emulsion at the surface, "sedimentation" as above except that heavier phase or emulsion concentrates at the bottom,

"coarsening", usually colour or texture change and complete separation, the formulator's nightmare, termed "breaking".

CONCLUSION

The discussion of such a vast topic as emulsion science and technology, application if you will, in a paper such as this, can at best, be only a compromise. However, if some of the myth and mystery surrounding emulsions, has been dispelled, to be replaced by curiosity and investigation - even contemplation - then this overview, complemented by the unique applications to wood preservation, exemplified, has achieved its purpose.

Emulsion science and technology embodies the potential to solve many problems facing wood preservation today. The resource, the forest which has been a major factor in the survival of human, animal and plant through millions of years is dwindling. So much is due to waste, to pollution and in so many areas the resource is gone forever. If there is to be a future for this vital, beautiful, diverse material, both in the forest and in industry - living as we know it and take so much for granted - then a change in attitude and use must be accompanied by an effort to stretch the resource to its limit, use it wisely and preserve what we must use. The potential exists to make it permanent.

Within emulsions lies the potential to modify wood, colour wood, glue wood, composite wood, waterproof and weatherproof wood, strengthen wood, and preserve wood, in fact to extend the life of a treated timber commodity to match that of other materials such as concrete and steel.

Above all, emulsion technology as it has been applied to the wood preservation industry so far, has demonstrated the means by which waste and pollution can be obviated.

The oldest bridges in the world were constructed in timber. A felled tree across a creek through to beautifully engineered structures. A few years ago a 120 year old, treated wooden bridge in England was finally dismantled, simply because the iron parts of the structure corroded beyond repair. Emulsions can build the causeway to safely extend the life of a threatened resource and provide the breathing space for its regeneration.

REFERENCES

1. Becher, P. EMULSIONS. Theory and Practice. Second Edition ACS Monograph No. 162, Reinhold Publishing Corporation 1966.

2. Warren, L.J. The Stability of Suspensions. Chemistry in Australia **44**(12): 315-318.

3. Gigier, J. and Ramond, G. The Formulation of Emulsions. Bull. Liaison Lab. Ponts Chausséas 1974 (June), 32-7.

4. Torrey, S. (Ed.) Emulsion and Emulsifier Applications. Chemical Technology Review No. 229, Noyes Data Corporation 1984.

5. Robbins, P.J. The Application of Cationic Surface Active Agents to Road Materials. 1978 (October).

6. Bennett, H. Practical Emulsions Vol. I. Chemical Publishing Company Inc. New York, 1968.

7. Shinoda, K. and Friberg, S. Emulsions and Solubilization. John Wiley and Sons, New York 1986.

8. Sherman, P. (Ed.). Emulsion Science. Academic Press, London and New York 1968.

9. Swan, D.O. (Ed.) Macro- and Microemulsions Theory and Applications. American Chemical Society, Washington D.C. 1985.

10. Sherman, P. (Ed.) Rheology of Emulsions. Symposium Publications Division Pergamon Press, Oxford, London, New York, Paris 1963.

11. Myers, D. Surfactant Science and Technology. VCH Publishers Inc. New York 1988.

12. Reidy, B.L. Development Manager Organic Chemicals Group ICI Australia Petrochemicals Ltd. Correspondence, January, 1977.

13. Watkins, J.B. 1977. Timber Preservation. Aust. Patent No. 514897, 1977.

14. Murray, J.B. and Brinkies, H.G. 1978. The Use of Pigment Emulsified Coloured Creosote for Timber Impregnation. State Electricity Commission of Victoria. Research and Development Report No. 354, 1978.

15. Standards Association of Australia. High Temperature Creosote for the Preservation of Timber. AS1143-1973.

16. Chin, C.W., Watkins, J.B. and Greaves, H. 1983. Clean Creosote - Its development and comparison with high temperature creosote. Int. Res. Group on Wood Pres. Doc. No. IRG/WP/3235.

17. Dwarte, D.M., Cockayne, D.J.N. and Watkins, J.B. 1984. Distribution of Creosote oil and iron pigment in PEC-30 treated *Eucalyptus obliqua* poles. Third Asia Pacific Congress on Electron Microscopy, Singapore 1984.

18. Watkins, J.B., Chin, C.W. and Greaves, H. Preservative Composition, Aust. Patent No. 570984, 1989.

19. Parks, G.A. The isoelectric points of solid oxides, solid hydroxides and aqueous hydroxo complex systems. Dept of Mineral Engineering, Stanford University, Stanford, Calif. 1964.

20. Greaves, H., Watkins, J.B. and Chin, C.W. PEC - A family of oil-based preservatives. B.W.P.A. Annual Convention, 1986.

21. McIntyre, C.R. and Fox, R.F. Update on Wolman ET®. A new CCA/Oil treating system. A.W.P.A. Annual Proceedings 1990.

22. Watkins, J.B., Chin, C.W. and Greaves, H. Timber Preservative Composition. Aust. Patent No. 604471, 1990

INDUSTRY REQUIREMENTS FOR RESEARCH

By

I. S. Ferguson
Professor of Forest Science
University of Melbourne

Introduction

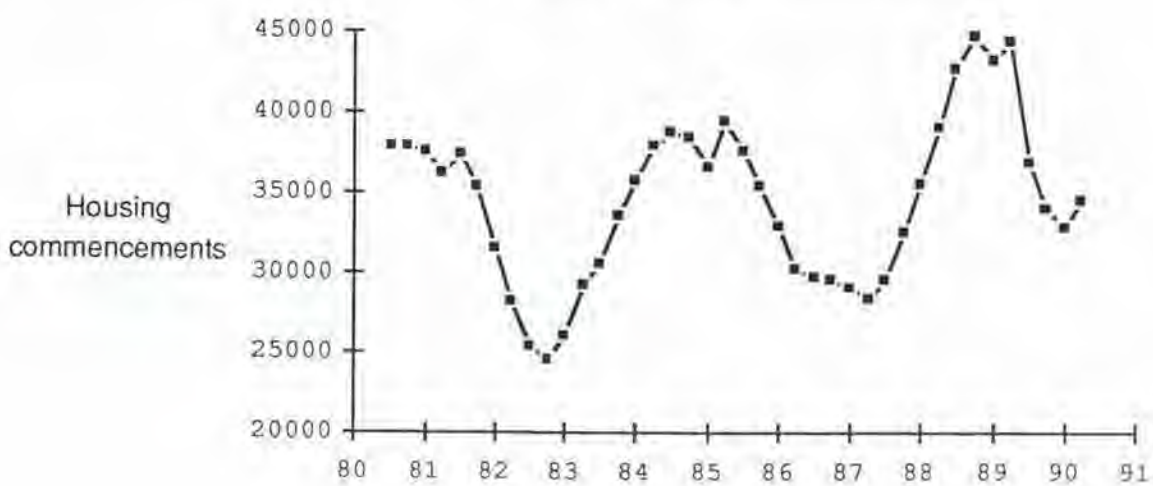
The aim of this paper is to review the decade that has past and to identify some of the major challenges ahead for the sawmilling industry. Given the state of the industry at the time of writing, near the pit of a recession, the latter may seem fatuous in that the immediate and all-consuming challenge is to survive. But building cycles do come and go, as Figure 1 shows, and it is therefore necessary to look beyond the immediate woes of the marketplace.

Much of this paper reflects the scene as viewed from a Victorian perspective. Yet the major trends are common to most, if not all, states.

Markets in the Eighties

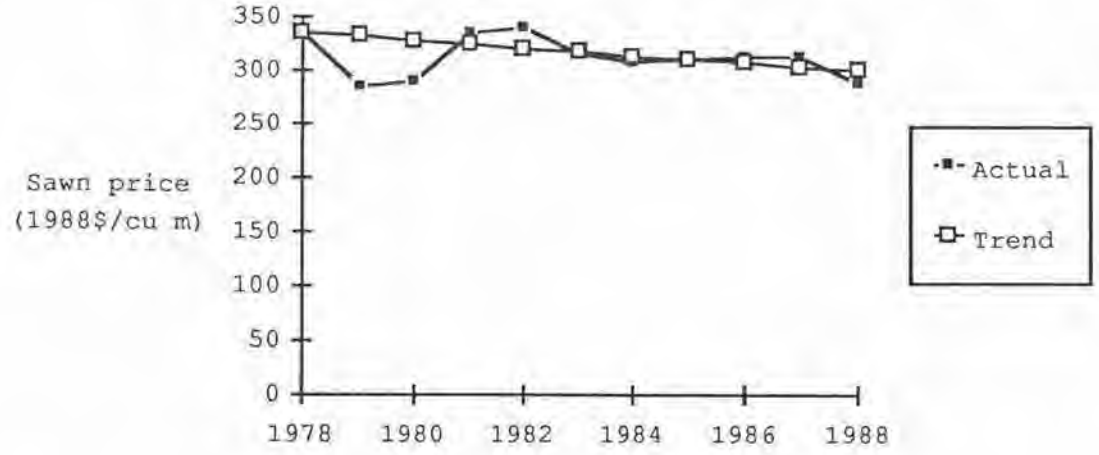
Viewed from afar, the eighties represented a decade of markedly cyclical growth in housing commencements (Figure 1), relatively stable levels of aggregate consumption of sawn timber, slowly declining real prices for softwood timber (Figure 2), and massive changes in the use of different species and substitute materials .

Figure 1: Housing commencements



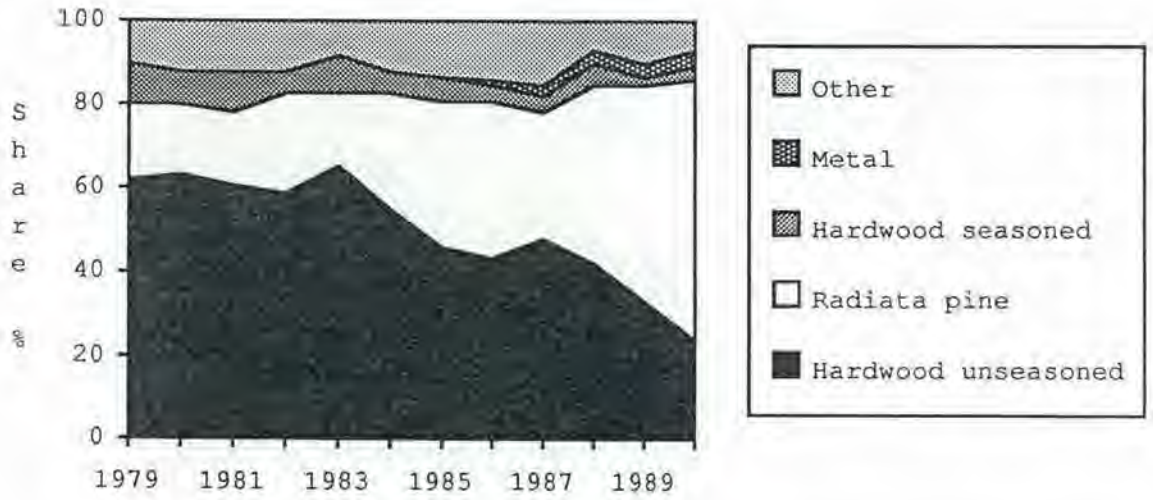
Paper for 23rd Forest Products Research Conference, 19-22 Nov. 1990.
Held at CSIRO Division of Forestry and Forest Products, Clayton.

Figure 2: Sawn softwood price (average mill return)



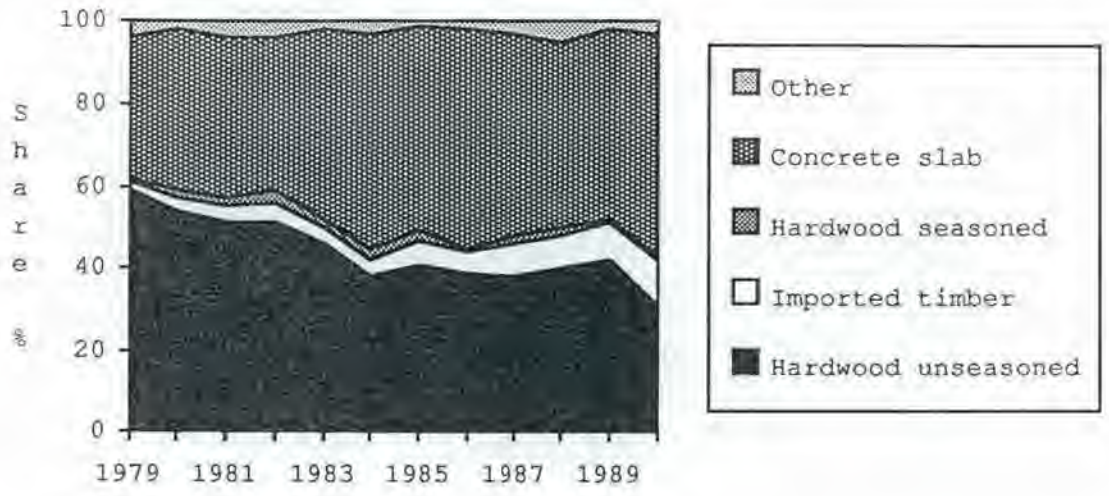
The changing species/materials mix is especially significant. According to the Victorian statistics (Timber Promotion Council, 1990), radiata pine is winning market share in wall frames against unseasoned hardwood (Figure 3a).

Figure 3a: Wall Frames



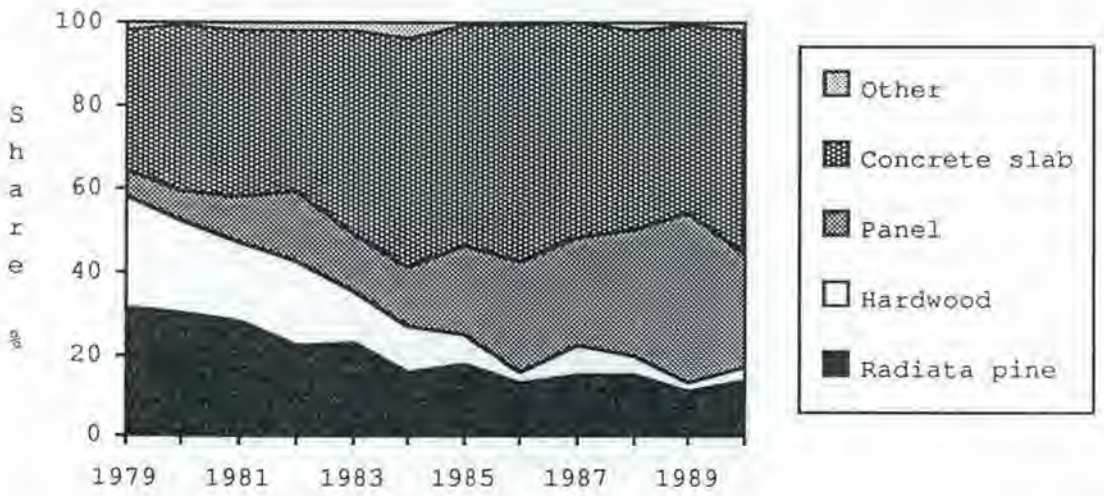
Contrary to some hopes, seasoned hardwood has lapsed badly after a promising start but metal is clearly accelerating. In floor frames (Figure 3b), concrete slabs still seem to be gaining ground on unseasoned hardwood (Timber Promotion Council, 1990).

Figure 3b: Floor Frames



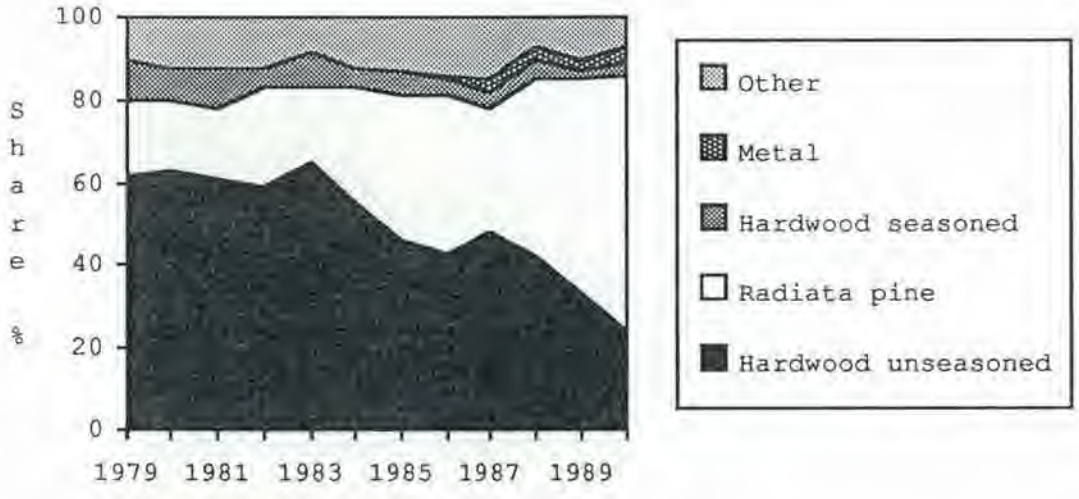
In floor surfaces (Figure 3c), concrete slabs are still increasing their share, but wood panels have been stealing share from both hardwood and radiata (Timber Promotion Council, 1990).

Figure 3c: Floor Surface Materials



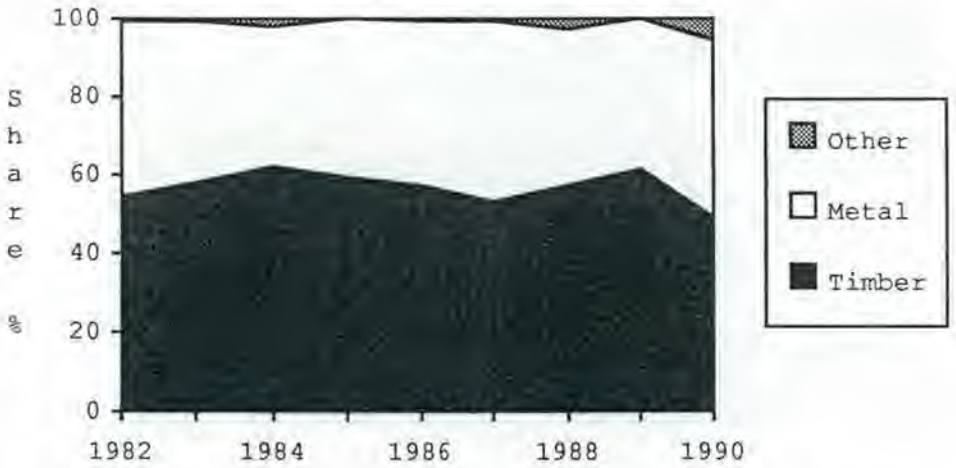
In roof frames (Figure 3d), radiata pine and, to a lesser extent, imported timber, have gained share at the expense of unseasoned hardwood, with metal a late starter that is becoming significant (Timber Promotion Council, 1990).

Figure 3d: Roof Frames



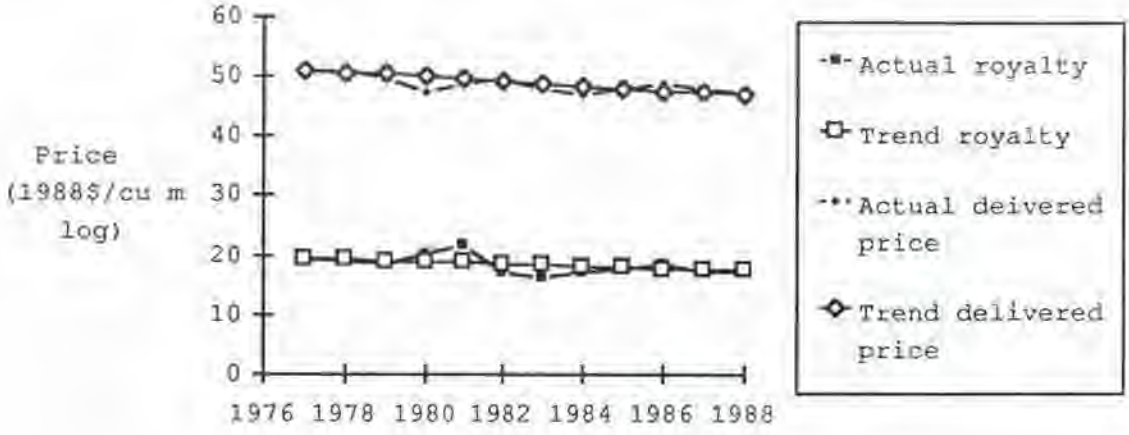
In window frames (Figure 3e), the pattern is erratic, with timber's share remaining relatively static (Timber Promotion Council, 1990).

Figure 3e: Window Frames



The reasons for the changes in market share by domestic timbers are obvious. Radiata pine has enjoyed an increasing competitiveness relative to hardwood as more supply has come on stream from newer and larger mills. The real price of softwood timber (Figure 2) declined as a result of these changes, aided by decreases in the real royalties and in the delivered costs of softwood sawlogs (Simons *et al* 1990) of softwood sawlogs (Figure 4).

Figure 4: Softwood royalty and delivered price



Hardwood, on the other hand, has suffered in terms of uncertainties and reductions in supply as the National Estate and other land use battles have continued to rage. The real price of hardwood timber has probably risen somewhat over the period. Despite some significant progress in restructuring of the hardwood industry, productivity gains seem to have been far less than in radiata pine and one can reasonably surmise that the hardwood industry has felt the pressures of increasing real labour costs more acutely than the softwood sector.

Viewed Australia-wide, imports are running at similar levels to the start of the decade, although changing in species mix somewhat away from the specialty staples such a Douglas fir and meranti into a wider array. Sawn timber, in general. has lost market share. In part, it has lost to panel products, and in part to substitute materials. Within the domestically produced sawn timber, radiata (and other plantation-grown) pine have gained market share at the expense of hardwood. A superficial diagnosis would suggest that radiata pine timber has been fairly price competitive against substitutes and hardwood not at all.

Imported Timbers

Recent econometric studies by Bigsby (1989) indicate that there is no evidence of significant substitution between domestic and imported timbers. To all intents and purposes, the markets treat them as differentiated products with quite different uses. Neither domestic production nor imports appear to react to changes in the other's prices. This is not surprising in view of the apparent constant share of imports in Australian markets.

This is necessarily true of imports of radiata pine in the future. These will obviously be close substitutes for domestically-produced radiata pine.

Nevertheless, this result signals that the principal source of competition in the past has been between domestic hardwoods and softwoods, not between them and imported timbers.

Softwood Sawmilling

Studies sponsored by the Forestry and Forest Products Council on international competitiveness (Poyry, 1986; Simons *et al*, 1990) suggest that the softwood industry is generally capable of improving its competitive position as further supplies of radiata pine become available. This stems principally from the capacity to pursue substantial economies of scale that are well documented (Poyry, 1986). But they also stem from economies of scope in terms of the range of products that can be produced from a full range of log sizes. Greater diversification of softwood products is already apparent in those regions in which a full and relatively stable range of size classes and qualities are available and includes the development of laminated timber products and of preservative treated timbers. This potential for diversification places radiata (and other exotic) pine in a good position to increase market share in linings, mouldings, sub-floor and roof frames, mainly at the expense of hardwood (Andersen, 1988).

The studies of international competitiveness (Poyry, 1986; Simons *et al*, 1990) suggest that the natural protection afforded by our isolation provides a competitive advantage to Australian producers in domestic markets. However, that advantage is not so great that it insulates us from the threat of serious competition from the presently lower-cost producers of radiate pine in New Zealand and Chile. Much depends on future movements in exchange rates, shipping rates and our own capacity to increase productivity in sawmilling.

On the other hand, the possibilities of developing competitive and continuing exports of radiata pine timber seem remote unless there is a major improvement in the productivity and cost structures of Australian mills relative to these competitors. This is not to discount the possibility of opportunistic forays into export markets when domestic markets are depressed.

What is clear then, is that the Australian softwood sawmilling industry cannot afford to be complacent about domestic markets in the long term and that it needs to improve productivity, cost structures, product diversification and quality if it is to hold its share of the Australian market. Much greater efforts will be needed if it is to increase its share.

Hardwood Sawmilling

The hardwood timber sector remains a dilemma, trapped between the need to invest and re-structure to handle increasing quantities of logs from regrowth forests and

the.uncertainties of supply in an aggressively environmental era as well as those posed by the strong competition in all of its traditional markets.

Although the data were not available to enable a formal analysis, there can be no doubt that domestic hardwood and softwood timber are close substitutes in most structural and finishing uses and that relative prices are therefore critical. Thus while particular hardwood mills may be able to exploit locational advantages in local markets and continue to compete across the range of structural and finishing uses with radiata pine, the general trend is one of a continuing loss of market share because of the difficulty of realizing similar productivity gains to those in the softwood industry. The difficulty is relative and not absolute and should not be taken to rule out productivity and other gains in hardwood sawmilling from economies of scale and scope. However, the more variable nature of the hardwood resource and the problems inherent in milling and drying regrowth hardwoods represent disadvantages relative to radiata pine.

An inter-regional analysis of timber trade in Australia developed by Bigsby (1989) painted a relatively stark scenario for the decade ahead in terms of the competition between softwood and hardwood timber The large increase in domestic supply of radiata pine expected over the next decade will cause the real price of domestic timber to drop substantially, placing even greater pressures on the hardwood sector. This assumes that imports continue to hold a constant share of the market, which may be optimistic in the light of the probable increases in exports by New Zealand and Chile. But it also assumes optimistically that all the additional log volume will be milled as and when it becomes available. The likely lag in milling available volume will tend to be counterbalanced by the increase in imports, so the overall result of the analysis seems reasonable.

This suggests that the future strategy for hardwood producers must be to differentiate their products more from the traditional uses that compete with radiata, so as to develop specialist niches where the properties of hardwoods confer advantages over radiata and other substitutes. Such a strategy is also compatible with and conducive to value-adding and the development of exports of hardwood timber as a specialty product aimed at particular niches (Leslie 1987).

Value Added Hardwood Sawmilling

In late 1988. the Forestry and Forest Products Advisory Council established a Working Party to investigate and report on the opportunities for value-added production in the hardwood sawmilling industry. Value-added is a policy rubric widely advocated by the Commonwealth and State governments as a means of increasing international competitiveness. The term itself is something of a problem

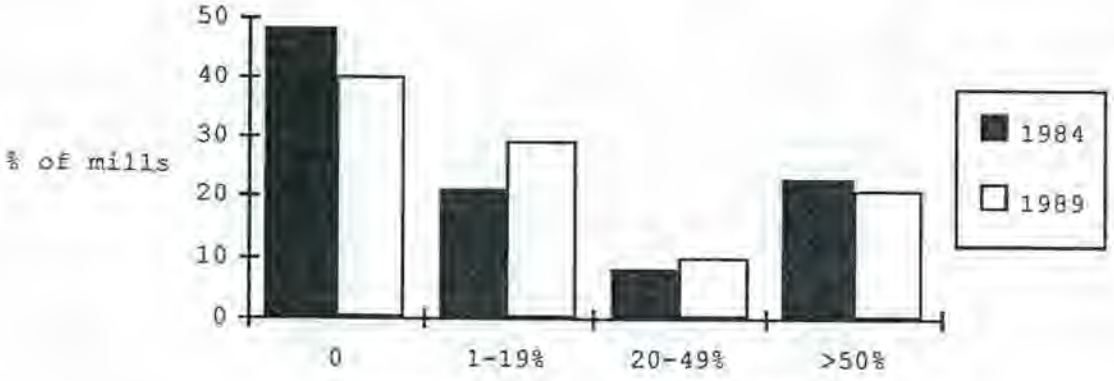
because the formal definition used by the Australian Bureau of Statistics is "turnover plus the increase (or less the decrease) in the value of stocks less purchases, selected expenses and rent, leasing and hiring expenses". which is rather sterile and cumbersome. The Working Party therefore adopted a working definition that value-added activities refer to processing of timber beyond the green sawn timber stage.

The Working Party believed that the size of sawmill needed to be a key element in undertaking any survey. and to that end the sample of companies was designed to cover a wide range of sizes. Questionnaires were forwarded to companies in the sample, with a fair response rate being achieved for this type of survey. The non-respondents were much more heavily concentrated in the smaller mill sizes and might be expected to reflect a greater proportion with little interest or activity in value-adding. Thus the results may overstate the extent of value adding, especially in smaller mill sizes.

Recent trends in value adding

Figure 5a shows the results from the survey concerning value added activity for 1984 and 1989 (FAFPIC,1990).

Figure 5a: Trends in value-added activity

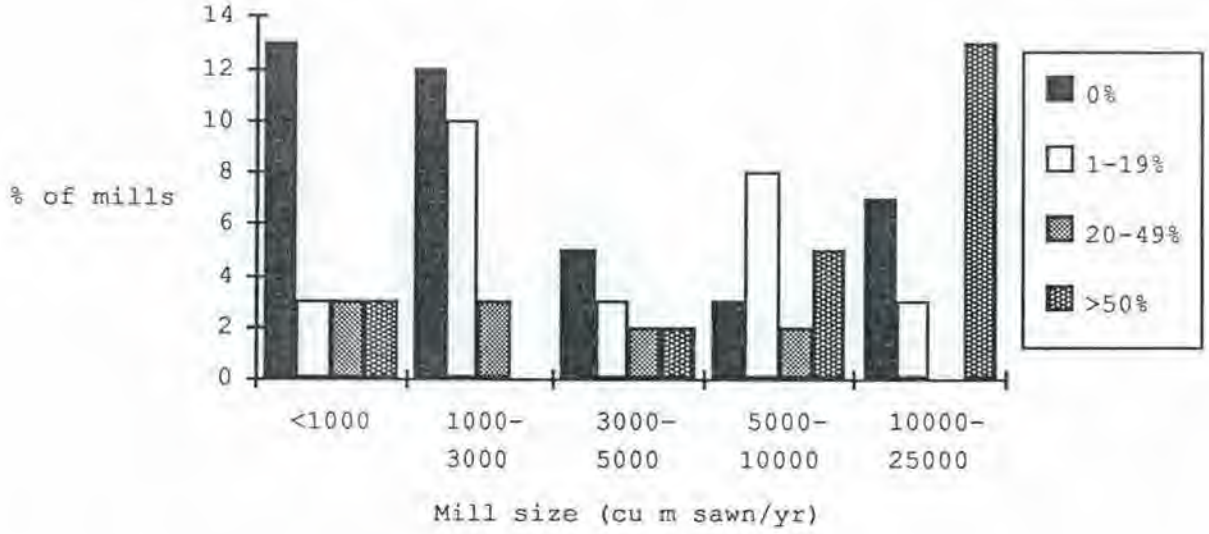


Despite some restructuring in the industry there is little evidence of substantial change over that five years. The majority of mills still undertake little or no value-added activity and only 20% engage in substantial (more than 50%) value added activity.

Effects of mill size

Figure 5b summarizes the results concerning the distribution of value adding activity by mill size in 1989 (FAFPIC,1990).

Figure 5b: Value added activity by mill size

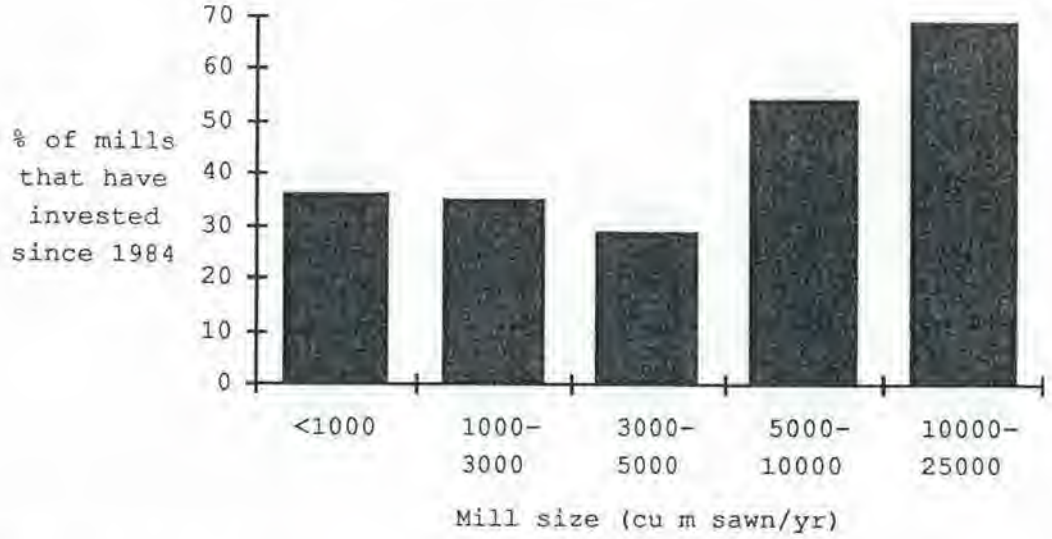


As might be anticipated, large mills dominate the pattern of substantial value adding, supporting the thesis that the magnitude of investment may be a constraint for small companies. However, some 46% of larger mills were not engaged in substantial value adding, so that size in itself is not a sufficient precondition for value adding.

Investment

Some 55% of mills had invested in plant and machinery since 1984, and 45% had not. The latter is itself a revealing and concerning figure, considering that this period covered a relatively good sequence of years for sales of timber. As Figure 5c shows, investment was more common among the larger mills (FAFPIC,1990).

Figure 5c: Investment and mill size

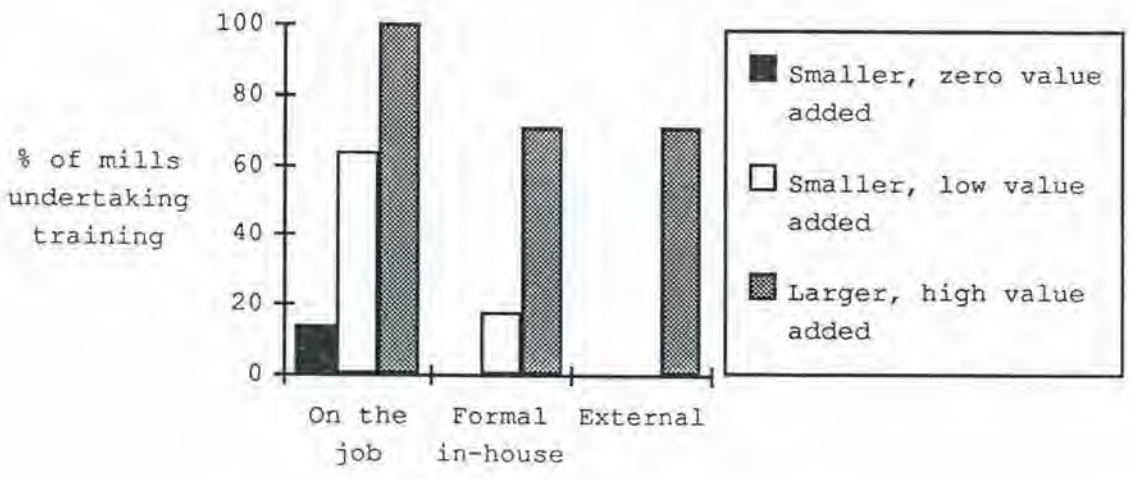


Skills and training

Some 41% of mills indicated they were experiencing difficulties in recruiting or retaining skilled labour, especially experienced sawyers and dockers. However, there was a marked disparity between the responses according to mill size, with 71% of large mills experiencing shortages. compared to 36% of the smallest sizes.

The distribution of mills that engaged in various forms of training followed similar patterns, as Figure 5d shows (FAFPIC,1990).

Figure 5d: Training by mill size/value added



The contrast between the larger and smallest mills in the patterns of training is especially marked. Apart from the obvious reasons relating to cost and proximity, it has been suggested that a lack of basic literacy skills may be another important impediment for many companies. Only 15% of mills utilized government training schemes

Research and development

Some 29% of respondents indicated that they undertook formal research and development activities. This is higher than the Australian Bureau of Statistics estimates and should be treated with some reserve. The major areas of activity were dressing and drying techniques, new product development and further processing..

Of those firms conducting research, over 63% spent less than $50 000 in the previous financial year and only 21% over $100 000. Very few utilized the 150% taxation concession for research and development expenditures.

Marketing

Some 41% of mills sold their output direct to end-users; 29% relied on independent merchants and 30% utilized their companies own marketing outlets. As might be expected, most smaller mills sell direct and most large mills through their own outlets. Some 31% employed no marketing personnel, 29% only one, and 18% five or more

Only 14% of mills engaged in exports, all being concentrated in the larger mill sizes. Most of the exports were in flooring and decking, joinery and furniture. Some 75% of exporters had invested in plant and machinery over the past 5 years, underscoring the inter-relationships of scale, value-adding and exporting.

It will be clear from the results of this FAFPIC(1990) study that the hardwood industry has a long way to go in order to position itself to meet the challenges ahead.

Challenges of the Nineties

There are one or two likely policy initiatives that have comparatively minor implications for the sawmilling industry in the nineties. The first is the Greenhouse Effect and likely pressures to increase the extent of forested land to address this problem. The second are the closely related concerns to increase afforestation on marginal and degraded farmlands in order to ameliorate land degradation and diversify and revitalize the agricultural economy. These are important initiatives but their impact on supply will not be felt until 2010 or later. Nevertheless, both offer good reason to pursue research into the utilization of regrowth and plantation eucalypts in order to guide the development of profitable plantations of species and genotypes with the best properties.

The prospects for profitable plantations for pulpwood are reasonable well established but there will be a community limit of tolerance towards large-scale pulpwood plantations, just as for radiata pine, unless growing can be diversified across individual farmers. The obvious scope for small plantations lies in the development of sawlog strategies involving short rotations and relatively intensive management, but these are suspect on the basis of present economics (FAFPIC, 1989). Given the uncertainties relating to utilization of plantation sawlogs and of traditional hardwood products, the development of more cost-effective and value-added processing of solid-wood products from such sources is obviously critical to the success and profitability of any programme to encourage planting of eucalypts or management of regrowth forest by farmers and private land-owners. This programme is thus a vital complement to the development of large-scale industrial operations.

The effect of current concerns relating to the harvesting and importing of tropical timbers is of more immediate impact. While it seems unlikely that government bans will be imposed on these imports, the unfavourable publicity is having some impact on architects and home builders and the delays in unloading will contribute to this through to higher prices, deplorable though the latter activities may be. The resulting changes in demand create opportunities to develop the use of domestic species as substitutes. The current campaign over the 'Ancient Forests' in the West Coast of the United States and Canada is likely to raise the prices of premium-quality specialty timbers such as western red cedar, redwood and large section Douglas fir, with similar consequences.

Not all the possible changes in imports are so benign. As noted earlier, New Zealand and Chilean exporters will move into the Australian market rapidly unless the Australian softwood industry maintains and preferably outstrips the changes in productivity in those countries. That, in itself, is no small challenge.

Nevetherless, the most certain and dominant change is from within Australia and relates to the continuing substitution of radiata (and other) pine for hardwoods in most traditional hardwood end-uses. The challenge for the hardwood sector is therefore to differentiate its products while improving productivity and adapting to regrowth and plantation logs.

Research, training, managerial efficiency and market development all need to be pursued vigorously, if the domestic industry, and the hardwood sector in particular, are to prosper..While there are encouraging signs of acceptance of such developments, the hardwood sector suffers from a lack of experience in using research, and to a lesser extent training, as vehicles to provide new directions and solutions. With notable exceptions, there is a mind-set in the hardwood industry that seems to reflect

the experiences of the sixties and seventies. A radical shift in thinking is needed for many, if they are to stay in business through and beyond the nineties. Pump priming of research and training may be needed to accelerate the change.

Paper for 23rd Forest Products Research Conference, 19-22 Nov. 1990. Held at CSIRO Division of Forestry and Forest Products, Clayton.

Literature Cited

Andersen & Co, Arthur, 1988. A study into value-added opportunities for the Victorian timber industry. Report for the Timber Industry Council, Melb., 87pp.

Bigsby, H.R., 1990. Inter-regional trade in sawn timber in Australia.Ph.D.thesis, University of Melbourne, 119pp.

FAFPIC, 1989. Potential role of hardwood plantations in supplementing Australia's forest resources. AGPS, Canberra, 20pp

FAFPIC, 1990. Factors influencing value-added production in hardwood sawmilling. Forestry and Forest Products Industry Council,Melbourne,35pp

Leslie, A.J., 1987. International logic of a high-value policy. Chapter 2 in J. Dargavel and G. Sheldon (Eds), Prospects for Australia's Hardwood Forests. CRES Monograph 19.

Poyry, Jaakko, 1986.Competitiveness of Australian forest industries. Main Report. Report for FAFPIC. Jaakko Poyry, Helsinki, 181pp.

Simons Ltd, H.A, and McLennan Magasanik Associates, 1990. Competitiveness of Australian forest industries. An update of the 1985 competitivess study. Forestry and Forest Products Industry Council,Melbourne, 6 Chapters and Appendices.

Timber Promotions Council, 1990. Survey on the use of building materials in new home construction, March Quarter, 1990, Victoria. Timber Promotions Council, Melbourne, 23pp.

THE ROLE OF COMPUTER-BASED MODELS IN WOOD DRYING

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ABSTRACT

There is considerable pressure on the timber industry to add value to forest products. In many cases this requires drying material for which kiln schedules have not been proven. Computer-based mathematical models of the process of drying wood have the potential to greatly reduce the difficulty of choosing appropriate drying conditions and equipment. The characteristics of a useful model is described and examples of its use are discussed.

INTRODUCTION

Changes in the resource available to the timber industry together with political and commercial pressure to make better use of that resource has revealed inadequate knowledge of how to process sawn wood from it. This is particularly so in the area of drying.

Part of the problem relates to the material, which may be from species previously only used green or not utilised at all, or from regrowth material. Much of the latter has been found to be more likely to incur drying degrade than mature material of the same species. Faster growth rates, generally lower density, different density patterns and higher green moisture content may contribute to this.

The kiln drying schedules compiled by Campbell (1) for a wide range of species represent many years of painstaking research and industry experience. For young material of a particular species the listed schedule can only be a guide, and further testing is needed. The extent of the work needed can be greatly reduced with the aid of mathematical models, run on personal computers, such as *DRYWOOD* which was developed at the University of Tasmania and which is discussed later in this paper.

The timber industry in Australia must process a growing proportion of smaller and lower grade logs and to make better use of the wood from them. In order to get reasonable recovery of material from smaller logs it is no longer possible to saw predominantly quartersawn boards. The susceptibility of backsawn boards to surface checking early in drying is widely appreciated but, until *DRYWOOD* was developed and generously made so widely available, there were no methods other than laborious testing for

determining how to modify the conventional drying schedules to reduce this form of degrade.

A great deal of effort has been put into modelling the drying process in recent years, much of it for drying wood. Of 35 papers presented at an IUFRO Wood Drying Symposium in Seattle in 1989 (2), eight applied models of the drying process to degrade control or process improvement and nine dealt in some way with modelling the mechano-sorptive effect.

As wood is a hygroscopic, porous material the processes involved in drying are quite complex. Some of the processes can be modelled analytically, based on the known physical principles. In this category are the heat transfer and the psychrometric relationships. Other aspects are less easy to model and empirically derived information must be used, usually by statistical fitting. Practical models will usually combine theoretical principles and actual data.

To model the drying of wood many researchers have been forced to make simplifications which restrict the application of their model to particular material properties and to a narrow range of drying conditions. The variability of wood and its drying behaviour has been discussed by Kayihan (3) and provision made in a drying model for this variability, as discussed below.

DISCUSSION OF DRYING MODELS AND EXAMPLES OF THEIR USE

DRYWOOD

The basis of this model (4) was described by Oliver (5). Since it has become available it has certainly met the stated objectives of its authors and become a valuable teaching and research tool. Although it is restricted to one-dimensional drying at constant air velocity, temperature and humidity, with wide boards of backsawn or quartersawn eucalypt wood, the model gives a realistic picture of the way in which the stresses develop, and predicts the onset of surface checking.

The procedure for running the model allows the various parameters which can affect the onset of drying degrade to be changed one at a time and the effect seen in the output of the model, so that the most important parameter can be identified and the drying conditions chosen to minimise the degrade.

Since most hardwood timber is dried using schedules which are comprised of several steps, generally increasing in severity as drying proceeds, the development of a more advanced model able to handle kiln schedule changes is eagerly awaited. The timber industry will benefit by supporting this further development.

COURSEDRY

This model was developed by a number of researchers at Weyerhaeuser Technology Centre, Tacoma, WA, USA, originally to run on a mainframe computer. Recently the numerical methods have been refined to allow its use on personal computers. Although the model has not been made generally available it has been described in several papers (6,7,8).

The model simulates the drying behaviour of a stack of timber in a batch kiln. It is a stochastic model using population balance techniques and the output is a prediction of drying rate against time and the distribution of the average moisture content of the boards. To use the model the drying flux parameters must be fitted to the kiln and material characteristics. Results of drying tests with individual boards were used to derive these parameters, and to estimate the random errors associated with drying rate as well as those due to moisture content. The input data include the board and stack dimensions, board density, an initial moisture content distribution for the batch of boards, and details of the drying schedule. Kiln conditions can be varied freely, and changes can be made progressively over time i.e. ramped up or down. The model can handle the situation which can occur with fan reversals where one side of a stack may be absorbing water while the other side is drying.

COURSEDRY does not predict moisture gradients within boards nor degrade development. It is intended to be used to better understand how to run batch kilns, and Kayihan (6) has proposed that the model be used as the basis for adapting the drying schedule during a kiln run, using average stack moisture content as the input parameter.

Using *COURSEDRY*

The way in which kiln and wood parameters affect the final outcome of kiln schedules has been explored by Mitchell and Bigbee using the model (9). Comparing the results in terms of final moisture content distribution against a base case, which represented an appropriate kiln schedule for Western hemlock, they investigated:

lack of uniformity of dry bulb temperature in the kiln
inaccurate measurement of wet bulb temperature
non-uniform air velocity throughout the kiln
irregular or missing fan reversals
variations in sticker thickness
variations in stack width
differing initial moisture content
the target final moisture content

variation in timber thickness

differing wood density

In each case the model predictions are generally consistent with existing knowledge but their value lies in demonstrating the limits for successful operation, providing valuable guidance for kiln operators.

Simulations of drying radiata pine

Another illustration of the use of this model is an exploration of the drying of radiata pine at the conditions possible in modern high temperature kilns in Australia.

Current practice is to maintain constant drying conditions throughout the whole period of drying. This set of simulations used as input data the initial moisture content distribution previously determined for a batch of Australian radiata pine (Figure 2(a)), and the drying flux parameters were fitted to the results of laboratory tests with radiata pine (Northway, unpublished data). The model prediction of drying 100mm x 40mm boards at a dry bulb temperature (DBT) of 150°C, wet bulb temperature (WBT) of 80°C and air velocity of 8m/s with 25mm stickers is shown in Figures 2(b) and 2(c). The effects of progressively reducing the dry bulb temperature after six hours can be seen in Figure 3. The final moisture content range is reduced, but at the expense of increasing drying time by one hour. Figure 4 shows that reducing the temperature even earlier i.e. after four hours, further reduces the moisture content range but adds almost another hour to the drying time.

Reducing the air velocity after eight hours in addition to reducing temperature has almost no effect on final moisture content (Figure 5), confirming that the drying rate at this stage is dependent on resistance to moisture movement within the wood.

Conclusions on simulation results

These results have not yet been tested with real timber, but the drying times and moisture content predictions are consistent with industry and research experience. There seems to be some scope for saving heat by reducing the dry bulb temperature and fan energy usage by slowing the fans. Although the model incorporates adsorption, the prediction of moisture gain and moisture equalisation during the final steaming was surprisingly accurate.

Drying pine at high temperature can seem to be a simple process but these simulations suggest a role for process models to significantly improve current practices.

REFERENCES

1. Campbell, G.S. 1980. Index of kiln drying schedules for timbers dried in Australia. CSIRO Division of Building Research. Un-numbered report.

2. Kayihan, F., Johnson, J. and Smith, W.R. (Editors). 1989. Proc. IUFRO Int. Wood Drying Symposium: Upgrading wood quality through drying technology, July, 1989. Seattle, Washington, USA.

3. Kayihan, F. 1987. Wood drying from theory to practice. Proc. IUFRO Wood Drying Symposium: Stress development and degrade during wood drying. September, 1987. Skelleftea, Sweden.

4. Oliver, A.R., Mills, R. and Ralph K. 1986. Pascal program DRYWOOD. Tasmanian Timber Promotion Board.

5. Oliver, A.R. 1986. A model to correlate measurements directed towards reducing drying degrade in sawn eucalypt timber. Proc. 22nd Forest Products Research Conference, November, 1986. Clayton, Victoria.

6. Kayihan, F. 1984. The process dynamics and the stochastic behaviour of batch lumber kilns. Proc. Annual AIChE Meeting, November, 1984, San Francisco.

7. Kayihan, F., Stanish, M.A. and Schajer, G.S. 1984. A mathematical model of drying for hygroscopic porous media. Proc. Annual AIChE Meeting, November, 1984, San Francisco.

8. Kayihan, F. 1986. Adaptive optimal scheduling and control of batch lumber kilns using a population balance model. Proc. 1986 Int. Drying Symposium, August, 1986, Boston.

9. Mitchell, P. and Bigbee, K. 1989. Drying variables affecting drying rate and moisture content distribution in western hemlock. Proc. Western Dry Kiln Association Meeting, May, 1989. O.S.U. Corvallis, Oregon

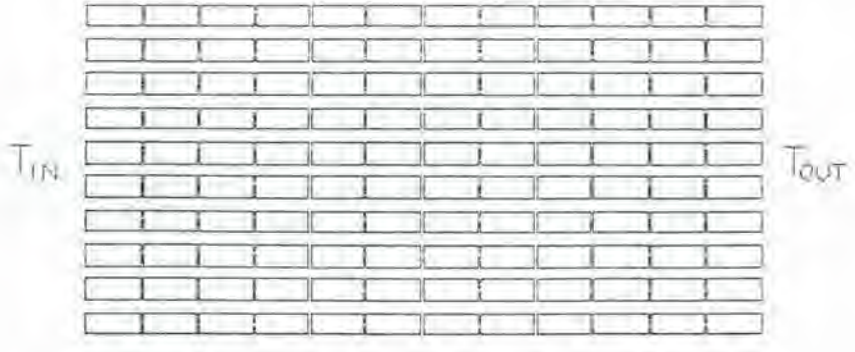

Figure 1. Stack of timber in batch kiln

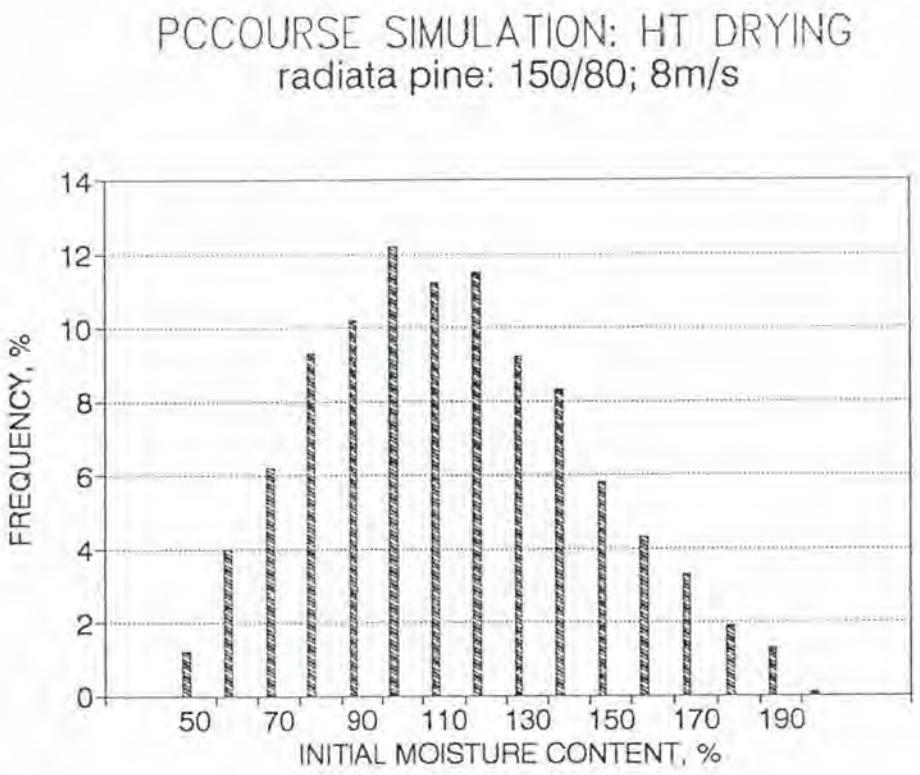

Figure 2(a).

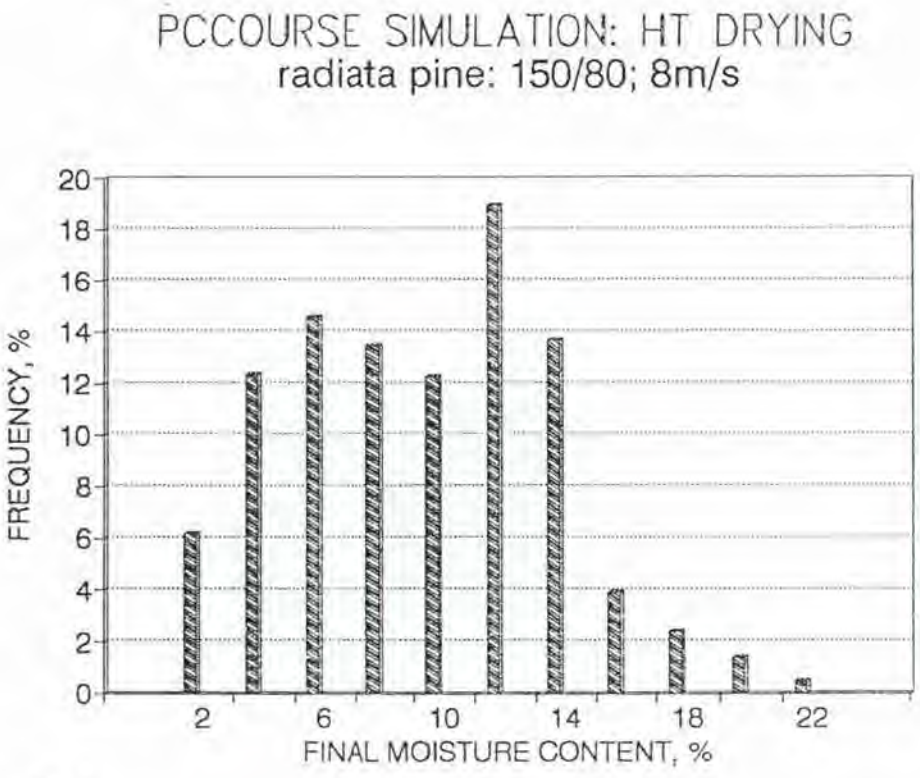

Figure 2(b).

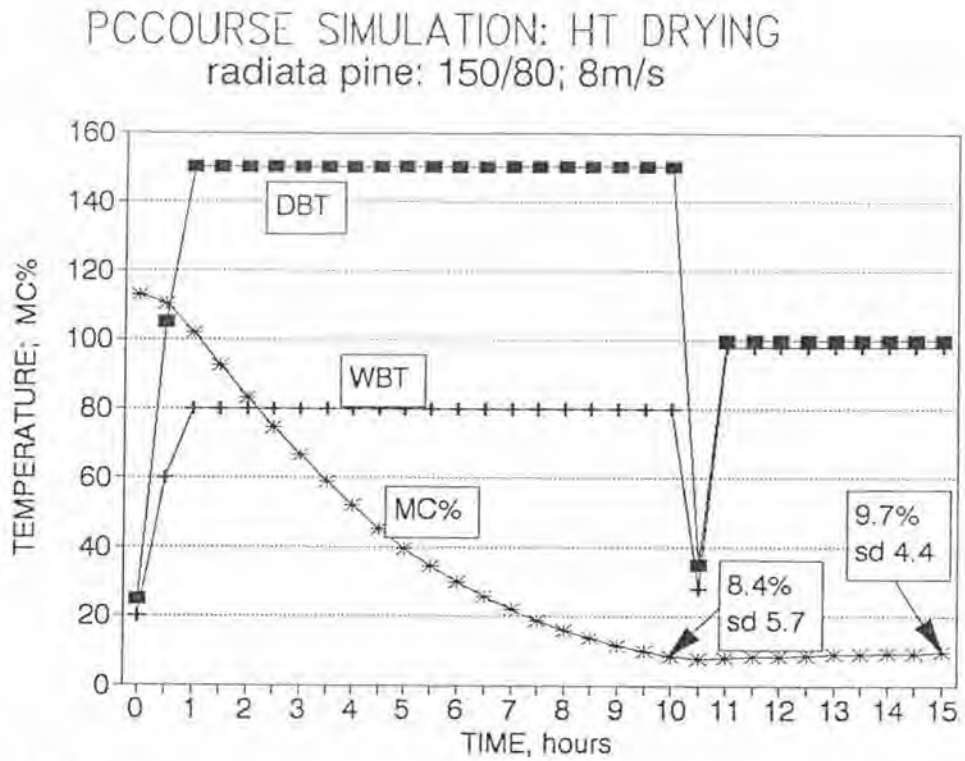

Figure 2(c).

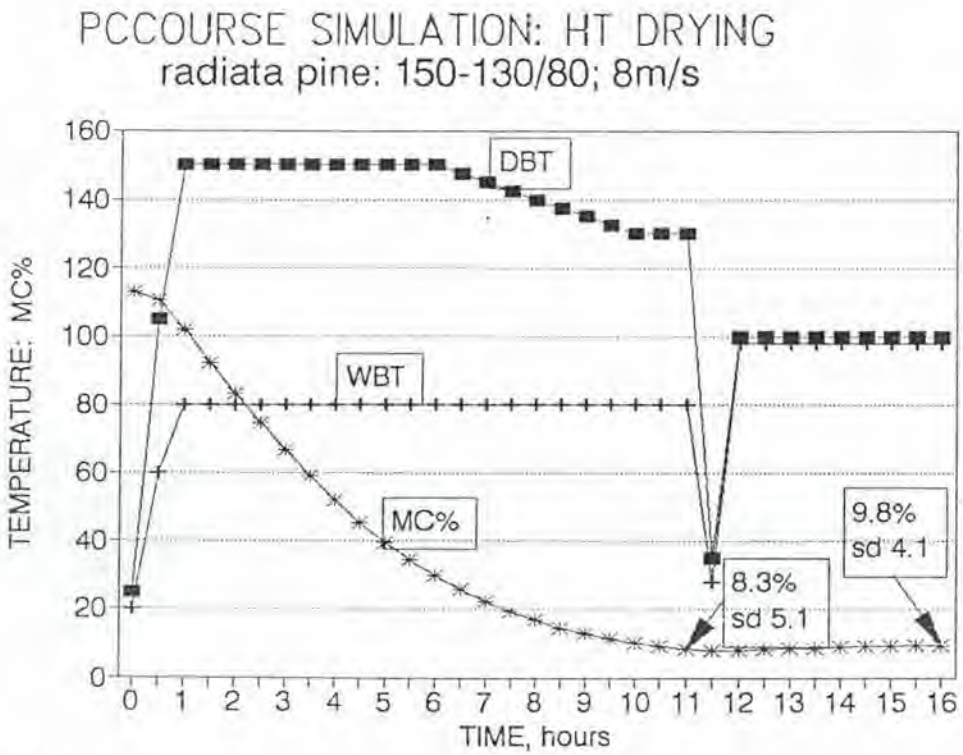

Figure 3.

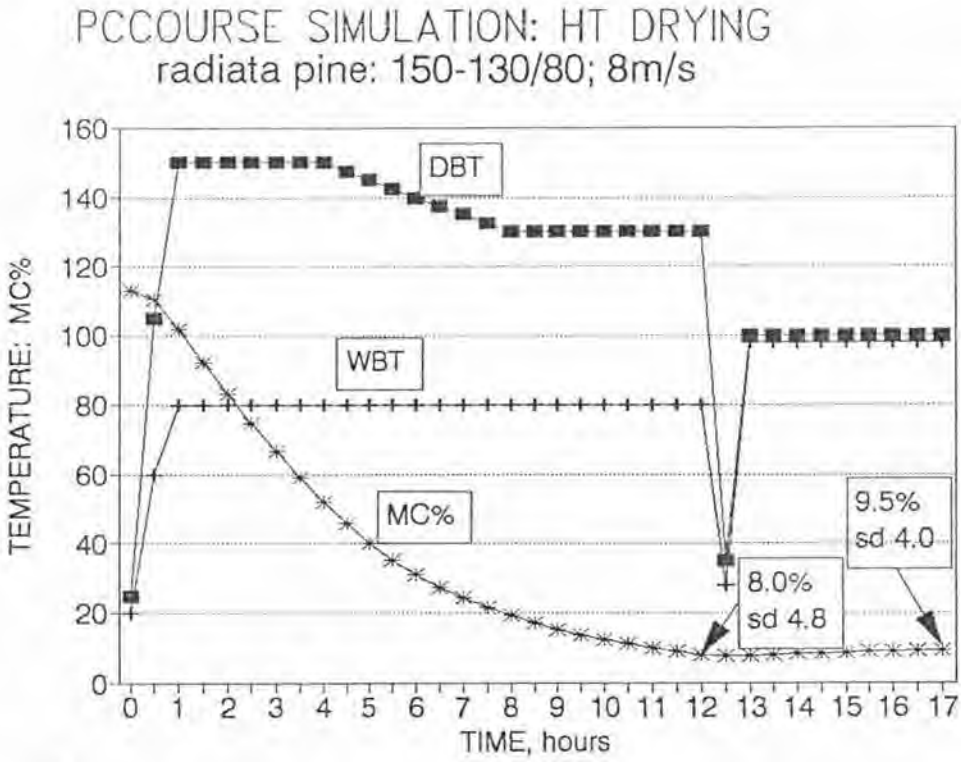

Figure 4.

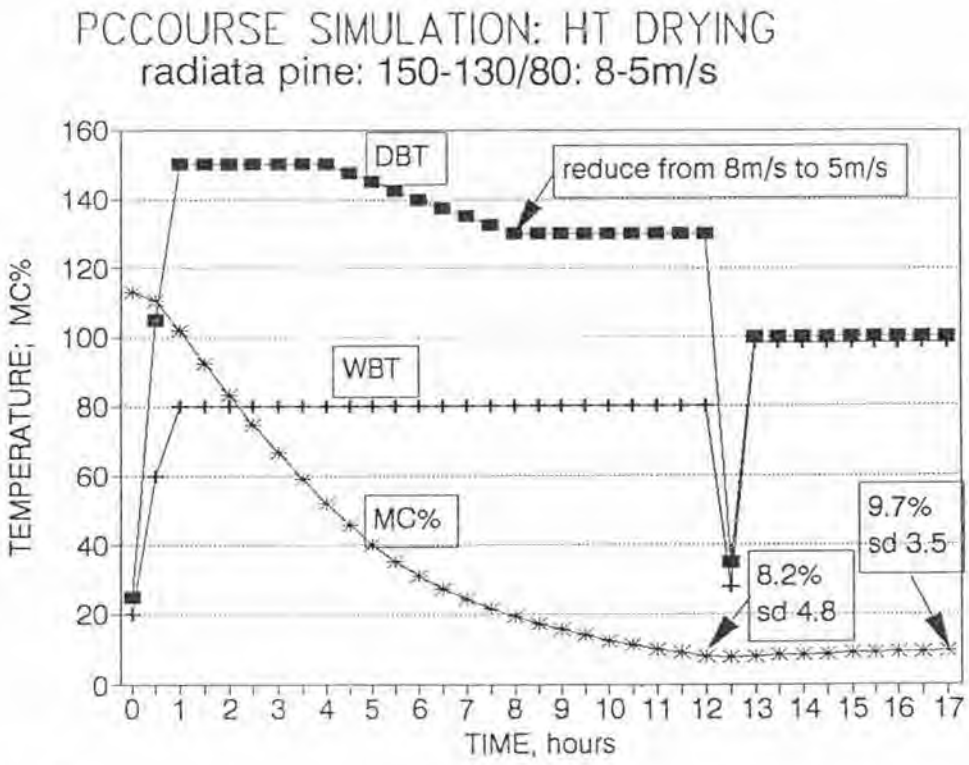

Figure 5.

LAMINATED VENEER LUMBER, IN-GRADE TESTING

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ABSTRACT

This paper describes how a manufacturer of Laminated Veneer Lumber has utilised the concept of in-grade testing and evaluation in order to exploit the inherent reliability of the material by presenting reliable or trustworthy design properties to designers.

It describes how such a technically based marketing approach has created a new interest in timber engineered materials.

In-grade testing and evaluation is further presented as a valuable tool in efficiently utilising resource whilst still maintaining reliable product properties.

BACKGROUND

In 1985, International Panel and Lumber (Australia) Pty Ltd, a wholly owned subsidiary of the South Australian Timber Corporation, purchased a Laminated Veneer Lumber (LVL) equipment and technology package from Metsaliiton Teollisuus OY of Finland. The equipment included their pilot LVL manufacturing plant which had been in operation in Finland since the early seventies and manufactured product for both the European and North American markets. Metsaliiton had replaced this plant with higher capacity equipment.

The Finnish LVL product, called Kertopuu LVL uses European Spruce (Picea abies) for resource whereas the IPL products, Hyspan LVL and Hyplank use Radiata Pine from the Mount Gambier region.

Since the initial in-grade testing and evaluation performed by CSIRO at Highett, Hyspan LVL has seen only the one major change in manufacturing specification, dated February 1988. This involved increasing the number of scarf jointed layers, previously only the outer layer, to include the outer three layers. This change was only implemented after conducting further in-grade testing for sensitive properties.

In July 1990, the manufacturing plant was extended to approximately double its capacity in order to meet market demand.

MARKETING CONCEPTS

At the time of purchase of the manufacturing plant, IPL management had been exposed to the potential for timber engineered systems chiefly via the Plywood Association of Australia (PAA) and also through contact with the American Plywood Association who were involved in development of performance standards and in-grade testing. It is also evident from internal company reports that there was a flow on of the need for a technically based marketing approach from Metsaliiton Teollisuus OY to IPL management. Other examples of technically based marketing by companies involved in the manufacturing and marketing of LVL were observed in Gang Nail and Trus-Joist in the United States.

The influence of CSIRO in promoting the in-grade testing path for Hyspan LVL cannot be underestimated. It was significant that the in-grade procedures base document, the authoritative reference, albeit in draft Australian Standard format only [1], was in place at the time IPL needed to utilize it.

Youngquist [2] expresses the "incentives for the commercial development of processes aimed at producing new, high yield structural products from wood 1) overcoming the problem created by the diminishing supply of large logs suitable for lumber of large dimensions, and 2) optimizing the economic picture by using

an increasing percentage of the forest bio-mass previously considered forest residues".

Whilst LVL products clearly encompass the first of these incentives, the second is not as obvious in the Australian experience. Veneer that is used in LVL would otherwise be used in plywood manufacture, although this would be limited to DD grade plywood of significantly lower value. The opportunity to manufacture laminated veneer lumber represents better utilization of resource rather than utilization of waste.

A third incentive which Youngquist does not specifically identify is the issue of structural reliability.

The reasons for the high order of inherent reliability of LVL have been documented by Lyngcoln [3]. Table 1 shows a comparison between the co-efficient of variation for Hyspan LVL, and various grades of machine stress graded Australian Grown Radiata Pine.

TABLE 1 COMPARISON BETWEEN CO-EFFICIENTS OF VARIATION

STRUCTURAL PROPERTIES	HYSPAN[13] LVL	MACHINE STRESS GRADED RADIATA PINE [14]		
		F5	F8	F11
Bending Strength	0.14	0.42	0.32	0.26
Tension Strength	0.14	0.37	0.33	0.31
Modulus of Elasticity	0.08	0.21	0.15	0.14

The advantage of this inherent reliability can only be realised in a system where the designer is given reliable design data. In-grade testing and evaluation coupled with third party audited in process quality control provides such a system.

Madsen, regarded by many as the instigator of in-grade testing expresses the essential logic thus [5].

"This paper endeavours to describe the steps necessary to evaluate timber to a position of being a respectable and reliable structural product for use in our high-tech society" and further

he describes in-grade testing as "a philosophy for deriving realistic strength properties for timber".

Carson [6] records the following sequence of event related to use of stress graded timber for critical structural elements.

"In September, 1986, Leicester and Keating put a proposal to the Timber Standards Board which in essence stated that where it is intended to use timber in engineered structures, other than domestic houses, unless a species grade has been evaluated by in-grade testing it should be reduced by one stress grade. Similar opinion was expressed in the November, 1988 Timber Structures Seminar for the release of the 1988 AS 1720.1. The following text is reproduced from the seminar notes.

"It should be noted that in this second method, the timber is assessed without benefit of data on structural size timber. While this is quite satisfactory for use in the design of framing for housing and other structures that involve extensive load-sharing features, it may be prudent when designing critical structural elements to reduce the design stresses by one stress grade below the assessed value."

In September, 1990, the committee responsible for AS 1720 Timber Structures Code decided to recommend inclusion of a clause expressing the above as a requirement.

In 1986, the above philosophies were a basis for the decision to not only perform in-grade testing to generate reliable design data, but to go one step further and totally avoid the stress grade classification system for marketing identification of Hyspan LVL. It was argued that 1) the utilization of the product could be optimised by publication of reliable and defined design properties without being fettered by the relationships between properties imposed by the stress grade system and 2) the image of the product as an engineering material would be enhanced by disassociating it from the stress grade description.

This decision was taken despite considerable disquiet from some within the marketing side of the organisation but has been vindicated by the ready acceptance of Hyspan LVL as an engineering material. Our own experience confirms the following

observation by Lyngcoln [7] in 1987 when discussing the opportunities for performance based standards including those based upon in-grade testing.

"There is ready acceptance of performance standards by consumer groups and building and specifying authorities. This situation should be universally exploited in promoting wood based products".

IMPLEMENTATION

Lyngcoln [7] describes seven essential steps in the implementation of the in-grade method of assuring reliable mechanical and physical properties for structural timber products.

"(1) Define the variables which affect the critical mechanical and physical properties such as basic working stresses, elastic moduli and bond durability. For a manufactured structural timber product the following variables are deemed critical; species, density, laminate quality, jointing of laminates, manufacturing process, tolerances, arrangement of laminates, laminate thickness, adhesive type and bond quality.
(2) Prepare a manufacturing specification which sets limits on the variables defined as critically affecting material properties.
(3) Develop a manufacturing process quality control program to ensure the minimum requirements specified in the manufacturing specification can be strictly adhered to. As was the case with application specific performance standards this requirement is critical if the engineering data generated by the in-grade performance standard is to be reliable.
(4) Manufacture the product utilising the process quality control to ensure the product meets the requirements of the manufacturing standard.
(5) Take a random sample of the manufactured product, manufactured under tight process quality control to meet the manufacturing standard, and have the material tested by a recognised authority for all required mechanical properties.

Usually a sample size of 100 is considered adequate to establish modulus of elasticity, bending strength, tension strength, compression strength, shear strength, modulus of rigidity and nail holding properties. Standard test methods must be used in the testing program and working stresses and elastic moduli must be established from the test results using standard statistical procedures such as those defined in Draft Australian Standard DR83205-1986 (1).

(6) Test bond quality and durability using standard test procedures similar to those established for structural plywood (8).

(7) Design a sampling and testing program for both in mill and third party quality audits. It is usually sufficient to test one mechanical property for quality assurance purposes. Because of the non-destructive nature of the test method, modulus of elasticity is usually the selected control property".

SAMPLE PREPARATION

In order to meet both commercial and marketing objectives to have technical literature available prior to commissioning the reassembled plant for commercial production, it was decided to produce samples for in-grade testing in a 2.4 m long plywood press. Such sample was produced in accordance within the minimum requirements of a proposed LVL manufacturing specification and required strict observance of such variables as veneer grade, veneer density and the disposition of butt joints in adjacent internal veneers throughout the matrix. The thickness of the assembly was limited to 33 mm or eleven laminations, as it was believed that the less laminates, the more conservative the evaluation would be in respect of thicker assemblies.

From a manufacturing point of view, and in anticipation of a third party audited system of quality control including final product testing, it is important that such sample is based on the minimum criteria set out in the manufacturing specification. To do otherwise, invites high rates of fall down or reject product if poor or over optimistic initial sampling leads to the

establishment of unrealistic published design properties which cannot be efficiently produced from the available resource.

To give some appreciation of the sample volume used in the first evaluation study, 100 pieces of 33 mm thick LVL were manufactured in sheets 2.4 m long by 1.2 m wide and supplied to CSIRO for sample preparation.

TESTING AND EVALUATION

Two series of tests were performed for Hyspan LVL against a background study and evaluation of overseas test results for Kertopuu LVL. A small amount of verification testing of Kertopuu LVL was performed by CSIRO.

Table 2 shows the full range of properties that were tested and evaluated for Hyspan LVL.

The extent of product testing should be related to the intended end use applications. Hyspan LVL is intended for non specific structural use and in this circumstance, the suite of properties described in Table 2 was thought appropriate. It could be argued that the testing has been deficient in that it implies assumptions for the characteristics of LVL in respect of

1. Duration of load for strength (including joint strength)
2. Duration of load for deformation
3. Size effects
4. Relationships between strength properties and moisture content

Lyngcoln [3] argues in respect of duration of load characteristics that,

"In LVL manufacture, the longitudinal wood structure is kept intact. Laminates are bonded with a rigid thermosetting phenolic adhesive in a similar manner to plywood or laminated beam. The duration of load factors for strength and stiffness specified in AS 1720 Timber Engineering Code Tables 2.4.1.1 and 2.4.1.2 for solid timber glue laminated beam and plywood are equally applicable to LVL. Other modification factors detailed in AS 1720 for solid timber are also applicable to LVL. Thus the basic

working stresses published for LVL can readily be converted to design stresses by applying the appropriate modification factors from the Code".

TABLE 2 PROPERTIES DETERMINED BY TESTING

1. Tension Strength
2. Bending Strength - on flat
   - on edge
3. Modulus of Elasticity - on flat
   - on edge
4. Compression Strength parallel to grain
5. Shear in beams - on flat
   - on edge
6. Shear at joint details
   - shear in plane of lamination
   - shear perpendicular to plane of lamination
7. Compression perpendicular to grain
   - in direction of planes of lamination
   - perpendicular to planes of lamination
8. Nail Capacities
   (a) Nail driven parallel to plane of lamination
      - withdrawal
      - laterally loaded both parallel and perpendicular to grain
   (b) Nail driven into face
      - withdrawal
      - laterally loaded both parallel and perpendicular to grain
9. Laterally loaded bolts
   - bolt axes parallel to plane of lamination
   - bolt axis perpendicular to plane of lamination

It is further true, that in excess of twenty years experience with the use of LVL in North America and Europe has not exposed any fundamental problem with adopting the assumption that LVL behaves similarly to solid wood in respect of duration

of load. Further, Madsen [9] establishes that all postulated duration of load curves for structural timber are relatively flat when plotted in real time. It may, however be slightly steeper for LVL which would approach the behaviour of clear wood. However, even if the long term strength is lower than anticipated that this is unlikely to lead to structural failure except in the few instances where the critical design load is of a permanent nature.

The current AS 1720 Timber Structures Code factor to account for size effects is believed conservative for LVL because the laminating effect leads to less within component variability compared with solid timber and therefore should also result in less size effect. Testing of this aspect would result in more efficient utilization of material.

Hyplank scaffold planks require high order reliability, good stiffness and high flexural strength characteristics for short term loading.

For such a product, the optimum approach is a combination of in-grade testing for the relevant mechanical properties such as bending strength, shear strength and modulus of elasticity on the flat coupled with proof testing verification. This is a good example where the necessary extent of the in-grade testing is limited by the application.

SAMPLE SIZE

The Draft Australian Standard for Evaluation of Strength and Stiffness of Graded Timber DR83205, contains a penalty where only small sample sizes are tested. The sample factor k_s reduces as either the number of samples tested decreases or as the co-efficient of variation of the population increases.

Table 3 shows the relationship between the sample size 'n', the co-efficient of variation and the penalty sample factor k_s.

For LVL with co-efficients of variation in the region 0.10 to 0.20, sample sizes of 30 pieces or more are recommended.

TABLE 3 EFFECT OF SAMPLE SIZE ON SAMPLE FACTOR				
NUMBER OF SAMPLES 'n'	CO-EFFICIENT OF VARIATION			
	0.10	0.20	0.30	0.40
	SAMPLE FACTOR (k_s)			
10	0.915	0.829	0.744	0.659
20	0.940	0.879	0.819	0.759
30	0.951	0.901	0.852	0.803
50	0.962	0.924	0.885	0.847
100	0.973	0.946	0.919	0.892

TABLE 4 DERIVED AND PUBLISHED STRUCTURAL PROPERTIES				
MEASURED PROPERTY	SAMPLE SIZE	CO-EFFICIENT OF VARIATION	CSIRO (1986)	PUBLISHED (1986)
Tension Strength	100	0.14	F't = 10.5	F't = 10.0
Bending Strength				
- on flat	100	0.21	F'b = 16.2	F'b = 16.0
- on edge	100	0.14	F'b = 16.4	F'b = 16.0
Modulus of Elasticity				
- on flat	100	0.09	E = 13.3 GPa	E = 12.5 GPa
- on edge	100	0.08	E = 13.2 GPa	E = 12.5 GPa
Compression Parallel to grain	52	0.08	F'c = 13.7 MPa	F'c = 13.0 MPa
Shear in beams				
- on flat	52	0.10	F's = 2.0 MPa	F's = 0.95 MPa
- on edge	52	0.12	F's = 1.8 MPa	F's = 1.70 MPa

RESULTS OF TESTING AND PUBLICATION OF DATA

Items 1 to 5 in Table 2 were evaluated using in-grade testing of structural sized laminated veneer lumber. The sample sizes tested, the coefficients of variation, the resulting basic stress and stiffness values are given in Table 4 and compared with the values published by IPL for the use of designers in their "Technical Bulletin No. 2 - Structural Design Using Hyspan Laminated Veneer Lumber, December 1986 [10]".

As discussed earlier, the logic of in-grade testing lies with the reliability of the data. Any manufacturer must be mindful of the need to maintain properties of product on the safe side of published claims. With a new product, such as IPL had with Hyspan LVL in 1986, it is unlikely that the manufacturer will have sufficient understanding of the significance of the effect of variation in manufacturing variables. For this reason, the manufacturer must decide the target properties to publish according to his confidence in being able to maintain such after considering such possible variations.

It was both for this reasons, and also on the basis of test data for Kertopuu LVL that decided IPL upon the initial suite of published values as shown in Table 5.

DEVELOPMENT STRATEGIES

Since the initial publication of design values, IPL has explored the effects of altering manufacturing variables with two significant changes.

In February, 1988, the construction of both Hyplank and Hyspan LVL was altered such that the outer three veneers are scarf jointed instead of just the outermost veneer. The principal effect of this change was to reduce variability of bending strength on the flat from 21 % to 15 % and increase the basic bending strength on the flat from 16.2 MPa to around 22 MPa. These values are based on two separate product samplings, each comprising twenty tests and evaluated in accordance with the draft Australian Standard for Evaluation of Strength and

Stiffness of Graded Timber [1]. This evaluation has been performed in-house and therefore has not been regarded as a basis for any alterations in published values and should not therefore be used for design purposes. It has been included as a positive example of the degree of control and knowledge that the in-grade procedures give to a manufacturer.

In October, 1988, IPL published a revised version of their Technical Bulletin No. 2 - Structural Design Using Hyspan [11] in which the published Modulus of Elasticity was increased from 12.5 GPa to the CSIRO derived value of 13.2 GPa.

This change was made possible through a series of investigative trials that revealed a capacity to target even higher Modulus of Elasticity values than the 13.2 GPa value derived by CSIRO. The decision whether to adjust the published value is between the efficient resource utilization and market considerations. It should be noted that a 50 % increase in Modulus of Elasticity will only reduce beam depth by approximately 15 % [12].

QUALITY ASSURANCE

The in-process quality control of Hyspan LVL seeks to control the input variables such that the published properties are reliably maintained.

Some variables such as log variables associated with source or the micro growing environment are not readily controlled and yet they may be significant in the final determination of properties. IPL are most fortunate in that they peel their own veneer and are therefore able to select log specifically for their LVL production. This contrasts with most North American manufacturers who are isolated from their veneer sources. Trus-joist need to ultra sonically scan veneer for sorting purposes and produce multiple LVL grades as a consequence.

The CSIRO report 86/27 [13] Design Properties for a Commercial Radiata Pine Laminated Veneer Lumber states under the heading Quality Assurance

"Because LVL is a manufactured product some method should be devised to verify that the product sold commercially is similar

to the product investigated for this report. The simplest method of doing this is to base quality assurance on testing of some significant property that is listed in Tables 1, 2 and 4-6. In these tests the mean value of the property should be not less than $R(1-2\ V_R/\sqrt{N_Q})$ where R and V_R is the mean and co-efficient of variation of the property given in Tables 1, 2 and 4-6 and N_Q is the sample size used in the quality assurance test. A suitable value for N_Q is five".

This recommendation has been adopted with the use of an in-house testing machine measuring Modulus of Elasticity on the flat. Samples are regularly measured and the results recorded for each thickness of LVL product.

This procedure enables drifts in product values to be detected and remedial action taken. In addition, samples are regularly sent to a nearby laboratory for Modulus of Elasticity determination both on the flat and on edge and Modulus of Rupture on edge determination. This testing is used as a check upon the in-house testing and includes additional properties for comparison with published data.

In 1991, five years after the initial testing and evaluation, IPL plan to instigate another series of independent in-grade testing and evaluation data. This will act as yet another quality assurance component and also provide data for possible changes in manufacturing specification or published data.

CONCLUSION

This paper has sought to describe the significance of the in-grade testing approach to the marketing, the product evaluation, product development and quality assurance components of Hyspan Laminated Veneer Lumber.

This logical technically based approach is a substantial factor in generating specific confidence in the reliability of Hyspan LVL.

The inroads that Hyspan LVL is making into markets that have been dominated by steel are evidence of the rewards associated with adopting this approach.

REFERENCES

1. Standards Association of Australia, 1986. Draft Australian Standard for Evaluation of Graded Timber, DR83205, Sydney, Australia.

2. Youngquist, J.A. 1985. Laminated Veneer Lumber - A high quality structural lumber substitute. Symposium on Forests Products Research International Achievements and the Future, Pretoria, South Africa.

3. Lyngcoln, K.J., 1986. Laminated Veneer Lumber, Newstead, Australia.

4. Leicester, R.H., Grant, D.J., Rumball, B.L. and Young, F.G., 1988. Structural Engineering Properties of Machine Stress-graded, Australian-grown Radiata Pine. CSIRO, Division of Construction and Engineering, Technical Report TR88/1, Highett, Australia.

5. Madsen, B. A Design Code for Contemporary Timber Engineering and its implications for International Timber Trade.

6. Carson, J., 1989. Strength Grouping for Timber Utilisation Past, Present, & Future. Australian Timber Research Institute Inc., Internal Report.

7. Lyngcoln, K.J., 1987. Performance Based Standards and Their Role In Promoting The Utilisation of Forest Resources and The Development of New Products. Rome, September and October, 1987.

8. Standards Association of Australia, AS 2098.2-1977. Method of Tests for Veneer and Plywood - Bond Quality of Plywood, SAA, Sydney, Australia, 1977.

9. Madsen, B. Duration of Load Effects In Timber.

10. International Panel and Lumber (Aust.) Pty Ltd., 1986. Structural Design Using Hyspan Laminated Veneer Lumber. Technical Data Bulletin No. 2.

11. International Panel and Lumber (Aust.) Pty Ltd., 1988. Hyspan Technical Bulletin - Structural Design Using Hyspan. Technical Data Bulletin No. 2 - revised October, 1988.

12. Hutchings, B.F., Leicester, R.H., 1988. Scrimber, Proceedings of the 1988 International Conference on Timber Engineering, Seattle, Washington, USA.

13. Leicester, R.H., Lhuede, E.P., and Breitinger, H.O., 1986. Design Properties For A Commercial Radiata Pine Laminated Veneer Lumber. CSIRO, Division of Building Research, Internal Report No. 86/27, Melbourne, Australia.

14. Standards Association of Australia. Timber Structures Seminar, November, 1988.

BREEDING EUCALYPTS FOR MANUFACTURE OF PULP AND PAPER

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ABSTRACT

Research into the inheritance of wood and pulping properties has demonstrated that these are generally highly heritable, and that variations have a high impact on overall cost of production. This implies that breeding for improved properties is very worthwhile, but to be successful must use the best available knowledge.

Techniques for rapid screening of large numbers of trees are in need of development and refinement. This will enable screening for candidate trees for more extensive evaluation. Generally such techniques do not correlate sufficiently well with whole-tree values to be used to estimate those values, e.g. for use in a clonal program.

INTRODUCTION

Eucalypt pulps are now commonly used throughout the world as an important component of paper furnish. Interest in these pulps began relatively recently, but has grown rapidly because of their excellent properties. These include bulk, formation, softness (important for tissue and towelling grades), opacity (printing and writing), and better drainage and drying properties than other hardwood pulps(1,2). Consequently, although eucalypt capacity is just over 10% of the world's total chemical paper grade market pulp capacity (1986), there is strong interest in expansion of capacity, particularly in Brazil (3).

APPM has over 50 years experience of making pulp and paper from eucalypts. A wide range of papers is produced with emphasis on fine writing and printing papers, especially copy paper. Pulps currently produced include Soda-Anthraquinone and chemi-mechanical processes, and are all consumed within the APPM group of companies. The wood supply is native forest hardwoods, mainly eucalypts, and a small proportion of Pinus radiata.

Woodchips from native forest woods are also exported, and the parent

company, North Broken Hill Peko Ltd., has expressed an interest in establishing an export pulp mill based on this resource. A recent proposal was for a kraft mill producing 440,000 tonnes (air dry)/annum of bleached pulp.

Eucalypt tree farm establishment on company freehold is concentrated in north-western Tasmania and commenced with 400 ha/annum in 1975. The program offered prospects of quality wood and potential cost containment through mechanization, and the estate is increasingly regarded as a valuable wood supply option for the future. The total planted area is currently 18,000 ha, with a planting rate of 2,500 ha/annum.

The APPM Breeding Program

APPM is interested in all aspects of eucalypt breeding in this context. Species trials have been established and the best performing species to date are Eucalyptus globulus and E.nitens: other species are under evaluation, e.g. E.regnans. Geneticists have emphasized the importance of breeding stategy (5,6) and company staff have given it due attention. The importance of large base populations is realised and APPM now has in excess of 500 seedlots for each of E.globulus and E.nitens as a genetic resource. A series of trials has been established to compare seedlots on a range of typical sites.

Much of the company land available for planting is on a basaltic plateau at about 600m altitude, and latitude 41 degrees. E.globulus is very frost susceptible and is not suitable on these sites. Even E.nitens is sometimes damaged. Accordingly there is interest in producing hybrids, e.g. between E.globulus and E.nitens, which might effectively extend the range of E.globulus. There is also interest in breeding for increased frost resistance of E.nitens, and techniques have been introduced to screen the seedling progeny of candidate trees (7).

Vegetative reproduction , usually by cuttings, is a useful technique for inducing uniformity, and capturing genetic gain from preferred individuals. Such 'clonal' forestry is either practiced or sought by many leading forestry companies in tropical, or sub-tropical climates. Unfortuately the cool-temperate eucalypts are extremely difficult for vegetative reproduction. None-the-less APPM has commenced a research program to develop commercial techniques for clonal forestry (8).

Breeding for improved wood properties

APPM interest in breeding for improved wood and pulping properties was prompted by results from provenances of E.globulus. A collection of wood samples and seed from Tasmania and southern Victoria was made by the Forestry Commission of Tasmania (9), and APPM was approached for possible interest in wood evaluation. The wood was subsequently pulped, by the Soda process to give provenance

averages ranging from 40 to 56% pulp yield (10). Such differences were regarded as very significant in economic terms.

These results were followed by assessment of a provenance trial of E.obliqua at Lisle in north-eastern Tasmania (11). The design of this trial was such that site effects could be removed during analysis. Differences between provenances were significant and pulp yield ranged from 40.3 to 52.7% by the Soda process. Heritabilities, when selecting between provenances, were pulp yield%, 0.72; bulk, 0.05; tear index, 0.36; and tensile index, 0.26. These results gave expectations that wood properties could be improved by breeding, and the company decided to upgrade wood evaluation facilities.

The next trial to be evaluated was the progeny of the E.globulus parents referred to above. Wood evaluation was carried out on 18 seedlots, and 10 trees per seedlot. These results confirmed high levels of heritability for wood properties (12), and results from elsewhere support this (see table 1). This trial raised a number of issues which merit further discussion, viz.

i) sub-sampling methods are critical to sampling strategy;
ii) selection criteria and economic weights are very important;
iii) improving pulp strength properties.

Sub-sampling methods

Breeders must have sampling methodology to enable identification of superior genotypes. They commonly seek sampling techniques which do not destroy the trees of interest. In addition within-tree variation is large compared with the variation between trees. Thus breeders have a dilemma; on the one hand to take fewer, and smaller samples, so as to contain costs and not damage the tree; and on the other hand to take sufficient sample as to adequately represent the tree.

Breeding also is a numbers game. The breeder must have at his disposal as wide as possible a choice of genetic material for the traits of interest. In practical terms this has usually meant gaining access to large numbers of seedlots collected from the wild. Progress is then assisted by relatively intense selection among genotypes. This implies that genotypes can be correctly identified, and that the technique is efficient enough to be applied to large numbers. One optional strategy for APPM, "nucleus breeding", requires a small number of selections to be made at 1 per 1000 (4). Some Brazilian clonal programs aim at selections at a rate of 1:1000, to 1:10,000 (13).

Consider figure 1. This illustrates some results from a Brazilian pulping experiment (14). In this experiment samples from 25 trees, from each of 3 diameter classes, were pulped from each of 10 locations within the tree. The experiment was repeated for each of 2 soda levels, and for 2 species. Results are shown for E.grandis at one soda level: 99% confidence limits are shown for the central diameter class. There is very large variation within the tree. By comparison the standard deviation

between trees in (12) was 1.3%. A sample from breast height would come from a region of very rapid change in pulp yield along the trunk. What we hope for is that a single sample from breast height will correlate very well with whole tree values.

In a simulation study (see appendix) the pulp yield data from the E.globulus experiment (12) was copied 17 times, and then random noise introduced to the copied variables in successively increasing amounts. Heritabilities were then calculated for the variables with the introduced noise. Predictably the heritabilities were at a much reduced proportion of the original level. Correlations with the original pulp yield were also calculated. This data was plotted to show how the usable heritability value falls rapidly as the method correlation with the whole tree becomes weaker. (see figure 2). The trend is illustrated with a fitted spline curve tuned to show the overall trend.

Thus the whole-tree heritability value will not apply unless the sub-sampling method correlates extremely well with the whole tree value. Table 2 shows method correlations reported in the literature.

These data were processed further to determine the extent to which rankings using sub-sampling will correspond to rankings using whole-tree values. The simulation was carried out with assignment to 3, 4, 5, 10, 20, and 50 rank classes (see figure 3). The results showed that unless the sub-sampling method results correlate extremely well with those from the whole tree, and unless the number of classes into which trees may be assigned is small, then the percentage of trees correctly assigned will also be small.

APPM has decided on sampling from multiple locations within the tree when reliable estimates of individual tree values are required. At the same time we are developing a micropulping option in order to have a method suitable for rapid screening of large numbers. Near infrared reflectance spectroscopy also shows promise in this regard (31).

Selection criteria and economic weights

The objective of breeding is not as easily determined as it might seem. The traditional goal is to improve volume production per hectare; or perhaps disease resistance; or a combination of all of these. Improvement in wood properties has often been considered. So production of dry wood per hectare might then be a goal, by combining volume production and basic density.

A more modern objective might be to maximize the reduction in wood costs after transport and chipping; or the impact on overall mill productivity.

When asked, managers or technologists can provide a long list of criteria they wish to improve, viz. volume, form, branching, bark thickness, basic density, pulp yield, fibre length, moisture content, fibre coarseness, pulp strength properties etc. And yet Australian tree breeders are not at all satisfied with progress in breeding for these traits.

It is not enough for managers to list traits of interest. They must be described more fully. Does the trait have a level which is critical to success? This might apply to frost resistance, or a certain level of pulp strength. Or is the trait rather of economic importance? And what is the importance relative to other traits?

In this sense, all traits must be given a relative economic importance.

Economic weights can be derived as the relative economic sensitivity of the trait in influence on the overall cost of wood at the mill, and on overall mill productivity. This can be done by firstly constructing a model of wood procurement costs which contains all the traits of interest, as components of the model. These can each be varied in turn by a small fixed percentage, to determine the effect on overall costs. The relative change on overall costs is a measure of the relative economic sensitivity (12,15)

It is not necessarily appropriate to breed for a long list of criteria. If there are appropriate correlations between traits, then improvement in one trait may bring a correlated benefit in the other. If correlations are antagonistic then attempting to improve both traits at once may cost a lot and achieve very little.

If the emphasis given does not accurately reflect the economic importance of the trait then the overall effect will not be optimum. There is little point in improving a trait if such improvement does not show a meaningful economic or other benefit.

Breeders have come to understand that the emphasis given a trait should reflect its heritability, its level of variation, its economic importance, and the correlations it has with other traits. These factors can be considered concurrently by construction of a selection index (16).

Use of such indices is mandatory to achieve an optimum balance of a wide range of potentially conflicting information. A comparison between an index based on volume production per hectare, and an index including the effect of wood properties on transport and production costs, showed that the latter index was many times more cost effective (12).

Improving pulp properties

There have been several published references to genetic studies of fibre length in eucalypts (e.g.17,18,19) but historically assessment techniques have been very slow, and hence interest has been restricted by the lack of cost effective techniques. More recently, however, the advent of the Kajaani fibre analyser has allowed cost effective assessment of large numbers of samples, e.g. 10+ samples/person/day, with a straight forward procedure, and automatic analysis and printout of results.

Aracruz are among the world leaders in eucalypt plantation establishment and breeding, and a paper describing their current plantation program specifically discusses fibre length and presents Kajaani data (20).

An advantage of microscopic methods is the ability to identify the nature and physical condition of what is being counted. Malan, for example, selected 90 unbroken fibres at random, and used the arithmetic mean length as his statistic (17). By contrast the Kajaani counts everything: vessels, broken fibres and debris: are all counted. There are theoretical ways of mathematically reconstructing a correct distribution (21) but these have not yet been implemented.

An experiment at APPM tested three Kajaani statistics currently produced to examine their statistical behaviour (22). These were the quadratic mean (mean length, weighted by length), the cubic mean (mean length, weighted by the square of length), and the median. The median showed the least skewed distribution, and had the highest genetic correlations with pulp yield, with the lowest standard error (see table 3)

The genetic correlation showed that breeding for improved pulp yield would cause a correlated improvement in fibre length. The heritability was such that it would be worth selecting for improved fibre length. However it would make much more economic sense to breed for improved pulp yield and benefit from the correlated response mentioned.

The heritability of fibre coarseness was so poor as to exclude the possibility of genetic improvement for this dataset.

Improvement of other pulp properties is potentially more difficult: since rapid screening of large numbers for pulp strength is very expensive. South African work shows promise (32) with correlations of micropulping with whole-tree values acceptable for some properties (tear index, 0.86; bulk, 0.71; see table 2). A more likely solution is that correlations with pulp yield will prove beneficial. As pulp yield improves there is less alkali required to achieve target kappa number for chemical pulps. In turn this means less fibre damage during cooking.

Results from E.globulus support this tentative conclusion (12). Phenotypic correlations of strength properties with pulp yield were bulk, 0.59; tear index, 0.88; zero span tensile index, 0.85. The generally similar work from the E.obliqua study has already been mentioned (11). These correlations are very encouraging where the aim is to improve pulp yield, and make incidental improvements to other properties.

The more useful correlations are those predicted to occur among progenies of the trees under scrutiny (genotypic), rather than among the trees themselves (phenotypic). However so far the cost of estimating genetic correlations has been prohibitive.

Conclusion

Results to date have indicated the generally very high heritabilities in wood properties. We can therefore be assured that effort spent will be well rewarded. It is now appropriate to develop techniques for rapid screening of candidate trees, and to

find out more about the nature of variation within the species of interest.

We need also to find out more about the relationships between pulping, wood, and fibre properties. This will enable us to breed for one set of traits and predict the correlated reponse in another set. We should be prepared to establish genetic correlations, as well as phenotypic correlations, so as to predict responses among progeny. Initially this will prove expensive.

TABLE 3

KAJAANI FS-100 FIBRE LENGTH GENETIC STATISTICS

Statistic	Genetic Correction with Pulp Yield	Standard Error	Heritability
quadratic mean length (mm)	0.41	±0.35	0.27 (±0.19)
cubic mean length (mm)	0.21	±0.43	0.21 (±0.19)
median length (mm)	0.60	±0.31	0.29 (±0.20)
fibre coarseness (mg/100)	n/a	-	0.03 (±0.16)

TABLE 1

Published Heritability Estimates for Wood Properties in Eucalyptus

Pulp Yield	Soda demand	Shives level	Fibre length	Basic density	Moisture content	Bark Mass	Euc. species	Age	Ref.
FAMILY HERITABILITIES									
.	.	.	.	0.68	.	.	deglupta	0.5	23
.	.	.	.	0.91	.	.	citriodora	0.5	24
.	.	.	.	0.85	.	.	grandis	0.5	25
.	.	.	.	0.83	0.60	.	grandis	1	26
.	.	.	0.42	0.61	0.52	.	viminalis	3	18
0.48	.	.	.	0.84	.	.	obliqua	7	11
0.62	0.84	0.00	.	0.80	0.81	0.84	globulus	8	12
.	0.65	0.30	0.38	0.62	0.50	.	nitens	8	22
.	.	.	0.54	0.45	.	.	grandis	9	17
.	.	.	.	0.5	.	.	globulus	4	27
.	.	.	.	0.6	.	.	globulus	7	27
0.18	.	.	.	0.6	.	.	globulus	10	27
0.26	.	.	.	0.5	.	.	globulus	12	27
INDIVIDUAL TREE HERITABILITIES									
.	.	.	.	0.44	.	.	deglupta	0.5	23
.	.	.	0.52	0.46	.	.	regnans	1	19
.	.	.	.	0.80	0.28	.	grandis	1	26
.	.	.	0.12	0.55	0.35	.	viminalis	3	18
0.43	0.57	0.00	.	0.83	0.88	0.99	globulus	8	12
.	0.74	0.23	0.32	0.69	0.47	.	nitens	8	22

TABLE 2 Sub-sampling Method v. Whole-Tree correlations

		Breast height cores	Breast height discs	2 discs (10% & 50%)	5 discs (10,30,50, 70,90%)	Trees	Age	Whole tree discs	Literature reference
Basic density	E. grandis		0.91			50	7	5	28
	E. saligna		0.80			"	"	"	"
Basic density	E. grandis		0.73			59	7	5	29
Basic density	E. grandis		0.69			35	10	5	30
Pulp yield	3 Pinus sp.	0.67				26	20	10	31
Pulp yield	14 Pinus sp.	0.40	0.39			32	13-25	10	32
Tear index		0.86	0.80			"	"	"	"
Breaking length		0.45	0.59			"	"	"	"
Specific bulk		0.71	0.68			"	"	"	"
Pulp yield	simulation		0.83*	0.91	0.92	75	7	10	#
Basic density	E. globulus		0.91*	0.97		186	8	5	12
Moisture content			0.90*	0.97		"	"	"	"
Bark (% mass)			0.93*	0.98		"	"	"	"
Bark (% vol)			0.82*	0.94		"	"	"	"

* = 10% of tree height # = Dean, G.H., Unpublished APPM study using data from (12) and (14).

References

1. Sidaway,S. (1988) "The availability and use of eucalypt pulps", Tappi Journal, December 1988, 47-51

2. Maddern,K.N. (1990) "How eucalypts (and Australian Eucalypts in particular) compare internationally as a pulping material", Appita 44th Annual General Conf., Presented in NZIF program, Rotorua, April 1990, 12p.

3. Slinn,R.J. (1987) "Eucalyptus: An inch a day is a pretty amazing story", PaperAge, August 1987, 7-9

4. de Little,D.W. (1990) "Establishing eucalypt tree farms in cool temperate environments", Greening Australia Conf., Adelaide, May 1990

5. Griffin,A.R. (1989) "Strategies for the genetic improvement of yield in eucalyptus", in 'Biomass Production by Fast-Growing Trees', Pereira,J.S. and Landsberg,J.J (eds), Kluwer Academic Publishers, 247-265

6. Eldridge,K.G. and Davidson,J. (1988) "Strategies used for domestication and improvement of eucalypts for plantations", Int. For. Conf. for the Aust. Bicentenary, Albury-Wodonga, April-May 1988, session V, 12p.

7. de Little,D.W. and Tibbits,W.N. (1988) "Breeding Eucalyptus nitens (Shining Gum) for pulpwood production in cool-temperate climates", Proc. Int. For. Conf. for the Australian Bicentenary, April-May 1988, Vol. 5, 9p.

8. Tibbits,W.N.; de Little,D.W. and Ravenwood,I.C. (1989) "Improving short-rotation, fast-growing, cool temperate eucalypts through controlled pollination, hybridization and vegetative propagation", Comm. For. Conf., Session 6 - 'Temperate plantation management', September 1989, 17p.

9. Orme,R.K. (1977) "Eucalyptus globulus provenances", Third World Consultation on Forest Tree Breeding, Canberra, March 1977, 3:207-221

10. Turner,C.H.; Balodis,V. and Dean,G.H. (1983) "Variability in pulping quality of E.globulus from Tasmanian provenances", Appita, 36(5):371-376

11. Matheson,A.C.; Turner,C.H. and Dean,G.H. (1986) "Genetic variation in the pulp qualities of Eucalyptus obliqua L'Herit", Appita 39(3):205-212, May 1986

12. Dean,G.H.; French,J. and Tibbits,W.N. (1990) "Variation in pulp and papermaking characteristics in a field trial of Eucalyptus globulus", Appita 44th Annual General Conf., Rotorua, April 1990

13. Rodrigues,L.C.; Silva,A.P. and Freitas,M. de (1988) "Eucalypts plantation for pulp and paper in Brazil"(sic), Int. For. Conf. for the Aust. Bicentenary, Albury-Wodonga, April-May 1988, session I, 17p.

14. Manfredi,V. (1985) "Variations in the yield of sulphate pulp along the trunk of Eucalyptus grandis Hill ex Maiden and E.saligna Smith", Masters thesis , University of Sao Paulo, Piracicaba, Sao Paulo, Brazil. Also Manfredi,V. and Barrichelo,L.E.G. (1985), ABCP Congr. Anual 18th (Sao Paulo), vol. 1:5-29 (Nov 1985)

15. Dean,G.H. and Baker,L.R. (1986) "APPM Eucalypt plantation selection criteria for pulpwood", Proc. 9th Meeting RWG No.1, CSIRO Forest Research, 83-86.

16. Cotterill,P.P. and Dean,C.A. (1990) "Successful tree breeding with index selection", CSIRO Publications, 80p.

17. Malan,F.S. (1988) "genetic variation in some growth and wood properties among 18 full-sib families of South African grown Eucalyptus grandis: A preliminary investigation", South African Forestry Journal 146:38-43, September 1988

18. Otegbeye,G.O. and Kellison,R.C. (1980) "Genetics of wood and bark characteristics of Eucalyptus viminalis", Silvae Genetica 29(1):27-31

19. Rudman,P.; Higgs,M.; Davidson,J. and Malajczuk,N. (1969) "Breeding eucalypts for wood properties", Second World Consultation on Forest tree Breeding, Washington, August 1969, FAO Ref.: FO-FTB-69-4/7

20. Campinhos,E. Jr. and Claudio-da-Silva,E. Jr. (1990) "Development of the eucalyptus tree of the future", ESPRA Spring Conf., Seville, Spain, May 1990, 29p.

21. Balodis,v.; Yang,J-L.; Evans,R. and van der Touw,J. (1989) "Fibre length of Eucalyptus regnans with Kajaani FS-200", Appita 43rd Annual General Conf., Brisbane 1989

22. Dean,G.H. (1990) "An investigation into Kajaani Fibre length statistics for use in tree breeding (E.nitens, Hampshire S.S.O., age 8 y.o.)", APPM internal report, unpublished.

23. Davidson,J. (1972) " Variation, association and inheritance of morphological and wood characters in an improvement programme for Eucalyptus deglupta Blume", PhD thesis, Australian National University

24. Almeida,C.M.V.C.; Brune,A.; Silva,J.C. and Oliveira,L.M. (1981) "Estimativas de herdabilidades e correlacoes em progenies jovens de Eucalyptus citriodora Hook.", Revista Arvore, 5(2):250-268

25. Oliveira,R.J.D.P. de and Brune,A. (1985) "Variacao da densidade basica da madeira e capacidade de regeneracao entre e dentro de origens de Eucalyptus grandis" W. Hill ex Maiden", Revista Arvore, 9(1):40-48

26. Wang,S.; Littell,R.C. and Rockwood,D.L. (1984) "Variation in density and

moisture content of wood and bark among twenty Eucalyptus grandis progenies", Wood Sci. Technol. 18:97-100

27. Celbi (1979) "Heredity studies of Eucalyptus globulus", Tech. consultations on fast growing plantation broadleaved trees for mediterranean zones, FAO Ref.: FO:FGB-7-3/5, Lisbon, Portugal, October 1979

28. Souza,V.R. de (1986) "Basic density of provenances, diameter classes and at different heights in Eucalyptus grandis and E.saligna", IPEF, Piracicaba (33):65-72, August 1986

29. Busnardo,C.A.; Gonzaga,J.V.; Foelkel,C.E.B. and Menochelli,S. "In search of ideal quality of eucalypt wood for producing pulp. (4). Ideal height of a sample for evaluating the average density for Eucalyptus grandis trees", ABCP Congr. Anual. 20th (Sao Paulo): 17-33 (Nov. 1987)

30. Camargo,F.R.A. de; Barrichelo,L.E.G. and Amaral,W.A.N do (1987)"Technological characterization of wood from stands of Eucalyptus grandis - Hill ex Maiden.", ABCP Congr. Anual 20th (Sao Paulo):1-15 (Nov. 1987)

31. Wright,J.A.; Birkett and Gambino,M.J.T. (1990) "Prediction of pulp yield and cellulose content from wood samples using near infrared reflectance spectroscopy", Tappi Journal, August 1990, 164-166

32. Wright,J.A.; Shaw,M.J.; Hadebe,W. and Raubenheimer,S. (1989) "The correlation of the pulp and paper traits between micropulping and full-scale pulping", Tappi Journal, April 1989, 191-194

APPENDIX

Procedure for Simulation of Sub-sampling Efficiency

i) Usable heritability fraction

The simulation commenced with actual data for pulp yield corrected to kappa number 18. The data were from E.globulus, age 8 years, grown in a seed orchard at Woolnorth, a company property west of Smithton in north west Tasmania (12).

Seedlot, replicate, and pulp yield(%) were extracted from the available data. Dummy variables (METH01 .. METH17) were created to simulate alternative sub-sampling methods. These contained the original level for pulp yield(%), plus increasingly larger amounts of noise, added at random from a normal distribution.

Subsequently, heritabilities, and correlations with pulp yield(%) were calculated for each of the new variables. Thus METH04 contained a small amount of random noise, correlated well with pulp yield(%) (r=0.93), and had a high heritability, 86% as large as the original. METH13 by contrast, contained a large amount of random noise, correlated poorly with pulp yield(%) (r=0.30), and had a heritability only 10% of the original value (see table).

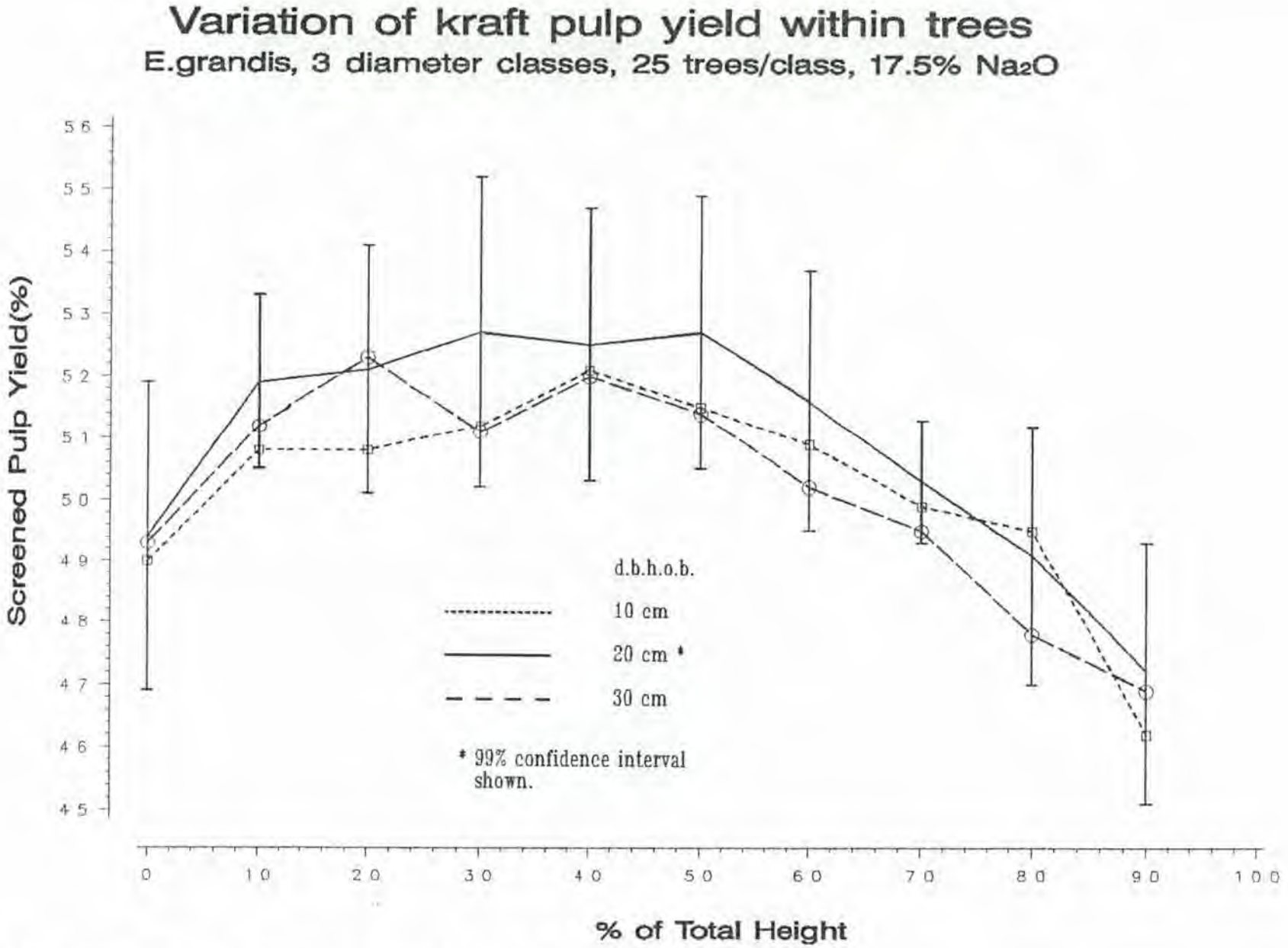
A smooth spline curve was fitted to this data and this is displayed in figure 2.

ii) Class assignment ability

The data generated in i) above were put into rank classes as follows. The trees were sorted on pulp yield(%) and allocated to three classes, viz. good, medium and poor, on that sorting. The trees were then sorted on METH01 and again allocated into three classes. The allocation did not correspond exactly since METH01 contained some random noise and so some trees were incorrectly allocated to the three classes. The degree of correspondence was recorded as "correct class assignment %", where a perfect
correspondence scored 100%.

This was repeated for all dummy variables, with the agreement on assignment of trees becoming less and less as the variables contained more and more noise. The procedure was then taken through again for different numbers of rank classes, viz. 4, 5, 10, 20, 50. As might be expected the percentage of correctly assigned trees became less and less, as the number of classes increased. A series of smooth spline curves were fitted to this data and these are displayed in figure 3.

FIGURE 1



Original data from Manfredi,V.(1985), Masters thesis 'Variacao do rendimento em celulose sulfato ao longo do tronco do Eucalyptus grandis Hill ex Maiden E E.saligna Smith', Piracicaba, Sao Paulo, Brazil. Table 21, p.75

FIGURE 2

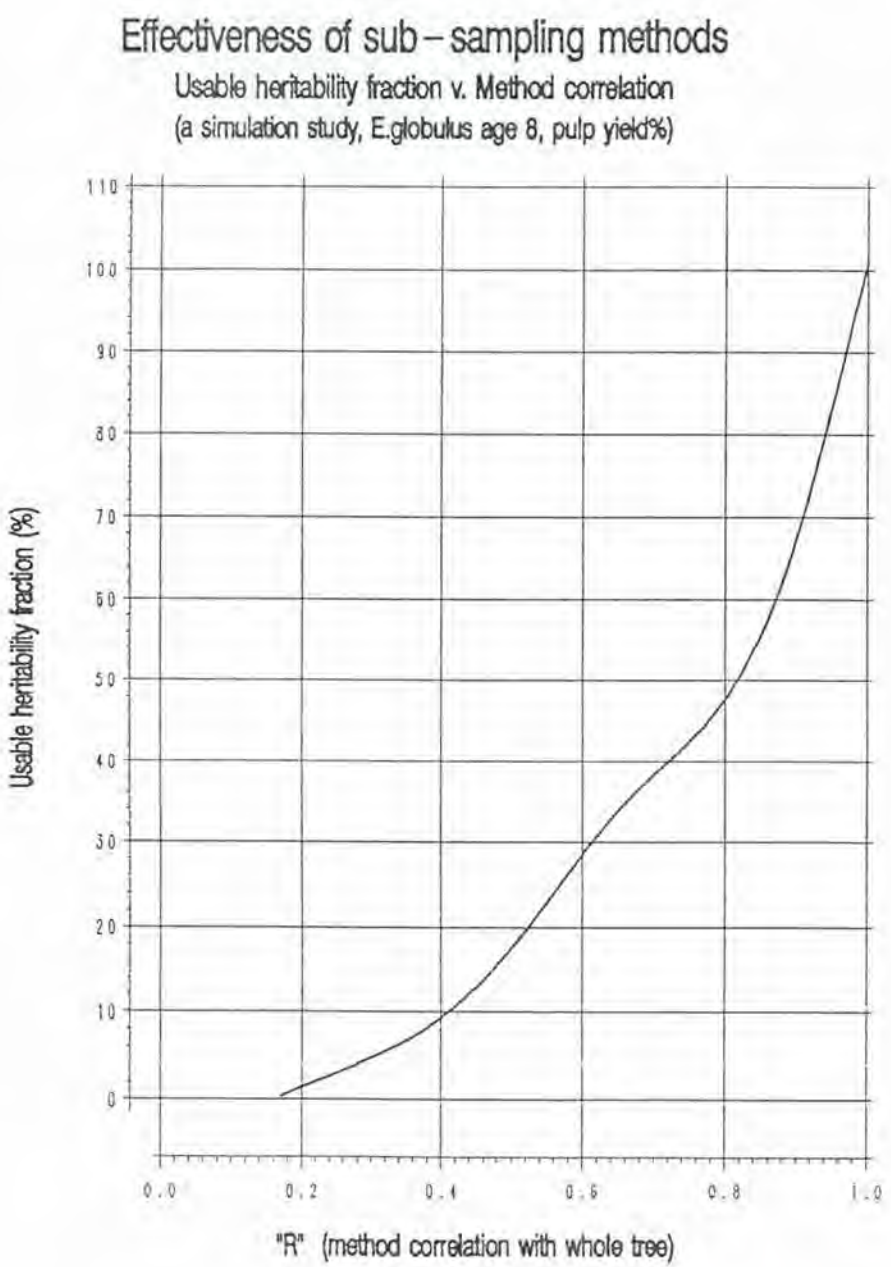
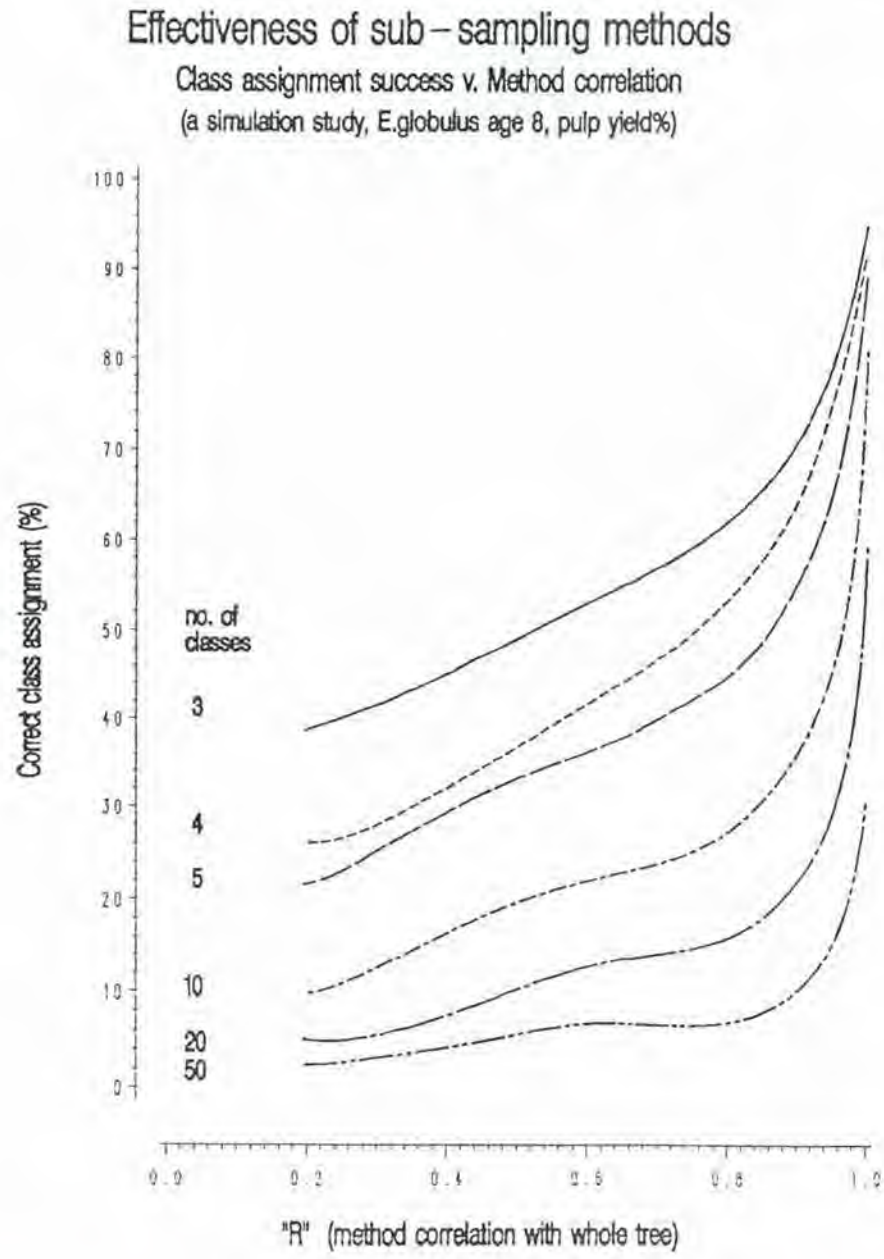


FIGURE 3



THINNING REGROWTH ASH AND ITS EFFECT ON WOOD AND FIBRE YIELDS

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ABSTRACT

Participant's in the Young Eucalypt Program combined their resources to investigate five regimes appropriate to the management of the faster growing, ash-type eucalypts of Tasmania and Victoria One regime was unthinned, the other four were based on different thinning strategies.

Harvesting and debarking technologies to thin the natural regrowth were introduced and studied to establish production costs and damage levels. The response of the stands to thinning was predicted by STANDSIM, a growth model developed for *Eucalyptus regnans*. The ammount of usable wood produced by all the thinned regimes was greater than the unthinned; the increase for the most favoured regime was about 60%.

Different sawing and drying technologies for smaller, younger, faster grown sawlogs were explored by a mix of mill studies and simulation techniques, to establish sawmill production costs and the value of sawn products from the different regimes, The effect of damage caused by thinning operations was established. Pulping studies of wood between the ages of 10 and 110+ years established the effect of age on pulpwood values.

The economic analysis indicated that the regime involving early-age spacing followed by the harvesting of thinnings at year 20 and final felling at 50 years was the most profitable. All thinned regimes were more profitable than the unthinned regime at a real interest rate of 4%.

It is conservatively estimated that there are at least 100 000 ha of highly productive forest in both Tasmania and Victoria and about 300 000 ha of moderate to highly productive forest in all States that could be thinned.

INTRODUCTION

The thinning of eucalypts to increase productivity is not a new idea - what is new is the coincidence of an increasing demand for hardwood pulp and the availability of technologies that enable us to harvest small trees without damaging the forest.

The Young Eucalypt Program pooled resources with the forest services and industries of Tasmania and Victoria and CSIRO's Division of Forest Research, to establish the technical and economic implications of thinning the faster-growing ash-type regrowth forest common to the two States. Major projects included:

* The introduction and evaluation of spacing and thinning technologies
* Predicting growth response to thinning
* The extent and implication of damage caused during thinning
* The development of debarking techniques for fibrous barked thinnings
* Sawing and drying regrowth and sawn timber values
* Pulpwood values
* Area's of regrowth suitable for thinning
* An economic analysis of the costs and benefits of the alternative management regimes

The regimes chosen to compare the different strategies are outlined in table 1.

Table 1. Regime Features - Years of forest operations

Regime	1	2	3	4	5
T1		25	15	5	5
T2			30	20	20
CF	80	65	60	50	80

Note: T1 refers to first spacing/thinning, T2 to second thinning and CF to clearfall

The different regimes involve different thinning technologies and produce products in different volumes of different qualities at different times.

NEW TECHNOLOGIES - BRIEFLY

The spacing, thinning and debarking of stands at an early age required the introduction of technologies not previously used in native forests. Similarly the sawing and drying of regrowth has required alternative solutions to those used for mature wood.

Spacing and Thinning

Maximum advantage in terms of both wood production (Table 2) and financial return (Table 6.) was obtained from the early-age spacing (non-commercial thinning), in spite of the treatment costs. The harvesting of thinnings by both shortwood and tree length systems, was effective at about 20 years of age. Damage to retained trees by both systems was less than 15% although it is anticipated that damage and the visual impact of the operation will be less for the shortwood system. Thinning costs on truck were extremely sensitive to tree size, ranging from $20 per tonne with a mean-stem value of 0.36m^3 to $27 with a mean-stem value of 0.14m^3 [1]. All operations, however, were conducted at a cost that was matched by income from wood sales.

Debarking:

There has been much development in the debarking of small diameter eucalypts both in the forest and at the mill [2]. The commercialisation of the experimental machine developed by CSIRO as part of the Program, is now being pursued. This device appears capable of removing all bark under all conditions. At least two different makes of grapple-harvester and the "crab-grab" type loaders have been adapted to remove most of the bark, most of the time. The trough debarker installed by TPFH Pty Ltd at their Triabunna mill in Tasmania is another solution that, while not fully developed, is successfully debarking thinnings and significantly, the more crooked crownwood from older trees. We have concluded that the removal of fibrous bark from small diameter thinnings is no longer the constraint it was perceived to be at the beginning of the project. Steady and sustained improvement of machines and better organisation should see costs reduced and debarking quality improved. Some clarification of debarking standards required by pulpmills and of the potential value of bark to both the grower and the mill, is also required before it is clear as to the which will be the preferred solutions. It is most likely that a range of solutions will be needed.

Sawing and drying:

Thinning can reduce the time taken to produce a sawlog from about 80 to 50 years and substantial economies accrue from this shorter rotation. However, the younger, faster grown wood has characteristics that influences both sawing and drying processes. The work on Sawn Products strongly supports the need for backsawing techniques and more precise control of drying schedules must be used for younger, faster grown sawlogs.

The successful expansion of both thinning and sawmilling operations based on regrowth is dependent on the introduction of new technologies. By-and-large the equipment is available but it is not currently in use by industry and the skills required for both their operation and management remain a limiting factor.

WOOD AND FIBRE YIELDS

The different management regimes will produce different amounts of wood and wood of different characteristics. The following examines the extent of those differences and attributes values to them.

Wood Volume:

The Thinning Response and Growth Modelling work predicts how thinning might decrease the time taken to produce a merchantable tree and increase the volume of usable wood grown per hectare per year [3].

Table 2. Regime Features - Mean Annual Increments (MAIs) (m3/ha/year)

Regime	1	2	3	4	5
Rotation (years)	80	65	60	50	80
Sawlog	5.7	6.5	6.0	8.5	9.6
Pulplog	6.0	7.6	6.5	9.7	6.5
Total	11.7	14.0	12.5	18.2	16.0

Wood Value - Pupwood:

Kraft pulping, bleaching and papermaking tests conducted on wood of different ages [4]. Wood density and pulp yield per unit dry weight of wood largely determine pulpwood values. These measures are illustrated for the different regimes in Table 3. The value of pulpwood increases until 40 year, plateaus and then falls. The value of the regrowth pulpwood at clearfall is substantially higher than that from the mixed age, mixed species forests we are currently harvesting. Thinnings harvested at 20 years of age were of lesser value of kraft pulp than thinnings from stands of more than 30 years of age. This younger, lower density wood will have a higher value than the older wood for thermo-mechanical pulping processes.

Table 3. Regime Features - Pulpwood density and yield
(kg/m3 & kg pulp/tonne dry wood)

Regime	1	2	3	4	5	Ref[a].
Rotation (years)	80	65	60	50	80	
Density						
T1		460				
T2			482	460	460	
CF	522	521	522	519	520	530
Yield*						
T1		563				
T2			568	563	563	
CF	557	564	564	567	560	450

* unbleached pulp

[a] mixed age, mixed species eucalypt woodchips from Tasmania.

It can be seen that there are very small differences between the densities or yields of the different regimes but bigger differences are apparent between the densities of thinnings and clearfelled wood. Variations in pulpwood quality (as determined by density and yield) between regimes are not important determinants of relative profitability. On the other hand, the high values of pulp yield at clearfall in all regimes when compared with mixed age, mixed species pulpwood are very important in determining that all regimes are profitable.

Wood Value - Sawn timber:

The age and intensity of thinning can substantially influence the value of sawn product recovered. The younger wood has characteristics that are markedly different from the old growth wood. Heavy early thinning can be expected to reduce wood value due to increased knot size and frequency. Damage caused during thinning operations can increase internal decay. For these reasons the early spacing and thinning regimes proposed have been relatively light or postponed until the green canopy is high enough to provide a clear butt log.

Table 4. Regime Features - Loss of sawlog due to thinning damage (m3/ha at harvest)

Regime	1	2	3	4	5
Rotation (years)	80	65	60	50	80
Harvested sawlog	457	421	357	426	764
Thinning loss	0	21	15	12	28
Percent loss	0	5	4	3	4

Experimental work has led us to conclude that damage can be considerable at the start of trials but that it can be reduced as techniques are developed. Training and vigilance will be needed to keep damage to a minimum and it is likely that bonus and penalty payments will be part of any commercial system, these items have not been included in this analysis.

The level of damage that occurred during thinning operations and the rate of expansion of discoloration and decay is described and analysed [5]. The results indicate that damage could be restricted to 15% of the crop trees and that at this level, economic losses were less than the gains accruing from the more rapid growth.

Table 5 presents the sawn wood values and costs incorporating the losses due to thinning damage. Backsawing techniques and the amended grading strategies were used in determining these values [6].

Table 5. Regime Features - Sawmill values and costs ($/m3)

Regime	1	2	3	4	5
Rotation	80	65	60	50	80
Average Sales Price	314	320	315	315	310
Sawing Cost	152	162	157	154	142

ECONOMIC ANALYSIS

The primary purpose of the economic analysis has been to provide consistency between the results of different research areas and to search for new insights for research and development. The experimental results were used in calculations of the net present values (NPV's) of the five management regimes (7). This comparative analysis of stands is limited and land managers must usually consider many more factors outside those considered here in their decisions about management. Issues such as the availability of funds and the local market for wood are two such issues. Never-the-less this type of analysis is influential in setting policies and practice.

Values for pulplogs and sawlogs have been calculated from the economics of processing, not from current royalties and reflect the forecast quality of those logs. They represent a surplus that processors could afford to pay for logs after meeting costs and including a return on their capital.

Pulpwood from regrowth thinnings and clearfelled logs were compared with pulpwood from mixed age, mixed species logs valued at $40 per cubic metre delivered and debarked. They were compared assuming that the logs were pulped using the kraft process in a mill which was limited by the amount of pulp it could sell, the annual volume of wood it could pass through its digesters or the amount of black liquor it could burn. Under the digester limited assumption (the intermediate value thinnings were worth about $40 per cubic metre and clearfellings were worth $72 per cubic meter). The value of thinnings for pulpwood exceeded the cost of thinning in all cases analysed.

Sawlogs were valued assuming that they were either quarter-sawn or back-sawn for either appearance or engineering products. If a log was calculated to be of more value as pulplog than as sawlog then it was allocated to pulplog. When quarter-sawing for appearance grade products was assumed, only 5% of the clearfall yield was allocated to sawlog in Regimes 1 through 4. This figure increased to 15% for Regime 5. When backsawing for either engineering grade or appearance grade was assumed, approximately 50% of the clearfall yield was calculated to be of more value as sawlog than as pulplog. Given professed sawlog-driven strategies in both Victoria and Tasmania and 80 year unthinned rotations the success of backsawing seems essential. Backsawing for appearance grade products were only slightly more profitable than backsawing for engineering grade products. Nett present value (NPV) calculations have been based on backsawing for engineering grade products.

Table 6. NPV for an infinite number of rotations.
Interest rate 4%

Regime	1	2	3	4	5
Rotation (yrs)	80	65	60	50	80
$000/ha	1.8	2.7	3.2	5.8	1.8

At a real interest rate of 4% per annum, the Regime which is thinned to waste at age 5, thinned for pulpwood at age 20 and clearfelled at age 50 has a NPV of $5800 per hectare. This compares with $1800 per hectare for the NPV of an unthinned 80 year rotation. Other Regimes have NPV's which are intermediate between these values.

The ranking of regimes is insensitive to reasonable changes in key parameters chosen from the projects of the the Young Eucalypt Program. A major reason for this insensitivity is thought to be the forecast that thinning results in very similar stands at 50 and 80 years in terms of both volumes and quality to logs. Shortening the rotation by 30 years is a major economic gain.

The YEP estimated that there are approximately 100 000 hectares of highly productive regrowth forests suitable for thinning in Victoria and Tasmania. A

program of thinning (possibly 3000 hectares per annum) could be significant in terms of wood supply without being disruptive to existing markets. The existing "thinnable" regrowth forest could maintain such a program for 30 years.

APPLYING THE RESULTS

Scaling-up

It is important that the task of making the transition from a limited scale operation to routine industrial operations is not under-estimated. In the former, equipment and sites have been carefully selected, and implementation and supervision has been in the hands of a core of people committed to making the system work. In a routine industrial forestry operation the required skills and motivation may need to be developed and some conflict of interest between the forest owner, logging contractors and users of wood can be anticipated and must be addressed. It is essential that the planning, briefing, training, monitoring and systems development effort described in the final report of the Program, is implemented.

Further Research

Scaling-up activities provide an opportunity to address a number of research issues not addressed by the Young Eucalypt Program. Some of these are outside the scope of the original research in areas such as environmental studies, fire and water catchment while others are more directly related to the thinning activity. The relatively small areas that were thinned and the short time period of the program precluded sensible studies of many of these areas.

CONCLUSIONS

Thinning ash regrowth can substantially increase sawn wood and fibre yields. Pulpwood values for kraft pulping are at a maximum between 40 and 80 years and are much higher than those for the mixed age, mixed species wood currently being exported.

It has been shown that sawn product yields from thinned stands are at least as profitable as for unthinned stands but that new sawing and drying technologies, reconsideration of grading strategies and some market development will be

essential to the successful sawing of any regrowth material - thinned or unthinned.

Maximum wood yields and NPV's were obtained from the regimes spaced at an early age but all thinned regimes grew more usable wood and were more profitable than the unthinned regime at 4% real interest.

Certain requirements must be met in terms of terrain, stand access and stocking if the thinning strategies are to be effective. It is estimated that there is at least 100 000 hectares of young, fast-growing ash-type regrowth in Tasmania and Victoria that meet those requirements.

An effort is being made to ensure that the momentum built up by the YOung Eucalypt Program is continued and that the scaling-up which has already commenced in both States, proceeds successfully.

REFERENCES

(1) Roberts, E.R. and McCormack,R.J. (1991) Thinning technologies. In "The Young Eucalypts" , eds Kerruish and Rawlins, CSIRO Melbourne, (in press).

(2) Wingate-Hill, R. and MacArthur, I.J. (1991) Debarking small diameter eucalypts. In "The Young Eucalypts", eds Kerruish and Rawlins, CSIRO Melbourne, (in press).

(3) West, P. (1991) Thinning response and growth modelling. In "The Young Eucalypts", eds Kerruish and Rawlins, CSIRO Melbourne, (in press).

(4) Clark, N.B. (1991) Pulpwood quality and value. In "The Young Eucalypts" eds Kerruish and Rawlins, CSIRO Melbourne, (in press).

(5) White, D.A. and Kile, G.A. (1991) Thinning damage and defect. In "The Young Eucalypts" eds Kerruish and Rawlins, CSIRO Melbourne, (in press).

(6) Waugh, G.A. and Rosza, A. (1991). Sawn products from regrowth. In "The Young Eucalypts" eds Kerruish and Rawlins, CSIRO Melbourne, (in press).

(7) Rawlins, W.H.M. (1991) Economic considerations. In "The Young Eucalypts" eds Kerruish and Rawlins, CSIRO Melbourne, (in press).

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