# 20th FOREST PRODUCTS RESEARCH CONFERENCE

**16.–20. NOVEMBER 1981**

**HELD AT**

## CSIRO

**DIVISION OF CHEMICAL TECHNOLOGY**
**SOUTH MELBOURNE, VICTORIA,**
**Australia**

**VOLUME 1**

**WOOD QUALITY-DRYING-CONVERSION-ADHESIVES-ENGINEERING**

8
F.O.R

E. 14:-

p. 6 - under table, '$FP_A$' - "F17+" to "F17".
p. 7 - Table 6, Heading - add "of" after "Breakage".

E. 15:-

p. 3 - para 3, line 7 - "1%" to "10%".
p. 4 - para 1, line 1 - "stress-graded" to "stress-grade".
p. 5 - para 2, line 1 - "Sturctural" to "Structural".

T. 4:-

p. 4 - FIGURE 1 - "(38)" to "(27)".
p. 7 - para 3, line 3 - "Fogires" to "Figures".
p. 7, para 4, line 2 - "fibre" to "fibres".
p.10, para 1, line 6 - add ",38" after "28".
p.10, para 2, line 4 - add ",38" after "27".
pp. 21 & 22 - check for clarity of printing - spare copies available at desk.
p. 26 - para 3, last line - "thicker" to "thinner".
p. 27 - Ref. 1. - Delete "Appita ..... 128" and substitute "Trans. Formation and Structure of Paper" Symp.: 537-572 - Tech. Sect. Br. Ppr. and Bd. Mfrs. Assn., London.
p.29 - Ref. 27 - page nos. should be "95-110".
p.29 - Ref. 34 - Alter title and source to "The effect of pulping upon the dimensions of wood tracheids. Wood and Fiber 7(3): 226-233".
p.30 - Ref. 39 - Delete "the" before "changes".

==========

*Corrigenda*

Please note the following corrections to papers W.Q. 9, 10, 11, E. 14, 15 and T. 4:-

W.Q. 9:-

p. 3, para 2, line 7 - "A 12-joule" to "An 18-joule".
p. 3, para 3, line 2 - "an" to "and".
p. 7, Table 6, line 2 - add symbol '+' after Beerburrum.
p. 7, Table 6, footnote '+' - add "(see Table 7)" after "instrument".
p. 7, Table 6, under last line - add "+ - pooled across site qualities".
p. 8, Table 7 - insert extra headings "6-joule Pilodyn" above columns 5 & 6 and "18-joule Pilodyn" above columns 7 & 8.
p. 9, Figure 1 - add "quality" after L. 'Low' site, A. 'Average' site and H. 'High' site.
p.10, Para 1, line 3 - "one" to "an".
p.10, third bottom line, "curve linear" to "curvilinear".
p.11, para 3, line 4 - delete "indicated".
p.12, References, 1/, line 2 - "diun" to "d'un".

W.Q. 10:-

p. 2, para 4, line 4 - "$26^{o}28'$" to "$11^{o}30'$".
p. 3, inset - after Melville Isd. - insert "(Lat. $11^{o}30'$, El. $100^{m}$.)".
p. 6, line 2 - add "and Caribbean Pine on Melville Island" after Queensland.
p. 8, bottom line - add "and Caribbean Pine on Melville Island".
p.10, para 2, 3rd last line - add "within" between "20-tree" and "plot".
p.11, Conclusion 5., line 2 - insert "really" between "only" and "beyond".

W.Q. 11:-

p. 3, last para, 1st line - insert "a" in front of "diametral".
p. 4, para 3, line 1 - "pairs" to "sets".
p. 8, para 1, line 3 - "no" to "not really".
p. 8, References, 4., line 2 - change "Malayan" to "Malaysian".

P.T.O. (page 2)

D-06478-S

CSIRO Library Network System
3 9009 00698989 7

| PAPERS | TOPIC NO. |
|---|---|
| A Stability Test for High Temperature Dried Pine. A.N. Rozsa. | WQ1 |
| Some Observations on the Relationship Between Basic Features and the Performance of High Temperature Dried Radiata Pine. W.E. Hillis and A.N. Rozsa | WQ2 |
| Wood Identification by Microcomputer. J. Ilic. | WQ3 |
| Relationship of Anatomical Features and Wood Properties of Eucalypts. W.E. Hillis and J. Ilic. | WQ4 |
| Characteristics of Radiata Bark Extracts in Relation to its Use for Wood Adhesives. Y. Yazaki. | WQ5 |
| Growth Stress in Eucalypts. W.E. Hillis, S.C. Chafe and J.CH. Ferrand. | WQ6 |
| Wood Quality Research in New South Wales. R.K. Bamber. | WQ7 |
| Rqpid Field Estimation of Wood Density Using the "Pilodyn". W.J. Smith, P.J. Allen and D.B. Eccles. | WQ9 |
| A Survey of Wood Density Variation in Queensland Plantation Softwoods. W.J. Smith, D.B. Eccles and P. Allen. | WQ10 |
| Comparative Wood Quality Evaluation of "Foxtail" and "Normal" Trees in *Pinus caribaea* var. *hondurensis*. W.J. Smith and D.B. Eccles. | WQ11 |
| Distortion in Dried Heart-in Studs - With and Without Presteaming. R.L. Northway and F.J. Christensen. | D1 |
| Restraint Forces Needed to Hold Radiata Pine Heart-in Studs Straight During High Temperature Drying. R. Northway. | D2 |
| Psychrometry in High Temperature Kiln Drying - Minimising Wet Bulb Temperature Errors. R. Northway. | D3 |
| Drying and Stress Grade of Studs from Young Radiata Pine. F.J. Christensen and R.L. Northway. | D4 |
| Determining End-Point for Softwoods Dried at High Temperature. F.J. Christensen. | D6 |

CSIRO RECEIVED 7 FEB 1982 LIBRARY DIVISION OF FOREST RESEARCH

| | |
|---|---|
| Effects of Drying Temperatures on Movement and Moisture Content of *Pinus radiata* Boards. K.W. Fricke. | D7 |
| Design Proposals for a Low Cost Prototype of the CSIRO Continuous Feed Kiln. R.L. Northway and F.J. Christensen. | D8 |
| Continuously Varying Schedule - A New Process for Timber Drying. N.M. Nassif. | D9 |
| Moisture Content Variations in Kiln Dried Radiata Pine. J. Hartley and P. Lind. | D10 |
| A Method of Comparing Drying Rates During Experimental Kiln Drying of *Pinus radiata*. J. Hartley. | D11 |
| The Application of an Orthotropic Fickian Diffusion Model to Timber Drying. R.D. Schaffner and P.E. Doe. | D12 |
| Further Development and Use of Solar Kilns in Queensland. D.K. Gough and D.G. Hiley. | D13 |
| Design and Construction of a Laboratory Experimental Kiln. S. Panow. | D14 |
| A System for Monitoring Power Consumption. E.P. Lhuede, T.J. Stevens and P. Grusovin. | C1 |
| Dimensions of Sawn Scantling. E.P. Lhuede. | C2 |
| Another Look at Sawdust-Concrete. E. McArthur. | C3 |
| Derivation of a Relationship Between Veneer Yield and Raw Material Variables. B. McCombe. | C4 |
| Veneer Yield from *Pinus radiata*. B. McCombe, A. McNaught and D. Atkins. | C5 |
| New Product from *P. radiata* and Eucalypt Wastes. A.Krilov | C7 |
| Grade Yields for Scantling Timber Sawn from Radiata Pine Trees Sampled from Stands of Various Ages and Site Qualities. D.J. Grant and K. Groves. | C8 |
| A Fluidized Bed Carbonizer-Boiler Pilot Plant. P.Y.H. Fung | C9 |

| | |
|---|---|
| A Study of Woodchip Carbonization in a Fluidized Bed. P.Y.H. Fung and B. Singh. | C10 |
| Wood Charcoal as a Filler for Rubber. P.Y.H. Fung and Z.T. Nowak. | C11 |
| Some Physical Properties of Fluidized Bed Charcoal. P.Y.H. Fung, T. Brown and D.N. Crook. | C12 |
| Peat Moss Alternatives from Pine Residues. H. Mamers and D.J. Menz. | C13 |
| Resource Evaluation by Sawmill Studies of Queensland-Grown Exotic Pines. D.K. Gough and D.G. Hiley. | C14 |
| The Effect of Sulphite Treatment on Viscosity, on Gelation and Bond Quality of *Pinus radiata* Bark Extract. K.F. Plomley and P.J. Collins. | A1 |
| Cold Setting Adhesives Based on Mixtures of Wattle Tannin with a Commercial Phenol-Resorcinol-Formaldehyde Adhesive. K.F. Plomley and P.J. Collins. | A2 |
| Response of Melamine-Bonded Particleboard Flooring to Humidity Cycling. G.N. Christensen. | A3 |
| Crack Propagation and the Durability of Glue-Lines. G.N. Christensen and E.R. Pankevicius. | A4 |
| Steel to Wood Bonding for Structural Joints. H.F.A. Hergt and G.N. Christensen. | A5 |
| Exposure Trials on Finger-Jointed Radiata Pine Studs Bonded with Modified Casein Glues. H.F.A. Hergt. | A6 |
| Glue-Line Temperature - Its Effect on Setting Time and Bond Quality of Resorcinol Type Adhesives. P.J. Collins. | A7 |
| Hygroscopic Movements in Radiata Pine Structural Plywood. E.R. Pankevicius and M. Spicer. | A8 |
| The Development of Pre-Press Adhesion in Glued Veneer Assemblies. E.R. Pankevicius. | A9 |
| Laboratory Assessment of Potential Preservatives for Short-Term Portection of Exposed Casein-Glued Joint. J.D. Thornton and H.F.A. Hergt. | A10 |

| | |
|---|---|
| Damage Due to Proof Loading. R.H. Leicester, H.O. Breitinger and R. McNamara. | E1 |
| Strength of Slender Plywood Webs in Shear. L. Pham and R.H. Leicester. | E2 |
| Models for Evaluating Stress Grading. R.H. Leicester and B.T. Hawkins. | E3 |
| Duration of Loading Effect on Structural Timber. H.O. Breitinger. | E4 |
| Timber Piles for Houses on Expansive Clays. P.F. Walsh and D.A. Cameron. | E5 |
| Effect of Specimen Size on Test Results from Standard Clear Timber Specimens. P.U.A. Grossman and P.J. Pahl. | E6 |
| Mechanical Grading of 1926 Regrowth Mountain Ash. A. Anton and A.A. Garbellini. | E7 |
| Grading Timber for Strength. A. Anton. | E8 |
| The Strength and Stiffness of Visually and Mechanically Graded Radiata Pine with Cross-Sections of 35 mm x 150 mm and 35 mm x 200 mm. D.J. Grant. | E9 |
| Method for Derivation of Correction Factors for Strengths with Reference to Moisture Content. M. Ghali. | E10 |
| In-Grade Tension Tests on 90 mm x 35 mm Radiata Pine (F8), to Establish the Relationship Between Tensile and Bending Strength. A. Anton and P. Chapman. | E11 |
| Exploratory Study into the Gluability of Six Hardwood Timber Species of New South Wales. M. Ghali. | E12 |
| Engineering Aspects in Utilisation of Shining Gum Trees Infested by Ambrosia Beetles. M.B. Ghali and D.T. d'Espaignet. | E13 |
| Proof Grading - Developments in Queensland. C. MacKenzie, G.R. Siemon and W.J. Smith. | E14 |

Stress Grade Clarification and Test Standardization, with Special Reference to Stiffness. S. Panow and W.J. Smith. E15

A Simplified Timber Design Code. P.U.A. Grossman. E17

Influence of Atmospheric Changes on Tooth Plate Connector Joints. E.P. Lhuede and P.U.A. Grossman. E18

# A STABILITY TEST FOR HIGH TEMPERATURE DRIED PINE

A.N. ROZSA
Forest Products Laboratory
Division of Building Research, CSIRO

ABSTRACT

The moisture uptake of dried radiata pine wood was found to be an important indicator of the stability of stud material in service. The proposition is expressed that this may be a simple quality control test aimed at assessing the effetiveness of drying procedures.

## 1. INTRODUCTION

Radiata pine has seen a growing acceptance in the Australian timber industry in recent years. This is due to its increasing availability, cost competitiveness, and rigid quality control standards. In the past much of the material from young trees of radiata pine and that close to the pith in older trees has been considered unsuitable for structural use and has been relegated to low grade applications or pulping. The increasing demand for the most effective use of forest resources and the advent of high temperature drying techniques, has enabled this juvenile material to be converted into structural stud lengths meeting relevant standards.

The Australian practice is to dry heart - in radiata pine structural material at high temperatures, (116-160°C) (RPAA 1979) under considerable restraint with an initial plasticisation period and a final steam reconditioning, with the aim of initially softening the timber and then whilst drying, "set" it in a straight condition.

CSIRO
RECEIVED
9 FEB 1982
LIBRARY
DIVISION OF FOREST RESEARCH

Recent work in this laboratory has shown that when green wood is heated, certain physical and chemical changes take place which permanently alter the behaviour of the wood after it has dried (Hillis 1975, Hillis & Rozsa 1978). This line of research led to the possibility of predicting the stability of dried wood in service. Green radiata pine sticks (5 x 5 x 250 mm) were subjected to various drying regimes, their rigidity distortion was measured with a torsional load, followed by soaking in water for one minute. The samples were then reloaded and the decrease in torsional resistance measured. Relationships were found between the decrease in torsional resistance, drying conditions, the age of the specimen and its origin (Hillis and Rozsa in preparation). It was postulated that the tendency of the wood to soften when it absorbs moisture was an indication of the stability of that sample in service. Whilst this method appeared to have a high degree of reliability, there was no estimate of its validity and it was too laborious to be a practical field test. There was found to be a high correlation ($r_p$ 0.830) between the increase in distortion on rewetting, and the weight of water absorbed (hygroscopicity). Measuring the amount of water uptake was considered a more practical measure of stability in a sawmill situation and that the degree of relaxation or instability, which will occur in a stud is the result of many factors. If stability were to be co-related with hygroscopicity a relatively simple test could be devised as a routine quality control assessment to predict the stability of the product in use.

The aim of the following study was to establish a means of measuring the water absorption of a representative sample of heart-in stud material which had been subjected to weathering tests and establish a relationship to stability in terms of twist, spring and bow.

## EXPERIMENTAL

Representative sample studs were taken from four drying treatments. Each sample consisted of 10,090 x 35 mm studs evenly spread through at least one truck of a kiln load of heart-in radiata pine structural material (i.e. within 50 mm of the core).

The four drying schedules were as follows:-

TABLE 1

Drying Schedules

| Sample | Stack dimensions (L x W x H) m | Stack restraint | Plasticisation period | Max. dry bulb temp. | Min. wet bulb temp. | Final steaming period | Average moisture content % | Time in kiln |
|---|---|---|---|---|---|---|---|---|
| 1-100S | 2.48 x 1.68 x 2.34 | 1319 kg/m$^2$ | 4 h | 127$^o$C | 82$^o$C | 3.75 h | 14.8 | 15 h |
| 101-200W | 4.9 x 1.68 x 2.34 | 650 kg/m$^2$ | 0 | 127$^o$C | 95$^o$C | 4 h | 10.9 | 12 h |
| 201-300W | 4.9 x 1.68 x 2.34 | 650 kg/m$^2$ | 2 h | 127$^o$C | 95$^o$C | 4 h | 9.8 | 16 h |
| 301-400S | 2.78 x 1.68 x 2.34 | 1178 kg/m$^2$ | 6 h | 135$^o$C | 71$^o$C | 6 h | 7.4 | 21 h |

After cooling, the stack restraints were removed, and the boards planer gauged. The 100 samples from each drying treatment were taken after machining such that:-

(i) All showed pith on one face.

(ii) They were spread evenly through a truck load.

(iii) All were visually graded to meet the RPAA standard except that the twist limit was reduced to 6° over 2.4 m (or its equivalent).

A 400 mm long piece was cut from one end of the selected 2.4 m studs, wrapped and retained for the moisture absorption tests. The remaining 2 m length was measured for moisture content (with a needle type electrical resistance moisture meter) and distortion (in terms of bow, twist and spring). The samples were then hung from one end in an exposed test site.

At intervals of 10, 20 and 40 days the specimens were taken down and remeasured. If, after each measurement period, rainfall had been less than 10 mm for the previous 10 days the studs were hosed for 5 minutes on being rehung.

The 400 mm off-cuts from each stud were returned to the laboratory, and using a sharp saw with a planing blade each end was cleanly cut to leave a length of 300 mm. They were then sawn down the centre of the wide face. These pairs of specimens from each stud were weighed (+ 0.01 g) and held under the surface of clean waer (18-20°C) for 5

minutes. The excess water was then wiped off and the samples again weighed. The samples were then dried in an oven (105°C) and reweighed so that moisture contents could be expressed on an oven dry basis.

RESULTS

The major aim of the experiment was to seek a correlation between the water absorption of dried boards and the "after drying distortion" of those boards when exposed to the weather. It was found that movement in terms of bow and spring were minor so that twist was used as the major measure of distortion after 40 days (see Table 2, Fig. 1). It was noted that the mean direction of twist was towards a greater degree of twist distortion for samples 1 to 300. Samples 301 to 400 tended to decrease their degree of twist distortion over the period of 40 days (see Table 2). The number of studs which would have been rejected as not grading for twist at the end of 40 days is shown in Table 3.

The sections of studs used in the hygroscopicity tests were short and had a relatively high ratio of end grain to longitudinal surfaces despite the samples being sawn through the middle. It was found, however, that samples which were not end coated before dipping ranked in high correlation ($r_s$ 0.88) with the same samples which were redried at low temperature end coated and redipped. Similarly machining 2 mm from the longitudinal surfaces of the studs did not change their hygroscopicity indicating that the effect was not due solely to changes of the surface and the heating had some degree of penetration. Tests also showed that as long as a reasonably consistent approach was used, the test conditions (length of time in water, delay, wiping excess water and temperature) were not critical.

DISCUSSION

The test showed a relationship between gross physical properties such as movement and water absorption reflecting possible changes in the chemistry or microstructure of this wood during the drying process.

The overall movement of the sample studs was less than that which may have been

expected considering the various drying treatments used. Although samples 300S-400S which had been dried under RPAA recommended conditions (RPAA 1979) tended to be least stable, this movement was generally in such a direction as to decrease the distortion of the stud. It must be remembered that this test was not a judgement of drying treatments. However, it was interesting to note that the samples which had been poorly dried (IS-100S) in the sense that they came out at the kiln relatively wet, would have had a rejection rate of 23% if graded for twist after 40 days exposure.

Overall the experiment showed that heart-in pine studs when dried to around 10% moisture content or below are stable in service and in fact overdrying may lead to as much movement as underdrying (although in the former the movement tends to be that of "straightening"). The major component of in-service movement is twist. The behaviour of this wood in terms of stability may be predicted by using a relatively inexpensive simple physical test which could be used as a routine quality control procedure.

Before this test can be recommended as a standard procedure some further work is needed to determine the minimum statistical samples required in testing and further samples would need to be assessed to determine the range of variability due to origin, drying treatments and exposure conditions.

ACKNOWLEDGEMENTS

This study was carried out with the co-operation of the Radiata Pine Association of Australia. The RPAA Quality Control Officer, Mr W. Pratt, the Woods and Forests Department, South Australia and Sapfor Timber Mills, Mount Gambier contributed greatly in terms of both time and test materials.

REFERENCES

Hillis, W.E. (1975). The role of wood characteristics in high temperature drying. J. Inst. Wood Science 7(2), November.

Hillis, W.E. and Rozsa, A.N. (1978). The softening temperatures of wood. Holzforschung 32(2), 68-73.

Radiata Pine Association of Australia, Code of practice for the high temperature seasoning under restraint of heart-in radiata pine structural material (RPAA 100-1979).

TABLE 2

Movement relationships

| Sample | Mean increase in moisture content after 5 min % S.D. | Movement after 40 days in exposure test | | | | | | Mean change in moisture content (40 days exposed) % |
|---|---|---|---|---|---|---|---|---|
| | | Twist | | Bow | | Spring | | |
| | | absolute mean (degrees) (a) | mean showing direction (degrees) (b) | absolute mean (mm) | mean showing direction (mm) | absolute mean (mm) | mean showing direction (mm) | |
| 1S-100S | 3.38 (1.28) | 1.73 (1.96) | +1.39 | 1.83 | +0.22 | 0.85 | +0.31 | +3.81 |
| 101W-200W | 2.59 (1.28) | 0.64 (1.10) | +0.09 | 2.33 | -0.94 | 1.74 | -0.30 | +5.05 |
| 201W-300W | 2.91 (1.24) | 0.98 (1.10) | +0.06 | 2.05 | -1.09 | 1.76 | +0.01 | +6.91 |
| 301S-400S | 3.95 (1.31) | 2.31 (1.66) | -1.52 | 2.62 | -2.08 | 0.81 | +0.17 | +10.02 |

(a) Axial movement of dried material at end of test.

(b) Mean measurement of direction of twist, when + represents increase in twist, - represents decrease in twist or effectively straightened.

TABLE 3

Studs which would be rejected on the basis of excessive twist after 40 days weathering

| Sample | Number of studs rejected* |
|---|---|
| 1S-100S | 23 |
| 101W-200W | 3 |
| 201W-300W | 3 |
| 301S-400S | 0 |

* Basis of grading is 8.5 mm ($6^{\circ}$) of twist for a 2.4 m, 90 mm x 35 mm stud, which is half that allowed in the grading rules AS1490-1973.

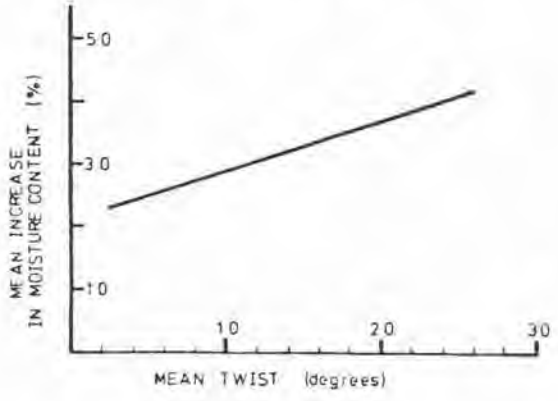



FIG. 1

Water absorption of sample stud ends and twist of exposed studs

# SOME OBSERVATIONS ON THE RELATIONSHIP BETWEEN BASIC FEATURES AND THE PERFORMANCE OF HIGH TEMPERATURE DRIED RADIATA PINE

W.E. HILLIS and A.N. ROZSA
Division of Building Research, CSIRO

ABSTRACT

Hemicelluloses play an important role in the flexibility of green wood during high temperature drying and in the ultimate stability of dried wood. Attention is drawn to the similarity of procedures and results between press-dried paper and high temperature dried wood.

## INTRODUCTION

The work on the behaviour of Radiata pine of different ages under different drying conditions and previously reported at the 19th Forest Products Research Conference has been confirmed and prepared for publication. Work involving similar principles and relationships has been underway with the Madison development of press-dried paper (1). This procedure increases the utility and strength of high-yield hardwood pulp by overcoming fibre bonding deficiencies of conventional papermaking and producing a much more dimensionally stable paper. The standard procedure involves drying at 200°C for 30 seconds under 2.7 MPa (400 lbs/in$^2$).

## CONCLUSIONS

Some of the conclusions drawn from our studies on radiata pine are:

1. The lower (about 78°C) of the two softening points of radiata pine is due to hemicelluloses. The softening temperature is lowered by presteaming or preheating. The relevant peak or point in the softening curve is removed or

weakened with dilute acetic acid and is poorly defined in young (less than 6 yr) wood.

2. The softening changes depend on a temperature-time-moisture relationship interacting with the chemical composition of the matrix.

3. Change or reduction in hemicelluloses plays a key role in the strength and stability of high temperature dried wood and press-dried paper. The improved strength and stiffness properties of press-dried paper sheets are apparently directly related to the hemicellulose content and their location (1). It is important in this process that the peak temperatures are reached very quickly to allow the interaction of water and hemicelluloses to take place over the longest period of time available. This facilitates flow of the hemicelluloses on the fibre surface and their softening in the cell wall to promote fibre flexibility. Preheating green wood at temperatures above 100°C for a short period before drying would be expected to have a similar effect to presteaming for a longer period, provided there is adequate time to allow softening of the interior of the studs to take place.

4. Evidence indicates the moisture content should be above 40% to enable most improvement in adhesion of the fibre mat of paper and the flow of hemicelluloses when pressure is applied. Most of the bonding occurs if total restraint is applied over the range 40 to 20% moisture content (based on initial wet weight; (1). The softening point of hemicelluloses in solid wood is no longer evident below the fibre-saturation point.

5. Increase in stability is achieved by heating either wet wood or dry wood for limited periods above 100°C. In the latter case the physical changes lower the accessibility of hydroxyl groups in hemicelluloses to water ("hornification") with resultant decrease in swelling.

6. Lower stabilities were found in dried wood of a young age than from wood of 10 or more years of age. Stability differed for wood from different plantations. Extended heating of dried wood reduced these effects. It is noteworthy that Zobel et al. (2) found higher amounts of hemicelluloses in young than in old wood. Presumably because of higher hemicellulose content, longer heating is

required for "hornification" and resistance to swelling, and thus increased stability.

REFERENCES

(1) Setterholm, V.C. and Benson, R.E. 1977. Variables in press drying pulps from sweetgum and red oak. USDA Forest Service Research Paper FPL 295.

(2) Zobel, B.J., Stonecypher, R., Brown,C. and Kellison, R.C. 1966. Variation and inheritance of cellulose in the southern pines. Tappi 49(9), 383-7.

# WOOD IDENTIFICATION BY MICROCOMPUTER

by

J. ILIC
Division of Building Research, CSIRO

## ABSTRACT

The advantages of edge-notched card-sorting keys currently used for timber identification are outlined. The necessity for a microscope-slide and a reference wood collection is noted. To enhance the speed and accuracy of wood identification, the feasibility of using a microprocessor-based system has been tested for data sorting. An interactive programme IDENT was written using BASIC (language). Data and information from a macro-card-sorting key for Fijian timbers consisting of 60 cards was used. Under IDENT numbers corresponding to anatomical features were input resulting in either a correct identification, a situation where input data was insufficient, or a no match situation. Some advantages and disadvantages of using microprocessor systems are presented. The work currently in progress and some ideas for further development are discussed.

## WOOD IDENTIFICATION BY MICROCOMPUTER

Methods of timber identification vary according to the individual. A tradesman, for example, develops his own scheme for timber identification from the general appearance and working qualities of the timber. In the laboratory those familiar with timbers of a certain locality develop the faculty for identification based on general appearance. However, when using such macroscopic features, e.g. checking, growth-ring pattern, colour, density, etc., it is possible to get into difficulties when the possibilities are wider than the local sphere allows. The most accurate method of wood identification is by the comprehensive examination of the characteristic anatomical features

of the timber (1).

To facilitate a systematic approach certain lines of attack must be followed. These must work by a process of elimination.

For these and other reasons, edge-notched card-sorting keys have been developed and are used for rapid and systematic wood identification. In this key system, the possible variations in the physical appearance and anatomical properties are keyed against the edge of a perforated card. The presence of anatomical features and physical characteristics can be indicated by notching the appropriate position. When this is done for a number of taxa, the timbers represented by these cards can easily be sorted out using the appropriate characteristic features.

This type of key has the following advantages over other systems, e.g. Dichotomous keys, tables, etc.:

(i) any characteristic feature may be chosen at any time.

(ii) the key is portable and may be used in the field

(iii) the key may be expanded by adding new cards

(iv) keys may be prepared on different bases, e.g. identification to:

a. macroscopic or microscopic level

b. family, genus or species level

(v) results are obtained relatively quickly.

In addition to card-sorting keys, a microscope-slide and reference wood collection is absolutely essential. These collections are indexed and therefore need careful maintenance. Retrieval of data and specimen for comparative purposes is frequent. Furthermore, a well indexed wood collection is essential for eventual development of new identification keys.

MICROCOMPUTER IDENTIFICATION

The dramatic rise in microprocessor technology has opened up new ways of

computerized data acquisition and wood identification. These developments have lowered cost and increased the speed and storage capacity of microcomputer equipment. Although computer identification of wood and plants is not new (2,3), the interactive use of a large computer complex like CSIRONET is unfavourable because of the high cost to the user. For effective use in wood identification, the system used must be interactive. It must be able to provide a speedy answer to the user soon after he has entered his data. The system must be capable of warning the user if insufficient data has been used. Although this can be done on a large computer system the cost is prohibitive.

To overcome some of these problems and to have a certain amount of independence from a large computer system an attempt was made to test the feasibility of using a microprocessor based system for wood identification. A card sorting key developed for the identification of Fijian timbers was implemented on the CSIRO microprocessor based image processor system used for quantification of wood anatomical features (4). A programme was written in BASIC in two parts: in the first part, both the numerical data corresponding to features, the species names and text were entered as ASCII characters. This data was stored in arrays.

The second part of the programme was written to carry out a semi-interactive sort routine. This routine prints out the number of matching taxa following input of data corresponding to anatomical features of an unknown sample. The maximum number of matches permitted was limited to 4 for any particular input, consequently if more than 4 matches are found the sort routine is terminated and the programme prompts the user returning to the beginning requesting a new set of features. The matching of taxa is carried out by matching taxa reference numbers. When a match is obtained the programme requests the user to indicate if a printout is required.

In its present form the IDENT programme was written for a total of 60 cards each having a maximum of 60 features. The whole system, data, text, programmes and a BASIC INTERPRETER reside in 32K of 8 bit bytes of memory. On average a general set of features can be matched within 35 sec with 55 sec for a "no-match" search.

A print of a simulated identification obtained from the microprocessor system executing the IDENT programme is presented in the appendix. The following cases are shown:

(i) no match

(ii) successful match found together with printout of taxon, data and remarks

(iii) insufficient data for match

(iv) key of features and corresponding feature numbers.

One very important feature of the computer type system is that unlike the card key it is not limited to searching on features alone but also on key words, or groups of words. Consequently, any particular anatomical information may be obtained about a species if only the common name is known. This procedure forms the basis of a simple data base system. The following are advantages of the microcomputer system:

(i) easy addition of other features to enhance the description of taxa

(ii) an interactive programme for instructing inexperienced users

(iii) easy access to text, descriptive and nomenclatural information

(iv) ease of duplication of information in both printed or programme form

(v) facility for easy modification to comply with any special user requirements, e.g. addition of new taxa

(vi) convenience of use, minimization of sorting errors

(vii) relative speed and low cost.

Ultimately, this method of wood identification would seem to be ideal. However, it has the following disadvantages:

(i) has small working memory relative to bigger computer-installations and requires more frequent-mass storage access, e.g. from floppy-disk.

(ii) unlike the card-sorting system, field use is precluded

(iii) because of relatively small working storage, high speed capability of larger machines is not available (more disk accessing required and hence

loss of speed).

The identification programme as presented in this communication is a relatively small one. However, it can be concluded that an effective wood identification data system can be implemented on a microprocessor having at least 32K bytes of working storage and some form of mass storage device with quick random access such as a floppy disk.

## CURRENT WORK AND FUTURE DEVELOPMENTS

As an initial step towards a total interactive identification system, all available anatomical data from existing card sorting keys developed by the Division of Forest Products and ourselves has been punched up on standard computor cards. This data is in an identical format to that of the sorting cards. This anatomical data and text will be transferred from CSIRONET to a series of floppy-disks which can be used in a microprocessor based system.

The total sum of identification data consists of 14 card sorting keys, the largest key being the family sorting system. This key works down to family level offering a number of genera as possibilities, together with considerable text. It is the largest key in terms of information and data occupying about 300K of storage. A microprocessor system using floppy-disks with a storage capacity of 400K bytes has been designed and will be used to handle this large family sorting system and other keys. All the keys in use currently are considerably smaller in size. Unfortunately, each of these keys was designed with a different set of features and a different feature numbering scheme. Clearly some rationalization of these keys is required.

Software for an interactive identification system is currently under development. This will include:

(i) the family-sorting-system

(ii) rationalization of other keys into a single working unit with standardization of features and feature numbering

(iii) identification programmes to run on CSIRONET for other users

(iv) consideration of interfacing a hard disk system capable of storing 10 mega bytes of information

(v) establishment of a data base for a more effective maintenance of the index system for the wood and slide collections.

REFERENCES

(1) Jane, F.W. (1970). The structure of wood, second edition, London, A & C Black, 295.

(2) Morse, L.E. (1974). Computer programmes for specimen identification by construction and description printing using taxonomic data matricies, Mich. State Univ. publ., Biol. Series 5(1), 1-128.

(3) Pankhurst, R.S. (19710. Botanical keys generated by computer. watspmoa. 8, 357-368.

(4) Ilic, J. (1981). Wood structure analysis, Pres. Symp., Microscopical Society of Australia, Sydney.

# RELATIONSHIP OF ANATOMICAL FEATURES AND WOOD PROPERTIES OF EUCALYPTS

W.E. HILLIS and J. ILIC
Division of Building Research, CSIRO

## ABSTRACT

The presence of sufficient thick-walled fibres in the wood of ash-type eucalypts prevents the occurrence of collapse on drying. The relationship is disclosed by the ratio of fibre wall area to lumen area. Samples with ratios having an upper 10 percentile value ($LW_{10}$) less than 5 are collapse prone. The presence of thick walled fibres in the tension wood of other eucalypts leads to abnormal shrinkage. Possible reasons for the different behaviour of thick walled fibres is given.

## Introduction

One of the most significant factors affecting the production of dried wood from eucalypts is degrade caused by collapse and checking. The problem varies according to the species, the provenance of the species, and the position of the wood within the stem. An anatomical study was commenced on samples with varying degrees of collapse (2) and this can be conducted precisely with the aid of a Digital Image Processor (3).

## Cell Wall Thickness and Collapse

After examining various anatomical data, the ratio of fibre wall area to lumen area was studied in detail. The upper 10 percentile ($LW_{10}$)* of wall to lumen ratios were found to be indicative of collapse when the values were below about 5 (2). Earlier work was extended to over 60 samples of ash-type eucalypts (E. regnans, E. delegatensis and E. obliqua) and the relationship confirmed. One sample of E. rubida and one sample of

* The designated value exceeded by one tenth of the determinations.

E. dalrympleana also showed this relationship. It is assumed the thicker walled fibres (i.e. when wall to lumen ratio exceeds 5) in the impervious heartwood can withstand the high surface tension forces associated with collapse during drying above the fibre saturation point.

Presence of Tension Wood

When tension wood with its thick walled fibres and gelatinous layers was present, as in E. rubida (two of three samples) and E. dalrympleana (six samples), collapse was evident even when the limits of $LW_{10}$ values began to exceed 5. One of the five samples of E. globulus examined, which was estimated to have 20% tension wood, had a range of $LW_{10}$ values of 3.6-21.0. This sample collapsed but not to the same extent as the other four samples containing higher proportions of tension wood. Those samples containing tension wood collapse after the moisture content falls below the fibre saturation point (4).

It is apparent from the contrasting behaviour of the two types of thick walled fibres that the formation of a tension wood fibre involves more than the addition of the cellulosic gelatinous layer to a thick walled fibre. The thick, non-gelatinous wall of a tension wood fibre must also differ from that of a normal fibre. The different formation of these two types of thick walled fibres must be initiated at the commencement of differentiation.

Drying Wood from Fast Grown Trees

High volumetric wood shrinkage has been associated with areas of high growth stress in the standing tree (5). These areas were characterised more by tension wood fibres in the severely leaning trees than by normal thick walled fibres although the proportion of the latter increased.

Recently there have been indications that the wood from fast-grown eucalypts can be more readily dried than that from slow grown specimens (1). However, because reaction wood is present more frequently in the young wood in fast-grown, short-rotation trees, than in older, mature wood, some variability in drying behaviour may be expected.

## Conclusions

The proportion and distribution of thick walled fibres appears to control the extent of collapse in ash-type eucalypt species free from reaction wood. Accordingly, segregation of logs or parts of logs with high $LW_{10}$ values from these trees could provide improved raw material for high quality dried wood. In the other eucalypt species examined, exclusion of tension wood by selection of the lower side of the tree would be required to produce high quality material.

## References

(1) Campbell G.S. & Hartley, J. 1978. "Drying and dried wood" in Eucalypts for Wood Production. ed. by W.E. Hillis & A.G. Brown pp. 328-336.

(2) Hillis, W.E., Ilic, J. & Soenardi, P. 1979. The relationship of anatomical characteristics with wood properties. Topic 1/5. 19th For. Prod. Conf.

(3) Ilic, J. & Hillis, W.E. 1981. Video Image Processor for Wood Anatomical Quantification, in preparation.

(4) Kauman, W.G. 1964. Cell collapse in wood. Holz als Roh- und Werkstoff. 22, 183-196; 465-472.

(5) Nicholson, J.E., Hillis, W.E. & Ditchburne, N. 1975. Some trees growth-wood property relationships of eucalypts. Can. J. For. Res. 5, 424-32.

# CHARACTERISTICS OF RADIATA BARK EXTRACTS IN RELATION TO ITS USE FOR WOOD ADHESIVES

Y. YAZAKI
Division of Building Research, CSIRO

## ABSTRACT

Various hot water extracts of bark from Pinus radiata were prepared and their behaviour characterised by ultrafiltration techniques. The filtration rate and yield of the filtrate from bulk bark extracts were always lower than those of outer bark extracts prepared under laboratory conditions. This was mainly due to the extractives from inner bark. Microfiltration efficiently removed the troublesome components from the bulk bark extracts.

## INTRODUCTION

Aqueous extracts from radiata pine bark have considerable potential as bases for wood adhesives. However, there are difficulties in the production of extracts with uniform quality and a suitable viscosity. The most promising method to overcome those difficulties is based on fractionation of the extracts (Yazaki & Hillis 1980) and the processes of ultrafiltration and reverse osmosis can provide bases for wood adhesives with uniform quality (Yazaki, Hillis & Collins 1979).

The industrial feasibility of this method depends largely on filtration rate and yield of the filtrate (filtration efficiency). The efficiency varies according to the source of bark, extraction conditions and filtration systems used. This paper reports characteristics, particularly filtration efficiencies, of radiata bark extracts, which were prepared in different ways.

## EXPERIMENTAL

*Pinus radiata* bark: the bark samples were taken from two 38 year old trees of *P. radiata* at Myrtleford, Victoria. The bark was removed from the butt log of each tree and hogged in a hammer mill.

Bulk extraction: the air-dried bark samples were sieved to remove wood fibres and bark blocks which were larger than 27 mm, and then extracted with hot (> 95°C) water. The hot water solubles were concentrated in a thin film evaporator and then freeze-dried.

Laboratory extraction: outer bark, inner bark and wood chips were taken from the air-dried bulk bark, ground in a Wiley mill with a 4 mm mesh sieve, extracted with hot water and then freeze-dried.

Filtration: the freeze-dried extracts were dissolved in water and the aqueous solutions were filtered at pH 8.0 with either an Amicon stirred cell or an Amicon thin channel filtration system. The retentate and filtrate were freeze-dried and weighed to determine the yields.

## RESULTS AND DISCUSSION

An 84% yield of ultrafiltrate (molecular size less than $10^6$ m.w. Dextran) was obtained from the outer bark extracts prepared by laboratory extraction. However, ultrafiltration of the extracts prepared in bulk bark extraction gave only 60% yield of the ultrafiltrate after 23.5 hours and the yield finally reached to 71% after 63 hours (Table 1). Thus the extracts prepared in bulk extraction contain some components which affect the ultrafiltration rate and also the yield of ultrafiltrate.

TABLE 1

Ultrafiltration results of the extracts from the outer bark (prepared in the laboratory extraction) and from the bulk bark (prepared in bulk extraction)

| Extracts | Time (hours) | Yield (%) | |
|---|---|---|---|
| | | Filtrate | Retentate |
| Outer bark | 23.5 | 84 | 16 |
| Bulk bark | 63.0 | 71 | 29 |

Purity of polyflavonoids reactive to formaldehyde in the extracts was determined by Stiasny precipitate. The hot water extracts from the outer bark prepared under laboratory conditions gave higher Stiasny precipitates (93%) than those (82%) in the bulk bark extracts (Table 2). The bulk bark sample contained 10% wood chips and 10% inner bark. This indicates that hot water extracts from either wood or inner bark or both may be responsible for the low filtration efficiency and the low value of Stiasny precipitate of the bulk bark extracts.

Wood and inner bark yielded 3.2% and 16% of hot water extracts, respectively and both extracts gave significantly lower Stiasny precipitates compared with those of outer bark extracts prepared in the laboratory extraction (Table 2).

TABLE 2

Yields of hot water extracts and Stiasny precipitate of the extracts

| Hot water extracts | Yield of extracts (%) | Stiasny precipitates (%) |
|---|---|---|
| Outer bark | 16.0 | 93 |
| Bulk bark | 6.2 | 82 |
| Inner bark | 16.0 | 52 |
| Wood | 3.2 | 30 |

The yield of ultrafiltration from a mixture of outer (90%) and inner (10%) bark extracts was only 64% and also the filtration rate was slower than that of the outer

bark extracts. The yield of the ultrafiltrate from a mixture of outer bark extracts (90%) and glucose (10%) was 80.5% and the ultrafiltration rate was faster than others. Furthermore, ultrafiltration of the inner bark extracts gave only 49.4% of the filtrate and the filtration rate was very slow.

Consequently, it is concluded that the low filtration efficiency of the bulk bark extracts was largely due to the presence of the inner bark extracts.

The viscosity of each of the various extracts is under investigation. Aqueous solutions have been found to be non-Newtonian fluids and the flow properties to vary according to the proportion of wood and inner bark extracts present in the extracts.

From a practical point of view, it is difficult to collect only outer bark separated from inner bark and wood chips by use of debarking processes currently used in industry. Also the amount of inner bark in bulk bark depends on its source, the age of the tree and which part of the tree the bark was taken from (Sands 1975). Therefore, after extraction of bulk bark with hot water, the components affecting the ultrafiltration efficiency must be removed from the extracts of the bulk bark. Recent experiment revealed that the components affecting the filtration efficiency can be readily removed by microporous filtration and that this process improves greatly the filtration efficiency of the extracts.

## CONCLUSIONS AND FUTURE WORK

The microporous filtration is the most important process prior to ultrafiltration of the extracts and more accurate conditions for the microporous filtration will be determined.

## ACKNOWLEDGEMENT

I thank Dr W.E. Hillis for his valuable discussion, Mr A.N. Rozsa for his help in collecting the bark samples and in preparing the extracts in bulk extraction and Australian Forest Industries Pty. Ltd. for supplying the bark sample.

REFERENCES

Sands, R. 1975. Radiata pine bark - aspects of morphology, anatomy and chemistry. N.Z.J. Sci. 5(1), 74-86.

Yazaki, Y. and W.E. Hillis. 1980. Molecular size distribution of radiata pine bark extracts and its effect on properties. Holzforschung 34, 125-130.

Yazaki, Y., W.E. Hillis and P.J. Collins. 1979. Purification of bark and Wood extracts for wood adhesives. Provisional Patent Application, May 2, PD 8616/79. Australian Patent Application No. 57753/80, Chilean Patent Application No. 442/80, New Zealand Patent Application No. 193,500 and South African Patent Application No. 80/2664.

# GROWTH STRESS IN EUCALYPTS

W.E. HILLIS*, S.C. CHAFE* and J.CH. FERRAND**
*Division of Building Research, CSIRO
**Station d'amelioration des arbres forestiers

## ABSTRACT

Growth stress and its related effects are significant factors causing degrade of hardwoods. The methods used to determine growth strain are listed. Peripheral longitudinal growth stress varies with height in the tree and may increase or decrease depending on position in the stem. The level of growth strain is significantly less in trees growing on high quality sites, and when grown at wide spacings or when subjected to a heavy early thinning.

Growth stress and strain and their related effects are possibly the most significant factors causing the degrade of hardwoods. They are common and can be severe in the woods of the Eucalyptus genus (5) but there are little quantitative data concerning their distribution. The effects of growth stress show considerable variability both between and within species and within individual trees (3).

The effects are displayed in three major ways:

(1) the splitting of logs, poles and posts so as to affect their use in that form or in their conversion to other products

(2) the presence of a "brittle heart" or a central portion containing a high proportion of fibres with compression failure and resultant low strength for solid wood uses and for some pulping processes

(3) the anatomical differences from unstressed wood resulting in a higher proportion of thick walled fibres, higher density and shrinkage (7).

## I. METHODS OF ESTIMATION

A reliable and rapid method of estimating growth stress is needed to survey its extent in the forest resource, to determine the effect of silvicultural practices and of methods of alleviation in the material available.

The quantitative methods available are those of (a) Nicholson (6) which involves removal of a segment from the periphery of the tree, the direct and accurate measurement of its reduction in length by an extensiometer after removal and the determination of Young's modulus of the specimens to enable computation of growth stress. This method gives reliable and reproducible results but is time consuming (taking about 20 minutes for the field measurements) and requires care.

(b) Sauret & Gueneau (9). With this method, a strain gauge is attached by a special adhesive to the outer surface of the specimen and the extension of length measured after two large holes are drilled either side of the gauge.

(c) Polge & Thiercelin (8). Within each set of comparisons all core samples are removed with the same auger (5 mm diam.) and the tangential diameters measured with an accuracy of $10^{-6}$ metre every 0.25 mm from 5 to 25 mm from the bark. The change in tangential diameter is taken as an indicator of the longitudinal growth strain level. The method provides comparative data which have been indirectly related to growth stress. It is easier to apply than the earlier methods. It has been used in a study of the effect of thinning on *E. nitens* and *E. delegatensis*.

(d) Withelmy & Kubler (10) used a probe to measure the changes in dimensions due to strains in a hole drilled into a log or stem. The method is not applicable to general studies.

(e) Hardness. Nicholson *et al.* (7) found an association between growth stress and proportion of thick walled fibres. However, the expected association between growth stress and hardness of the wood has been found to be insufficiently accurate to use as an assessment method (2).

The most suitable method currently available for survey purposes are those of Nicholson (6) and Polge and Thiercelin (8).

## II. VARIATION IN LONGITUDINAL GROWTH STRESS WITH HEIGHT IN THE TREE

In the eucalypts, height in the tree has been reported to have little or no effect on regrowth stress (1,6). However, recently a weak relationship with height in the tree has been found in three American hardwoods (11). Peripheral longitudinal growth stress increased up to 8 m but then declined at 11 m.

Two studies have been carried out on five trees of 39 year old E. regnans regrowth (4) and ten trees of 8 year old plantation grown E. nitens (Chafe, in preparation) using the Nicholson technique. The average values for growth stress in E. regnans increased from 10.2 to 12.4 to 13.4 MPa at heights of 2.5, 5.0 and 7.5 m respectively. With the younger E. nitens trees a high (8.5 MPa) average value of growth stress at 1.5 m was followed by a significantly lower value (7.0 MPa) at 3.0 m, slight increases to 7.5 MPa and 7.2 MPa at 6.0 m and 9.0 m and then a decline to 6.3 and 5.5 MPa at 12.0 and 15.0 m respectively. The results of these two studies tend broadly to follow the observations of Yao (11), although in the case of E. nitens high values at 1.5 m suggests a more complex relationship between growth stress and height in the tree may be present.

## III. VARIATION OF GROWTH STRESS WITH SILVICULTURAL TREATMENT

The "surround" trees around various plots of spacing trials of E. delegatensis were examined by removing a sample (8) from the upper side (over 90% of the trees were leaning slightly) of the stem and a sample from the opposite side. An examination of thinning trials of E. delegatensis and E. nitens has also been made. It was concluded from the results that the level of growth strain in trees is significantly less on sites of high quality index and at wide spacings and that a heavy early thinning but not a moderate thinning decreases the strain. Growth strain is not related to dominance as large dominant trees in unthinned plots had strains higher than similar trees in heavily thinned plots (J.Ch. Ferrand, in preparation).

REFERENCES

(1) Boyd, J.D. 1950. Growth stress III. The origin of growth stresses. Aust. J. Sci. Res. B3, 294-309.

(2) Chafe, S.C. 1979. Wood hardness as a poor indicator of growth stress. Aust. For. Res. 9, 147-148.

(3) Chafe, S.C. 1979. Growth stress in trees. Aust. For. Res. 9, 203- 3.

(4) Chafe, S.C. 1981. Variations in longitudinal growth stress, basic density and modulus of elasticity with height in the tree. Aust. For. Res. 11, 79-82.

(5) Hillis, W.E. 1978. Wood quality and utilization In "Eucalypts for wood production" ed. by W.E. Hillis & A.G. Brown published by CSIRO pp. 259-289.

(6) Nicholson, J.E. 1971. A rapid method for estimating longitudinal growth stresses in logs. Wood Sci. Technol. 5, 40-8.

(7) Nicholson, J.E., Hillis, W.E. and Ditchburne, N. 1975. Some tree growth-wood property relationships of eucalypts. Can. J. For. Res. 5, 424-32.

(8) Polge, H. and Thiercelin, F. 1979. Growth stress appraisal through increment core measurements. Wood Science 12, 886-92.

(9) Saurat, J. and Gueneau, P. 1976. Growth stresses in beech. Wood Science Technol. 10, 111-23.

(10) Wilhelmy, Y. and Kubler, H. 1973. Probe for measurement of strains inside solid bodies. Experimental Mechanics 13(3), 142-4.

(11) Yao, J. 1979. Relationship between height and growth stress within and among white ash, water oak and shagbark hickory. Wood Sci. 11, 246-51.

# WOOD QUALITY RESEARCH IN NEW SOUTH WALES

R. K. Bamber
Wood Technology and Forest Research Division
Forestry Commission of N.S.W.

## ABSTRACT

Wood quality research in the Forestry Commission of N.S.W., both current and planned is reviewed. This research is following three main lines; within-tree variation; induced variation; elite tree assessment.

Studies of within-tree variation are concerned with the determination of the natural pattern of variation in the tree, the principal sources of variation being age or distance from pith, height in tree and stem orientation. Studies of induced variation are concerned with the effect of environmental conditions such as fertilizer application and silvicultural treatments in general. Wood quality assessment of radiata pine has concentrated in the past on spiral grain but future selections will incorporate other features such as density.

## INTRODUCTION

The nature of the forest crop in N.S.W. and no doubt in other states is gradually changing as the quantities of exotic pines increase and the age of logged hardwood trees decreases. In addition the scarcity of raw materials world wide has put greater demands on industry to reduce waste and to make more effective use of the forest crop.

This change in the nature of the forest crop has focussed attention on wood quality and the factors influencing it. Wood quality is determined primarily by variations in such properties as density, grain orientation and the presence of abnormal tissue and study of the patterns of variation and the factors influencing such variation are fundamental to the understanding and control of wood quality.

Because of limitations imposed by staff and equipment wood quality research in the Commission has had to be focussed on the most pressing problems and has covered aspects of the following lines of research; within-tree variation of wood properties; induced variation in wood properties; and assessment of wood properties in relation to the tree breeding programme.

## WITHIN-TREE VARIATION

The magnitude of within-tree variation in wood properties is large and is principally associated with age or distance from the pith. It is necessary that it be known for the assessment of trees for breeding and also for the evaluation of the effects of silvicultural treatments or environment (induced variation).

The within-tree variation in a number of species of eucalypts has been established. Considerable variation in both density and cell dimensions have been found and this variation is large enough to signficantly influence wood quality. It is planned to extend these studies to *Eucalyptus sieberi*. Information on the within-tree variation in this species will enable the wood properties of young regrowth trees in areas of intensive logging, such as the wood chip operation in the Eden district, to be predicted. Investigations are also planned into the effect of height-in-tree on spiral grain and the incidence of compression wood in radiata pine.

Knots are one of the most serious defects in radiata pine. Apart from their most serious effect, which is on strength, they contribute to machining problems, paint failure and probably also paper and pulp quality. Branchwood is also a potential source of pulpwood in whole tree utilization.

To gain fundamental information on the nature of branchwood and knots a comparison of branchwood and stemwood in radiata pine has been made. Branches and stemwood were taken from the same height in the tree, approximately 30 m above the ground. The trees were aged about 40 years. The results of this experiment are summarized in Table 1. It will be noted that branchwood is a little denser, has more latewood and has smaller tracheids than equal aged wood from the stem. The most significant difference however was found in the relative amounts of compression wood, the branchwood having a high proportion of compression wood (about 45%) whereas as far as could be observed visually it was absent from the stem.

While the tracheid dimensions suggest that branchwood is a useful source of fibre for papermaking the large amount of compression wood present in branches indicates that the paper would be inferior. It would have to be mixed with stemwood in the correct proportions to make satisfactory paper.

The difference in density of branchwood and stemwood does not appear to be large enough to explain differences in hardness. The apparent hardness of knots appears to be principally due to grain orientation.

TABLE 1

Comparison of Some Properties of Branchwood and Stemwood of Radiata pine *, **

| Property | Branch | Stem |
|---|---|---|
| Density $g/cm^3$ | 41 | 34 |
| Percent latewood | 27 | 14 |
| Tracheid length mm | 1.9 | 2.4 |
| Tracheid radial diameter µm | | |
| Earlywood | 27 | 36 |
| Latewood | 15 | 20 |
| Tracheid radial wall thickness µm | | |
| Earlywood | 2.5 | 2.6 (N.S.) |
| Latewood | 2.8 | 3.4 (N.S.) |

* All figures means of rings 2-6 from pith.

** Compression wood excluded.

## INDUCED VARIATION

Environmental factors such as rainfall, latitude, fertilizers and thinning are known to induce variation in some wood properties. It is essential to monitor any large scale silvicultural procedures to determine the magnitude and nature of such effects particularly where the effects on tree growth are substantial.

A study has recently been completed of the effects of fast growth on the wood properties of *E. grandis*. In this experiment a number of cultural techniques were used to ensure that the trees grew as fast as possible, the sites were ploughed before planting, the trees fertilized, leaf eating insects controlled with insecticide and weed growth controlled with weedicides. Trees subjected to this treatment produced about 27 times the wood volume of the control trees.

Results of the wood examination are shown in Table 2. It will be observed that while structural tissue, fibres, and density do not appear to be affected by the treatment, the physiologically active tissue, vessels and rays, showed a distinct reaction.

An examination is currently underway into the effects of fertilizers on the density and percent latewood of radiata pine. Nitrogenous and phosphatic fertilizers are included in this study in which trees were fertilized when 15 years old.

TABLE 2

Mean Basic Densities, Cell Dimensions of the Wood of Fast and Normally Grown Trees of *Eucalyptus grandis* of Age 2½ years

| Property | Fast grown | Normally grown | Statistical analyses | |
|---|---|---|---|---|
| | | | Type of test | Level of significance |
| Basic density g/cm$^3$ | 0.46 | 0.42 | ANOVA | N.S. |
| Fibre length mm | 0.82 | 0.81 | Students t-test | N.S. |
| Fibre diameter µm | 13.5 | 14.3 | " " | N.S. |
| Fibre wall thickness µm | 2.1 | 2.2 | " " | N.S. |
| Vessel diameter µm | 61 | 74 | " " | 99% |
| Vessel frequency per mm$^2$ | 14.1 | 19.4 | " " | 95% |
| Ray volume % | 18 | 13 | " " | 99% |

## ELITE TREE ASSESSMENT

In the initial elite tree selections of radiata pine in New South Wales the only wood characteristic incorporated into the assessment was spiral grain. This was because the relatively small number of plus trees did not allow for a rigorous culling thought to be necessary to gain a significant improvement. Priority was given to spiral grain because of its influence on strength and stability.

It is planned however, to widen the range of wood properties used as selection criteria in the assessment of elite tree progeny. Consideration will be given to density, both whole ring and earlywood, percent latewood and the incidence of compression wood as well as spiral grain. A recent study (Nicholls et al., 1981) indicates that a selection ratio of 1 in 5 in radiata pine could result in a gain of about 6% in average density. It would appear that with the adoption of both spiral grain and density, significant improvements in the strength of the corewood are possible.

Examination of the wood of elite trees of loblolly pine has been made. Wood features were however not used in the selection as there did not appear to be any likelihood of significant gains in wood quality. The wood examination was considered to be necessary to detect the presence of parent trees with undesirable traits such as a high incidence of compression wood or spiral grain. Because of its comparatively straight grain and high density, loblolly pine is inherently stronger than radiata pine.

## REFERENCE

Nicholls, J. W. P., Morris, J. D. and Pederick, L. A. (1981). Heritability estimates of density characteristics in juvenile *Pinus radiata* wood. Silv. Gen. 29: 54-61.

/

# RAPID FIELD ESTIMATION OF WOOD DENSITY USING THE "PILODYN"

W.J. Smith, P.J. Allen and D.B. Eccles
Division of Technical Services
Queensland Department of Forestry
Brisbane

## ABSTRACT

The "Pilodyn" has been evaluated as a rapid field method for determining the basic density of standing trees.

Comprehensive testing over a wide range of localities, age-classes, and site qualities for slash, Caribbean and hoop pines indicates it can be used to closely estimate the mean density of populations and also to classify individual standing trees of these species into density classes, with varying degrees of precision which need to be predetermined for species/age-class combinations; site quality effects on predictive equations can probably be ignored.

Hoop pine density is more consistently predictable than in the exotics, followed by Caribbean and slash pines, in that order. In hoop pine, there was no difference in the relationship with age to 34 yrs., in contrast to the exotics.

Improved performance was obtained in older slash pine with an 18-joule instrument instead of a 6-joule one. The instrument is potentially very useful in resource estimation, weight-scaling, marketing, utilization and tree improvement.

## INTRODUCTION

There is a need for rapid field determination of the basic density of standing trees, both individually and in populations, as an indicator of wood quality for solid and reconstituted wood product utilization, as a parameter in estimating dry-wood-weight resources and yeilds, and as a parameter in tree improvement programmes.

Two instruments, the "Torsiometer" and the "Pilodyn", have shown potential for field use (1, 2, 3, 4, 5). The former measures torque-resistance in increment core extraction; the latter resistance to penetration of a spring-loaded pin in up to 70 mm of a tree's outer wood.

The Torsiometer was reported as an excellent estimator of outerwood basic density, regardless of age in *Pinus radiata* (2), but found to be of variable use in estimating whole-core basic density in *P. elliottii* and *P. caribaea* (6), with predictive performance varying with age and species in the latter studies.

In comparing both instruments in *P. radiata*, Cown and Andrew (7), concluded the torsiometer was a better estimator of individual tree density, but that they performed similarly in 5-tree plot and 25-tree family sample mean density estimation, and favoured the Pilodyn for multiple-tree sample assessments on ease of handling and other considerations. In an unpublished report, Cown (8) has attributed a high level of precision to the Pilodyn in estimating the basic density of *P. radiata* populations, with no significant effect of age nor site on the penetration/density relationships.

Evaluation of the Pilodyn on Queensland plantation-grown *P. elliottii* (slash pine), *P. caribaea* (Caribbean pine) and *Araucaria cunninghamii* (hoop pine) in a series of studies since 1978 confirmed its potential usefulness, but also showed species and age effects on predictive equations, as with the torsiometer. Species, age, locality and site-quality effects are being checked in conjunction with a State-wide density survey reported separately (9). The results of these studies so far available are reported herein.

## MATERIALS AND METHODS

For slash, Caribbean and hoop pines, a range of age-classes (upwards of 10 to 15 yrs) were sampled in localities of major occurrence for each species, and a range of site qualities ("low", "average" and "high") as available in each species/locality/age combination. Actual age and measured site index were recorded for each plot.

Data so far available covers:

1. slash pine 12 to 47 yrs old (15 plots) at Beerburrum (latitude 26°58', elevation 20 m);
2. Caribbean pine 13 to 27 yrs old (8 plots) at Beerburrum, 14 to 28 yrs old (4 plots) at Byfield (lat. 22°50', elev. 30 m), and from a separate study, 5.5 to 15.5 yrs old (3 plots) at Melville Island, N. Territory (lat. 11°30').

3. hoop pine 12 to 48 yrs old (6 plots) at Imbil (lat. 26°28', elev. 100 m).

Observations on samples of Caribbean pine taken or to be taken on north Queensland highlands and coastal lowlands are not covered in this present report.

Twenty (20) merchantable trees were sampled in each approximate 4 x 5 trees plot based on the site quality indicators. Diametrical increment cores were taken at 90° to any lean, and otherwise at 90° to the prevailing wind direction, to minimise compression wood incidence. Using a Pilodyn generally with a 6-joule spring and invariably with a 2.0 mm diameter pin, two penetration readings per tree were taken, one on each opposite side about 3.0 cm diagonally from the core position; the two readings were averaged. A 12-joule instrument was comparatively assessed on some older slash and Caribbean pine plots at Beerburrum.

Whole-core basic density was determined gravimetrically in laboratory. The pitch streaks commonly encountered in an towards the heart of slash and Caribbean pines in some age-classes and localities could not always be avoided in sampling. Their inflatory effect on unextracted density would be expected to confound assessment of the usefulness of outerwood density measuring instruments such as the Pilodyn and torsiometer as indicators of whole-core density, and results were analysed with and without cores with excessive pitch streak associated resin impregnation, to ascertain their effect.

Linear regression analysis was used to establish the relationships between Pilodyn penetration of the outerwood and diametrical whole-core unextracted basic density.

RESULTS

The results of the analysis, including mean basic density, mean penetration, the density-predictive value of the latter, and the precision of the estimate are presented in Tables 1 to 6, by species, locality, age and site-quality.

The full data tabulation is for samples excluding cores with abnormal resin impregnation. The effect of their inclusion on the predictive value of the Pilodyn is shown by the comparative coefficient of determination ($R^2$) in parentheses.

Table 4 gives results of an assessment for CSIRO's Division of Forest Research of the Pilodyn's potential for use in three age levels (5.5 to 15.5 yrs) of Caribbean pine on Melville Island, Northern Territory. This provided a useful extension of the larger study.

TABLE 1

Relationships between Pilodyn Penetration and Whole Core Basic Density for Various Age Classes and Site Qualities for Slash Pine at Beerburrum

| Plot no. | Age (yrs) | Site index$^{\phi}$ | Mean Pilodyn (mm) | Mean basic density (kg/m$^3$) | Intercept | Slope | Coefficient of determination$^{+}$ ($R^2$) | 95% C.I. ($\pm$ kg/m$^3$) n=1 | n=20 |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 12 | L 21.2 | 13.8 | 470.5 | 648.7 | -12.9 | 0.234 * | 46.6 | 14.7 |
| 2 | 12 | A 25.8 | 14.9 | 438.7 | 698.5 | -17.5 | 0.458 ** | 46.9 | 14.8 |
| 3 | 14 | H 28.7 | 13.2 | 441.6 | 702.1 | -19.7 | 0.353 ** | 54.8 | 17.3 |
| 4 | 20 | L 23.1 | 12.4 | 520.0 | 707.3 | -15.1 | 0.392 ** | 61.9 | 19.6 |
| 5 | 18 | A 25.1 | 12.8 | 486.0 | 599.8 | - 8.9 | 0.198 * | 36.7 | 11.6 |
| 6 | 16 | H 27.0 | 15.0 | 439.7 | 634.4 | -13.0 | 0.494*** | 33.6 | 10.6 |
| 7 | 25 | L 22.3 | 12.1 | 555.4 | 737.5 | -15.1 | 0.248 * (0.220 *) | 59.5 | 18.8 |
| 8 | 23 | A 23.4 | 12.4 | 537.6 | 861.5 | -26.2 | 0.418 ** | 59.0 | 18.7 |
| 9 | 23 | H 26.0 | 13.1 | 505.7 | 809.7 | -23.2 | 0.519*** (0.488***) | 52.3 | 16.5 |
| 10 | 34 | L 24.4 | 13.1 | 575.7 | 666.8 | - 7.0 | 0.060 NS | 65.6 | 20.7 |
| 11 | 34 | A 25.5 | 13.1 | 583.2 | 714.7 | -10.1 | 0.112 NS | 75.0 | 23.7 |
| 12 | 34 | H 27.3 | 13.5 | 556.0 | 739.8 | -13.6 | 0.138 NS | 78.6 | 24.8 |
| 13 | 44 | L 18.5 | 12.4 | 604.3 | 760.5 | -12.6 | 0.312 * (0.192 NS) | 78.2 | 24.7 |
| 14 | 47 | A 21.1 | 12.8 | 616.2 | 835.0 | -17.1 | 0.435 ** | 48.3 | 15.3 |
| 15 | 47 | H 24.5 | 13.0 | 601.2 | 828.5 | -17.5 | 0.127 NS | 62.8 | 19.9 |

+ Coefficients of determination in parentheses were calculated with resin affected cores included.

$\phi$ L,A and H indicate "low", "average" and "high" site qualities respectively for each age class.

***, **, * and NS indicate significance at the 99.9%, 99%, 95% levels and not statistically significant respectively.

TABLE 2

Relationships between Pilodyn Penetration and Whole Core Basic Density for Various Age Classes and Site qualities for Caribbean pine at Beerburrum

| Plot no. | Age (yrs) | Site index$^{\emptyset}$ | Mean Pilodyn (mm) | Mean basic density ($kg/m^3$) | Intercept | Slope | Coefficient of determination$^{+}$ ($R^2$) | 95% C.I. ($\pm$ $kg/m^3$) n=1 | n=20 |
|---|---|---|---|---|---|---|---|---|---|
| 16 | 14 | A 26.7 | 14.6 | 440.4 | 634.5 | -13.3 | 0.462 ** (0.432 **) | 42.0 | 13.3 |
| 17 | 13 | H 28.1 | 14.2 | 411.8 | 616.3 | -14.4 | 0.552*** (0.420 **) | 51.1 | 16.1 |
| 18 | 17 | A 26.7 | 14.5 | 472.5 | 668.8 | -13.5 | 0.550*** | 54.4 | 17.2 |
| 19 | 18 | H 29.0 | 16.1 | 442.4 | 630.1 | -11.6 | 0.540 ** (0.569***) | 61.6 | 19.5 |
| 20 | 26 | L 22.5 | 15.0 | 517.9 | 755.9 | -15.8 | 0.281 * (0.288 *) | 70.4 | 22.3 |
| 21 | 27 | A 26.4 | 15.0 | 502.0 | 906.1 | -26.9 | 0.759*** (0.454 **) | 53.6 | 16.9 |
| 22 | 27 | H 28.5 | 16.2 | 484.5 | 724.9 | -14.8 | 0.550 ** (0.086 NS) | 58.4 | 18.5 |
| 23 | 27 | H 30.1 | 16.3 | 483.2 | 714.3 | -14.2 | 0.526 ** (0.199 *) | 43.1 | 13.6 |

+ Coefficients of determination in parentheses were calculated with resin affected cores included.

*** Significant at the 99.9% level

** Significant at the 99% level

* Significant at the 95% level

NS Not statistically significant

$\emptyset$ L, A and H indicate "low", "average" and "high" site qualities respectively for each age class.

TABLE 3

Relationships between Pilodyn Penetration and Whole Core Basic Density for Various Ages on "Average" Sites for Caribbean Pine at Byfield

| Plot no. | Age (yrs) | Site index | Mean Pilodyn (mm) | Mean basic density ($kg/m^3$) | Intercept | Slope | Coefficient of determination+ ($R^2$) | 95% C.I. ($\pm$ $kg/m^3$) n=1 | n=20 |
|---|---|---|---|---|---|---|---|---|---|
| 24 | 14 | 26.0 | 15.0 | 449.1 | 632.1 | -12.2 | 0.367 ** | 47.1 | 14.9 |
| 25 | 18 | 24.0 | 14.6 | 480.3 | 612.9 | - 9.1 | 0.250 * (0.121 NS) | 42.4 | 13.4 |
| 26 | 23 | 25.0 | 14.2 | 496.7 | 787.1 | -20.5 | 0.572*** (0.509***) | 63.0 | 19.9 |
| 27 | 28 | 27.0 | 13.7 | 523.4 | 868.1 | -25.1 | 0.787*** (0.775***) | 34.0 | 10.8 |

+ Coefficients of determination in parentheses were calculated with resin affected cores included.

***, **, * and NS indicate significance at the 99.9%, 99%, 95% levels and not statistically significant respectively.

TABLE 4

Relationships between Pilodyn Penetration and Whole Core Basic Density for Various Ages for Caribbean Pine on Melville Island N.T.

| Plot no. | Age (yrs) | Mean Pilodyn (mm) | Mean basic density ($kg/m^3$) | Intercept | Slope | Coefficient of determination ($R^2$) | 95% C.I. ($\pm$ $kg/m^3$) n=1 | n=20 |
|---|---|---|---|---|---|---|---|---|
| 34 | 5.5 | 17.5 | 397.3 | 595.4 | -11.3 | 0.786 ** | 36.3 | 11.5 |
| 35 | 11 | 12.6 | 446.6 | 624.0 | -14.1 | 0.311 * | 67.7 | 21.4 |
| 36 | 15.5 | 12.2 | 519.1 | 835.6 | -26.0 | 0.740 ** | 48.5 | 15.3 |

**, * indicate statistical significance at the 99% and 95% levels respectively.

TABLE 5

Relationships between Pilodyn Penetration and Whole Core Basic Density for Various Ages on "Average" Sites for Hoop Pine at Imbil

| Plot no. | Age (yrs) | Site Index | Mean Pilodyn (mm) | Mean basic density ($kg/m^3$) | Intercept | Slope | Coefficient of determination ($R^2$) | 95% C.I. ($\pm$ $kg/m^3$) n=1 | n=20 |
|---|---|---|---|---|---|---|---|---|---|
| 28 | 12 | 28.9 | 15.7 | 475.3 | 640.3 | -10.5 | 0.620*** | 28.8 | 9.1 |
| 29 | 17 | 27.4 | 16.7 | 467.7 | 692.0 | -13.5 | 0.628*** | 35.5 | 11.2 |
| 30 | 21 | 26.7 | 16.6 | 463.5 | 698.8 | -14.2 | 0.756*** | 27.9 | 8.8 |
| 31 | 28 | 24.7 | 16.5 | 460.1 | 731.0 | -16.5 | 0.506*** | 45.8 | 14.5 |
| 32 | 34 | 25.9 | 17.1 | 460.0 | 694.6 | -13.7 | 0.617*** | 38.4 | 12.2 |
| 33 | 48 | 24.3 | 16.2 | 491.3 | 727.6 | -14.6 | 0.596*** | 43.9 | 13.9 |

*** indicates statistical significance at the 99.9% level.

TABLE 6

Relationships between Pilodyn Penetration and Whole Core Basic Density for each Age Class for Slash and Caribbean Pines at Beerburrum

| Species[ø] | Age (yrs) | Mean Pilodyn (mm) | Mean basic density ($kg/m^3$) | Intercept | Slope | Coefficient of determination ($R^2$) | 95% C.I. ($\pm$ $kg/m^3$) n=1 | n=20 |
|---|---|---|---|---|---|---|---|---|
| S | 10 to 15 | 14.0 | 450.2 | 630.8 | -12.9 | 0.245*** | 56.9 | 14.3 |
| S | 15 to 20 | 13.4 | 481.9 | 749.5 | -20.0 | 0.624*** | 53.9 | 13.6 |
| S | 20 to 25 | 12.5 | 532.2 | 852.0 | -25.5 | 0.493*** | 58.0 | 14.6 |
| S | 30 to 35 | 13.2 | 571.6 | 723.9 | -11.5 | 0.123 ** | 72.0 | 18.1+ |
| S | 45 to 50 | 12.8 | 607.4 | 788.6 | -14.2 | 0.260*** | 57.0 | 14.4 |
| C | 10 to 15 | 14.4 | 426.9 | 609.3 | -12.7 | 0.350*** | 56.5 | 15.3 |
| C | 15 to 20 | 15.2 | 459.1 | 659.3 | -13.2 | 0.590*** | 55.6 | 15.0 |
| C | 25 to 30 | 15.6 | 499.1 | 788.4 | -18.6 | 0.540*** | 57.9 | 14.1 |

+ This would be much improved using an 18 joule instrument.

ø S = Slash pine, C = Caribbean pine.

*** and ** indicate statistical significance at the 99.9% and 99% levels respectively.

Results of assessment of the relative performance of the 6-joule Pilodyn and an 18-joule model on older slash and Caribbean pines are given in Table 7.

TABLE 7

Coefficients of Determination and Confidence Intervals for the 6-joule and 18-joule Pilodyns for Three Plots of Slash Pine and Two Plots of Caribbean Pine at Beerburrum

| Plot no. | Species+ | Age (yrs) | Site index | Coefficient of determination ($R^2$) | 95% C.I. ($kg/m^3$) n=1 n=20 | Coefficient of determination ($R^2$) | 95% C.I. ($kg/m^3$) n=1 n=20 |
|---|---|---|---|---|---|---|---|
| 10 | S | 34 | 24.4 | 0.060 NS | 65.6 20.7 | 0.304 * | 56.3 17.8 |
| 11 | S | 34 | 25.5 | 0.112 NS | 75.0 23.7 | 0.483*** | 57.4 18.1 |
| 12 | S | 34 | 27.3 | 0.138 NS | 78.6 24.8 | 0.719*** | 45.0 14.2 |
| 20 | C | 26 | 22.5 | 0.281 * | 70.4 22.3 | 0.262 * | 63.2 20.0 |
| 23 | C | 27 | 30.1 | 0.526 ** | 43.1 13.6 | 0.339 * | 50.8 16.1 |

+ S = Slash pine, C = Caribbean pine

***, **, * and NS indicate significance at the 99.9%, 99%, 95% levels and not statistically significant respectively.

## DISCUSSION

The results show the Pilodyn to be usefully applicable as a predictor of whole core unextracted basic density in hoop, Caribbean and slash pines in a wide range of age classes, localities and site qualities. However, relationship varied greatly with species, age and, in some cases, site quality. (Examples of this variation are shown in Figure 1.) The effect of age on the relationship varied with species.

Density was most consistently predictable with the instrument in hoop pine. In this species, there was no significant age effect at the one location tested to age 34 yrs, in contrast to the exotics, but the density/penetration relationship for the 48 yrs old sample differed in slope and/or intercept from that for younger stock (Table 5). Consistency across such a wide range of age-classes in predicting whole core average density with an outerwood indicator was anticipated because of the remarkable uniformity in pith to bark density in this species (10).

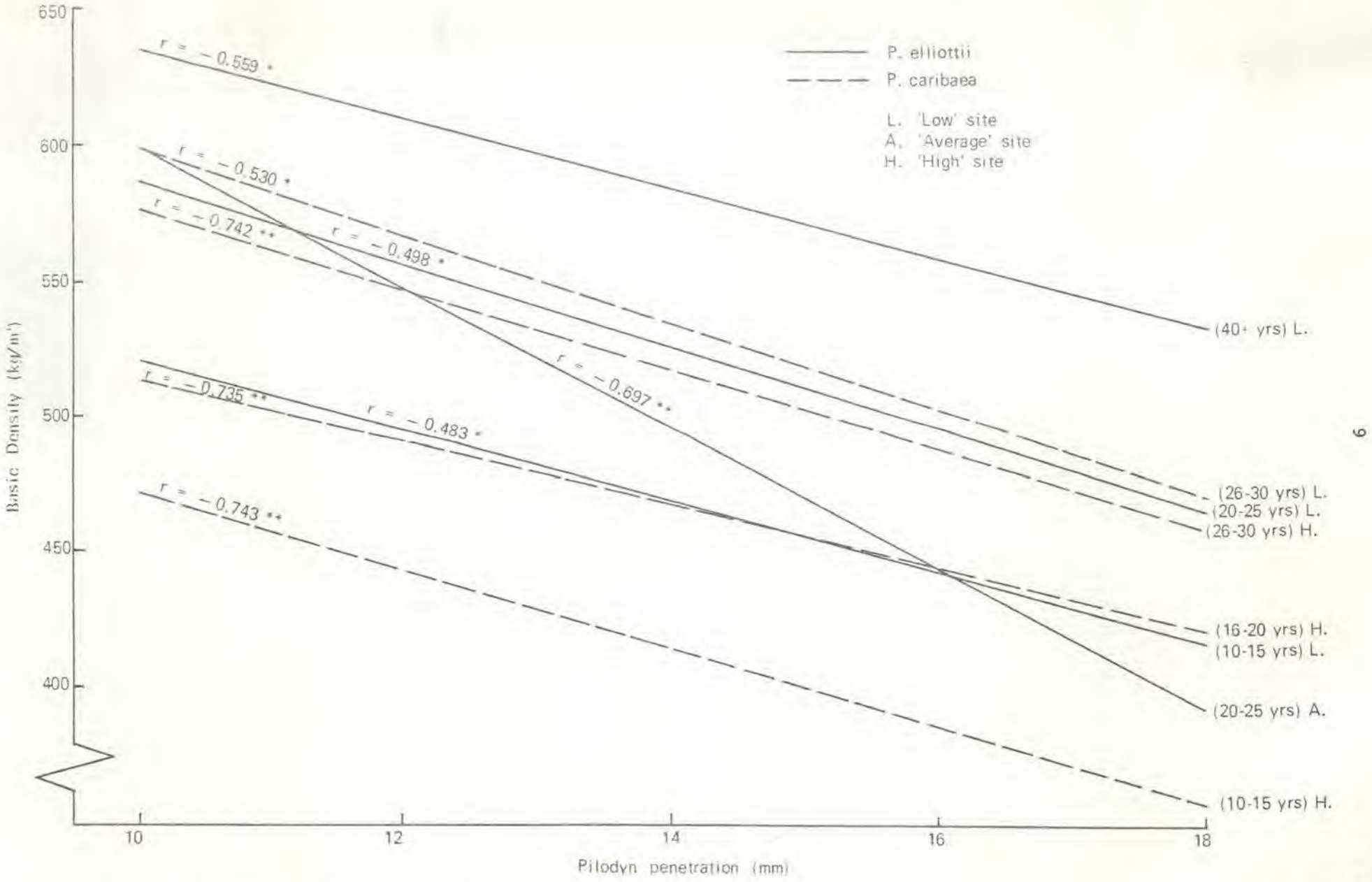



FIGURE 1. Examples of variation in relationship of basic density and Pilodyn penetration with species, age and site quality at Beerburrum.



60M

The change in the relationship is attributed largely to the effect of heartwood development on unextracted whole-core density. There is an indication from one apparent peak in the trend of $R^2$ with age in Table 5 that this began to exhibit some effect in the 20 to 25 yrs age-class.

The relationship was more variable in Caribbean and slash pines in that order, as shown in Tables 2, 3 and 4 and Table 1, respectively. It was often improved by excluding cores with abnormal pitch-streak-associated resin impregnation, particularly in older stock (Table 2), in which this defect is more prevalent.

The 6-joule instrument was not generally a useful predictor of density in older slash pine (34+ yrs), and a more powerful 18-joule model was tried on three of the 34 yrs old slash pine and two of the 26 to 27 yrs old Caribbean pine plots already sampled, to test the possibility that resistance to penetration of a greater depth of outerwood could prove a better indicator. A very marked and useful improvement was effected in the older slash pine, but not in the Caribbean pine (Table 7). In the latter case, the relationship was, in fact, not quite as good as with the 6-joule model, probably because the 18-joule spring was too powerful for the lower density Caribbean pine and several values had to be excluded because of maximum penetration registration.

Only a small part of the range of penetration of the 6-joule instrument was employable on the material studied. This, and the experience with the 18-joule model, suggest a 12-joule Pilodyn could be better applicable on Queensland-grown softwoods.

The effect of age on the density/penetration relationship in the two exotics was confounded by actual age and site quality variation for plots within age classes (Tables 1 and 2). A better indication was obtained by pooling data for species/locality/age-class combinations. The results in Table 6 show a definite age-associated effect on coefficient of determination, slope and/or intercept for both slash and Caribbean pines.

Apparent trends in the $R^2$ values with age suggest possible optimum performance in 15 to 20 yrs age class material in slash pine at Beerburrum and perhaps for Caribbean pine as well. These trends are similar to results achieved with the Torsiometer which was observed to perform better in 12 yrs old stock than at ages 7 and 23 yrs (6).

These results are explicable in terms of there being a point on a well-defined age-related pith to bark density curve linear gradient which will best estimate average density across the gradient using linear regression analysis. This point should be around the maturation age for this property.

Cown's (8) conclusion for *P. radiata* that neither age nor site affect the density/penetration relationship cannot be supported in respect to slash, Caribbean and hoop pines. In fact, the regression parameters from his study seem to vary over the 9 to 21 yrs ages much as for comparable material in the present study. There was a tendency for the $R^2$ values to increase with age to the limit studied, which may not have been old enough to detect any possible later decrease.

When related to appropriate ranges in average density the confidence intervals for individual-tree average density prediction using the Pilodyn (Tables 1 to 6), show the instrument can be used for classifying trees into at least two and up to four basic density classes, depending on species/age stratification, a capacity of real value in individual tree assessment for tree and wood quality improvement. Confidence limits on individual tree estimates generally ranged from $\pm$28-60 kg/m$^3$ using an appropriate instrument and regression equation. Where more precision is required, increment core sampling could follow Pilodyn stratification.

Mean density for populations can be determined much more precisely; with 20-tree samples, to within $\pm$13-15 kg/m$^3$ for slash and Caribbean pines, for age-classes ignoring site quality (Table 6) and as fine as $\pm$9 kg/m$^3$ for two hoop pine age-classes sampled. Use of an appropriate indicated regression equation and instrument is indicated.

The precision of these population estimates and the ease of field operation offer considerable scope for application of the Pilodyn in dry wood weight resource estimation, weight scaling, and guidance to forest management and industry in marketing and utilization. The results suggest profitable application in progeny and provenance assessment in tree improvement programme.

## CONCLUSIONS

It is concluded the Pilodyn is a very useful instrument for rapid field estimation of basic density in slash, Caribbean and hoop pines for:

1. the classification of individual trees into from two to four density classes; and
2. the estimation of mean density of crop or experimental populations to within $\pm$13 to $\pm$15 kg/m$^3$ (sometimes $\pm$9 kg/m$^3$).

Species, age and sometimes site quality affect the density-indicative use of the instrument. There is an age at which this use is apparently maximized. The age effect is less evident and much delayed in hoop pine, the instrument being more consistently reliable in this species than the two exotics tested.

Site quality effects can apparently be ignored without detriment in mean density estimation of populations, but predictive equations need to be developed for species/age-class combinations. Broader locality variation effects have not yet been assessed.

A 12-joule instrument could be more generally useful in at least slash pine over about 25 yrs old.

REFERENCES

1. Polge, H. and Keller, R. (1970). Premiere appreciation de la qualite du bois en foret par utilisation diun torsiometre. Ann. Sci. Forest 27: 197-223.

2. Nicholls, J.W.P. and Roget, D.F. (1977). Tests on a field method for the determination of wood density. Aust. For. 40(2): 144-50.

3. Harris, J.M., et al (1976). Wood density assessment by measuring torsion required to turn an increment borer in standing trees. N.Z. For. Ser., For. Res. Inst., For. Prod. Lab. Rep. No. FP/WQ23. (Unpublished).

4. Hoffmeyer, P. (1978). The Pilodyn instrument a non-destructive tester of the shock resistance of wood. Paper presented at the Non-destructive Testing Meeting, Vancouver, Washington, August 1978.

5. Cown, D.J. (1978). Comparison of the Pilodyn and Torsiometer Methods for the rapid assessment of wood Density in living Trees. N.Z. Jnl. For. Sci., 8(3): 384-91.

6. Smith, W.J. (1978). Wood Productivity and Quality improvement in Queensland. Status Report in Procs., Sixth Mtg., Res. Wkg. Gp. No.1 (For Genetics), Res. C'tee Aust. For. Cncl., Coffs Harbour. Div. For. Res. C.S.I.R.O., Canberra.

7. Cown, D.J. and Andrews, I.A. (1979). Comparison of Pilodyn, Torsiometer and Increment core methods for assessing wood density in progeny trials. N.Z. For. Ser., For. Res. Inst., For. Prod. Div. Wood Quality Report No. 29. (Unpublished).

8. Cown, D.J. (1980). Estimating tree densities in radiata pine using the Pilodyn wood tester. New Zealand Forest Service, Forest Research Institute, Forest Products Division Report No. FP/WQ38. (Unpublished).

9. Smith, W.J. et al. (1981). A survey of wood density variation in Queensland Plantation Softwoods. For. Prod. Res. Conf., Melbourne 1981.

10. Smith, W.J. and Eccles, D.B. (1979). The wood properties, Quality and Utilization of Hoop Pine *Araucaria cunninghamii* Ait. ex D.Don. pp. 25. In Procs., 1979 Routine-Research Conf., Qld. Dep. of For., Brisbane.

# A SURVEY OF WOOD DENSITY VARIATION IN QUEENSLAND PLANTATION SOFTWOODS

W.J. Smith, D.B. Eccles and P. Allen
Division of Technical Services
Queensland Department of Forestry
Brisbane

## ABSTRACT

Results to date are reported for a State-wide survey of the variation in wood density and dry wood weight productivity of the major plantation softwoods with species, age, locality, elevation and site-quality.

Basic density was found to vary directly with age and inversely with elevation, latitude and site quality in slash and Caribbean pines; and hoop pine density to be very uniform across age-classes to at least 34 yrs.

There was an increase with age in density difference between slash and Caribbean pines. A high final-crop wood density for slash pine is reported.

The interacting effects of growth-rate, elevation and latitude on wood density in the exotics are briefly discussed in relation to management, marketing and utilization.

Large and similar between-tree variation in Caribbean and slash pine density has been established, much of it within sites for locality/age combinations; there was somewhat less in hoop pine. Some wood quality improvement implications are considered.

## INTRODUCTION

Basic density is the best single indicator of wood utilization potential, being directly relatable to the strength and stiffness of sawn timber and inversely related to its workability. It is directly related to pulp and other reconstituted wood product yields and inversely related to conformability in paper production and to penetrability with pulping chemicals and preservative treatment solutions. Dry wood weight productivity, on an area and/or unit time basis, is a resource parameter always useful and often essential to forest management and industry in the establishment, location and development of pulping, particleboard and similar plants.

Wood density is under strong genetic control, but also subject to environmental influence (1). A State-wide survey of the variation in density and dry wood weight productivity of Queensland's major plantation-grown softwoods is in progress, to estimate the fibre resource by species, locality and age-class, to investigate the effect of variation in locality, age and site quality on density, as a guide to forest management, and to provide a firmer base for the assessment and improvement of wood quality. Results of the survey to date are reported herein. Per cent latewood variation being studied simultaneously is not reported.

## MATERIALS AND METHODS

*Pinus elliottii* (slash pine), *P. caribaea* (Caribbean pine) and *Araucaria cunninghamii* (hoop pine) were sampled in a range of nominal 5-yr age-classes upwards of 10 to 15 yrs and site-qualities ("low", "average" and "high") at the locations shown with latitudes and elevations in Figure 1. Coastal lowlands from south to north, and northern and southern highlands were covered, as well as a sampling from a small study of Caribbean pine at Melville Island, Northern Territory for CSIRO's Division of Forest Research.

Data so far available is reported for

1. slash pine 12 to 47 yrs old at Beerburrum (15 plots), 14 to 29 yrs old at Toolara (12 plots), 23 to 28 yrs old at Byfield (2 plots), and 24 to 26 yrs old at Gambubal (1 plot);
2. Caribbean pine 13 to 27 yrs old at Beerburrum (8 plots), 12 to 22 yrs old at Toolara (9 plots), 14 to 28 yrs old at Byfield (12 plots), 14 yrs old at Kennedy (3 plots), 12 to 22 yrs old at Atherton (3 plots), and 5.5 to 15.5 yrs old at Melville Island, lat. 26°28', elev. 100 m (3 plots); and
3. hoop pine 12 to 48 yrs old at Imbil (6 plots).

Plots classifiable as "low", "average" and "high" site qualities were selected as obtainable for species/locality/age-class combinations from Departmental data bank and field survey searches. Only two of the three site-qualities were available in some categories. The quality class site index range varied with age and locality and differences between classifications were very small in some cases, due to such factors as differing management practices, seed source, and site availability for planting. Where practicable, only routine stock was sampled, but this involved progressive genetic improvement in more recent plantings. Actual age and measured site index were recorded; also individual tree diameter breast high, height and straightness rating.

Figure 1. Plantation areas sampled for the wood density survey

Twenty merchantable trees were sampled in each approximately 4 x 5 trees plot based on the site quality indicators, as more convenient than a 2 rows x 10 trees crossed pattern pre-established as being no different in mean density or variation. The sample size was predetermined to estimate density to at least $\pm 20$ kg/m$^3$.

5 mm diametric or two opposite radial increment cores were taken approx. 1 m above ground at 90$^o$ to any lean and otherwise at 90$^o$ to the prevailing wind direction, to minimise compression wood incidence. Average breast high strip density had been found in a separate study here to most closely estimate volume weighted whole-tree average density.

Unextracted basic density was determined gravimetrically. Data for radii with abnormal resin impregnation from the pitch-streaks commonly occurring in the exotics were excluded from these results.

RESULTS AND DISCUSSION

Mean basic density for each locality/age-class/site quality combination for slash and Caribbean pines is tabulated in Table 1. The expected and observed trend for basic density to increase with age in these two species at each major Queensland location is better shown in Table 2 (in which site classes are combined within age-classes) and Figure 2. The hoop pine results for the six "average" site age intervals sampled at Imbil, for the three age-intervals of Melville Island Caribbean pine and the single sample of south Queensland highland (Gambubal) slash pine are also presented in Table 2 and Figure 2.

Ranges in individual-tree average density are included in Table 2.

Similar trends for increase in mean density with age were observed in both slash and Caribbean pines at all localities sampled sufficiently to allow its expression (Table 2, Fig. 2). Mean density was still increasing in slash pine to 45 yrs, although at a lower rate, and in Caribbean pine to 28 yrs. Initially small differences in density between slash (higher) and Caribbean pines in south-east Queensland increased with age from about 25 kg/m$^3$ at 10 to 20 years to about 40 and 60 kg/m$^3$ at 20 to 25 and 25 to 30 yrs, respectively.

There were no apparent differences in density between Beerburrum and Toolara for either of the exotics.

Slash pine wood averaged around 23 kg/m$^3$ denser on central than south-east Queensland lowlands.

At around 600 kg/m$^3$, the average basic density of Beerburrum final crop slash pine is higher than that of some mature Eucalypt hardwoods.

TABLE 1

Variation in Mean Basic Density with Locality, Age and Site Quality, for Slash and Caribbean Pine

| Nominal Age Class | Site Class† | Mean Basic Density ($kg\ m^{-3}$)‡ Beerburrum | Toolara | Byfield | Gambubal |
|---|---|---|---|---|---|
| **Slash Pine** | | | | | |
| 10 - 14.9 | L | 471(21.2) | 453(22.0) | - | See Table 2 |
| | A | 442(25.8) | 448(25.4) | - | |
| | H | 442(28.7) | 445(27.2) | - | |
| 15 - 19.9 | L | 520(23.1) | 486(22.0) | - | |
| | A | 486(25.1) | 495(24.4) | - | |
| | H | 440(27.0) | 475(26.6) | - | |
| 20 - 24.9 | L | 555(22.3) | 547(21.0) | - | |
| | A | 534(23.4) | 497(23.8) | 559(22.0) | |
| | H | 506(26.0) | 506(26.5) | - | |
| 25 - 29.9 | L | - | 588(19.6) | - | |
| | A | - | 550(24.0) | 580(26.0) | |
| | H | - | 537(26.2) | - | |
| 30 - 34.9 | L | 576(24.4) | | | |
| | A | 583(25.5) | | | |
| | H | 556(27.3) | | | |
| 40 - 50 | L | 604(18.5) | | | |
| | A | 616(21.1) | | | |
| | H | 601(24.5) | | | |

| Caribbean Pine | | Beerburrum | Toolara | Byfield | Kennedy | Atherton | Melville Island |
|---|---|---|---|---|---|---|---|
| 10 - 14.9 | L | - | 428(24.9) | 477(23.0) | 491(24.0) | - | See |
| | A | 440(26.7) | 431(26.2) | 449(26.0) | 473(27.0) | 376(31.0) | Table 2 |
| | H | 412(28.1) | 424(27.5) | 437(28.0) | 439(32.0) | - | |
| 15 - 19.9 | L | - | 466(23.6) | 493(19.0) | - | - | |
| | A | 472(26.7) | 459(25.0) | 480(24.0) | - | 426(31.0) | |
| | H | 442(29.0) | 454(26.7) | 443(27.0) | - | - | |
| 20 - 24.9 | L | - | 485(24.1) | 538(20.0) | - | - | |
| | A | - | 481(26.0) | 497(25.0) | - | 409(30.0) | |
| | H | - | 470(28.1) | 478(26.0) | - | - | |
| 25 - 30 | L | 518(22.5) | - | 537(21.0) | - | - | |
| | A | 502(26.4) | - | 523(27.0) | - | - | |
| | H | 484(28.5) (30.1) | - | 470(29.0) | - | - | |

† L, A and H: Low, average and high quality sites, respectively.

‡ Measured Site Index (m) in parentheses.

TABLE 2

Variation in Mean Basic Denstiy with Age and Location for Slash, Caribbean and Hoop Pines in Queensland

| Species and Age class | Basic density means and individual tree ranges (kg $m^{-3}$)† | | | | |
|---|---|---|---|---|---|
| **Slash pine** | **Beerburrum** | **Toolara** | **Byfield** | **Gambubal** | |
| 10-15 years | 452 (12-14) 360-534 | 449 (14) 387-540 | - | - | |
| 15-20 " | 482 (16-20) 401-605 | 487 (17) 395-564 | - | - | |
| 20-25 " | 532 (23-25) 427-641 | 518 (23) 452-591 | 559 (23) 467-604 | - | |
| 25-30 " | - | 558 (29) 473-645 | 580 (28) 505-636 | 350 (24-26) 326-379 | |
| 30-35 " | 572 (34) 484-658 | | | | |
| 40-50 " | 607 (44-47) 500-691 | | | | |
| **Caribbean pine** | **Beerburrum** | **Toolara** | **Byfield** | **Kennedy** | **Atherton** |
| 10-15 years | 426 (13-14) 355-493 | 428 (12) 362-516 | 454 (14) 385-567 | 468 (14) 386-579 | 376 (12) 301-443 |
| 15-20 " | 457 (17-18) 381-526 | 460 (18) 357-550 | 473 (18) 377-564 | - | 426 (19) 361-504 |
| 20-25 " | - | 478 (22) 379-577 | 502 (23) 396-587 | - | 409 (22) 356-469 |
| 25-30 " | 497 (27) 414-578 | - | 512 (28) 381-635 | - | - |
| | | **Melville Isd** (Nthn. Ter.) | | | |
| | | 397 (5 yrs) 322-464 | | | |
| | | 447 (11 yrs) 393-523 | | | |
| | | 519 (15 yrs) 435-599 | | | |

| Hoop pine | Imbil | Site Index (m) |
|---|---|---|
| 10-15 years | 475 (12) 435-508 | 28.9 |
| 15-20 " | 468 (16) 415-541 | 27.4 |
| 20-25 " | 463 (21) 406-504 | 26.7 |
| 25-30 " | 460 (28) 392-515 | 24.7 |

TABLE 2 (cont.)

| Species and Age class | Basic density means and individual tree ranges ($kg\ m^{-3}$) † | |
|---|---|---|
| Hoop pine | Imbil | Site Index (m) |
| 30-35 years | 460 (34) 403-510 | 25.9 |
| 45-50 " | 491 (48) 431-548 | 24.3 |

† Age or age range in parentheses.

In Caribbean pine, there was a general trend for density to increase from southern to central to northern localities on the coastal lowlands and to Melville Island. South to central differences were small, but those south to north more significant, especially when differences in site index were taken into account (see Table 1). There was an apparent rapid increase in density beyond 11 yrs at the most northerly location (Melville Island) if the age-samplings there were representative.

Basic density generally varied inversely with site quality in the exotics (Table 1). Although differences in site index were not always large enough to have an evident effect, they were associated with differences in density of up to 80 $kg/m^3$ in others. Differences between site classes within localities were greater than those between localities for age-classes on the coastal lowlands.

Lowland/highland differences were larger. At near the same latitude in south-east Queensland, an increase of about 1030 m in elevation was associated with a decrease in density of 24 to 26 yrs old slash pine by about 200 $kg/m^3$ to 350 $kg/m^3$ (Table 2), compared with coastal lowland stock. In north Queensland, despite a shift of $1^{\circ}$ northwards in latitude, an increase in elevation of 710 m was associated with a decrease in the density of 12 yrs old Caribbean pine by around 90 $kg/m^3$ to 376 $kg/m^3$.

The Gambubal slash pine density was similar to that for 25 yrs old trees (360 $kg/m^3$) from about lat. $37^{\circ}S$ in New Zealand (2), suggesting possible curvelinearity of any latitudinal effect over a broad range.

The locational, latitudinal and elevational variation for Caribbean pine density was similar to and generally confirmed earlier studies (e.g., Smith (3)).

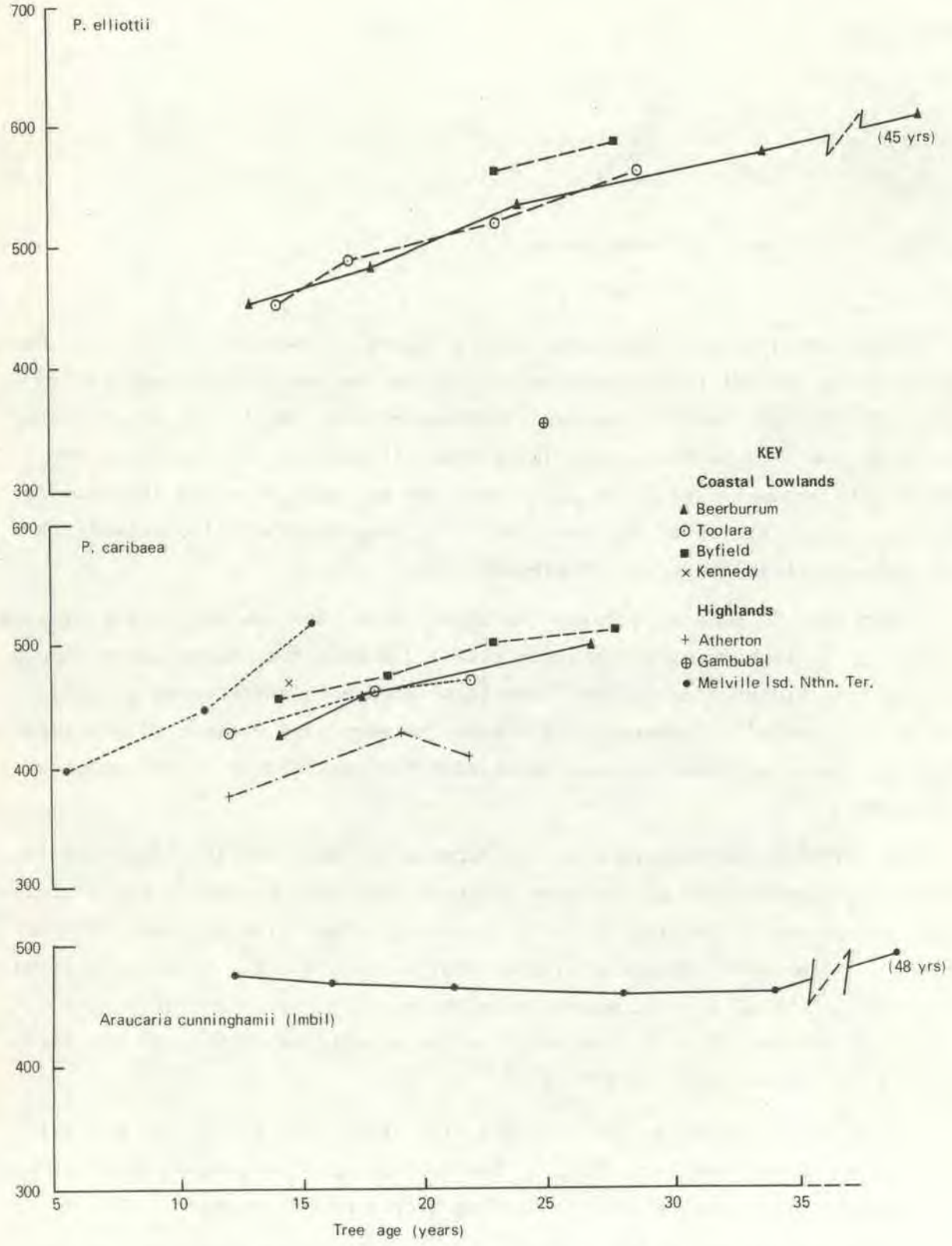



**Figure 2. Variation in Mean Basic Density with Age and Location for Slash, Caribbean and Hoop pines in Queensland plantations**

Areas of some concern regarding the wood density of exotic softwoods in Queensland have been:

1. the high density of slash pine, with its associated high latewood percentage. While advantageous for structural use and pulp yields, this is not as desirable in other applications for a general-purpose softwood.
2. the possibility that a tendency for Caribbean pine density to increase northwards could provide undesirably slash-like Caribbean pine in projected large scale northern coastal lowland plantations; and
3. the possible depreciation of density in Caribbean pine on high volume producing sites, especially in north Queensland, to a level adversely affecting structural application.

The survey has already provided information in all of these areas. Any problems with general purpose utilization of high density slash pine wood would be accentuated where planted on lower site qualities in the coastal lowlands. At the same time, such sites could be expected to yield higher strength structural timber, including poles, which, however, would be more difficult to treat with preservatives.

The depreciative effect of site-quality associated growth-rate on Caribbean pine density is not sufficiently pronounced to affect its utilization on the lowlands. Any effect of higher volume production associated with decreasing latitude is generally compensated for by a partially counterbalancing density trend to increase northwards. A reductive elevational effect compounds the generally fast growth-rate effect on the northern highlands to outweigh the counteracting latitudinal effect, with resultant low-density wood, which, while lower in structural potential, has a higher potential for higher-value furniture, joinery, mouldings, plywood and similar applications than lowland material. This offers scope, if desired, for the regional development in north Queensland of two complementary wood types in Caribbean pine for alternative markets - both capable of general purpose use but with any desired structural emphasis from lowland stock and, to eventually replace or supplement the traditional rainforest source, a higher-value joinery and plywood emphasis in highland production.

An apparent rapid increase in density outside the juvenile core of Caribbean pine in more tropical lowlands is indicated by the 519 $kg/m^3$ average at 15 yrs at Melville Island, higher than for any Queensland material to 28 yrs and comparable with 23 yrs old S.E. Queensland slash pine.

Hoop pine density has been checked in this study for only "average" site quality at one location (Imbil). The usual remarkable uniformity with age (4) was confirmed, with an apparent very small decrease over this interval to at least 34 yrs. An increase in 48 yrs old stock may have been at least partly associated with heartwood development.

Between-tree variation is of interest not only for utilization purposes, but particularly for application in tree improvement programmes. There was a surprising similarity in the large between-tree average density ranges for slash and Caribbean pines across age-classes to 30 yrs, localities and sites; 326 to 658 kg/m$^3$ and 301 to 635 kg/m$^3$, respectively. Variation with locality and age-class is shown in Table 2. Site-quality variation might be expected to account for much of the latter, but data not tabulated shows that up to 80% of the within-locality/age-class variation in Caribbean pine and up to 85% of that in slash pine existed within particular site-classes, a fact of special significance in the selection of breeding stock. The 20-tree plot ranges varied from around 80 to 170 kg/m$^3$ for slash pine and 90 to 200 kg/m$^3$ for Caribbean pine, depending on age, locality and site quality.

The between-tree variation in hoop pine at Imbil was less than for the exotics, with within-plot ranges around 70 to 120 kg/m$^3$.

Candidate-tree density assessments should and can now be related to data for age, locality and site quality combinations, providing a firmer base for selections. If further refinement was desired, individual tree increment core values could be related to the Pilodyn-estimated mean density of a 20-tree plot based on the candidate (Smith et al (5)).

The study is being extended to cover all localities, ages and sites planted and to other species. A softwood fibre resource inventory is being progressively developed.

## CONCLUSIONS

It is concluded that:

1. Basic density varied directly with age and inversely with elevation, latitude and site quality in slash and Caribbean pines;
2. Hoop pine density was remarkably uniform across age-classes to at least 34 yrs at Imbil;
3. Small early differences in density between slash (higher) and Caribbean pines increased with age.

4. Final-crop slash pine in Queensland has an average density higher than that of some Eucalypt hardwoods.

5. Latitudinal effects were evident from south to central Queensland in slash pine but only beyond central Queensland in Caribbean pine.

6. Often compensatory latitudinal and growth-rate effects are maintaining acceptable density in Caribbean pine northwards on the coastal lowlands.

7. An elevation-associated marked decreased in Caribbean pine density on north Queensland highlands indicates potential for the regional development of two complementary timber types for alternative markets.

8. Very large and surprisingly similar between-tree density ranges for Caribbean and slash pines, up to 80-85% of it at the site-quality/age-class/locality level, offer considerable scope for selection for wood density modification in either direction. There is less, but still useful variation in hoop pine.

9. The data is providing a firmer base for wood quality monitoring and improvement, and for management, marketing and utilization considerations.

REFERENCES

1. Smith, W.J. and Smart, J.A.J. (1972). Factors affecting wood quality in softwood plantations. Procs., 22nd Aus. T.I.S. Conf., Maryborough. 22 pp. Qld. Dep. For., Brisbane.

2. Hinds, H.V., and Ried, J.S. (Comp.) (1957). Forest Trees and Timbers of New Zealand. N.Z. For. Ser. Bull. No. 12. Gov. Prnt. Wellington, N.Z.

3. Smith, W.J. (1973). Wood yield, properties and quality in Queensland-grown *Pinus caribaea* Morelet. In "Selection and breeding to improve some tropical conifers" (Burley, J. and Nikles, D.G. eds.), Vol. 2 Commonw. For. Inst., Oxford and Queensland Dep. For., Brisbane: 45-69.

4. Smith, W.J. and Eccles, D.B. (1979). The wood properties, quality and utilization of *A. cunninghamii* Ait. pp. 25. In Procs., 1979 Routine-Research Conference, Qld. Dep. For., Brisbane.

5. Smith, W.J. et al (1981). Rapid field estimation of wood density using the Pilodyn. For. Prod. Res. Conf., Melbourne, 1981.

# COMPARATIVE WOOD QUALITY EVALUATION OF "FOXTAIL" AND "NORMAL" TREES IN *PINUS CARIBAEA* VAR. *HONDURENSIS*

W.J. Smith and D.B. Eccles
Division of Technical Services
Queensland Department of Forestry
Brisbane

## ABSTRACT

The wood quality of 5.5 yrs. old and 13-17 yrs. old "foxtail" and "normal" Honduras Caribbean pine at Beerburrum in S.E. Queensland has been compared.

Apart from some small differences in the central five-ring corewood, foxtail trees 13-17 yrs. old had wood not really different from normal trees (paired for age and growth-rate) in respect of most anatomical, physical and mechanical properties.

Small differences (slightly reductive) in some properties for the largely foxtail-phase formed core were not significant and disappeared and even reversed with age, with post-foxtail wood apparently superior to comparable wood in normal trees in most properties to sampling age.

55% of the foxtails' sawn yield was of joinery quality, compared with less than 3% for the normal stems.

Foxtail trees have a high potential for increased high value clearwood production with reduced pruning costs, justifying a critical reappraisal of the bases for discrimination against them in some management and tree improvement programmes.

## INTRODUCTION

"Foxtails" are pine trees unbranched for often considerable bole lengths, due to a form of apical dominance resulting in a failure to set lateral buds, with consequent continuous terminal growth over variable but often lengthy periods (1,2). They have longer and more persistent stem needles (1,2). The characteristic has been reported as apparently under genetic control (2,3), with its expression modified considerably by site and climatic factors and an apparently higher incidence under conditions favouring non-

seasonal growth (1,2,3,4). Foxtailing has been recorded for a number of pines, but particularly *Pinus caribaea* var. *hondurensis* (Caribbean pine) and *P. radiata*, (radiata pine) (1,2). Foxtail trees generally have a relatively short basal branched section, surmounted by the unbranched foxtail-growth period bole length and a branched top developed after reversion to normal growth after variable but often lengthy periods (2).

Foxtails have been disfavoured in forest management because of alleged or suspected lack of wind-firmness, reduced diameter increment, lower wood density and absence of latewood, compression-wood incidence and restricted seed production (1,2,3,5) and have been selected against as a defect in tree improvement programmes (e.g. 3). They have been discriminated against in early thinnings of Queensland Caribbean pine plantations (in 2).

They have a definite height advantage (2) and the suspected diameter disadvantage apparently does not prevail in Caribbean pine, at least on favourable sites (1,4). Observations in plantations subjected to cyclonic wind-storms in Fiji and Queensland suggest they may not be less wind-firm than normal trees, at least during the foxtail phase. In fact, six of the ten foxtail trees in the present study were residuals in a 17 yrs. old stand lowly stocked due to earlier cyclone damage.

Previous wood studies have been on young trees five to eight years old (1,6). Lanner found no latewood in *P. radiata* foxtails up to 5 yrs. old in Hawaii (1). In foxtail/normal *P. caribaea* wood comparisons for 8 yrs. old trees from Fiji and 6 yrs. old trees from Venezuela, Plumptre (6) found no tree mean density differences in the former case (but with lower density in the foxtail portions of stems), and significantly lower but small differences in the latter case (the foxtails having wood 8% less dense).

The apparently high potential of foxtail trees for knot-free wood production and utilization has been assessed in a comparative study of the anatomical, physical and mechanical properties and graded sawn recovery of paired foxtail and normal trees of *P. caribaea* var. *hondurensis* aged 13 to 17 yrs. and the density of 5 yrs. old foxtail and normal trees with the former still in the foxtail phase at Beerburrum in south-east Queensland. The results are summarised and briefly discussed herein. A more detailed report will be published separately.

MATERIALS AND METHODS

(1) Ten pairs of foxtail and normal Caribbean pine trees were selected in Beerburrum (S.E. Queensland) plantations - three, one, and six pairs aged 13 yrs., 15 yrs. and 17 yrs. respectively from Compartments thinned respectively once at 10 yrs. to approx. 705 stems/ha; twice at 11 and 15 yrs. down to 605 stems/ha; and twice at 11 and 12 yrs. down to 272 stems/ha. The quite high incidence of foxtails in these routine plantings is indicated by their persistence as residuals in thinned stands despite the characteristic's having been regarded as a defect in early selective thinning; these residual foxtails would have been the best of such trees, but this high-grading would also have applied to the residual normal component of the stand.

The foxtails were selected as trees which would have clearly exhibited the characteristic at first thinning, and not merely had long internodes. A few basal whorls were commonly present and accepted. One foxtail had been ground-pruned; the other 19 trees had had no pruning. Edge trees were excluded. Otherwise, foxtails were taken as encountered. A normal tree, comparable in girth, was taken as close as possible to each foxtail.

Stem size, form and branching parameters were measured, including height to base of foxtail section and length of branch-less stem. Stems were cut to log-lengths to suit subsequent sampling, which consisted of discs for anatomical and physical property studies at (a) the closest interwhorl to approx. 1 m above ground; at about 15 cm (b) above the base and (c) below the top of the foxtails' branchless stem sections and corresponding proportions of total height in each foxtail's partner. From each disc, diametral bark to bark strips were taken along a minor axis with the tree's longitudinal axis pre-marked for spiral grain determination on each outer surface.

Ring width, percentage latewood, basic density, percentage compression-wood, tracheid length, microfibrillar angle and spiral grain were determined from the strips (compression-wood only on a disc basis), mostly as pith to bark trends and always as mean values for each sample.

The logs were then sawn to diametral 40 mm thick bark to bark flitch along the minor axis and then 25 mm and 16 mm thick boards, maximizing recovery in common board and moulding sizes. The product, identified by tree and sub-log number was air-seasoned and the recovery, by grade distribution to the Australian Standard for Sawn Boards from Australian-Grown Softwoods (7), tallied for each sub-log. A measure of the relative persistence of stem needles was also obtained from the radial extent of needle traces on the central flitches.

Small clear specimens 2 cm x 2 cm x 30 cm were taken in a bark to bark series from appropriate diametral flitches to assess the mechanical properties of wood just above the base of the foxtail-formed portion of stems in comparison with those for clear wood at the same proportion of total height in normally branched stems. Modulus of Rupture (MOR) and Modulus of Elasticity (MOE) were determined by standard test methods as pith to bark gradients and as means for "corewood" (an approximate 5-ring central core), outer wood (the material outside that), and the whole diameter.

(2) Ten pairs of foxtail and normal Caribbean pine aged 5.5 years, the former still in the foxtail phase, were also sampled in an unthinned stand at Beerburrum, taking diametral strips from discs at approx. 1 m above ground from felled trees for basic density determination.

(3) Both pairs of trees were sampled at the same time by the Department's Forest Research Branch for foliar nutrient status studies.

RESULTS AND DISCUSSION

The more important results of the wood property and wood quality studies are summarised in Table 1. This gives comparative assessments of anatomical and physical properties at about 1 m above ground; mechanical properties near the base of the foxtail section and its comparable position in normal trees; sawn yields of joinery-quality wood; and some stem size, form and branching parameters.

Results of the Forest Research Branch's nutrient status studies have been summarised elsewhere (8).

The average basic density of 5.5 yrs. old Caribbean pine foxtail trees still in that phase was only slightly lower (by 4.6%) than that of adjacent normal trees. The difference was not significant, statistically nor practically. The average ring count at sampling level was about four.

In 13 to 17 yrs. old trees which had reverted to a branching habit after a foxtail phase, average breast-high density of the central five-ring core was only 3.7% lower than that of normal trees. The diametral average was almost identical with that of normal trees. The density results were generally similar to those reported by Plumptre (6) for 6 to 8 yrs. old trees.

Percentage latewood, tracheid length, Modulus of Rupture and Modulus of Elasticity also all exhibited slightly but not significantly lower values than paired adjacent normal trees for the five-ring corewood which would generally have encompassed most of the wood deposited in the foxtail phase. Spiral grain was slightly higher (i.e., worse) and ring width and microfibrillar angle not really different.

TABLE 1

Comparison of wood properties, sawn recovery and tree characteristics between foxtail and normal trees 5.5 and 13 to 17 yrs. old at Beerburrum, S.E. Q'ld.

| Feature | Foxtail Trees | Normal Trees |
|---|---|---|
| (A) AGE 5.5 years:- | | |
| No. of trees sampled | 10 | 10 |
| Basic Density (kg/m$^3$) (1) | 355 | 372 |
| (B) AGE 13 to 17 years:- | | |
| No. of trees sampled | 10 | 10 |
| Mean height (m) | 20.6 | 20.4 |
| Mean diameter breast high (cm) | 26.4 | 25.9 |
| Mean bark thickness (cm) (1) | 2.3 | 2.2 |
| Mean slenderness ratio (height (m)/ diameter (cm)) | 0.78 | 0.79 |
| Mean stem-form rating | 5.1 | 5.1 |
| Height to base of 'Foxtail' (m) | 1 to 3 | - |
| Mean length of branchless stem (m) | 8.2 | - |
| Range in length of branchless stem (m) | 5.3 to 10.8 | - |
| Persistence of stem needles - Radial extent (mm) | 31 | 22 |
| Taper | "Foxtails" less than the "normals" | |
| Yield of joinery quality sawn timber (%of total sawn yield) (6) | 55.4 | 2.7 |

| | Foxtail Trees | | Normal Trees | |
|---|---|---|---|---|
| | Core wood (3) | Whole Diameter (5) | Core wood (3) | Whole Diameter (5) |
| Mean ring width (mm) (1) | 12.0 | 7.7 | 12.2 | 7.3 |
| Basic density (kg/m$^3$) (1) | 411 | 455 | 427 | 460 |
| Percentage latewood (1) | 6.4 | 15.3 | 9.2 | 15.3 |
| Mean tracheid length (mm) (1) | 2.77 | 3.40 | 2.84 | 3.33 |
| Mean microfibrillar angle (°) (1) | 27.1 | 19.8 | 27.7 | 19.1 |
| Mean spiral grain (°) (1) | 2.6 | 2.8 | 2.3 | 2.5 |
| Compression wood percentage (2) | - | 2.0 | - | 1.6 |

| | Foxtail Trees | | | Normal Trees | | |
|---|---|---|---|---|---|---|
| | Core wood (3) | Outer wood (4) | Whole Diameter (5) | Core wood (3) | Outer wood (4) | Whole Diameter (5) |
| Modulus of Rupture (MPa) | 52.8 | 101.6 | 73.9 | 57.9 | 93.9 | 72.6 |
| Modulus of Elasticity (MPa) | 5,569 | 12,843 | 8,600 | 5,812 | 11,844 | 8,371 |

(1) Mean at about 1 m above ground

(2) Whole-disc average (along 2 diameters at right angles)

(3) Mean for five-ring core

(4) Mean for wood outside the core (3)

(5) Mean for whole diameter (pith to bark)

(6) Knot-free, seasoned timber in top two of five SAA grades.

The characteristics of the wood outside this foxtail influenced zone evidently improved on reversion to a branching habit to an extent such as to compensate and, in some cases, over-compensate for any slight foxtail-influenced depreciative effect. The strength (MOR) and stiffness (MOE) of the outerwood of foxtail trees was about 8% higher than that of normal trees and the mean-diameter values slightly but not significantly higher.

A similar effect must have prevailed in respect of basic density, per cent latewood and tracheid length, all of which had average stem values similar to or higher than normal trees. This was doubtless relatable to the improvements in strength and stiffness.

Microfibrillar angle and spiral grain values did not change detectably from corewood to diametral average, remaining the same as for normal trees in the former case, and the same slight degree worse than them in the latter case.

These overall improvements in wood properties in the outer wood (largely post-foxtail) occurred despite an apparent increase in breast high diameter increment by about 7% over the normal trees outside the 5-ring core.

Compression-wood incidence, assessed only for the whole disc, was slightly higher (2.0% v. 1.6%) in the foxtails, but is considered low and not detrimental in both cases.

In the grading rules used in the sawing study (7), the top two of the five grades provide wood knot-free and suitable in other quality requirements for high-value joinery, furniture, mouldings and similar applications. In log, such wood provides high-quality face veneers. The most important result of this study was the clear evidence that foxtail trees have a vastly superior potential to provide such material with little or no pruning. 55.4% of the total seasoned sawn yield from the foxtail trees was joinery quality wood in these two top knot-free grades, compared with only 2.7% for the normal stems.

Meaningful percentage sawn yields on log volume were not obtainable from this study, because of the primary emphasis given to wood study sampling. However, both sets of samples were sampled the same way and cross-cut to the same proportional lengths, and it is noteworthy that the total sawn volume recovered from the foxtails was appreciably higher than for normal trees well paired for height, diameter and stem form. The potential of foxtails for low-cost clearwood production is highlighted by the long branchless stem sections in the study trees (average 8.2 m; range 5.3 to 10.8 m), compared with pruned stem lengths available from current Queensland management practice at high cost, and yielding clear wood only outside a central core about 175 mm in diameter (2.4 m and 5.4 m for ground and second stage pruning, respectively).

Although foxtails can yield considerable quantities of clearwood without pruning, their advantage would be much enhanced by early low-level pruning to remove the basal whorls (1 to 3 m from ground in the study trees) for longer-length clearwood recovery from the high-volume butt log.

Needle-trace from the more persistent foxtail needles degraded from No. 2 to No. 3 grade about 5.6% of their total sawn recovery and 7.3% of that from the foxtail section. It was not recorded as a limiting factor below No. 2 grade in the normal trees.

From their radial extent and ring-width measurements (Table 2), it seems foxtail needles may persist about 40% longer than on normal trees in Caribbean pine, tending to support observations in Malaysia (2,4). This is probably a factor compensating in part for their appreciably lower foliar volume (4) despite greater needle length (1,2) in maintaining increments apparently competitive with normal trees (1,4). It seems reasonable to conclude that foxtails are photosynthetically highly efficient compared with normal trees. The implications of nutrient status (8) in interaction will be discussed in another report. It is particularly interesting that, after a slightly wood property depreciative foxtail phase, they seem to have a capacity to produce wood slightly superior in wood properties for perhaps at least 5 to 10 years.

## CONCLUSIONS

Apart from some small differences in the central five-ring corewood, foxtail Caribbean pine trees 13 to 17 yrs. old at Beerburrum had wood not different from that of normally branched trees (paired for age, growth-rate and site) in respect of average basic density, per cent latewood, microfibriller angle, and moduli of rupture and elasticity. Tracheid length, grain spirality and compression wood incidence were slightly but not significantly higher.

Small differences in some wood properties for the largely foxtail-phase formed five-ring core (reduced basic density, per cent latewood, tracheid length, and moduli of rupture and elasticity and increased spiral grain) were not statically nor practically significant and (except for spiral grain) disappeared and even reversed with age, due to an apparent tendency for wood formed in the post-foxtail phase period to be somewhat superior to those of normal trees in most of these properties at least to the age sampled.

Foxtail trees have a well demonstrated potential for increased high-value knot-free wood production for joinery, furniture, mouldings, plywood face veneers and similar applications, evidence by a 55% component of their sawn yield in joinery quality, compared with less than 3% for normal trees.

There is an apparent capacity for genetic and silvicultural improvement of this already high potential for the production of knot-free wood with inherent anatomical, physical and mechanical properties at worst no different from that of normal trees. There also seems to be good reason to reassess present bases for discrimination against foxtails in some management and tree improvement programmes. This latter discrimination is of particular concern in relation to its effect on the genetic base available for selection in residual stands in the event of a possible decision to select for rather than against the characteristic.

In any such reassessment, the assured vastly higher yields of much-needed high value clearwood on shorter rotations would need to be carefully weighed against suspected lesser wind-firmness or lower volume production which may not have been objectively established.

The occurrence of foxtailing in other pines, including radiata pine grown under favourable less seasonal conditions, also merits closer attention in relation to their clearwood potential.

REFERENCES

1. Lanner, R.M. (1966). The phenology and growth habits of Pines in Hawaii U.S., For. Ser. Rp. PSW-29.

2. Kozlowski, T.T. and Greathouse, T.E. (1970). Shoot growth and form of pines in the tropics. UNASYLVA 24(4): 6-14.

3. Slee, M.U. and Nikles, D.G. (1968). Variability of *Pinus caribaea* Mor. in young Queensland plantations. Paper prepared for 9th Comm. For. Conf. 1968; Qld. Dept. of For., Brisbane.

4. Ibrahim, Sheikh and Greathouse, T.E. (1972). Foxtailing in exotic pines - preliminary results of a study in West Malaysia. Malayan Forester. xxxv(1): 17-23.

5. Lange, P.W. (1966). The occurrence and development of abnormal long leaders in *Pinus radiata* D. Don in Cape Midlands. For. in Sth. Af., 7: 1-10.

6. Plumptre, R.A. (1978). Variation in wood density in *Pinus caribaea* var. *hondurensis* Barrett and Golfari, grown in plantations. Methods developed to study it and possible ways of reducing it. In: "Progress and Problems of Genetic Improvement of Tropical Forest Trees". Vol 1; 46-73. (Ed. Nikles, Burley and Barnes) C'wealth For. Inst., Oxford.

7. Standards Ass. of Australia. (1975). Australian Standard 1781-1975 - Sawn boards from Australian grown conifers (Softwoods) (Excluding Radiata pine and Cypress pine). Sydney.

8. Queensland Dept. of For. Res. Rept., 1979 - Q'ld Dept. of For., Brisbane.

# DISTORTION IN DRIED HEART-IN STUDS - WITH AND WITHOUT PRESTEAMING

R.L. NORTHWAY and F.J. CHRISTENSEN
Division of Building Research, CSIRO

## ABSTRACT

Four matched batches of heart-in (HI) radiata pine studs were dried in an experimental kiln, two with and two without presteaming but in all other respects according to the schedule recommended by the Radiata Pine Association of Australia (RPAA) for this material.

Statistical analysis of levels of distortion after drying revealed no significant differences between those presteamed and those dried directly from the green. Likewise, presteaming had no obvious effect on stabilizing levels of residual,reversible distortion in dried matched HI studs that were selected from each kiln run and cycled between extremes of psychrometric conditions.

## INTRODUCTION

Presteaming of HI studs has been claimed (1) to improve their "stability" after drying. It is also a mandatory requirement of the RPAA Industry Standard 100-1979 (2).

Doubts held by sections of the local softwood industry on the beneficial effect of presteaming have led to widespread criticism of the requirement on the grounds of increased cost, stack handling, steam usage and total processing time.

This study was undertaken in an attempt to determine if presteaming is an essential prerequisite to producing straight, "stable" H.I. studs by high temperature drying. Earlier experiments by the authors had suggested that studs dried directly from the green would meet requirements to about the same extent as those that were presteamed first.

## EXPERIMENTAL PROCEDURE

### Drying

A parcel of HI studs each 2.5 m long and approximately 105 x 42 mm in cross-section (i.e. 90 x 35 mm dry finished size), was sawn from a second-thinning operation in a 30 year-old stunted radiata pine plantation in South Australia. Studs were randomly allocated to four kiln runs of 72 pieces each. In each run, there was approximately the same proportion of studs sawn from the 2.5 m long butt log, the next-to-butt log and logs higher in the tree.

Each run of 72 studs was stacked in 6 layers of 12 across with adjacent studs in each layer off-set to give a square-ended stack 3.1 m long. A double row of stickers was placed at each end of the stack to provide support close to both ends of each stud. Top loading was applied through a heavy torsionally rigid frame with additional hydraulic loading to the total equivalent of 900 kg/m$^2$, if the top surface area of the stack is taken as 2.5 x 1.3 m.

The four separate kiln runs were conducted in pairs of which one was presteamed and the other was not. Presteaming, where used, and final steaming were both for 4 hours. Drying conditions were 130°C DBT and 70°C WBT with 6 m/s air velocity through the stack. Distortion measurements were made before and after drying.

### Cyclic conditioning

To assess any effect presteaming might have had on the "stability" of HI studs in service, two batches of 24 studs were cycled between fixed high and low humidity conditions. These corresponded to wood equilibrium moisture contents (e.m.c.) of 20 and 5% respectively. One batch of studs was from top logs and the other from butt ones. Each batch contained six studs from each of the four kiln runs, matched as far as possible for cut, spiral grain angle and behaviour during drying.

After four 96-hour cycles and one 14-day cycle, each batch was held in the laboratory for 17 days, first at 12% then at 9% e.m.c. conditions, placed under water sprays for 7 days, conditioned at 12% e.m.c.for 7 days and finally held for a further 7 days in the laboratory at 9% e.m.c. These exposure conditions are illustrated in the top graph of Fig. 1. At each change of conditions, each stud was weighed and measured for twist, spring and bow.

## RESULTS AND DISCUSSION

### Drying

From an average green moisture content (m.c.) of 85%, one stack from each of the presteamed and not-presteamed runs was dried to 12% and the other to 9% average m.c. after final steaming and cooling. These degrees of drying meet the requirements of both the RPAA (2) and the Australian Standard AS1490-1973 (3) respectively. Drying times are given in Table 1.

The effect of the 4 h presteaming treatment was to reduce drying time by about 1 h, but at the expense of both increased handling of stacks and total processing time by at least 4 h.

### Distortion after drying

The percentages of dried studs meeting the combined limits of distortion allowed in AS1490 for each of twist, spring and bow are given in Table 1 together with those meeting the more realistic half-limits for twist and spring but the full-limit for bow. The latter criterion approximates the distortion levels tolerated by most users of the material, whereas the former are largely based on structural considerations.

TABLE 1

Percentages of dried heart-in studs meeting AS1490 combined distortion limits (72 studs/run)

| Run No. | Presteamed | Final m.c. (%) | Drying time (h) | Full-limits (%) | Half-limits (%) |
|---|---|---|---|---|---|
| 1 | Yes | 9 | 13 | 99 | 79 |
| 2 | No | 9 | 14 | 93 | 71 |
| 3 | Yes | 12 | 10.5 | 100 | 82 |
| 4 | No | 12 | 12 | 97 | 81 |

Statistical analysis of the half- and full-limits acceptance figures showed no significant differences in distortion between runs for each pair of presteamed and not-presteamed stacks. This remained so even when figures for studs containing pith and those without pith were analysed separately. However, studs containing pith twisted considerably more as would be expected, but with most still within the full-

limits. Furthermore, separating studs into those from butt logs, next-to-butt logs and top logs and analysing these figures did also not reveal any significant differences between runs.

Close examination of the experimental material and results indicated other reasons than presteaming for its apparently beneficial effect shown in Table 1. In run 2, for example, there were more studs containing pith close to one edge than in the others; and, consequently, the results were biased by the more severe incidence of spring. When like studs only from runs 1 and 2 were compared, any differences between figures for presteaming and not-presteaming were quite small.

Cyclic conditioning

The effects of changing psychrometric conditions on the moisture content and distortion in a "typical" HI stud are shown in Fig. 1. "Typical" refers more to the direction of the changes rather than to their magnitude which is related to certain characteristics of the timber, principally steepness of sloping grain, cut, and elastic/plastic properties.

Sloping grain may occur naturally or be induced by sawing at an angle to the grain. Both occur together in most pieces of HI timber. Cut is meant to include growth ring orientation with respect to the width of the timber, the presence or absence of pith and where the pith is located within the cross-section of a stud. The elastic/plastic properties determine how much relaxation of the distortional stress produced by drying is converted to plastic set and how much remains as a residual elastic component to appear as distortional strain when the applied restraint is released at the end of the seasoning process.

Fig. 1 shows a direct relationship between the magnitude of the moisture content and the distortion changes, but an inverse one with respect to the direction of these changes. When resoaked under water sprays, the increase in moisture content to about fibre saturation point removed almost all of the three forms of distortion present in this particular stud. (Although this near straight condition is unusual, the direction of the changes follows the established pattern). However, when redried back to about 10% m.c. after spray soaking, twist and particularly bow were comparatively more severe than their initial values measured at about the same m.c. This would suggest some recovery of the plastic set induced by initial drying under restraint.

Such movement is superimposed on the reversible deformation changes occurring in response to moisture content changes.

Thus, HI studs cannot be completely stabilized against cyclic moisture content changes as long as they contain sloping grain. But where the grain is substantially straight, as does occur in material sawn away from the central core, there are virtually no moisture- related distortion changes in twist, spring and bow. Studs cut from such timber are naturally not distortion prone, not through the intervention of part or all of a seasoning process.

The occurrence of substantial levels of twist and spring in HI studs immediately after drying is caused by a number of factors, either alone or in combination. Mention has been made of sloping grain, cut and elastic/plastic properties. If corewood is used for studs, then greater care in sawing may ameliorate but certainly not eliminate distortion levels after drying. Likewise, some or all of the strain, which would otherwise be manifested as twist resulting from the residual distortional stress, can be partly or wholly converted to plastic set by stacking the restrained timber on a base with built-in slope opposite in direction to that in which the timber has a natural tendency to twist (4). Lack of adequate restraint during seasoning is another important contributor to distortion in dry timber. This may be due to insufficient or unsuitable stack weighting and/or to excessive variations in sawn timber and sticker thickness, deficiences that have obvious solutions.

On the other hand, a gross lack of "stability" in HI studs some weeks or even months after kiln drying is likely to be initiated by their inadequate drying whilst restrained throughout the seasoning process and caused by further drying down to ambient e.m.c. while not restrained. A clear example of this phenomenon is provided by the gross distortion levels occurring in studs from at least the top layers of stacks air dried from the green without restraint. The answer to this problem is to overdry the timber to an average final m.c. of 8-10% whilst it is restrained in the kiln. This will minimize the range of moisture contents after drying and largely eliminate the development of additional distortion weeks or months after kiln drying is completed.

While much of the preceding discussion has been of a general nature, it is specifically relevant to the work reported in this paper. It should be emphasized that high temperature drying can reduce the wood's hygroscopicity and, therefore, reduce the magnitude of the distortion which would otherwise have occurred in response to a given moisture content change, but it does not eliminate completely, in sloping grain material, distortional changes resulting from moisture content changes.

Observations made on the absence of any apparent effect of presteaming in stabilizing levels of residual, reversible distortion in cycled material were based on graphical evaluation of results, not on statistical analysis of them. Results for the latter are not yet available.

## CONCLUSIONS

Distortion in dried HI studs is related to both the sloping grain angle and the cut of the timber. The steepness of the grain directly influences the degree of distortion whilst the cut mainly determines its form, although pith can also affect the intensity.

Dried HI studs subjected to cyclic psychrometric conditions exhibited a direct relationship between the magnitude of the m.c. and distortion changes, with the latter having a wide range of values for different specimens. The direction of the distortion changes is the inverse of that for the m.c. ones.

Reversible dimensional movement is an inherent characteristic of HI studs and was not eliminated or even apparently reduced by presteaming in the experiments reported in this paper. However, results indicate that repeated cycling can increase the level of distortion, possibly by recovery of some of the plastic set induced by drying under restraint.

Presteaming did not significantly improve the straightness of HI studs after drying even when compared on the basis of separation into groups with pith, without pith, and from butt, next-to-butt and top logs.

The direct, gas fired kiln used in this present work reaches operating temperature very quickly. The demonstrated lack of any obvious need for presteaming HI studs is thought to be applicable to all modern high-temperature kilns used by industry. This does not exclude the possibility of a different outcome when such timber is dried in older type kilns with much slower rates of initial heating.

REFERENCES

(1) Mackay, J.F.G. and Rumball, B.L. (1971). Drying of distortion prone radiata pine for house studs. Aust.Timb.J.,37(6):43-57.

(2) Radiata Pine Association of Australia (1979). High temperature drying of heart-in, radiata pine, structural material. Industry Standard 100-1979, Adelaide, South Australia.

(3) Standards Association of Australia (1973). Visually stress graded radiata pine for structural purposes. AS1490-1973, Sydney, Australia.

(4) Christensen, F.J. and Gough, D.K. (1975). Control of drying distortion in framing from young plantation slash pine. CSIRO, Div.Build.Res.Rpt.No.44.

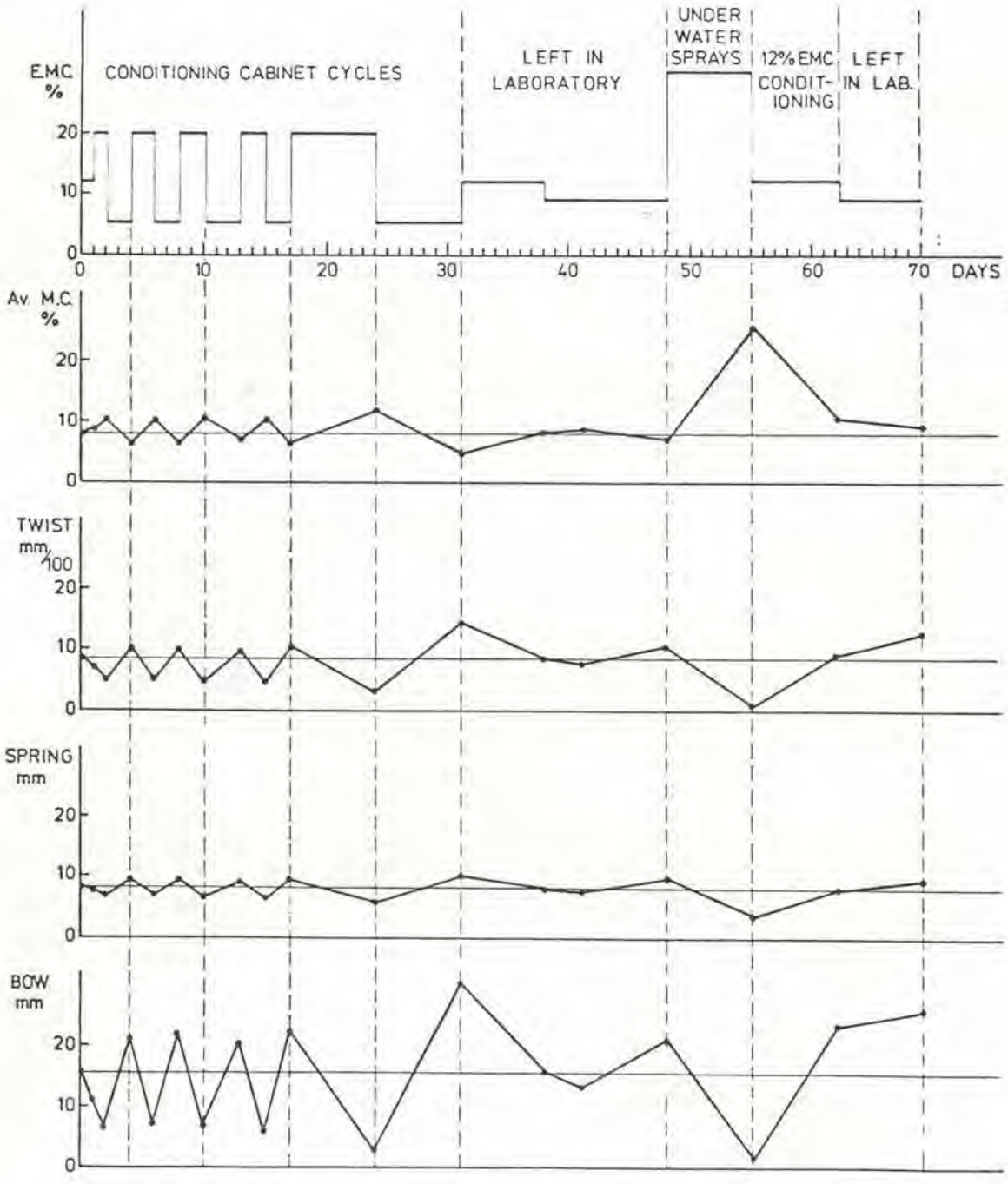



Fig. 1. Influence of changing equilibrium moisture content conditions on the moisture content and distortion of a "typical" 90 x 35 mm heart-in radiata pine stud.

# RESTRAINT FORCES NEEDED TO HOLD RADIATA PINE HEART-IN STUDS STRAIGHT DURING HIGH TEMPERATURE DRYING

RICHARD NORTHWAY
Division of Building Research, CSIRO

ABSTRACT

Samples of heart-in radiata pine studs were individually dried at a range of high temperatures while prevented from distorting and the forces needed for this restraint measured throughout the drying cycle. Some short and full-length specimens were restrained against twist and some full-length ones were restrained against spring and bow as well as twist. The plots of these forces against time illustrate the necessity for maintaining restraint throughout the complete seasoning cycle in order to minimise the residual distortion when the restraint is released.

## INTRODUCTION

To satisfactorily utilise thinnings from plantations of Pinus species, which characteristically have a high incidence of spiral grain near the pith, it is necessary to restrain sawn structural boards during kiln drying to minimise the distortion, primarily twist, which otherwise would develop. Concrete weights placed on top of kiln stacks have been demonstrated to be effective, particularly when used in conjunction with high temperature schedules (1, 2), and have been widely adopted by the Australian softwood industry. Current practice also includes a steaming treatment after drying (and before drying for heart-in (HI) studs), usually in a chamber separate from the kiln, in order to equalise moisture content through the boards and relieve drying stresses. In addition, the weights remain on the stacks during subsequent cooling. Thus the restraint is maintained throughout all phases of the seasoning cycle.

Mackay (3) found that the twist developed in 35 mm studs during drying and the torque required to prevent it, were each proportional to elapsed drying time. This was established by periodically measuring the free angle of twist and determining the torque needed to restore the stud to its original untwisted form. This provided information on the level of restraint required to prevent twist during the drying phase but not for the final steaming and cooling phases.

The work reported here was planned to determine how the restraint requirement varied during the separate phases of a cycle and to assess the importance of continuous restraint in controlling twist, spring and bow. The results presented are examples of those obtained from a wider range of material tested and have been chosen to illustrate the most significant features of the recorded behaviour. All material was pith-included (PI) as well as HI.

## EXPERIMENTAL METHODS

For measuring the torque developed by a short specimen, a jig (Fig. 1) was built which suspended the specimens transverse to the direction of air flow in a 305 x 305 mm cross-section tunnel kiln. The jig forms part of the roof of the kiln and includes a torque member carrying the mounting points of the four rods supporting the specimen. The specimen can be removed from the kiln for cooling or steaming in a separate chamber while still restrained in the jig. Mounting the sample support assemblies on the torsionally rigid roof of the working section of a large tunnel kiln allowed torsional restraint forces to be maintained with specimen lengths of up to 3 m.

A more elaborate jig (Fig. 2) mounted in the same way, allowed the forces required to prevent any twist, spring and bow from developing in 2500 mm long studs to be separately and simultaneously monitored during drying.

All specimens were effectively end coated to eliminate longitudinal moisture movement and avoid differences in mode of drying between short and long specimens.

## RESULTS AND DISCUSSION

The torsional restraint curve for a short sample of PI stud section dried at 180°C is shown in Fig. 3. This sample, which was all heartwood, was dried from 34% green

moisture content (mc) to 7.6% final mc. The sharp increase in restraining force during cooling and the relaxation during steaming are typical of the behaviour of all specimens near to the pith or with enclosed pith. The reducing slope of the latter half of the curve during drying is typical of the behaviour of short PI specimens. The differing curves for matched 300 mm and 2050 mm long PI specimens (Fig. 4) suggest that this is a length effect. It is thought that the mechanism allowing the partial relaxation or inflexion in the curve involves longitudinal shear at the ends of the specimen. On some specimens each end which had been cut squarely before drying exhibited an annular depression where greater longitudinal shrinkage had occurred about the rectangle 10 mm or so from the edges of the section. This deformation, obvious only at the ends of the specimen, was much more significant for short specimens than for long ones.

When the specimens were released at the end of the seasoning cycle the elastic deformation was, for specimens of similar density and final moisture content, approximately proportional to final restraining torque. For studs to finish straight it would be necessary to predict the amount of elastic recovery and to apply and maintain, throughout drying, a twist of opposite direction to that which they would normally tend to develop as they dried. Christensen and Gough (1) adopted this technique with slash pine corewood and it is used commercially by one Australian company to limit distortion to acceptable values.

While the curve for the 2050 mm long specimen shown in Fig. 4 shows a definite inflexion when compared to the generally linear curve obtained by Mackay (3) this is thought to be due to the differences in experimental methods. His curve was derived by periodically straightening an otherwise unrestrained 1200 mm long specimen during drying, a procedure which would be expected to reduce the degree of stress relaxation and plastic set induced with continuous restraint. In other experiments, where he restrained the specimen during drying and only periodically released it to measure twist and torque, he obtained much lower torque values.

Some relaxation also occurred in samples where the restraint was maintained for considerable periods after final conditioning and cooling to ambient temperature (Fig. 4). This appears to be dependent on moisture redistribution within the timber and, in some cases, moisture gain from the atmosphere.

Fig. 5 shows the forces required to fully restrain a stud held at each end and its midpoint. This PI stud, which was all heartwood, was initially straightened and dried from 30 to 10% mc. The restraint curves thus show both the initial forces required to straighten the specimen and those needed to hold it straight during drying. The two torque curves shown in Fig. 5 represent the separate torques required to prevent each end twisting relative to the centre. The spring and bow forces are those required to hold one end in line with the middle and the other end of the stud.

Some inflexions in the curves coincided with fan reversals, e.g. the large peaks near the end of drying for torque and spring force occurred when the drying was stopped and recommenced. The curves of restraint forces necessary to prevent all forms of distortion each show significant increases during cooling both before and after final steaming as well as major relaxation during final steaming. This confirms the necessity for continuous restraint during the complete seasoning cycle to prevent all modes of distortion.

In contrast to the behaviour of heart-in specimens, any material sawn 50 mm or more away from the pith (i.e. not heart-in by the definition of AS1490) needed only low restraint forces to keep it straight during drying.

## CONCLUSIONS

Although the levels of restraint forces given in this paper cannot be regarded as definitive, there is substantial agreement with the figures for twist reported by Mackay (3). The shapes of the curves for all forms of distortion do, however, show that continuous restraint is necessary throughout the whole seasoning cycle to minimise the final distortion.

This work has demonstrated that progressively increasing restraint forces are needed to keep heart-in radiata pine studs straight during drying, and that the restraint should be maintained throughout the periods of conditioning and, particularly, cooling of the timber. Even so, this will not be able to eliminate all final distortion because of elastic recovery on release of the restraint.

REFERENCES

(1) Christensen, F.J. and Gough, D.K. (1975). Control of drying distortion in framing from young plantation slash pine. CSIRO Div. Build Res., Rpt No. 44.

(2) Mackay, J.F.G. and Rumball, B.L. (1971). Drying of distortion prone juvenile core radiata pine for house studs. Aust. Timber J. 37 (7), 43-57.

(3) Mackay, J.F.G. (1973). The influence of drying conditions and other factors on twist and torque in Pinus radiata studs. Wood and Fiber 4 (4), 264-271.

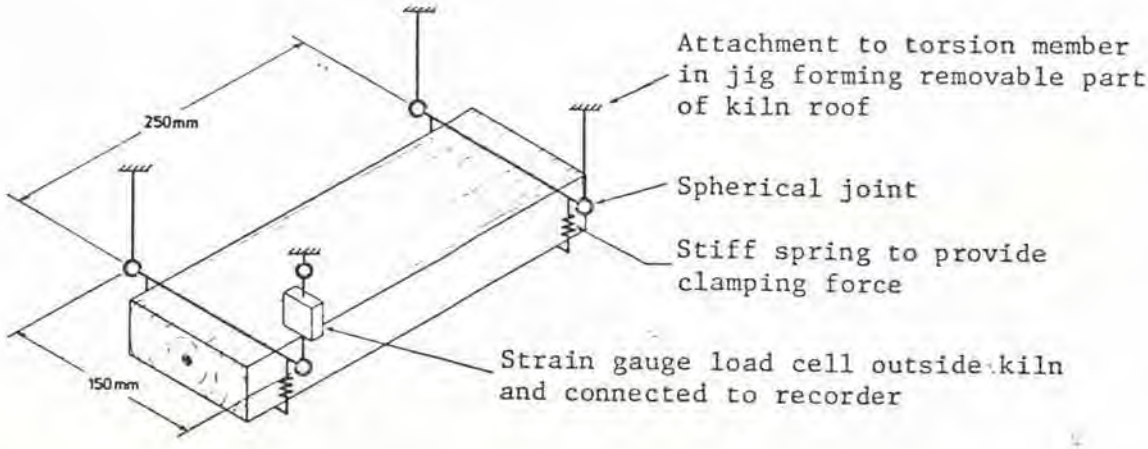



Fig. 1. Method of isolating and measuring the restraining force needed to prevent a sample from twisting during drying.

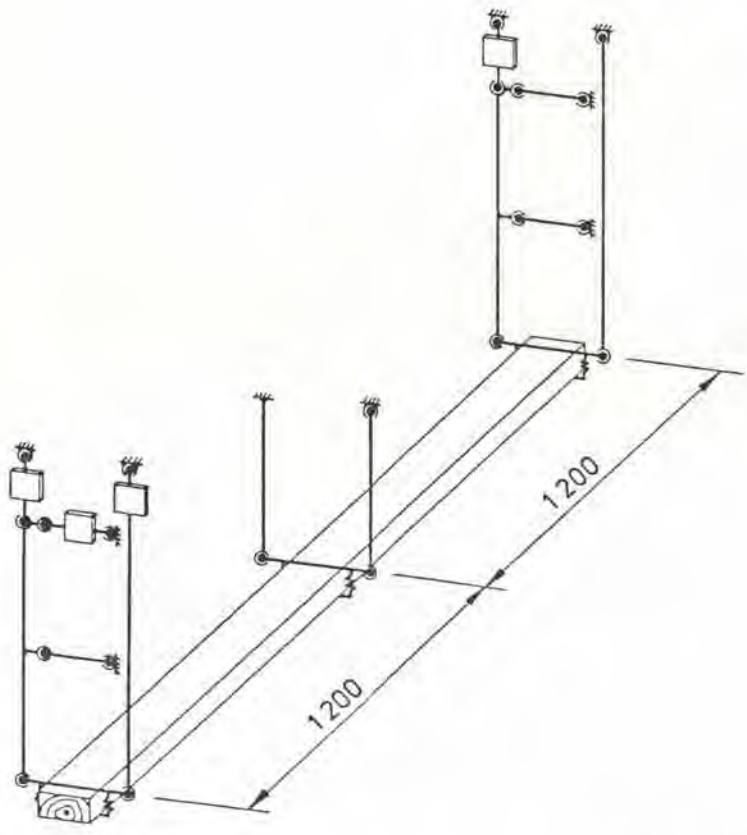



Fig. 2. Method of fully restraining a stud during a drying cycle to measure the forces necessary to prevent it from twisting, springing or bowing.

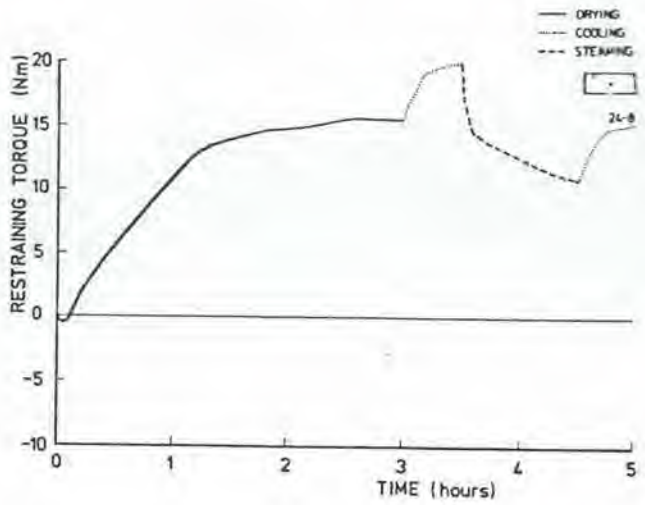



Fig. 3. Restraining torque required during the drying cycle to prevent twist in a 300 x 102 x 42 mm pith-included sample of radiata pine dried at 180°C whilst restrained as shown in Fig. 1.

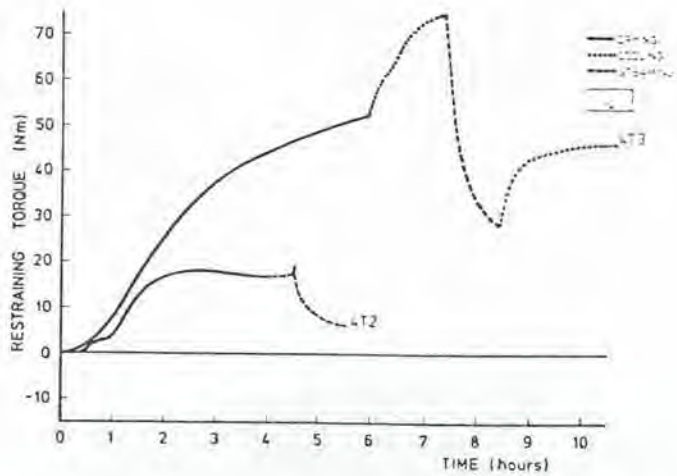



Fig. 4. Typical curves for restraining torque required during the drying cycle to prevent twist in end-matched short and long samples of pith-included radiata pine:

4T2 - 300 x 102 x 52 mm sample restrained as shown in Fig. 1 and dried at 180°C.

4T3 - 2050 x 102 x 52 mm sample restrained as shown in Fig. 1 but over 2000 mm spacing of supports, and dried at temperatures rising from 130°C at 1 h to 165°C at 3.5 h and thence held at 165°C.

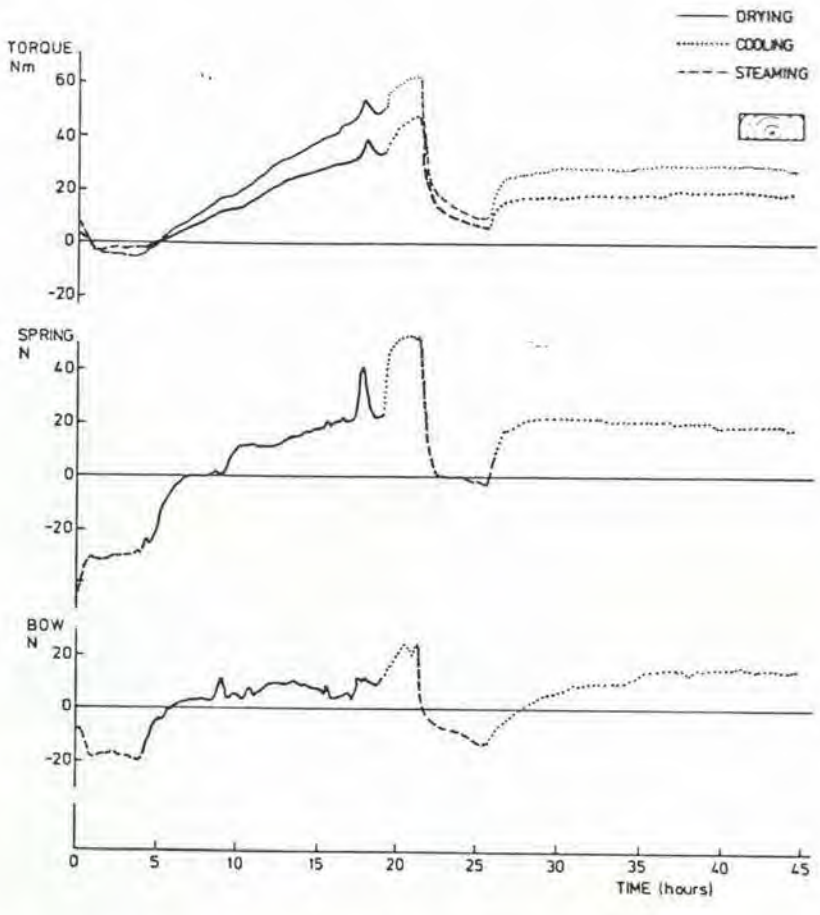



Fig. 5. Restraint forces required to initially straighten a 2500 x 102 x 42 mm pith-included radiata pine stud, and to hold it straight by the method shown in Fig. 2 whilst drying at 130°C.

# PSYCHROMETRY IN HIGH TEMPERATURE KILN DRYING - MINIMISING WET BULB TEMPERATURE ERRORS

RICHARD NORTHWAY
Division of Building Research, CSIRO

## ABSTRACT

Using wet and dry bulb temperature measurements to determine humidity in high-temperature kilns can be inaccurate because of errors in the wet bulb temperature reading unless care is taken. The sources of error are discussed and methods of ensuring that errors are within reasonable limits are described.

## INTRODUCTION

For kiln drying timber at temperatures below 100°C, the simple wet bulb installation can give sufficiently accurate measurements of wet bulb temperature (WBT) for adequate control of drying.

At temperatures above 100°C some features of the wet bulb installation assume more importance than at lower temperatures. Considerable error in WBT readings can occur if some care is not taken both with the design and operation of the installation.

## REQUIREMENTS FOR ACCURATE WET BULB TEMPERATURE MEASUREMENT

The function of the wet bulb wick is to hold a thin film of water on the WBT sensor. Cotton or linen cloth is usually used and should be clean and fit closely. Wicks should be free of grease, saturated with water before installation and preferably not handled with bare hands. The wick should be replaced whenever any discoloration can be seen. In high temperature pine kilns resin condensation can impair the

effectiveness of the wick very quickly. Once dried out a wick cannot usually be adequately re-wetted. Impurities in the water supply very quickly cause incrustations on the wick and distilled water should be used.

Because of the high rate of evaporation at high temperatures and large wet bulb depressions it is more difficult to keep the wick saturated; however this is essential for accurate WBT measurement. The water temperature should be close to WBT since significantly higher or lower water temperatures can reduce the area of wetted surface in equilibrium with the atmosphere and elevate or depress the indicated WBT (1).

Heat conduction along the stem of the wet bulb element can be reduced by minimising its length within the kiln and by extending the wick along the stem as far as possible.

Rosen and Simpson (2) concluded that WBT can be substituted for adiabatic saturation temperature to determine humidity using readily available charts and tables without unacceptable error. Threlkeld (3) showed that the difference between WBT and adiabatic saturation temperature is dependent upon the wet bulb diameter and the air velocity. For smaller wet bulbs the air velocity can be lower. For accurate measurements the velocity should be at least 2.5 m/s over the wick. As it is general practice to reverse the direction of air flow periodically care should be taken to ensure the adequacy of air flow over the wick in each direction. When the air flows vertically upwards the wet bulb trough may shadow the sensor; its effect should be minimised by making it as narrow as possible, rounding its bottom and either keeping it 50 mm or more from the wall or mounting if square to the wall.

## PRACTICAL WET BULB TEMPERATURE MEASURING SYSTEM

While the sewn cloth wick commonly used on wet bulbs can, if properly made and fitted, give satisfactory results tubular cotton braid has been found to have some advantages. Fig. 1 shows how the tubular wick is installed. The material is available in a range of sizes to suit various bulb diameters and is cheap. Since the braid tightens on the bulb when stretched it fits very closely and is less likely than cloth to dry out perhaps because of stronger capillary action. The constantly overflowing type of water supply should be used to ensure that an adequate water level in the trough is maintained.

For drying at very high temperatures with large wet bulb depression the system shown in Fig. 2 has been developed. Here the water is supplied through the sensor stem under the wick to a point about 20 mm from the sensing element. The stem slopes up to the sensor so that excess water runs away from the sensor to a small reservoir concentric with the stem. The reservoir overflows outside the kiln. This system ensures that water is supplied to the wick over the sensor by capillary action so that the water film is thin and the water supply is brought to near WBT before it is supplied to the wick. Provided that there is water overflowing this gives consistent results even with the water in the reservoir close to boiling point while the WBT is around 60°C and the DBT 180°C.

Fig. 3 shows the installation depicted by Fig. 1 modified by extending the water supply tube through the reservoir to supply the wick directly. This should ensure reliable measurements of WBT in high temperature kilns.

## CONCLUSIONS

Adherence to the requirements outlined, preferably applied as shown in Fig. 3, will allow the kiln operator to be confident of the accuracy of WBT measurements and corresponding humidity determinations in high temperature kilns, provided of course that the measuring instruments are maintained in calibration.

## REFERENCES

(1) Worrall, R.W. (1965). Psychrometric determination of relative humidities in air with dry bulb temperatures exceeding 212°F. In A. Wexler, ed., Humidity and moisture measurements and control in science and industry. Vol. 1, pp. 105-109.

(2) Rosen, H.N. and Simpson, W.T. 1980. Evaluating humidity at dry bulb temperatures above the normal boiling point of water. Wood and Fiber, 13(2) pp. 97-101.

(3) Threlkeld, J.L. 1970. Thermal Environmental Engineering. 2nd Ed. Prentice-Hall, Inc., N.J. pp. 205-210.

# DRYING AND STRESS GRADE OF STUDS FROM YOUNG RADIATA PINE



F.J. CHRISTENSEN and R.L. NORTHWAY

Division of Building Research, CSIRO

ABSTRACT

Studies made on 360 predominately juvenile wood studs sawn from 14 to 20 year-old radiata pine trees demonstrated that, with recommended high temperature drying procedures, distortion in most dried pieces was kept within the current code requirements.

However, results of machine stress grading tests showed the bulk of the heart-in material to be inherently weak and even moderate use of it for framing would have to be based on F4 rather than F5 stud grade.

## INTRODUCTION

In softwood plantation thinning operations, particularly the early ones, a considerable number of stems are suitable for conversion into house studs. Yet much of this material is essentially juvenile wood having properties that might make a relatively large proportion of it unsuitable for such a purpose.

Three of the more important of these properties, which can prevent complete utilization as intended, are its density, seasoning and strength characteristics. If any one is unsatisfactory, then the economically attractive option of using much of this material for studs would no longer be open. This could result in a reduced availability of logs for this purpose with its consequent effect on the early economic viability of the plantations.

The current work explores the drying, distortion and stress grade of studs sawn from small diameter logs obtained from first and second thinning operations. It was initiated after an approach from a sawmiller who had an unacceptably high rejection rate for heart-in (HI) studs because of high levels of distortion after high temperature drying. It is expected that the results reported here will have a very wide relevance to the local softwood industry.

EXPERIMENTAL PROCEDURE

A total of 360 radiata pine studs, each 3m long by 90x35mm finished size, was dried under high temperature conditions in five separate runs with 72 studs in each run. A dry bulb temperature (DBT) of 130°C was used in every run while the wet bulb temperature (WBT) was varied between 60-90°C to cover the range of values being used by industry. In four out of the five runs, the kiln was rapidly heated to operating temperature in 10-20 minutes but over a 6h period in the remaining one to simulate the normal rate of heating attainable with older type kilns. Details of conditions used in each run are given in Table 1. In all cases, air velocity through the stack was $6ms^{-1}$ and top loading equivalent to $750kgm^{-2}$ of stack area was applied during all stages of seasoning. Material was cooled after drying and then steamed for 3h; it was not presteamed.

Two distinct batches of material were supplied. That used in runs 1-3 was randomly allocated to each of those runs, whereas the separate identities of each of the two parcels comprising the second batch were maintained in runs 4 and 5 respectively. All material was harvested from plantations in the Portland-Dartmoor region of Western Victoria.

In runs 1-3, practically all of the timber was heart-in (HI) from 14 year-old first thinnings. Generally, 12mm thick linings were cut from the centre of the logs and studs from just outside that region, thereby reducing the incidence of pith-in (PI) material to about 7-15% of all pieces. The timber for runs 4 and 5 was sawn from 20 year-old second thinnings. All but one stud in run 4 was HI and some 28% also PI, presumably from top logs because of the presence of little well-defined heartwood. The studs in run 5, which came from both butt and upper logs, tended to be sawn further from the pith than those in the other runs, but only about 30% could be classified as sapwood. Of the remainder, 50% were HI by the AS1490(1) definition of radius less than 50mm and 20% intermediate between the other two categories. Out of the non-sapwood material, about 35% appeared to be heartwood.

Run 3 material was thicknessed to 42 mm green after measurements on runs 1 and 2 disclosed wide fluctuations in thickness, including taper at the ends.

All studs were measured for twist, spring and bow before and after drying in 3m lengths and again, after subsequent docking and planing, over a 2.4m span. The sawn 3m lengths were visually graded according to AS1490 after drying, and later machine stress graded in 2.5m lengths after planing to finished size.

## RESULTS AND DISCUSSION

### Drying

Data for the 5 runs are given in Table 1. The initial average moisture content of the young juvenile wood was extremely high at 141-150% (oven-dry basis) in runs 1-4 while the run 5 material had the significantly lower value of 112%. The drying rate of the young HI juvenile wood was closely aligned to that of sapwood rather than mature HI wood from the same central zone in the tree. (The last-mentioned usually dries at less than half the rate of sapwood but more quickly from its much lower initial moisture content of 30-50%).

Increasing the WBT from 70°C in run 2 to 90°C in run 3 increased drying time by about one-third when the kiln was rapidly heated to the operating DBT of 130°C in 10 and 20 minutes respectively. The combination of 90°C WBT and the slow rate of heating to 130°C in 6h (run 4) almost doubled the drying time.

### Distortion

Average values with standard deviations for twist, spring and bow in 3m long sawn studs, before and after drying, are given in Table 2. The main feature of these results is the comparatively high levels of distortion in the green material before any drying had taken place. Twist and bow values had doubled or trebled after drying whereas spring showed little change between green and dry values. Still, all averaged dry values are small compared with the limits permitted in AS1490: not greater than 30mm for twist, 15mm for spring and 40mm for bow, for the size of studs involved.

The lowest level of bow after drying occurred in run 4 where more studs had been sawn from the centre of logs and contained the highest proportion of PI material. Compared with the distortion in dried sawn studs, that in dressed dried studs (not given here) revealed a substantial and consistent reduction in twist and bow but practically none in spring.

Percentages of dried studs meeting the combined full-limits for distortion permitted by AS1490 and half those limits for twist and spring are shown in Table 3, as are independent rankings for half-twist and half-spring limits. Almost all of the material met the combined distortion full-limits (column 2) compared with 71-94% meeting the more realistic half-limits(2). Based on this criterion, excessive spring was the sole cause of the downfall in runs 1-3 but much of it was already present in the green material (e.g. only 76% of green studs in run 1 were within the half-limit for spring). However, any strong propensity for these studs to twist had been reduced by sawing lining boards from the centre of the logs as described earlier. It is not possible to say definitely whether the improved result for material in run 3 was due to thicknessing of the studs before drying or to the WBT of 90°C.

In run 4, which contained a relatively high proportion of PI studs, the high level of twist after drying was responsible for the high downfall. As would be expected, the best result was obtained for the run 5 material with the lowest proportion of young juvenile wood.

Stress grading

Results for visual and machine stress grading of all dried studs are given in Table 4 together with combined distortion acceptance levels for dressed studs measured over a 2.4m span. The distortion criteria are AS1490 full-limits in the first column and half those limits for twist and spring in the second column. Comparison of full-limit acceptance levels in Tables 3 and 4 shows almost identical values for the 3m and 2.4m spans respectively, distortion limits having been adjusted for stud length differences.

On the average, 65% of the visually stress graded material made F5HI or higher compared with only 31% of the same sample reaching F5 or higher with machine stress grading. The greater falldown with the latter can be attributed to the influence of low density on the stiffness of many pieces, the basis of assessment by the machine stress grading machine used. There is no such downgrading with the visual grading of any stud grade material because low density does not have to be considered in making the assessment.

Assuming a market exists for F4 machine stress graded studs, then 64% of the studs examined in the current work would make that grade. This still leaves some 35% of the material which is below F5HI visual stress grade or 36% below F4 machine stress grade for which alternative uses would need to be found. The problem is how to detect this material before it is sawn and committed to a particular end use.

## CONCLUSIONS

In terms of green moisture content, drying times and permeability, young juvenile wood is more akin to sapwood than mature HI timber.

Drying times were almost doubled by using a high wet bulb temperature (90°C) and a slow rate of initial heating (6h to 130°C).

Comparatively little distortion, in terms of AS1490 requirements, was induced in young juvenile wood studs dried under restraint with high temperature schedules but without initial presteaming. A large proportion of the distortion, particularly spring, was present in the green sawn timber.

There was no definite evidence that high wet bulb temperatures produced less drying distortion than lower ones.

Over one-third of the young juvenile wood studs were below current minimum requirements for use as studs according to either F5HI visual stud grade or F4 machine stress grade.

Only 31% of the machine stress graded studs were F5 or over. Much of the downfall can be attributed to low density of the young juvenile wood.

Two problems still to be solved are finding alternative uses for low stress grade juvenile wood and how to detect it with confidence before it is sawn and/or dried.

ACKNOWLEDGEMENTS

The authors thank their colleague, Gary Waugh, for visual grading of the studs and the South Australian Woods and Forests Department for use of their machine stress grading facilities.

REFERENCES

(1) Standards Association of Australia (1973). Visually stress graded radiata pine for structural purposes. AS1490-1973, Sydney, Australia

(2) Northway, R.L. and Christensen, F.J. (1981). Distortion in dried heart-in studs : with and without presteaming. Topic D1, 20th For.Prod.Res.Conf., Melbourne, Australia. 8 pages.

TABLE 1

Drying data for 3m by 90x35mm studs from 14-20 year-old radiata pine thinnings (72 studs/run)

| Run | Drying Conditions (°C) DBT | WBT | Drying time (h) | Average moisture content (%) Initial | Final |
|---|---|---|---|---|---|
| 1 | 130 | 60 | 14 | 142 | 7 |
| 2 | 130 | 70 | 12 | 142 | 12 |
| 3 | 130 | 90 | 16 | 141 | 10 |
| | | | 7 | | |
| 4* | 130 | 90 | 24 | 150 | 13 |
| 5 | 130 | 70 | 10.5 | 112 | 10 |

*Slow heating up: 6 h to 130°C; other runs: 10-20 minutes to 130°C.

TABLE 2

Average distortion levels in 3m by 90x35mm studs
before and after drying
(72 studs/run)

| Run | Green (mm) | | | After drying (mm) | | |
|---|---|---|---|---|---|---|
| | Twist | Spring | Bow | Twist | Spring | Bow |
| 1 | 1.7 | 5.1 | 3.8 | 3.9 | 6.3 | 11.2 |
| | (1.4) | (3.4) | (2.5) | (3.2) | (5.5) | (6.7) |
| 2 | 1.5 | 4.8 | 4.0 | 3.6 | 4.6 | 9.2 |
| | (1.3) | (3.4) | (2.8) | (3.3) | (3.7) | (5.8) |
| 3 | 1.8 | 3.9 | 3.3 | 3.2 | 4.5 | 8.0 |
| | (1.4) | (3.3) | (2.6) | (2.6) | (3.3) | (6.1) |
| 4 | 2.2 | 2.6 | 3.4 | 7.6 | 3.4 | 5.8 |
| | (3.9) | (2.6) | (2.4) | (4.5) | (2.7) | (4.3) |
| 5 | 1.5 | 2.4 | 3.9 | 4.4 | 3.2 | 8.7 |
| | (1.6) | (2.0) | (2.4) | (3.6) | (2.7) | (7.3) |

( ) Standard deviation

TABLE 3

Percentages of dried 3m by 90x35mm studs meeting
AS1490 combined distortion limits and other criteria
(72 studs/run)

| Run | AS1490 limits | | User acceptable limits | |
|---|---|---|---|---|
| | % not >30mm Twist or >15mm Spring or >40mm Bow | % not >15mm Twist or >8mm Spring >40mm Bow | % not >15mm Twist | % not >8mm Spring |
| 1 | 94 | 71 | 100 | 71 |
| 2 | 100 | 82 | 100 | 82 |
| 3 | 100 | 83 | 100 | 83 |
| 4 | 100 | 86 | 95 | 92 |
| 5 | 100 | 94 | 100 | 94 |

TABLE 4

Percentages of dried 90x35mm studs meeting
specified distortion and stress grade limits
(72 studs/run)

| Run | + % not >24 Twist or >10 Spring or >25 Bow | ++ % not >12 Twist or >5 Spring or >25 Bow | Stress grading method *Visual grade | | | **Machine grade | | |
|---|---|---|---|---|---|---|---|---|
| | | | <F5 | F5HI | ≥ F5 | <F4 | F4 | ≥ F5 |
| 1 | 97 | 72 | 44 | 43 | 13 | 31 | 38 | 31 |
| 2 | 97 | 86 | 33 | 42 | 25 | 39 | 33 | 28 |
| 3 | 100 | 78 | 39 | 44 | 17 | 38 | 40 | 22 |
| 4 | 100 | 96 | 39 | 56 | 5 | 48 | 28 | 24 |
| 5 | 100 | 93 | 21 | 47 | 32 | 25 | 25 | 50 |

\+ AS1490 limits for 2.4m studs
++ Half-limits for twist & spring

* 3m long, rough sawn
** 2.5m long, dressed

# DETERMINING END-POINT FOR SOFTWOODS DRIED AT HIGH TEMPERATURE

F.J. CHRISTENSEN
Division of Building Research, CSIRO

## ABSTRACT

High kiln temperatures, short drying times and wide timber variability largely invalidate the application of conventional drying end-point methods to current Australian softwood drying practices. The use of the drop in dry bulb temperature across the stack is described and supported as an appropriate end-point index for the intended drying task. Measuring systems based on this method are being used effectively by sectors of the industry.

## INTRODUCTION

Traditional methods of determining drying end-point are either unsuitable or inadequate for softwoods dried at high temperature. Kiln drying times are only 8-24h for 19-45mm thick finished size timber and kiln attendants, for physiological or operational reasons, cannot enter kilns running at 120-150°C for more than very brief periods.

The two most common end-point measuring methods are the use of sample boards of predetermined oven-dry mass that are weighed at intervals to determine their current moisture content (1) and electrodes inserted inside the timber and connected by leads to a resistance type electrical moisture meter located outside the kiln(2). Another method advocated is the measurement of wood surface temperature as an indicator of moisture content (3).

The most serious problem with these methods for softwoods is the difficulty of selecting a representative sample of material that truly reflects the drying behaviour of a whole kiln charge. Other complicating factors are the practical limitations on the numbers of samples or electrodes that can be used and where they are placed within a stack, particularly with the constraints of high temperature drying conditions.

Frequently, procedures used with these methods are adopted on the basis of expediency rather than for sound technical reasons. Furthermore, even with the greatest of care, none of the above methods will yield particularly accurate results because of inbuilt deficiences. For sample boards, sources of error are lack of precision in estimating oven-dry masses, atypical end moisture gradients, poor end-coating and the selection of thinner material to facilitate the removal and replacement of sample boards in the stack. With the moisture meter/internal electrode method, the commonest measurement errors arise from lack of application, availability or precision of reliable species and temperature correction data.

An unsatisfactory variant form of the moisture meter/electrode method is that in which nails are driven into the edges of several boards on the outside rows of a stack. This applies whether wires are taken outside the kiln to the moisture meter or readings are made with a meter taken into the kiln towards the anticipated end of drying.

The following method overcomes many of the inherent disadvantages and sources of errors of the traditional methods. The principle is not new, being an adaptation of a method developed by the author for determining end-point in veneer drying (4).

## TEMPERATURE DROP METHOD OF END-POINT DETERMINATION

In driers without reheat coils, the energy for drying is supplied at the expense of the dry bulb temperature (DBT) and is manifested as a drop in DBT across the stack, whereas the wet bulb temperature (WBT) remains nearly constant. This is shown schematically in Fig. 1 for early, mid and late stages of drying. As would be expected, the drop in DBT across the stack decreases with decreasing drying rate and increasing drying time.

Actual DBT drops across the stack for 35mm thick radiata pine studs during drying in a modern high temperature commercial kiln are given in Fig. 2. The kiln, heated with heat transfer oil, did not reach target conditions of 150/75°C (DBT/WBT) until near the end of drying because the combined heat demand from all kilns operating at once exceeded the supply. Average air velocity across the timber, with special baffles installed above and below the stack, was just over 8m/s with 22mm thick stickers. Direction of air circulation was changed at 4h intervals following the first change after 2h.

In Fig. 2, the drops in DBT across the stack were obtained from readings of individual thermocouple junctions mounted on each side of the three stacks in the kiln. The individual and mean values show a distinct though not uniform drop in DBT across the stack during the course of drying. The different values for the three stacks reflect, inter alia, differences in initial moisture content, mix of material and possibly drying conditions in

different parts of the kiln. The latter, in well designed, constructed and maintained kilns, are usually uniform except possibly in the near vicinity of the door end of the kiln. Some of the fluctuations shown in Fig. 2 are obviously related to changes in the direction of air circulation in the kiln and their consequent effect on the drying conditions. For the final average DBT drop across the stack of 4°C, the average moisture content of the timber in all three stacks was 11±2%.

At its present stage of development, the DBT drop method for end-point determination during the high temperature drying of softwoods is an empirical one, and the appropriate temperature drop for a particular application needs to be determined by experimentation. Parameters affecting the DBT drop can be divided into two groups: characteristics of the timber and of the drying conditions. Among the former are species, thickness, cut (back or quarter sawn), sapwood/heartwood and moisture content. The latter include DBT, WBT, air velocity, stack width, sticker thickness, degree of venting and elapsed time since the last change of direction of air circulation. Since most of these parameters are fixed for a particular kiln drying operation, the task of determining the appropriate temperature drop becomes relatively simple.

## PRACTICAL MEASURING SYSTEMS

A simple method for measuring DBT drop across three stacks simultaneously is indicated in Fig. 3. The connection of the thermocouple wires in this way makes an elementary thermopile which adds arithmetically the electromotive force generated by the pair of junctions across each stack, thereby increasing the accuracy of measurements. This is particularly important as the drying end-point is approached, when quite small temperature differences need to be precisely established.

More sophisticated thermocouple configurations can be provided to give independent measurement of temperature drop across each stack or sector of a stack as well as series/parallel arrangements to average drops across all stacks. Such an arrangement enables a check to be made on the approximate stage of drying of individual stacks. It may even indicate problems with the heating or circulating systems to the kiln operator without the need to enter the kiln.

For convenience, the thermocouple junctions should be mounted on rods fixed to the sub-ceiling structure of the kiln, in such a way that they are unlikely to be a hazard to the kiln operator or damaged as stacks are taken in or out of the kiln.

The reliability of the DBT drop across the stack method of drying end-point determination is improved by holding the drying conditions as steady as possible as the end of drying is

approached. Temperature variations can be markedly reduced by leaving vents closed as little venting is required during the final stages of drying. These measures diminish the magnitude of fluctuations in DBT drop across the stack, thus helping to reduce the uncertainty in deciding when the end-point in drying has really been reached.

Application by sectors of the industry of measuring systems based on the DBT temperature drop have demonstrated its effectiveness when used as generally recommended in this article. Commercial experience with the temperature drop method has confirmed laboratory observations that recording the temperature drop on a circular or strip chart is superior to using an indicator only. With a centre-zero instrument or digital electronic indicator, the reversing switch shown in Fig. 3 is not necessary.

## CONCLUSIONS

Experimental results given in this paper demonstrate that the drop in dry bulb temperature across a stack of timber, when it has reached the degree of drying required, can be used as a measure of its final moisture content.

As a drying end-point method, measurement of the DBT across the stack has the advantage over other methods of not being dependent on the drying characteristics of just a few, probably poorly selected and unrepresentative samples, or affected by other sources of error inherent in these methods.

The DBT drop method senses the integrated effect of rate of evaporation of moisture, manifested as a temperature drop, from all timber in the region of a stack covered by the junctions of a differential thermcouple mounted opposite one another on each side of it.

In the first instance, the DBT drop appropriate to the required final moisture content is found empirically for particular kilns, drying conditions and timber characteristics. Thereafter, the DBT drop remains appropriate as long as no substantial changes are made to any of the factors listed.

A series of differential thermocouples, configured as an elementary form of thermopile, increase the accuracy of measurement and can be used to effectively average the temperature drops across all and individual stacks in the kiln as required.

Laboratory and commercial experience has shown that recording of the temperature drop makes it easier to see the approach of end-point, especially when fluctuating drying conditions create random disturbances to values displayed by an indicator.

REFERENCES

(1) Anon. (1947). Sample boards - Their use in timber seasoning. CSIRO, Div.For.Prod., Trade Circ.No.7, 2nd impression, Melbourne.

(2) Marshall, P.E. and Lee, D.G. (1967). Quality kiln drying through instrumentation. Aust.Timber J.,33(2),29-35.

(3) Kotok, E.S., Lowery, D.P. and Jansen, C.E. (1969). Surface temperature as an indicator of wood moisture content during drying. For.Prod.J.,19(9),80-82.

(4) CSIRO, Div.For.Prod. (1954). Resume of work for the periods 1st March to 31st May and 1st June to 31st August.

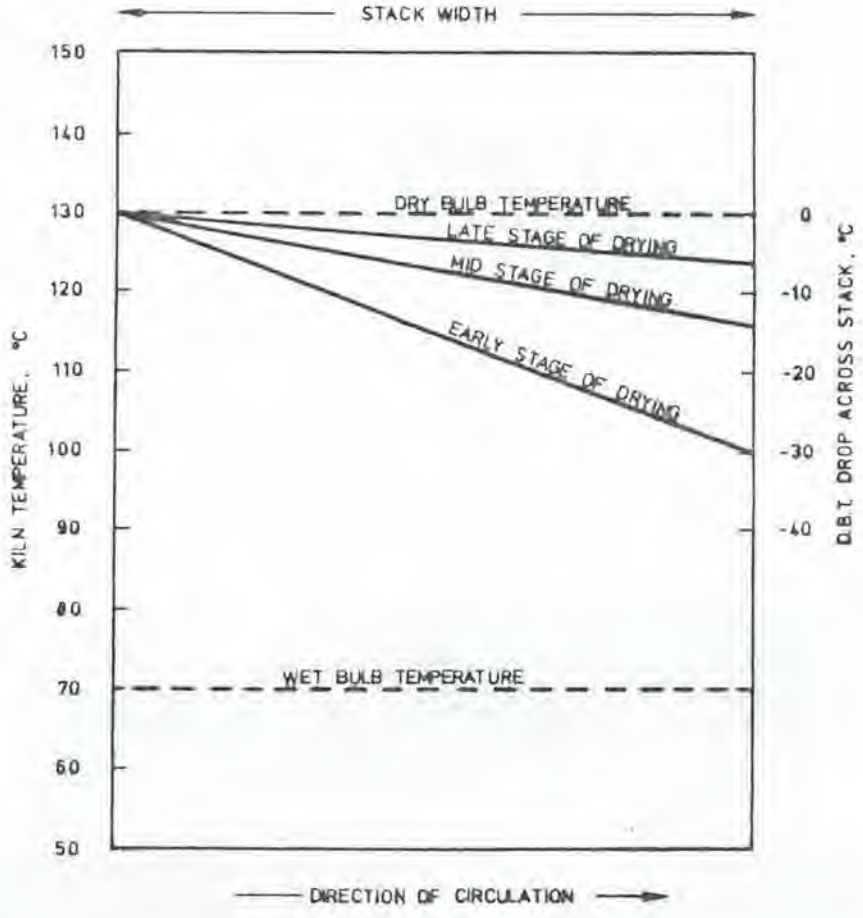



Fig. 1. Schematic representation of the dry bulb temperature drop across the stack at three stages in the drying of softwoods at high temperature.

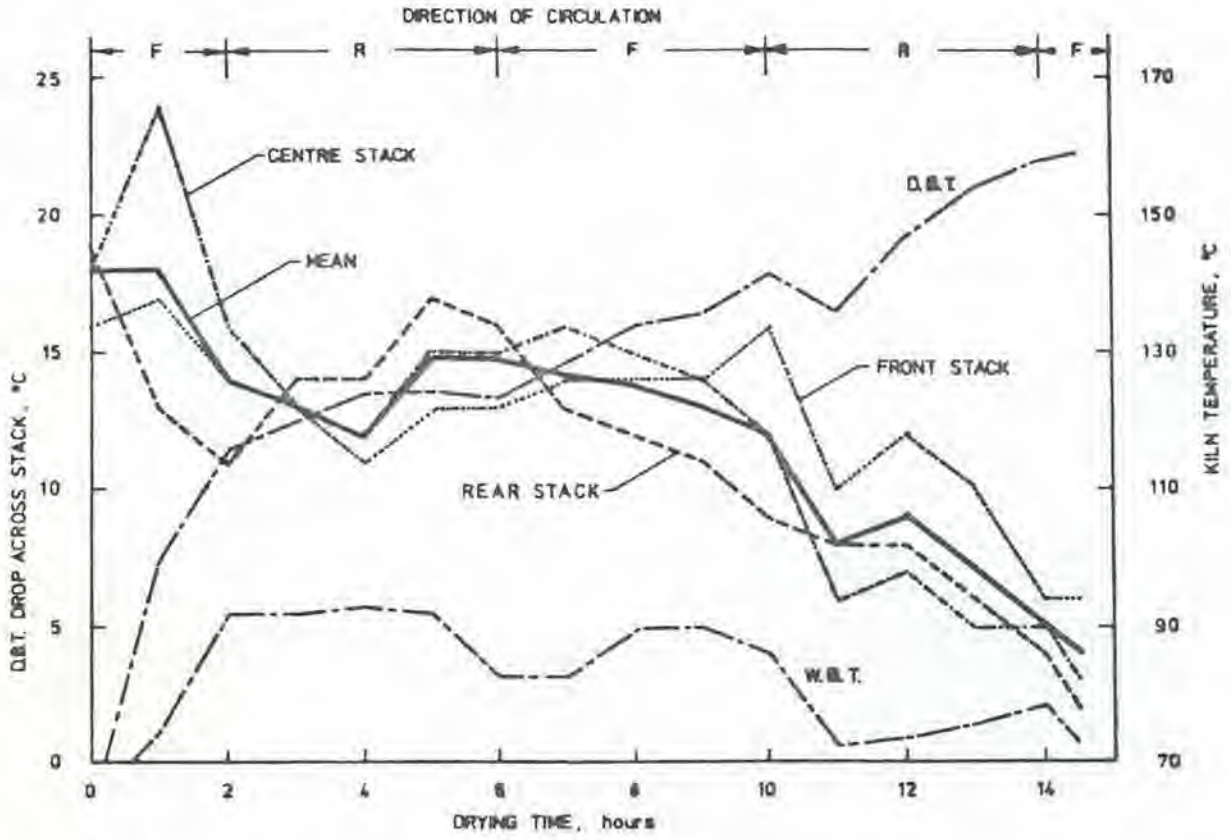
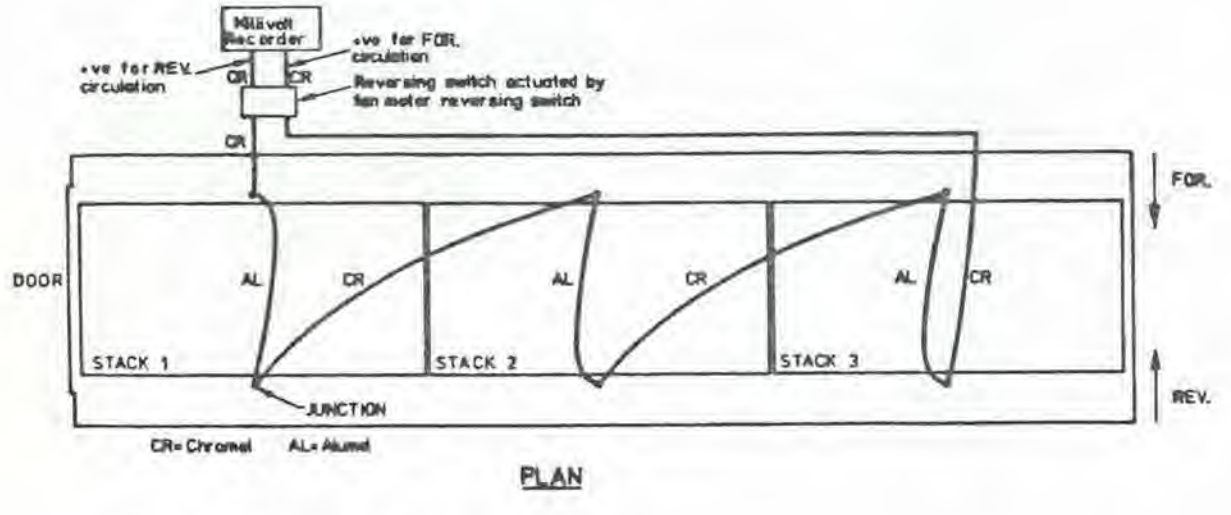



Fig. 2. Individual and mean drops in dry bulb temperature across stack at 3 positions along length of kiln during drying of 35 mm thick radiata pine studs.



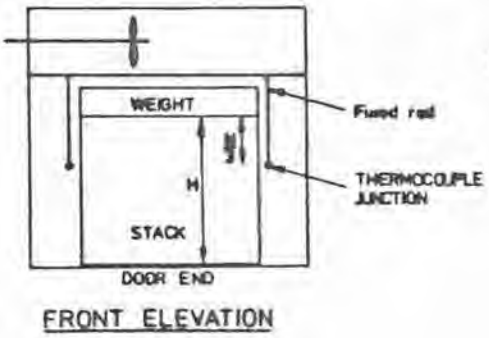




Fig. 3. Sketch indicating construction and positioning of thermopile to measure average drop in temperature across three stacks in a kiln during drying for the purpose of recording drying end-point.

# EFFECTS OF DRYING TEMPERATURES ON MOVEMENT AND MOISTURE CONTENT OF PINUS RADIATA BOARDS

K.W FRICKE
Division of Building Research, CSIRO

ABSTRACT

Preliminary results are given for tests made to determine the effects of different drying temperatures, from ambient to 210°C, on the movement and mc (moisture content) changes in Pinus radiata boards when cycled between 5% and 17% emc (equilibrium moisture content) conditions.

## EXPERIMENTAL

The test material was selected from boards cut from mature P. radiata logs at a sawmill in Harcourt, Victoria. Eighteen test boards were sawn from different logs in such a way as to give, as nearly as possible, six truly backsawn (B) sapwood boards, six truly quartersawn (Q) boards taken as far from the pith as possible, and six "heart in" (H) boards with the pith running through the centre of the cross section.

The green boards were machined to 100 mm by 25 mm and eight 300 mm long samples were cut from each board (seven test samples and one spare). These samples were weighed while green and measured for width and thickness. Pieces from both ends of each sample were used to calculate the green mcs of the samples by the oven drying method. From this basis all mcs were subsequently calculated by weighing the samples.

Separate sets of eighteen samples, each randomly selected and comprising six H, six Q and six B specimens were dried at each of the seven different temperatures which ranged from ambient to 210°C, as shown in Table 1.

The ambient temperature run was air dried under cover during winter for 70 days when drying virtually stopped at an average mc of 17%. The run was placed in a 12% emc room, operating at 38°C with a positive air flow, in an effort to reduce the mc, but after 17 days the average mc was still 16% when drying was deemed to have stopped.

In the meantime all the kiln dried runs were steamed after drying, as would occur in commercial operations, and then weighed immediately after steaming. The steaming time of 2.75 hours for the 60°C run was reduced to 2.0 hours for the remaining kiln dried runs to try to reduce the mc increase from about 6% to 3-5% during steaming.

After steaming, all the kiln dried runs were put into the 12% emc room to condition the samples to a static mc condition and this took 26 days.

Table 1 lists the details of drying, steaming and conditioning for the different cuts and drying temperatures.

After all the runs were conditioned in the 12% emc room, they were placed in a 5% emc room and conditioned, then in a 17% emc room and conditioned, and then back in the 5% emc room and conditioned. This cycle was repeated four times and all samples were weighed and measured for width and thickness at the end of each 5% and 17% emc stage.

The test is still in progress and it is intended to condition to 12% emc from both 17% and 5% emcs to investigate hysteris effects before finally oven drying the samples to enable more accurate mcs than those so far obtained, to be calculated.

RESULTS

Preliminary results, averages only, from one of these emc changes (a 17% to 5% emc change) have been processed to date, and these are shown graphically in Figs 1 to 3.

Fig. 1 shows a gradual decrease in mc change with increase in drying temperature, reaching a minimum at 150°C and then increasing at 180° and 210°C. From Fig. 1 it appears that the mc change due to changing atmospheric conditions is greatest for air dried material and least for material dried at 150°C. For the range of drying temperatures investigated, the maximum reduction in mc change (that is, the difference between the mc changes for

samples dried at ambient and 150°C) averaged about 1% mc for the nominal 12% mc change, with the change for the Q samples reducing less than that for the the B and H samples. On the other hand, the mc change is consistently least for the H samples and most for the B samples. This is possibly an indication of slight differences in hygroscopicity in heartwood and sapwood.

Fig. 2 shows the rate of change in thickness in terms of UM (unit movement), that is, the change in dimension expressed as a percentage of the green dimension for each 1% mc change. The UM values for thickness are reasonably constant for this cycle, indicating that dimensional change is mainly due to mc change. One interesting aspect shows that although the H samples are predominantly quarter sawn, the erratic relationship between the Q and H results, particularly at both ends of the temperature range, indicate that some variable other than cut may be responsible for the diversions in the curves.

Fig. 3 shows the rate of change in width in terms of UM. The UM values for width for all samples are reasonable constant with increasing drying temperatures, again implying that dimensional change is mainly due to mc change. As would be expected, the positions of the B and Q curves are interchanged with respect to those shown in Fig. 2 due to the different rate of tangential and radial movement.

It is of interest to note that the published unit shrinkage values for P. radiata (0.27 tangential and 0.19 radial) (1) are close to the B and Q values shown here.

CONCLUSION

At the present stage of the tests it appears that the movement of P. radiata boards dried at temperatures ranging from ambient to 210°C can be directly related to mc changes due to changes in ambient conditions.

However, the effect of increasing drying temperatures from ambient to 210°C seems to gradually reduce the amount of mc change to a minimum at 150°C and then to reverse and increase at 180° and 210°C.

The tests are continuing.

REFERENCE

(1) Kingston, R.S.T. and Von Stiegler, A.E. (1966). Shrinkage and density of Australian and other woods. CSIRO For. Prod. Newslett. Nos. 332-6; 9.

TABLE 1

Details of Drying, Steaming and Conditioning P. radiata samples

| Drying temp °C | Cut | Green MC % | Drying time No : time | Dry MC % | MC after steaming % | MC after conditioning in 12% emc room % |
|---|---|---|---|---|---|---|
| Ambient | H | 35 | 6 : 70 d | 18 | - | 17 |
| | Q | 61 | " | 17 | - | 16 |
| | B | 105 | " | 18 | - | 17 |
| | Av. | 67 | | 17 | - | 16 |
| 60 | H | 35 | 6 : 29.0 h | 13 | 19 | 15 |
| | Q | 66 | " | 13 | 19 | 14 |
| | B | 96 | " | 14 | 20 | 15 |
| | Av. | 66 | | 13 | 19 | 15 |
| 90 | H | 35 | 6 : 15.8 h | 9 | 12 | 13 |
| | Q | 60 | " | 10 | 13 | 13 |
| | B | 99 | " | 10 | 15 | 14 |
| | Av. | 64 | | 10 | 13 | 13 |
| 120 | H | 36 | 5 : 5.0 h<br>1 : 6.0 h | 12 | 15 | 14 |
| | Q | 61 | 4 : 5.0 h<br>2 : 6.0 h | 10 | 14 | 13 |
| | B | 96 | 4 : 5.0 h<br>1 : 6.0 h<br>1 : 7.0 h | 10 | 14 | 13 |
| | Av. | 64 | | 11 | 14 | 13 |
| 150 | H | 35 | 6 : 2.6 h | 7 | 13 | 12 |
| | Q | 61 | 5 : 2.6 h<br>1 : 2.8 h | 9 | 15 | 13 |
| | B | 92 | 5 : 2.6 h<br>1 : 3.3 h | 7 | 15 | 14 |
| | Av. | 63 | | 8 | 14 | 13 |
| 180 | H | 35 | 6 : 1.7 h | 8 | 13 | 13 |
| | Q | 67 | 5 : 1.7 h<br>1 : 2.1 h | 9 | 14 | 12 |
| | B | 95 | 3 : 1.7 h<br>1 : 2.1 h<br>1 : 2.3 h<br>1 : 2.8 h | 9 | 15 | 12 |
| | Av. | 66 | | 9 | 14 | 12 |
| 210 | H | 35 | 3 : 0.8 h<br>2 : 0.9 h<br>1 : 1.1 h | 10 | 15 | 13 |
| | Q | 63 | 1 : 0.8 h<br>1 : 0.9 h<br>2 : 1.1 h<br>1 : 1.3 h<br>1 : 1.7 h | 9 | 15 | 12 |
| | B | 102 | 2 : 0.9 h<br>1 : 1.3 h<br>1 : 1.6 h<br>1 : 1.8 h | 10 | 16 | 14 |
| | Av. | 67 | | 9 | 16 | 13 |

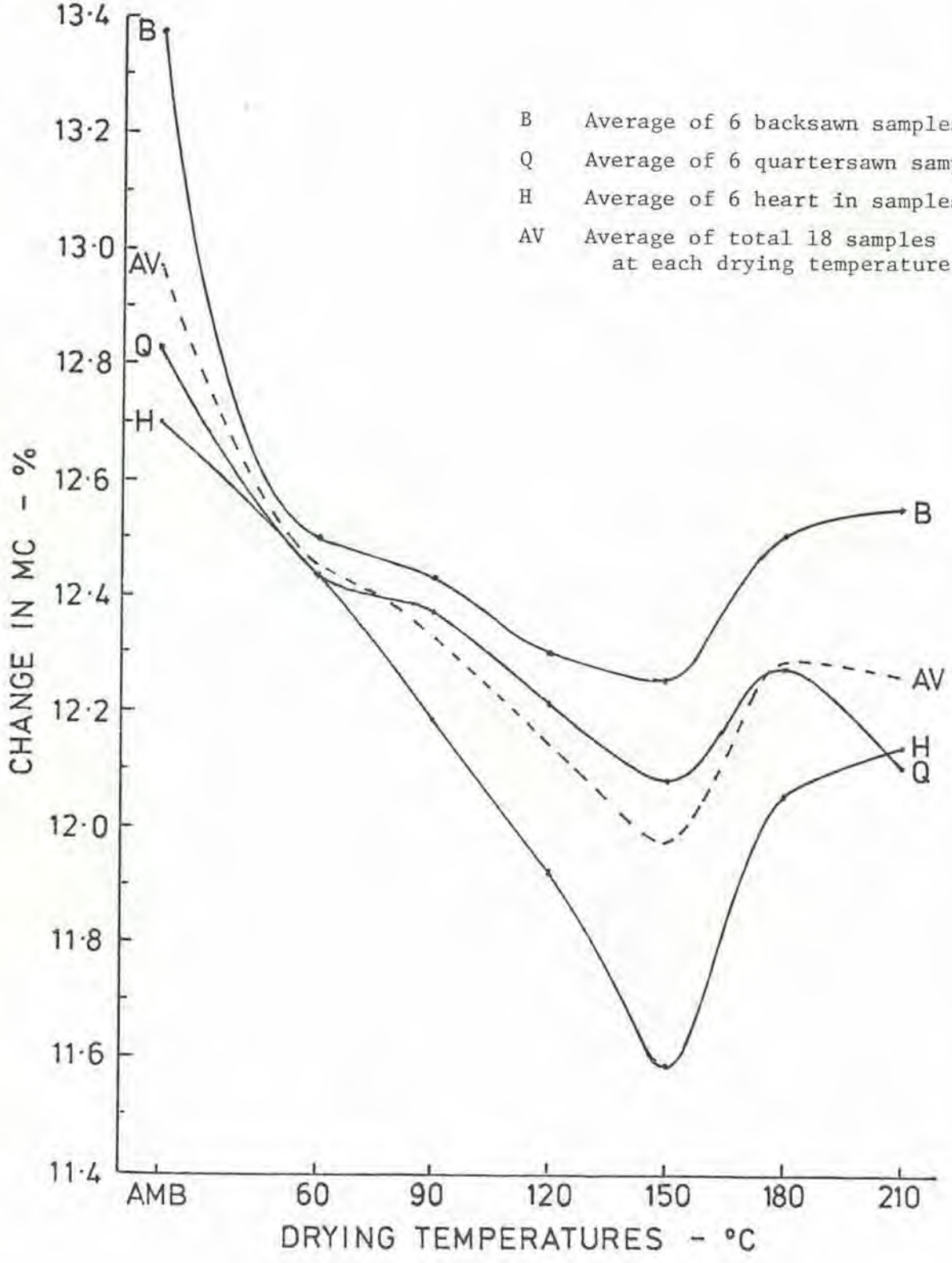



FIG. 1. Change in mc of nominal 100 mm by 25mm P. radiata boards when cycled from 17% to 5% emc after drying at various temperatures.

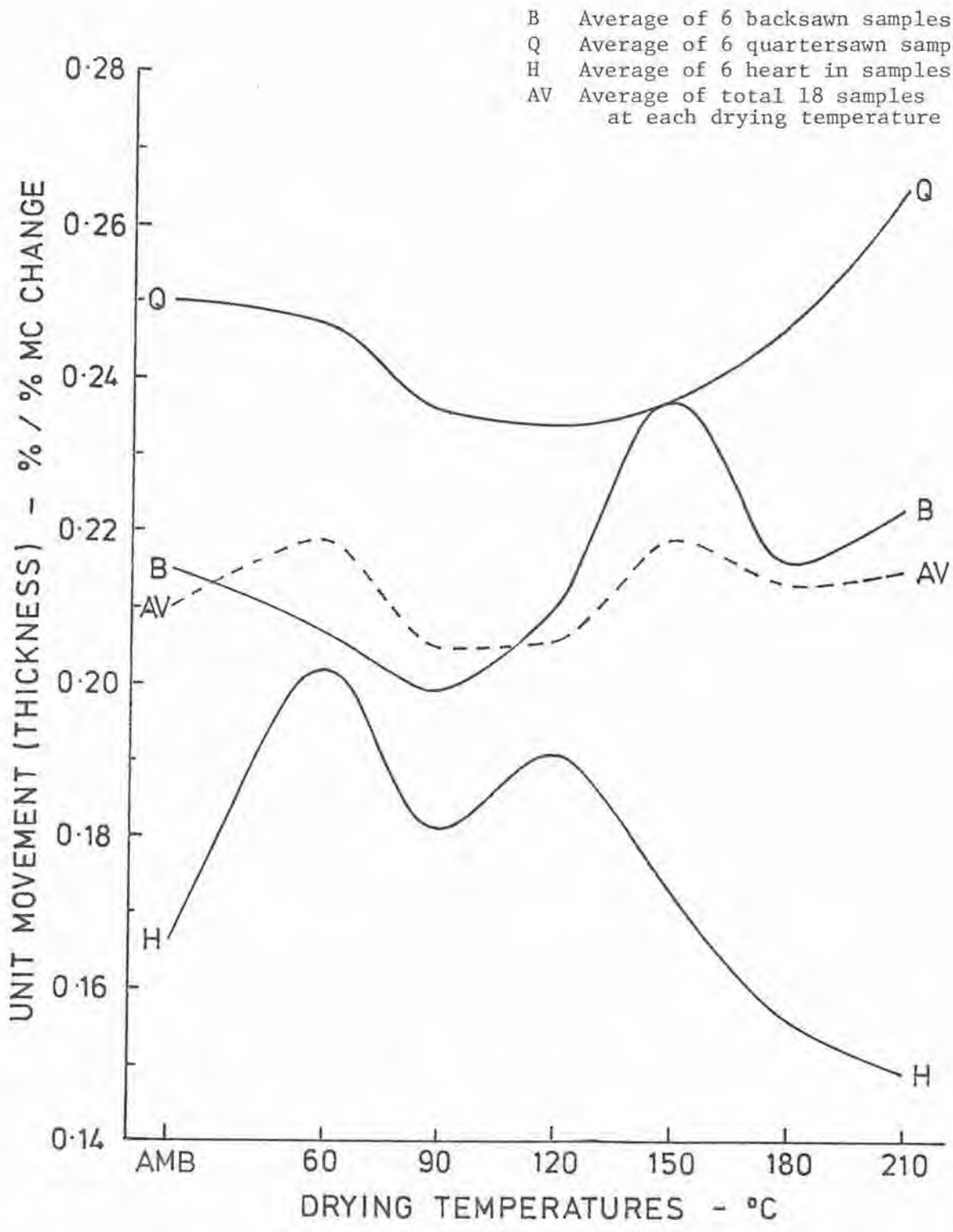



FIG. 2. Unit movement (thickness) of nominal 25 mm thick P. radiata boards when cycled from 17% to 5% emc after drying at various temperatures.

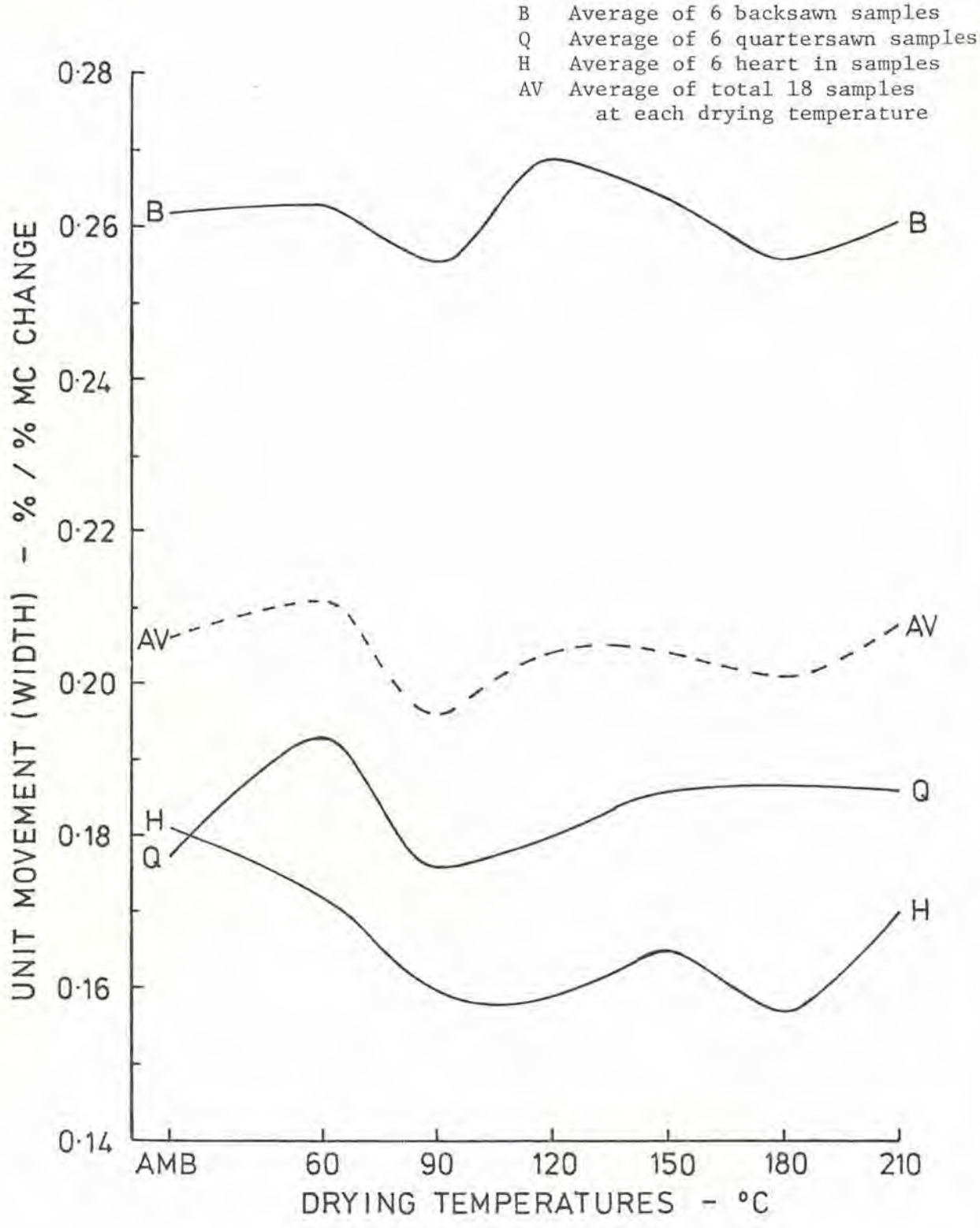



FIG. 3. Unit movement (width) of nominal 100 mm wide P. radiata boards when cycled from 17% to 5% emc after drying at various temperatures.

# DESIGN PROPOSALS FOR A LOW COST PROTOTYPE OF THE CSIRO CONTINUOUS FEED KILN

by R.L.Northway and F.J.Christensen

## ABSTRACT

This paper presents the important design and operating features of a transportable prototype of the continuous feed kiln capable of drying commercial quantities of softwood timber at an estimated rate of up to 21 $m^3$ (finished size)/24 h day operation.

It also outlines a plan for assessing the kiln's potentialities and capabilities in a commercial environment with help, including financial, from co-operating softwood companies around Australia.

## INTRODUCTION

The feasibility of the vertical version of the CSIRO continuous feed kiln for softwood drying has been well researched over the past few years and has progressed to the stage where a detailed design of a full-scale unit has been prepared by the licensee in consultation with the authors (1). Lacking a prototype kiln, it has been necessary to resort to simulation studies in our large tunnel kiln to demonstrate the efficacy of the continuous feed kiln for improving dried timber quality, a result that should be accompanied by significantly lower drying costs than with conventional high temperature kilns. Obviously, with our available equipment, it has been impossible to test the moving mechanical parts or the proposed operating system of a continuous feed kiln. Establishing these aspects would help to dispel any doubts held on mechanical features by prospective users.

The reluctance of any member of the softwood industry to be the first to commit themselves to the substantial prime cost and possible developmental costs associated with the first and yet untried kiln is understandable. It is for just this reason that the reduced scale prototype outlined in this paper was designed and is now being offered to the industry.

The logical development of large scale mechanical equipment commonly proceeds via an intermediate scale model which incorporates the basic characteristics of the larger

machine but at much reduced cost. The proposed prototype kiln (Fig. 1) will be of sufficient scale to test the mechanical components and operating procedures yet capable of producing high quality dried timber in relatively small commercial quantities.

This prototype incorporates certain features that facilitate its disassembly and reassembly in manageable sized units for transporting. It is proposed that performance data and operating costs be determined by installing it in certain sawmills and operating it at each for extended periods in a production environment.

## REDUCED SCALE PROTOTYPE: DESIGN, CONTROL AND OPERATION

General : The kiln will be built generally to the design which has been described in several published papers (1,2) but with radically altered timber handling devices. This will eliminate the need for an operator at the top of the stack and reduce the size of steel members used in the main structure.

The stack will be 3.6m high, 1.2m wide and 2.5m long and stickers 25mm square steel tubing. Estimated drying times and outputs based on dry finished size dimensions are:

| Thickness of timber (mm) | 45 | 35 | 19 | 16 | 12 |
|---|---|---|---|---|---|
| Time in 1.6m drying zone (h) | 6 | 4 | 2 | 1.7 | 1.3 |
| Loading interval (minutes/layer) | 17 | 10 | 4 | 3 | 2.1 |
| Approx. dried output ($m^3$/24h) | 10 | 13 | 19 | 20 | 21 |

Circulation: Two centrifugal fans will recirculate the kiln atmosphere through the stack in four passes at a velocity of 12m/s through 35mm thick timber (Fig.2), and at substantially the same rate for all other thicknesses. Bypass doors will enable two passes only to be used in either the upper or the lower half of the drying zone (Fig. 3). This is to ensure adequate drying of all timber when changing thickness and when drying a discrete batch of test timber.

Venting: Outlet vents will be situated after the first and third pass through the stack. Make-up air will be induced through the main burner ducts, preferably after being preheated by drawing it through the stack between the drying and cooling zones. This will also assist in cooling the timber before it enters the steaming zone, thereby helping to ensure that adequate moisture is absorbed through the outside of the boards.

Heaters: Initially, the kiln will be gas heated for convenience. Three gas burners will be used, firing directly into the duct system. There will be one upstream of each fan to deliver hot air to the first pass at the green end of the drying zone. The third will reheat the air between the second and third passes. Burners will be fuelled with natural gas or with LPG as necessary. The entry duct configuration is intended to facilitate connection to a wood residue burner at a later stage.

Operating conditions: A drying temperature of 200 deg.C entering the first pass, reheating to about 180 deg.C entering the third pass and a wet-bulb temperature of about 60 deg.C should result in the drying times quoted above being achieved with plantation radiata pine from age 20 years onwards. Younger material may take longer to dry because of its higher moisture content.

Loading and unloading: Procedures have been developed to handle three distinct loading and/or unloading operations covering:

(a) Initial building of the stack
(b) Testing with the timber in one stack load only
(c) Continuous operation of the kiln.

Details will be published elsewhere.

Controls: The complete cycle for continuous operation will be controlled by a programmable controller or a microprocessor. Cycles with different timing periods for each thickness will be programmed into the controller and selected by the operator. When a change in thickness is made, the operator will move the cycle selector to the appropriate position and the controller will implement a transition programme until all timber of the previous thickness has been processed. Manual loading will be done during pauses in the cycle.

Drying of different thicknesses: Where volume of production does not support continuous operation with one thickness of timber only, the following procedures have been devised for changing thickness without substantially affecting final moisture content of all timber passing through the kiln during the change.

(a) To thinner timber - The circulation path is changed from that normally used (Fig. 2) to that shown in Fig. 3a after the last of the thicker timber has just entered the drying zone (at the thicker timber feed rate). Stack movement is halted for a time equal to the difference in drying times for the two thicknesses. The normal mode is then resumed with the kiln being loaded at the thinner timber feed rate.

(b) To thicker timber - The circulation path is changed to that shown in Fig. 3b when the drying zone has been completely filled with thicker material (at the thinner material feed rate). Stack movement is halted for the difference in the drying times for the two thicknesses, after which the normal circulation path is restored and loading resumed at the rate for the thicker timber.

## DISCUSSION

The design and operating features of a transportable continuous feed kiln have been described in this article as well as a method for changing from one timber thickness to another without substantially affecting the required final moisture content of all of the timber being dried at the time of the change-over.

Gas heating was selected as the most suitable drying medium for a transportable kiln, although other means such as direct firing with suitably filtered exhaust gases from wood burning furnaces or indirect heating with steam or heat transfer oil would be more appropriate for a fixed installation.

## FINANCIAL SUPPORT

Direct financial support from the timber industry is now needed to provide a reduced scale yet truly commercial prototype of the CSIRO continuous feed kiln for testing under service conditions at various sites around Australia. The acquisition of such a unit would enable the industry at large to observe how the kiln performs when operating in a commercial environment and to make an assessment of whether the continuous feed kiln would meet individual timber drying requirements.

## REFERENCES

(1) Christensen, F. J. and Northway, R. L. (1978). Development of the CSIRO continuous feed kiln for sawn timber to the commercial evaluation stage. Aust. For. Ind. Jnl., 44(8), 61-65.

(2) Christensen, F. J. and Northway, R. L. (1979). Status of the continuous feed high temperature kiln project. Topic 4A/8, 19th For. Prod. Res. Conf., Melbourne, Australia. 7 pages.

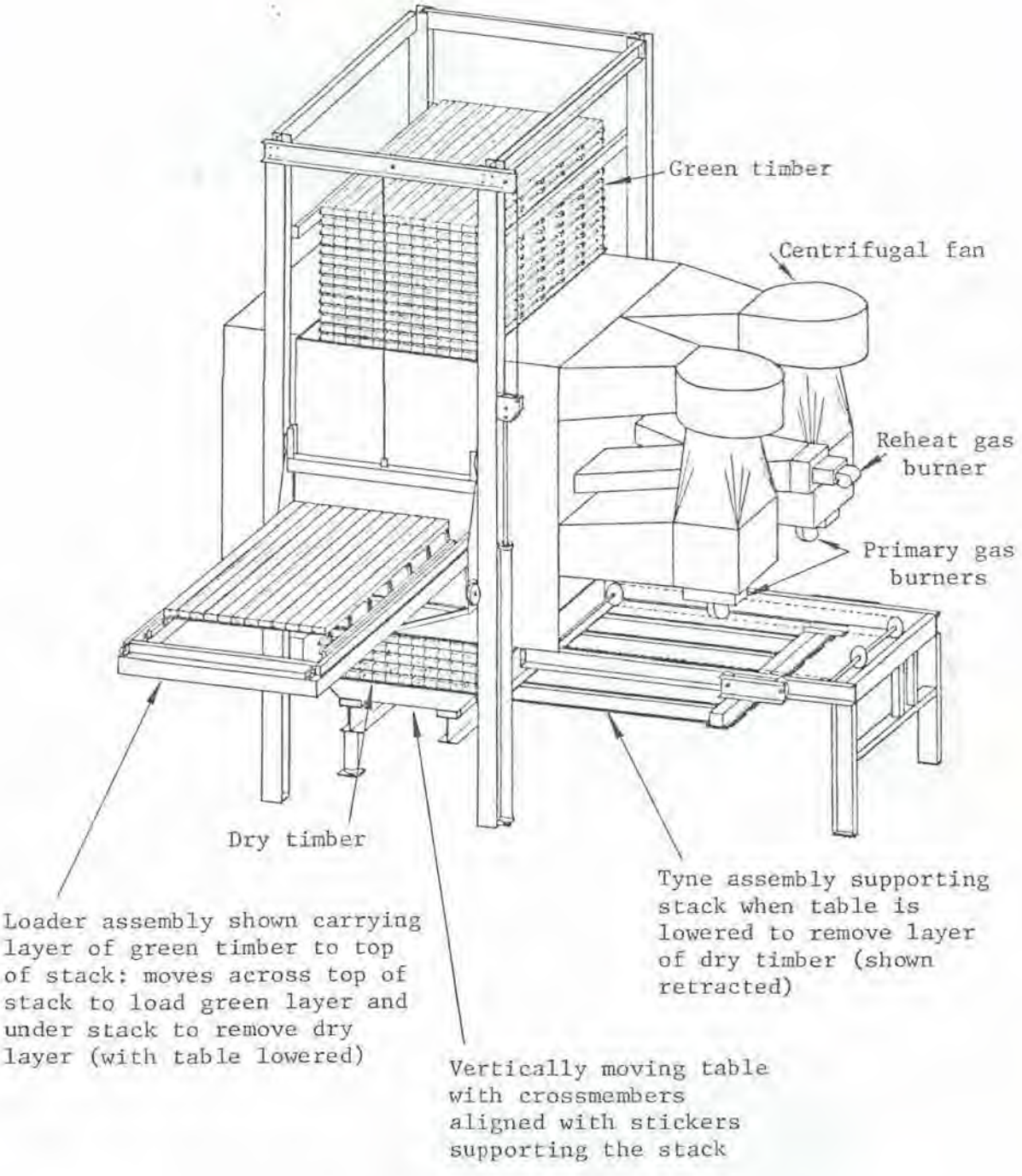



Fig. 1. Reduced scale prototype of the CSIRO continuous feed kiln

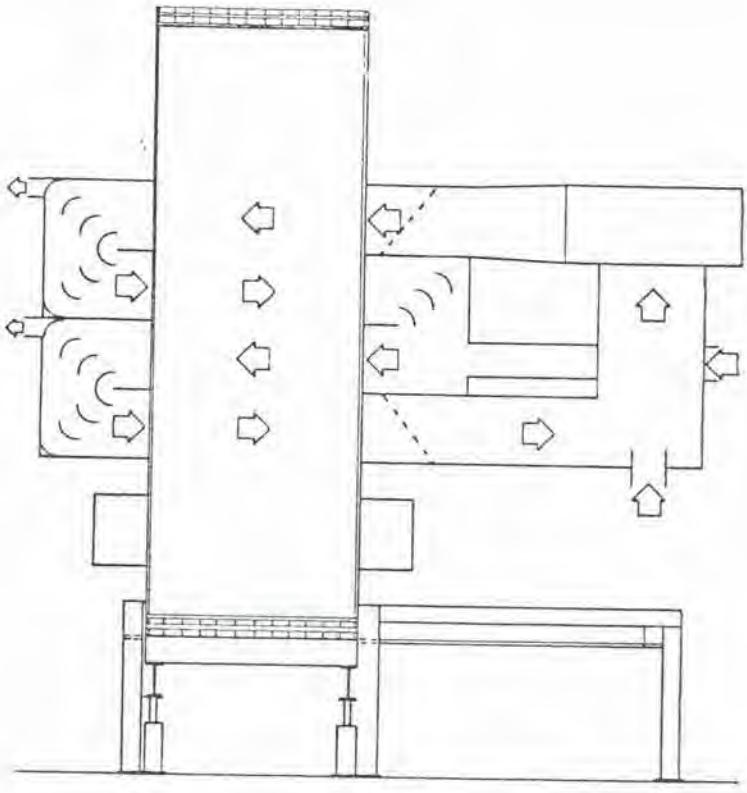
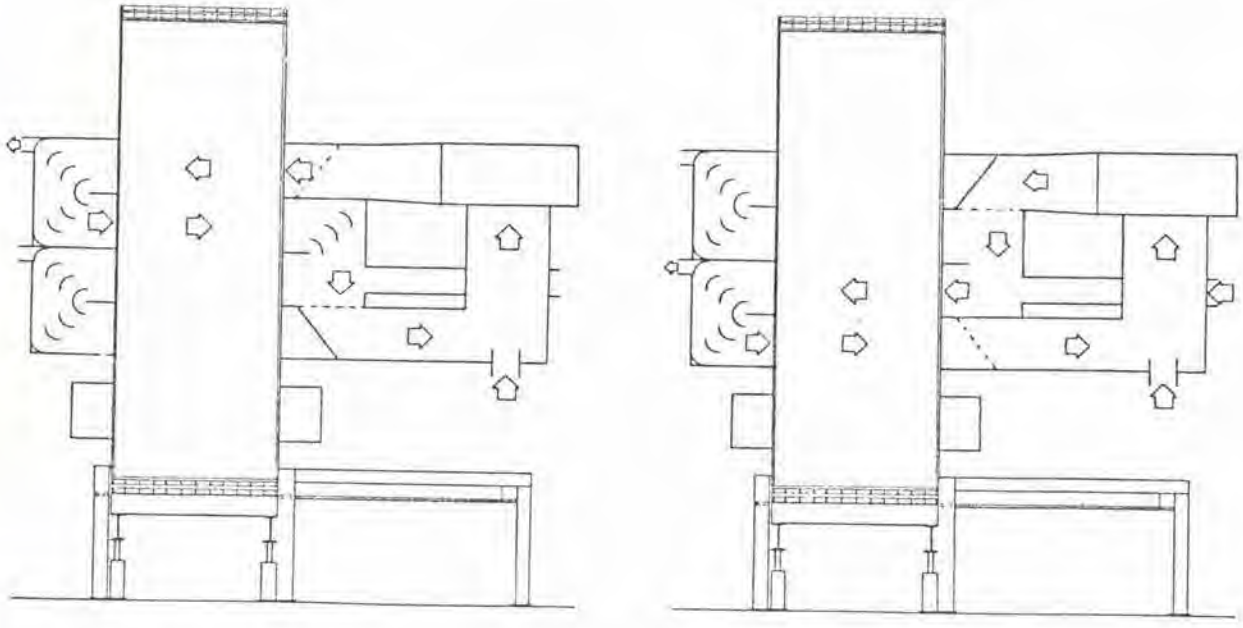


Fig. 2. Cross-sectional view showing normal air circulation path



(a) From thicker to thinner timber

(b) From thinner to thicker timber

Fig. 3. Air circulation paths during timber thickness changes

# CONTINUOUSLY VARYING SCHEDULE
# A NEW PROCESS FOR TIMBER DRYING

N. M. Nassif
Wood Technology and Forest Research Division
Forestry Commission of N.S.W.

## ABSTRACT

A new drying process called "Continuously Varying Schedule" (CVS) has been developed in the Wood Technology and Forest Research Division to dry green hardwood. Descriptions of the process and a comparison between CVS and the modified continuously rising temperature (CRT) process are reported. Drying time was reduced to one third that of the conventional process (1). Results indicate that CVS yields a higher recovery in volumetric shrinkage than the modified CRT.

## INTRODUCTION

Australian hardwoods make up the bulk of the timber-producing forest. This is true in New South Wales where these species provide a very desirable high strength timber for construction. It is widely recognized that the utility of these species would be considerably improved if an economical drying process can handle this timber from green to produce material of a final acceptable quality.

Prelimary work in this field was reported to the 19th Forest Products Research Conference (2) regarding the progress of developing CVS. The new CVS process was developed as a result of this work to suit the drying of dense hardwood from green. This paper gives details of the CVS process and compares it with the modified CRT process.

## METHODS AND MATERIAL

The CVS process is based on two features. The first is to increase the temperature continuously for both dry and wet bulbs from initial mild conditions at a suitable rate of increase per hour. The second is to use a low air velocity across the timber stack. In this process the temperature increase is characterized by two stages. The first is from green to below fibre saturation point at a relatively low rate of temperature increase, followed by a second stage using a higher rate. The CVS process was designed as two kiln drying stages

to reduce the risk of developing drying defects during the drying from green to fibre saturation point. The reason for using a low air velocity is to achieve as close as possible a state of laminar air flow. This laminar flow is characterized by an immobile layer of air around the timber surface, through which all the moisture escaping from the timber must pass and then diffuse into the main stream of air. The immobile layer becomes more saturated than subsequent layers. It is therefore possible to use air having a low relative humidity while maintaining a relatively high humidity condition at the timber surface.

The other method used was a modified CRT (3). Two modifications were introduced to the CRT process to suit the drying of hardwood. First, the rate of temperature increase was much lower than stated by Dedrick. Second, the increase in dry bulb temperature (DBT) was applied in two stages as described in CVS. The wet bulb temperature (WBT) was kept constant from green to final moisture content (m.c.). When the test was carried out the unavailability of suitable equipment required that the changes in temperature increase took place in the form of small steps.

The two processes were used to compare the drying time, volumetric shrinkage and drying defects of 100 x 50 mm back and quarter sawn silvertop stringybark (*Eucalyptus laevopinea*) and blue-leaved stringybark (*E. agglomerata*). Trees were selected from current logging operations in Glen Innes, Newcastle and Batemans Bay regions. Samples were sawn from central bark-to-bark flitches and randomly selected without any sorting for those containing any wood defects. 24 samples were dried using each method. After drying and reconditioning for four hours, all samples were dressed all round, then graded according to AS 2082-1977 (4). Air velocity used across the stack in the two runs was 1.3 m/s. Temperature schedules are expressed in the following equations:-

CVS

a) From green to below fibre saturation point

DBT = 40 + 0.1x

WBT = 38 + 0.05x

b) From fibre saturation point to final

DBT = final DBT reached at stage a) + 0.25x

WBT = final WBT reached at stage a) + 0.15x

x = time in hours

Modified CRT

DBT was similar to CVS equations

WBT = 38°C = constant

## RESULTS AND DISCUSSION

Table 1 gives drying data and their significant differences.

1. Mean m.c. at the end of drying was significantly different at 5% level. This could be overcome by extending the drying time of CVS by another 20 - 25 hours.

2. The recovery in volumetric shrinkage for CVS and modified CRT was 5.0 and 3.6% respectively. The difference after reconditioning was highly significant at 1% level.

3. Drying time in the same order was 412 and 400 hours, this is against 1305 hours for the conventional process (1).

4. After segregating the samples containing wood defects, which originally would be sorted at the mill before drying, the rest of the samples dried by the two methods were graded as structural grade No. 1. Although all samples met the requirement for internal checks, it was obvious that internal checking of samples dried by the modified CRT process was more pronounced than for the CVS process.

It is concluded that:

a) The two processes have similar drying times and both achieved a substantial reduction in time as compared to the conventional process.

b) The major advantage in the CVS process is a significantly lower volumetric shrinkage with a corresponding increase in timber recovery, there is also a probable reduction in internal checking.

c) The tests reported here were manually controlled. Automatic programming would be expected to reduce drying time and improve timber quality.

## REFERENCES

(1) Nassif, N.M. (1981). Kiln Drying New South Wales Hardwoods From Green. Statement presented at the Joint Timber Seasoning Committee Workshop, May, 1981.

(2) --- (1979). An Approach To The Drying of *Eucalyptus laevopinea* and *E. agglomerata* Using CRT (Constant Rising Temperature). Paper presented at 19th Forest Products Research Conference Melbourne.

(3) Dedrick, D.S. assignor to Weyerhaeuser Co. (1968). Kiln drying process. U.S. patent 3,404,464. (Patented Oct. 8, 1968).

(4) Standards Association of Australia (1977). Visually stress graded hardwood for structural purposes. AS 2082-1977. North Sydney.

TABLE 1

Results Of Drying Using CVS and Modified CRT Processes

| | CVS | Modified CRT | Significant difference |
|---|---|---|---|
| Mean initial m.c. | 66.3 | 60.6 | NS |
| Mean m.c. at end of drying | 14.5 | 12.2 | * |
| Mean m.c. after reconditioning | 14.1 | 14.6 | NS |
| Mean volumetric shrinkage at end of drying | 14.6 | 15.0 | NS |
| Mean volumetric shrinkage after reconditioning | 9.6 | 11.4 | ** |
| Mean drying time in hours | 412 | 400 | |

* indicates the significant difference at 5% level.

** indicates the significant difference at 1% level.

# MOISTURE CONTENT VARIATIONS IN KILN DRIED RADIATA PINE

J. Bartley[1] and P. Lind[2]

1. Wood Technology and Forest Research Division,

2. Economic and Data Services Branch,

Forestry Commission of N.S.W.

## INTRODUCTION

An experiment into the drying of radiata pine included kiln runs in which sawn material was dried from green. There were four runs - one for each combination of two material thicknesses (25 and 50 mm) and two kiln drying conditions (designated K1 and K2). This paper reports the variations observed in the final moisture contents (MC's) of the dried material, and their implications in commercial drying practice.

## MATERIAL

Commercial lengths of green nominal 100 x 50 and 100 x 25 mm sawn radiata pine were obtained from sawmills at Oberon and Tumut, N.S.W. The material was selected to range from backsawn to quartersawn and to be free of pith, but was otherwise "run-of-mill" production. The lengths were cut into 1.2 m long samples which were weighed, end-coated, individually wrapped, and stored in a cold room until required. The timber was kept wrapped as far as possible to minimise MC changes during transport, and sample preparation and storage.

## METHOD

Details of the drying conditions used and drying times are shown in Table 1. Constant conditions were used throughout each run and the kiln air circulation was not reversed.

The direction of the growth rings at the ends of the samples was used to classify them according to their direction of cut as backsawn, mixed sawn or quartersawn, for angles between the wide face of the samples and the mean growth ring direction of under $30^{\circ}$, $30^{\circ}$ to $60^{\circ}$, and over $60^{\circ}$ respectively.

Each kiln run contained 24 samples, providing four replications of the three directions of cut from the two sources (Oberon and Tumut). They were arranged in six layers (rows) each containing four samples (columns) so that the effect of row and column position could be included in the analysis of the results.

The four columns corresponded to the four replications of cut by source. Samples were kept in the same row/column position throughout each run. Each charge was built with a layer of "dummy boards" top and bottom, with the layers of samples separated by 25 mm thick stickers spaced at 0.6 m.

TABLE 1

Details of Kiln Drying Runs

| Run designation | | 25K1 | 25K2 | 50K1 | 50K2 |
|---|---|---|---|---|---|
| Nominal sample thickness | mm | 25 | 25 | 50 | 50 |
| Kiln drying: | | | | | |
| Designation | | K1 | K2 | K1 | K2 |
| Dry bulb temperature | °C | 70 | 120 | 70 | 120 |
| Wet bulb depression | °C | 12 | 50 | 12 | 50 |
| Air velocity | m/s | 2.5 | 5.0 | 2.5 | 5.0 |
| Drying time | h | 69.0 | 13.0 | 230.0 | 37.0 |
| Cooling time | h | 3.2 | 10.9 | 6.0 | 13.4 |
| Steaming time* | h | 3.0 | 3.0 | 5.0 | 5.0 |
| Final cooling and equalising time | h | 24.0 | 24.0 | 62.4 | 67.2 |

* Includes 1 h initial heating from ambient to 100°C.

The theoretical oven dry weight (TODW) of each sample was determined when it was prepared, from its weight and estimated MC, which was the mean MC obtained by oven drying sections cut at its ends. All samples were weighed at regular intervals during each run, and their MC's calculated from their weight, TODW, and known weight of end-coating. The charges were kiln dried until their estimated mean MC's were not greater than 11% or 6% for conditions K1 or K2 respectively.

After drying the charges were removed from the kiln, cooled, steamed (100°C saturated), then held in ambient conditions for final cooling and equalising. Details are shown in Table 1. All samples were weighed at the start and end of each stage.

Immediately after final weighing, two MC sections, with adjacent moisture distribution sections, were cut from clear wood in each sample, away from each other and the sample ends. The mean MC found by oven drying the sections was taken as the mean MC of the sample at the time of its final weighing, and used to re-estimate its TODW. This was used to re-calculate the MC of the sample at its previous weighings. These re-calculated MC's were used in the results and analyses.

The moisture distribution sections were cut and oven dried to determine case

and core MC's in the 25 mm, and case, intermediate and core MC's in the 50 mm samples. The difference between the mean MC's of the core and case sections was taken as the measure of the final MC gradient in each sample.

## RESULTS AND DISCUSSION

Mean initial and final MC's for each run are shown in Table 2. Figs 1 to 4 show histograms of the distribution of the mean MC of the samples in each run at the end of drying, after steaming, and finally, after cooling and equalising. The number of samples within each MC interval is subdivided according to source. The mean MC of all samples is also shown. All the MC distributions are skewed positively, and many samples had final MC's considerably higher than the 15% limit specified in Australian Standards (AS) (1,2).

TABLE 2

Mean Moisture Contents (%)

| Stage | Run | | | |
|---|---|---|---|---|
| | 25K1 | 25K2 | 50K1 | 50K2 |
| Initial | 131.2 | 121.4 | 118.2 | 114.0 |
| Final | 15.2 | 10.8 | 14.7 | 12.3 |

The MC's of the samples in each run were analysed for the effect of positioning in columns (replication) and rows, and source and direction of cut. Analyses were made of the initial and final MC's, and their interaction. The first analyses covered all samples in each run, then the 12 samples from each source were analysed separately, due to the effect of source reported below.

### POSITIONING IN COLUMNS AND ROWS

The analyses indicated differences (5% level) in only three of the 16 analyses made, but there was no systematic pattern of variation, and it was concluded that the differences arose by chance. No column (replication) effect was found in the final MC's.

### EFFECT OF INITIAL MC ON FINAL MC

There was no general systematic effect of initial MC on final MC. This indicates that, for the drying conditions and material used, sorting green into different drying charges on the basis of MC - obviously wet (sapwood) or relatively dry (truewood) - would be unlikely to have a significant effect on either the magnitude or uniformity of the final MC's.

### SOURCE

There were no significant differences between the initial MC's of the samples from the two sources. However, the final MC's (mean and variance) of the Oberon

samples were significantly lower than the Tumut samples in all four runs. Details are shown in Table 3. This can also be seen in Figs. 1 to 4, which show that the MC's of the Oberon samples were generally within acceptable limits, but the MC's of the Tumut samples had larger ranges, extending to unacceptably high values.

TABLE 3

Mean Final MC's (%) of Samples from Tumut and Oberon

| Run | Tumut | Oberon | Significance[1] | Variance ratio[2] |
|---|---|---|---|---|
| 25K1 | 17.8 | 12.6 | 1% | 32.3 |
| 25K2 | 11.8 | 9.7 | 5% | 12.8 |
| 50K1 | 16.7 | 12.7 | 1% | 6.8 |
| 50K2 | 16.0 | 8.7 | 1% | 42.9 |

[1] Significance level of the difference between the mean MC's.

[2] Ratio of variance of final MC's of Tumut to Oberon samples.

The differences, after identical drying, steaming, and conditioning, indicate that the material used from the two sources cannot be regarded as representing a single, common population.

No obvious differences could be seen in a visual examination of cross-sections of the samples from the two sources. They both contained a similar range of growth rates, and ratios of latewood to earlywood. It is also unlikely that there were appreciable differences in the ratios of sapwood to truewood, as the initial MC's were not significantly different.

DIRECTION OF CUT

The MC's of the samples from each source were analysed separately to determine the effect of direction of cut. The only significant differences found were in three cases for the Oberon samples. Details are shown in Table 4.

TABLE 4

Significant MC Differences With Direction of Cut in Samples From Oberon

| Run | MC stage | Mean MC (%) Direction of cut | | | Significance[1] |
|---|---|---|---|---|---|
| | | Back | Mixed | Quarter | |
| 25K1 | Initial | 159.7 | 143.9 | 93.2 | 1% |
| 50K1 | Initial | 147.4 | 103.0 | 65.5 | 5% |
| 25K2 | Final | 9.2 | 9.3 | 10.6 | 5% |

Means underlined with the same line are not significantly different at the level shown.

[1] Significance level of the difference between the mean MC's.

The lower initial MC's in the quartersawn samples may indicate a greater incidence of truewood, due to a higher proportion of them having been sawn from larger, older logs than the backsawn and mixed-sawn samples. However, this is not conclusive, as the effect was only significant in two of the four runs.

In all four runs the quartersawn samples from Oberon had higher final MC's than the backsawn and mixed-sawn samples, but the difference was only significant in Run 25K2 (Table 4). A similar trend was present in the samples from Tumut dried using conditions K2, but not for conditions K1.

The results indicate a general tendency for quartersawn samples to have the highest final MC's. The effect was generally not marked, and would not justify sorting green material into separate drying charges on the basis of direction of cut.

STEAMING, AND FINAL COOLING AND EQUALISING

Figs. 1 to 4 show that steaming after drying increased the MC's of the charges appreciably. The effect was greatest on the samples with the lowest MC's, but still considerable at the highest MC's. Steaming reduced the ranges of MC in the charges dried using K2 conditions, but had little effect in the K1 charges. The reduction in the MC ranges was not as great as anticipated.

Final cooling and equalising was long in comparison with much commercial practice (Table 1) (3), but insufficient to reduce the MC ranges of the Tumut samples to acceptable limits. The final ranges in the Oberon samples were generally acceptable, but were below the AS specification (1,2) of 10 to 15% in the K2 charges.

DRYING TIMES AND FINAL MC's

The drying times (Table 1) for conditions K1 were much longer than in commercial practice, as the conditions were unchanged throughout the runs, and drying became very slow in the later stages. These runs cannot be compared directly with commercial drying, except to observe that the MC ranges would probably have been greater using commercial conditions, as they reduced considerably in the slow later stages. The final MC's of the samples from Oberon were satisfactory, but the Tumut samples were generally above the AS upper limit of 15% (1,2), indicating that they should have been dried longer. The final mean MC's and MC distributions in the K1 runs may have been better if the charges had not been steamed.

The K2 runs were comparable to commercial high-temperature drying, but the drying times were relatively long (Table 1). The samples from Oberon were fully dried, with many final MC's below the AS lower limit of 10% (1,2). The final MC's of the Tumut samples were generally unacceptable, ranging from below 10% to

well above 15%, indicating that they should have been dried longer, to lower MC's, before steaming. An extended final equalising would also probably be required.

There was no evidence that retarded drying across the narrow (0.4 m) stacks, caused by not reversing the air circulation, significantly contributed to the variations observed in the final MC's.

MC GRADIENTS

The linear regression of the final MC gradient on final mean MC of all samples was calculated for each run. There was a highly significant (0.1% level) positive correlation in all cases, confirming the expectation that the samples with the highest MC's would also have the highest gradients. The regressions indicated that gradients would be minimal at mean MC's of about 12 to 12½% and 9½ to 10% for conditions K1 and K2 respectively. This confirmed the general desirability of drying to lower final MC's than was done in this experiment.

## CONCLUSIONS

1. Radiata pine from Oberon dried to generally satisfactory final MC's with the drying conditions used. Pine from Tumut dried slower and less uniformly, and had skewed distributions of final MC with many unacceptably high values.
2. High temperature drying times that were long compared to much commercial practice were insufficient to fully dry the pine from Tumut. A longer final equalising time than usual would probably also be necessary to reduce the range of final MC's in this material to standard limits.
3. Steaming after drying raised the MC's of all samples appreciabley and did not markedly reduce the ranges of MC in the charges.
4. Sorting green material into separate drying charges on the basis of green MC, or direction of cut, would probably not produce sufficient improvement in the uniformity of final MC's to be justified.

## ACKNOWLEDGEMENT

The authors wish to thank R. Lee and N. Nassif for their assistance in the experimental work.

## REFERENCES

1. AS 1489-1973. Sawn boards from radiata pine. Standards Assoc. Aust.
2. AS 1490-1973. Visually stress graded radiata pine for structural purposes. Standards Assoc. Aust.
3. RPAA Industry Standard 100-1979. High temperature seasoning under restraint of heart-in, radiata pine, structural material. Radiata Pine Assoc. Aust.

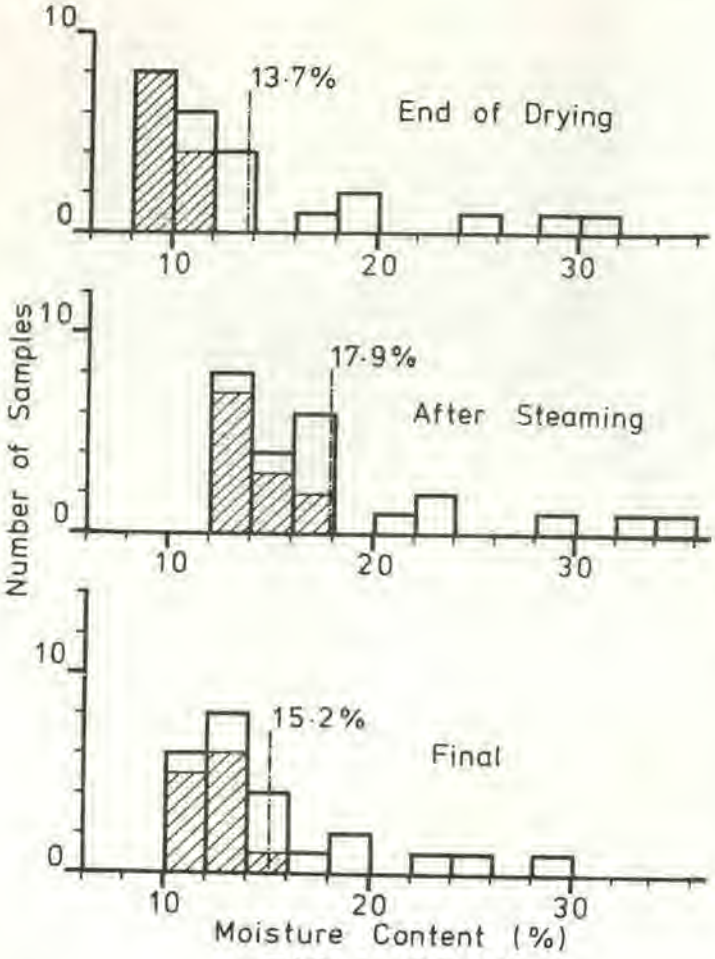



FIG 1: 25K1

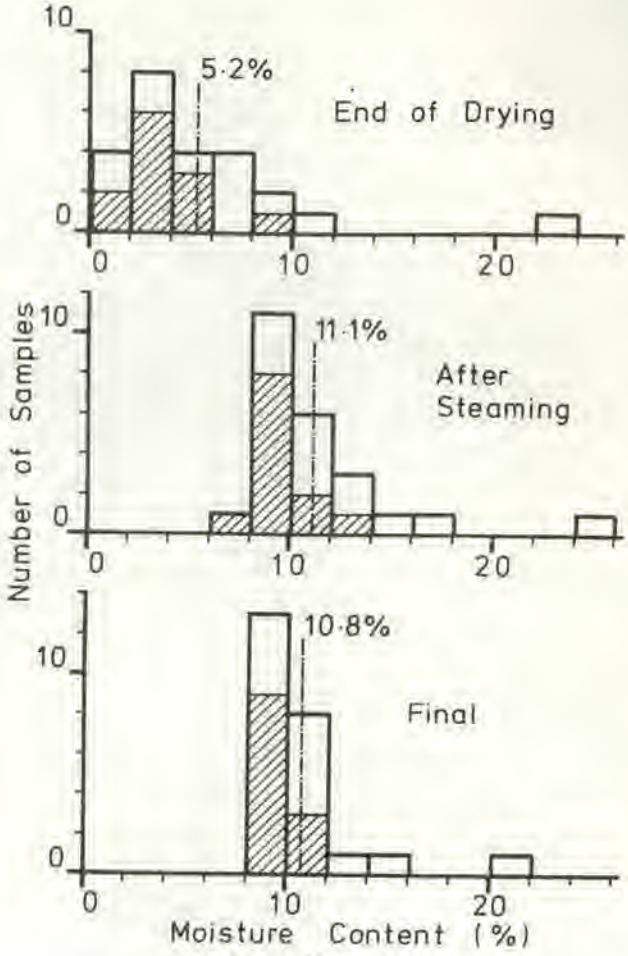



FIG 2 : 25K2

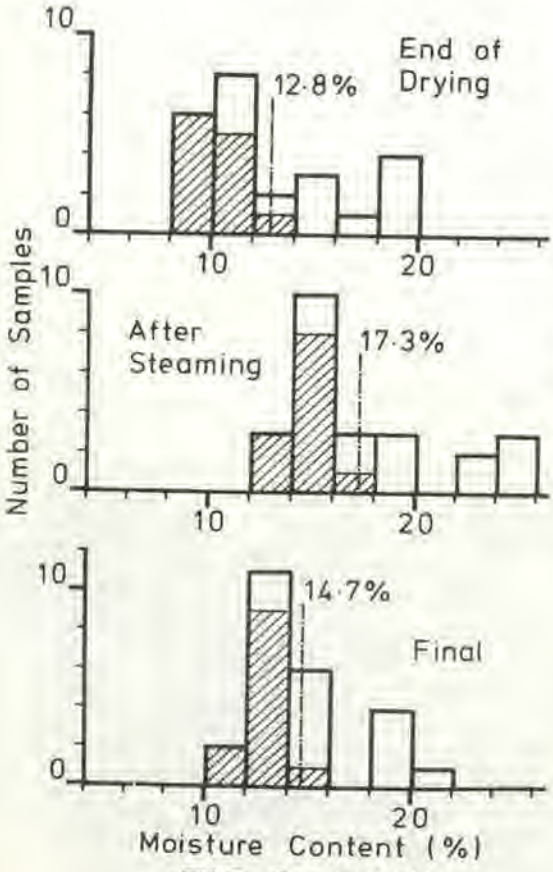



FIG 3 : 50K1

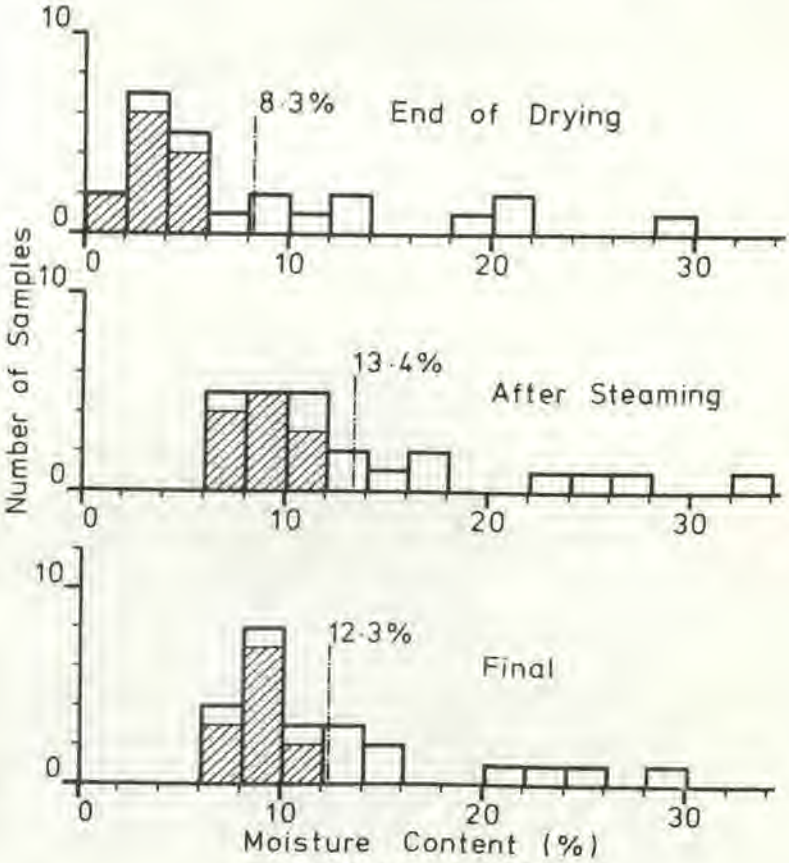



FIG 4 : 50K2

Legend — Oberon Tumut

FIGS 1-4 : Moisture Distributions after Drying

# A METHOD OF COMPARING DRYING RATES DURING EXPERIMENTAL KILN DRYING OF *PINUS RADIATA*

J. Hartley
Wood Technology and Forest Research Division
Forestry Commission of N.S.W.

## ABSTRACT

Sawn *Pinus radiata*, both untreated, and treated with CCA preservative after either pressure pre-steaming or conventional pre-treatment drying, was dried in a laboratory kiln as part of a research project. It was found that the drying could be closely approximated by expressing the moisture content (MC) of the samples used as either a simple exponential decay function of drying time, or exponential decay modified by the inclusion of the equilibrium moisture content corresponding to the drying conditions. The former gave the better fit to data from high temperature drying, and the latter to data from drying at conventional temperature. The rate of decay of the MC of the samples provided a measurement of their drying rate that could be used in assessing the effects of the project variables.

## INTRODUCTION

The conventional treatment of sawn radiata pine with CCA preservatives involves pre-treatment drying, pressure treating with an aqueous solution of CCA salts, then re-drying to the desired final moisture content (MC). The re-drying is often uneven and retarded, and accompanied by relatively severe drying degrade. This problem was investigated by Kininmonth (1), who found that the retarded drying was more marked in kiln drying than in air drying, and in 50 mm boards than in 25, and appeared to be primarily due to a reduction in permeability caused by pit aspiration, or some similar phenomenon, during the pre-treatment drying.

Johnstone (2) found that pressure pre-steaming green radiata pine markedly improved the retention and distribution of preservative in 25 mm boards that were subsequently pressure treated without pre-treatment drying. However, he did not investigate the effect of the treatment on the subsequent drying of the timber. Bamber and Johnstone (3) showed that the main reason for the improved

permeability appeared to be that pressure pre-steaming collapsed the ray parenchyma cells in the green wood.

It appeared possible that pressure pre-steaming green radiata pine, followed by pressure preservation and kiln drying, could be a practical method for producing treated dried material that would eliminate the retarded drying after conventional treatment, as there would be no pre-treatment drying. A project was undertaken to investigate this hypothesis. One aspect was assessing the effect of the experimental variables on the rate of final kiln drying. This involved expressing drying rates in a form suitable for use in the subsequent analyses. The time taken to dry between two MC levels, or the reduction in MC over a given time interval, were not suitable, due to the large differences in MC between individual samples. This paper reports the methods found for expressing the relationship between MC and drying time that were in good agreement with the experimental data, and provided a single numerical expression for the drying rate of each sample which could be used in subsequent treatment comparisons.

## MATERIAL AND METHOD

The material used, and details of sample preparation, were as described by Hartley and Lind (4).

The project involved drying twenty charges of sawn radiata pine in a laboratory kiln. Each charge contained 24 samples, providing four replications of three directions of cut (backsawn, mixed sawn and quartersawn) by two sources of material. The twenty charges consisted of the combinations of two kiln drying conditions, five treatments, and two sample thicknesses (25 and 50 mm).

Details of the two kiln drying conditions, designated K1 and K2, are given in Table 1.

TABLE 1

Kiln Drying Conditions

| | | K1 | K2 |
|---|---|---|---|
| Dry bulb temperature | (°C) | 70 | 120 |
| Wet bulb depression | (°C) | 12 | 50 |
| Air velocity | (m/s) | 2.5 | 5.0 |
| EMC | (%) | 7.5 | 1.3 |

Constant conditions were used throughout each run.

The five treatments, designated T1 to T5, were:

T1 Green samples pressure pre-steamed at 175 kPa (gauge), cooled, pressure treated with CCA, stored in a wrapped block stack, then kiln dried.

T2 As T1, but pressure pre-steamed at 350 kPa (gauge).

T3 Untreated. Kiln dried from green.

T4 Conventional. Pre-treatment air drying, followed by pressure treatment, storage, and kiln drying.

T5 As T4, but pre-treatment drying done by kiln drying, using conditons K1.

The MC's of all samples were determined from their weights at the start and end of, and at intervals throughout, each run, as described by Hartley and Lind (4). Re-calculated MC's, based on the re-estimated theoretical oven dry sample weights obtained at the end of each run, were used in all analyses.

The mean MC's of all samples in each run were examined to see if there were uniform patterns of drying that were common to a number of runs. Then the MC data for individual samples were examined to assess the form of the larger variations from the general patterns.

The mean MC's for the five treatments using 25 mm boards with kiln conditions K1, and 50 mm material with conditions K2, were graphed against drying time on semi-logarithmic paper. These groups of runs were designated 25 K1 and 50 K2 respectively.

The graphs were approximately linear, indicating that the drying could be represented by exponential decay, so a least squares regression analysis was used to assess the precision of fitting the data to two equations:

$$M = A \exp(-Bt) \quad (1)$$

$$M - M_e = A \exp(-Bt) \quad (2)$$

where M is MC (%),

$M_e$ is equilibrium moisture content (EMC) of the drying conditions (%),

t is drying time (h),

A, B are constants, determined experimentally.

These equations are linear on semi-logarithmic paper, using M or $M-M_e$ as the ordinate, and t as the abscissa. The intercept on the ordinate, A, at t = 0 is $M_o$, or $M_o-M_e$, for equations (1) or (2) respectively, where $M_o$ is the initial MC (%). The constant B is the slope of the line, i.e. the rate of exponential decay.

The values of EMC used were cross-checked between several references (6, 7, 8, 9), and are given in Table 1.

Analyses were done using the mean MC of all samples in each run over two time ranges:

(i) the full duration of the run, with the number of data pairs varying from six to nine;

(ii) a reduced range, omitting the first, and one or more of the last,

time intervals, as this generally gave a better correlation.

In further analyses, the MC's of each sample in the 25 K1 and 50 K2 runs were fitted to equations (2) or (1) respectively, over both the full duration of each run, and reduced time ranges. The data for the samples with poorer correlation coefficients were plotted on semi-logarithmic paper for examination.

At the time of writing, the data from the other two groups of runs - 25 mm boards with kiln conditions K2, and 50 mm material with conditions K1 (designated 25 K2 and 50 K1 respectively) - were still being assessed in detail. However, a preliminary examination has been made of fitting the data for the mean MC of all samples in each of these runs to equations (1) and (2). This is referred to in the results and discussion below.

## RESULTS AND DISCUSSION

Graphs of the mean MC of all samples in each of the 25 K1 and 50 K2 runs against drying time all showed the drying rate decreasing approximately linearly with time, with no systematic evidence of an initial "constant rate" period as described by Lyman (5) and others. The most obvious departures from straight lines occurred at the beginning and/or end of some runs. Those at the beginning were mostly due to a drying rate faster than indicated by the remainder of the line. In only two of the ten runs was it slower, as would occur in an initial "constant rate" period. A few graphs showed a drying rate towards the end of the run that was slower than indicated by the remainder of the line. This was due to some samples drying fully, and remaining at relatively constant MC, before the bulk of the charge was dry.

Table 2 contains data from the regression analyses for the mean MC of all samples in each of the 25 K1 and 50 K2 runs over both time ranges, using equations (1) and (2). The numbers of data pairs used, time intervals covered, and values of 100 $r^2$ obtained are given. The 100 $r^2$ value is the percentage of the variance of the MC data that is explained by the regression. All the regressions were statistically significant at levels of less than 0.1%.

Equation (2) gave the better fit in all the 25 K1 runs. Equation (1) gave the better fit in the 50 K2 runs, except over the full run for T4. The preliminary examination of the data for the other two groups of runs (25 K2 and 50 K1) gave a similar result, with equation (1) giving the better fit for the 25 K2 runs, and equation (2) for the 50 K1 runs. This indicates that equation (1) was more appropriate for the high-temperature conditions K2, with a low EMC, and equation (2) for the moderate K1 conditions.

The difference between the 100 $r^2$ values for the two equations was appreciable in the 25 K1 runs, showing the importance of the EMC term, particularly towards

TABLE 2

Regression Data For Moisture Content v. Time

| | | | | Treatment | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | T1 | T2 | T3 | T4 | T5 |
| 25 K1 | Full run | Data pairs | (No.) | 7 | 8 | 7 | 7 | 9 |
| | | Time interval | (h) | 0.0-69.0 | 0.0-76.0 | 0.0-69.0 | 0.0-65.0 | 0.0-88.0 |
| | | 100 $r^2$ for | 1 | 98.74 | 99.56 | 98.93 | 98.54 | 96.18 |
| | | Equation | 2 | 99.77 | 99.81 | 99.98 | 99.89 | 99.45 |
| | Reduced range | Data pairs | (No.) | 5 | 6 | 5 | 5 | 6 |
| | | Time interval | (h) | 11.5-57.5 | 9.5-65.0 | 11.5-57.5 | 7.5-53.5 | 9.5-65.0 |
| | | 100 $r^2$ for | 1 | 99.34 | 99.81 | 99.44 | 99.32 | 99.37 |
| | | Equation | 2 | 99.96 | 99.89 | 99.98 | 99.97 | 99.95 |
| 50 K2 | Full run | Data pairs | (No.) | 8 | 8 | 8 | 6 | 9 |
| | | Time interval | (h) | 0.0-41.0 | 0.0-40.0 | 0.0-37.0 | 0.0-36.0 | 0.0-44.0 |
| | | 100 $r^2$ for | 1 | 99.74 | 99.61 | 99.93 | 99.67 | 99.81 |
| | | Equation | 2 | 99.48 | 99.37 | 99.80 | 99.71 | 99.72 |
| | Reduced range | Data pairs | (No.) | 6 | 6 | 6 | 4 | 6 |
| | | Time interval | (h) | 6.0-36.0 | 6.0-37.0 | 6.0-33.0 | 7.0-28.0 | 6.0-36.0 |
| | | 100 $r^2$ for | 1 | 99.72 | 99.54 | 99.94 | 99.95 | 99.86 |
| | | Equation | 2 | 99.54 | 99.33 | 99.86 | 99.92 | 99.78 |

the ends of the runs when the MC's approached the EMC of 7.5%. This was clearly evident in graphs of the data. The difference was smaller in the 50 K2 runs, where the EMC of 1.3% was lower, but it was still apparent in graphs. However, in this case omitting the EMC term $M_e$ gave the better result.

The results of the regressions for each of the 25 K1 runs were better for the reduced time ranges than over the whole runs (Table 2).

The regressions for the 50 K2 runs were better for the reduced time ranges for treatments T3, T4 and T5, but not for T1 and T2 (Table 2). The graphs for T1 and T2 showed that this was due to a marked reduction in slope after the first interval, followed by a generally increasing slope as drying progressed. These runs were high temperature drying material that had been pressure pre-steamed, and it appears that this produced very fast early drying, followed by a slower drying period, then faster drying late in the runs than predicted by exponential decay. Accelerated early drying was also observed for treatments T4 and T5, but their subsequent drying was close to exponential decay.

The general tendency for the reduced time ranges to give the better results was consistent with the departures from straight lines at the beginning and/or end of some runs mentioned previously.

The graphs of the MC data for the individual samples with the poorest regressions were examined to determine the nature of their non-linearity. The samples graphed were those with 100 $r^2$ values of less than 98.5 over the reduced time ranges used for the mean MC's. This was chosen to cover an average of three samples in each run. There were 14 samples in the 25 K1 runs, and 15 in the 50 K2, and their graphs showed three types of general non-linearity:

(a) A general curvature, with drying rate not decreasing with time as fast as predicted. Drying of this type was on the "constant rate" side of exponential decay, but graphs on linear paper showed that it was much closer to the latter than the former.

(b) A marked reduction in drying rate towards the end of the run. This occurred in fast-drying samples that neared their final MC ahead of the remainder of the charge.

(c) A general curvature, opposite to (a), in which the rate decreased with time faster than predicted.

Some samples, particularly in the 50 K2 runs, also showed very fast drying in the first interval, similar to that observed in some of the mean MC graphs.

Twelve of the samples in the 25 K1 runs were backsawn, one was mixed sawn, and one quartersawn. Eight of the graphs for the backsawn samples were type (a),

and four were type (b). The graphs for the mixed sawn and quartersawn samples were types (a) and (c) respectively. The samples in the 50 K2 runs all had type (a) graphs. Eleven were backsawn and four mixed sawn.

The general trend was for the drying rate of some samples to be maintained throughout drying more than predicted by exponential decay. It was most apparent in some backsawn samples, indicating a tendency for them to dry relatively faster than the other directions of cut late in drying. This could be an aspect of the normal property of backsawn material drying faster than quartersawn, due to greater permeability in the radial than the tangential direction.

222 of the regressions for the 240 individual samples over the reduced time ranges were significant at the 0.1% level. The other 18 were all significant at the 1% level, and 14 of these were in treatment T4 in the 50 K2 runs, which only had four points, resulting in the very high requirement of 100 $r^2$ = 99.80 for significance at the 0.1% level. The lowest value of 100 $r^2$ for any sample in this run was 98.89. The curve fitting was generally better for quartersawn than backsawn samples, but in all cases it could be taken as a means of expressing MC as a function of drying time.

Equation (2) is similar to expressions derived by others. Tschernitz and Simpson (10) expressed the "falling rate" drying of red oak lumber in the form:

$$E = (M-M_e)/(M_o-M_e) = \exp(-Kt) \qquad (3)$$

where E is the unaccomplished moisture change,
K is an empirical constant,
and M, $M_e$, $M_o$ and t are as defined above.

A more general expression for drying, given by Rosen (11), is:

$$E = (M-M_e)/(M_o-M_e) = 1 - \frac{a^b}{b\Gamma(b)} \int_o^t \exp(-at^{1/b})dt \qquad (4)$$

where a is a constant called the rate factor,
b is a constant called the bend factor,
and E, M, $M_e$, $M_o$ and t are as defined previously.

For the particular case of b = 1 this reduces to equation (3) (with a = K), which can be expressed as:

$$M-M_e = (M_o-M_e) \exp(-Kt) \qquad (5)$$

When A and B are substituted for $(M_o-M_e)$ and K respectively this becomes equation (2), which was found to give a good fit to the data for drying radiata pine using the constant moderate conditions K1. However, equation (1), in which

the EMC term $M_e$ is omitted, gave a better fit to the data for the K2 high temperature drying conditions.

Equations (1) and (2) were used for expressing the MC as a function of drying time for the samples in the 50 K2 and 25 K1 runs, respectively. The regressions over the reduced time ranges were used throughout. This avoided the larger departures from linearity at the beginning and end of the runs, and gave results covering similar MC ranges for each treatment. The rate of exponential decay (B) was taken as the numerical expression of the drying rate of the samples, for use in subsequent comparisons of the effects of the treatment variables.

## CONCLUSIONS

It was found that the kiln drying of radiata pine could be expressed as either simple exponential decay (equation (1)), or exponential decay modified by the inclusion of an EMC term (equation (2)). Equation (1) provided the better fit to data from drying using the high temperature conditions K2, and equation (2) was better for the moderate K1 conditions. In both cases, the fit was better over the central part of the MC versus drying time curves, omitting time intervals at the start and end of drying. The coefficient B, expressing the rate of exponential decay, provided a numerical measure of drying rate for use in analysing the effect of the project variables.

## ACKNOWLEDGEMENT

The author wishes to thank R. Lee and N. Nassif for their assistance in the experimental work, P. Lind and M. Hinson for their help in processing the data, and the Radiata Pine Association of Australia for supplying the timber used.

## REFERENCES

1. Kininmonth, J. A. 1958. The drying of radiata pine sawn timber pressure treated with water-borne preservatives. Tech. Pap. No. 26 For. Res. Inst., N.Z. For. Service.

2. Johnstone, R. S. 1967. Pre-steaming an aid to pressure preservation of green radiata pine. Aust. Timber J. 33(9): 95-100.

3. Bamber, R. K. and Johnstone, R. S. 1968. The effect of pressure pre-steaming on the ray parenchyma cell walls of *Pinus radiata* wood. J. Inst. Wood Sci., No. 21: 21-4.

4. Hartley, J., and Lind, P. 1981. Moisture content variations in kiln dried radiata pine. Topic D10, 20th For. Prod. Res. Conf., Melbourne.

5. Lyman, L. C. 1965. Effect of air flow on heat transfer and water evaporation in jet drying systems. For. Prod. J. 15(10): 453-8.

6. Hildebrand, R. (Ed.) 1970. Kiln drying of sawn timber. Robert Hildebrand Maschinenbau GmbH. Wuertt. p. 30.

7. Wood Handbook. Ag. Handbook No. 72, For. Prod. Lab., For. Serv., U.S. Dept. Ag. 1955. p. 312-3.

8. Kauman, W. G. 1956. Equilibrium moisture content relations and drying control in superheated steam drying. For. Prod. J. 6(9): 328-32.

9. Rosen, H. N. 1980. Psychrometric relationships and equilibrium moisture content of wood at temperatures above 212 F. Wood and Fiber 12(3): 153-71.

10. Tschernitz, J. L. and Simpson, W. T. 1979. Drying rate of northern red oak lumber as an analytical function of temperature, relative humidity, and thickness. Wood Sci. 11(4): 202-8.

11. Rosen, H. N. 1980. Empirical model for characterizing wood drying curves. Wood Sci. 12(4): 201-6.

# THE APPLICATION OF AN ORTHOTROPIC FICKIAN-DIFFUSION MODEL TO TIMBER DRYING

R.D. Schaffner* & P.E. Doe+


## ABSTRACT

The literature contains much discussion on the basic nature of the transport processes which occur in wood when it is dried. Vapour pressure, spreading pressure and moisture concentrations have been proposed as driving mechanisms but many physical, chemical and biological processes take place. This paper demonstrates that Fickian diffusion in an orthotropic material is an adequate model of the multiplicity of processes occurring as timber dries provided appropriate data on the variation of the Fickian diffusivities with moisture content and temperature is obtained.


## INTRODUCTION

Seasoning of backsawn Tasmanian eucalypts by the usual air and kiln drying methods causes face checks or splitting on backsawn faces. As part of a project aimed at developing a commercially viable method of seasoning backsawn Tasmanian eucalypts, stress levels in timber were studied. In order to compute these stresses it is necessary to know the distribution of moisture within the timber at all times during the seasoning process.

## MOISTURE TRANSFER MODELS

Wood fibre can be described as highly hygroscopic, exhibiting energetic retention of water. Water is present as liquid, as water vapour and as molecules bound in various ways to the fibrous matrix. Some of the transport mechanisms likely to exist are capillary flow of liquid water, viscous flow of water vapour, thermal diffusion, osmosis, surface diffusion in a porous medium, gaseous diffusion and molecular diffusion (1). There is also the effect of the stresses generated within the material during drying.

The classical (Fickian) theory of diffusion assumes continuous random free motion of molecules (2). Another approach is 'bound water' duffusion in which only a very small part of the water molecules participate (3).

The nature of the driving force in diffusion is a matter for argument.

*Tasmanian Timber Promotion Board

+ University of Tasmania, Box 252C G.P.O., Hobart, 7001, Tasmania

Partial pressure of water vapour and 'spreading pressure' have been proposed as being more acceptable physically than the concentration gradient adopted by the classical theory (4). Whatever mode of transport is proposed as being dominant, a diffusion model must allow for the effects of the other transport regimes present. The relative dominance of these regimes will vary as the amount of water present in the material changes. In order to adequately describe timber drying behaviour with a simple model a variable diffusion coefficient is required.

FICKIAN DIFFUSION

Fickian diffusion is based on the hypothesis that the rate of transfer of a diffusing substance through a unit area is proportional to the gradient of the concentration of that substance normal to that area. If timber is considered orthotropic, having two mutually orthogonal axes with negligible moisture flow in the longitudinal direction during drying the diffusion equations are

$$-F_x = D_{xx} \frac{\partial c}{\partial x} + D_{xy} \frac{\partial c}{\partial y}$$

$$\text{and} \quad -F_y = D_{yx} \frac{\partial c}{\partial x} + D_{yy} \frac{\partial c}{\partial y} \quad , \qquad (1)$$

where $F_x$ and $F_y$ are the moisture fluxes in the radial and tangential directions [kg $m^{-2}$ $s^{-1}$].

C is the moisture concentration [kg $m^{-3}$]
and $D_{xx}$ etc. are the Fickian diffusivities [$m^2$ $s^{-1}$].

With the principal diffusion axes corresponding to the radial and tangential directions in timber, equation (1) leads to

$$\frac{\partial c}{\partial t} = \frac{\partial}{\partial r} \left(D_r \frac{\partial c}{\partial r}\right) + \frac{\partial}{\partial t} \left(D_t \frac{\partial c}{\partial t}\right) \quad , \qquad (2)$$

which is the Fourier type equation for transient mass transfer by diffusion.

The diffusivities $D_r$ and $D_t$ can be measured directly using diffusion cells (5).

An alternative approach is to infer diffusivities from the measured drying behaviour of timber samples dried under controlled conditions through the measurement of mass and volume.

RESULTS

VARIATION OF DIFFUSIVITIES WITH MOISTURE CONTENT AND TEMPERATURE

Discs of a commercial Tasmanian hardwoord, probably E.regnans 45mm dia,

0.5mm thick with growth rings parallel to the plane (radial diffusion) and normal to the plane of the disc (tangential diffusion) were sealed onto glass jars containing different saturated salt solutions which in turn were placed in an air space above saturated salt solutions. Rotating blades both inside the glass jars and in the external air spaces prevented layering of the air. Apparatus temperature was controlled to $\pm$ 3°C. Diffusivities were calculated from measured mass fluxes through the discs together with moisture concentrations determined from equilibrium moisture content curves and measured densities. Typical results are given in FIG. 1.

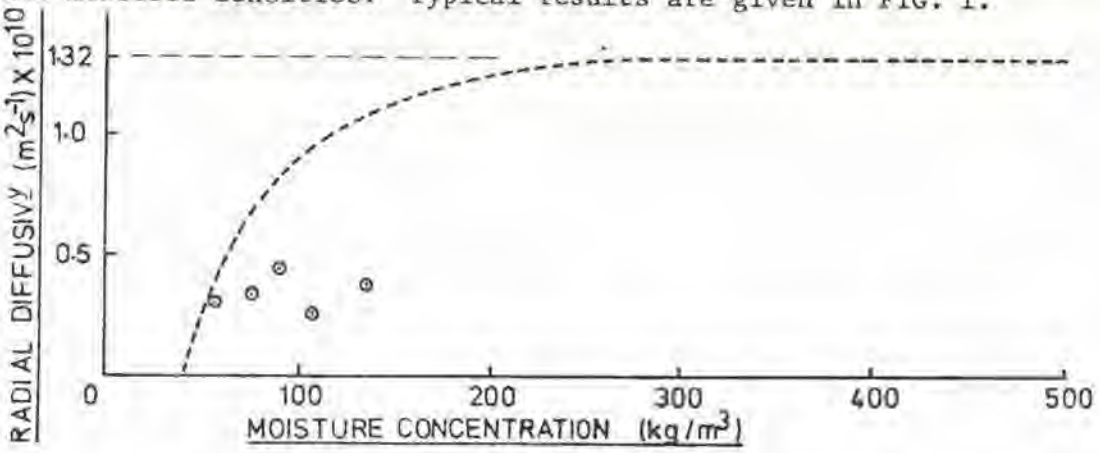



FIG. 1
Variation of Radial Diffusivity with moisture content.

The ratio of tangential to radial diffusivities was close to constant. The mean value of $D_t/D_r$ was 0.72 with a standard deviation of 0.10 from 9 measurements over a range of moisture concentrations from 56 to 135 kg/m$^3$ at a temperature of 20°C.

The dotted line in FIG. 1 is of the form

$$D_r = D_o\left(1 - \exp\left(-\left(\frac{C-40}{50}\right)\right)\right) \text{ where } D_o = 1.32 \times 10^{-10} \text{ m}^2\text{s}^{-1} \qquad (3)$$

Equation (3) is similar to that adopted by Bramhall (6) to fit variations with moisture content of a diffusion coefficient based on a vapour pressure gradient.

DETERMINATION OF DIFFUSIVITIES

FIG. 2 shows drying curves for fully quartersawn E.delegatensis boards, 700mm long sealed at both ends. Moisture concentrations plotted in FIG. 2 are mean values for the boards calculated from measured masses and densities. The lines drawn on FIG. 2 result from a mathematical model based on Equation (2) with diffusivities chosen to give the best fit to the measured data. In the case of the 136mm x 28mm board a variation in diffusivity as shown in

FIG. 1 was assumed; however a constant diffusivity $D_t = 0.7 \times 10^{-10}$ $m^2 s^{-1}$ produces a result indistinguishable from that shown in FIG. 2. Likewise a constant diffusivity $D_t = 0.21 \times 10^{-10}$ $m^2 s^{-1}$ gave an adequate fit to the measured drying data of the 177mm x 25mm board.

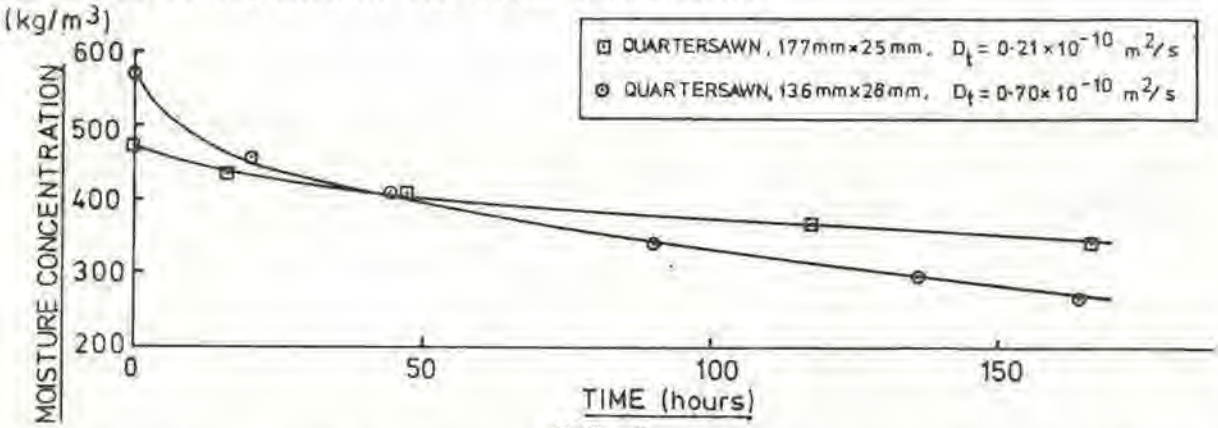



FIG. 2
Drying curves fitted to measured data by appropriate choice of diffusivities.

MOISTURE CONCENTRATION VARIATION WITHIN BOARDS

Sections of boards 108mm wide 27.4 mm thick were sliced into 0.7mm thick wafers. The wafers were oven dried to determine moisture contents and hence moisture concentrations. A typical measured variation in moisture concentration across a fully backsawn board is shown in FIG. 3. together with moisture concentrations computed from the mathematical model based on Equation 2 using diffusivities determined from FIG. 2.

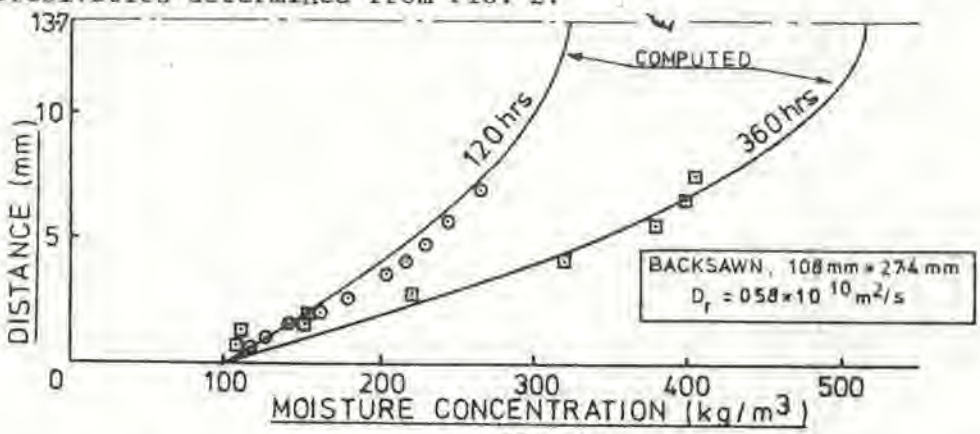



FIG. 3
Measured and computed moisture concentrations within a 108 x 27.4 mm board during drying.

DISCUSSION

Diffusion cell measurements of diffusivity are imprecise and subject to errors associated with the differences between adsorption and desorption isotherms. The alternative approach lumps the multiplicity of processes which occur during drying into two parameters which can be selected to fit the more easily measured drying curves. Care must be taken to ensure that

the mathematical model gives an adequate fit to the measured drying behaviour throughout the range of drying conditions and timbers to which the model is applied. This approach can also accommodate the shrinkage which occur as wood dries.

## CONCLUSIONS

The variability of timber properties between and within species is well known (7). Consequently there is little benefit in determining precise values of diffusivity or developing a model of diffusion based on one or more of the physical, chemical and biological processes thought to be occurring. The model described above is to be used to study the effects of different drying parameters on shrinkage induced stresses. For this purpose, an orthotropic Fickian diffusion model is adequate in that qualitative effects can be established for a variety of timbers while 'worst case' parameters can be used to predict the limits of drying for which no checks will occur.

## ACKNOWLEDGEMENT

This project is funded jointly by the Tasmanian Timber Promotion Board and the Government of Tasmania with assistance provided by the University of Tasmania.

## REFERENCES

1. Jason AC 1958 Fundamental Aspects of the Dehydration of Foodstuffs. London. Society of Chemical Industry. 103-105.

2. Crank J 1956 The Mathematics of Diffusion. London. Oxford University Press. 1.

3. Babbitt J D 1977 More on application of Fick's Laws. Wood Sci. 9 (4) 149-151.

4. Bramhall G 1979 Sorption diffusion in Wood. Wood Sci. 12 (1) 3-13.

5. Mackay J F G 1971 Moisture flux determinations influenced by air circulation inside diffusion cells. Wood Sci. 3 (4) 220-222.

6. Bramhall G 1979 Mathematical model for lumber drying. Wood Sci. 12 (1) 14-21.

7. Anon. 1969 Sampling of timber for evaluation of species properties. CSIRO Forest products technical note No. 5.

# FURTHER DEVELOPMENT AND USE OF SOLAR KILNS IN QUEENSLAND

D.K. Gough and D.G. Hiley
Division of Technical Services
Queensland Department of Forestry
Brisbane

## ABSTRACT

A solar kiln of 15 cu m capacity was built for demonstration and research purposes in Brisbane, Queensland in 1979. Details of design and construction (supplementary to article by D.K. Gough, 19th Forest Products Conference 4A/5/C) are given, together with drying rates for additional speci es dried in the solar kiln and matching air dried stacks. On a fine day the maximum temperature in the kiln is about 18°C to 24°C above the maximum outside temperature. The kiln is effective and can dry timber below equilibrium moisture content in a relatively short time. The most effective system of operation is to air dry the timber to about 20-25 per cent moisture co ntent before moving it into the kiln. For the denser hardwoods, the solar kiln has been found a more attractive proposition for 25 mm material than for thicker timber.

## INTRODUCTION

A solar kiln of 15 cu m capacity was built for demonstration and research purposes in Brisbane, Queensland in 1979 (27°S latitude). One of the aims in constructing the solar kiln was to provide a cheaper, faster method of drying small quantities of board size timber in conjunction with air drying to suit the needs of small sawmillers with low capacities, many of these being found scattered throughout Queensland. Obviously for these reasons also, it would be of immense value for third world countries.

## DESIGN AND CONSTRUCTION

The design of the kiln is based on the glasshouse principle. (Figure 1, Plate 1). External solar collectors are not used. The roof and walls of the demonstration kiln are of sheets of 3 mm window glass, lapped, and fitted to an aluminium glazing bar frame. Sheets of fibreglass reinforced polyester, either flat or corrugated, have also been used with almost the same efficiency. Cost and availability were the deciding factors which favoured glass in this

case. Protection from hail in summer thunderstorms may be necessary. In two and a half years we have received only two light hail storms in whcih only one pane of glass was broken. Motor mowers have broken two panes. The rear wall (southern) is of timber, lined inside with aluminium faced building paper. Loading doors are in this wall (Figure 1, Plate 2). A 1.1 m diameter reversible propellor fan, driven by 1.5 kw motor, provides air circulation of about 1.0 m/s through the stack. Uniformity of air circulation is good.

An important design consideration was to minimise heat losses from the system. Clear polyvinyl chloride film (0.15 mm thick) was fitted to the inside of the external frame to provide an insulation gap of 75 mm wide. Loss of heat to the ground is reduced by providing (a) a timber floor overlaid with building paper between the external walls and the screen walls; and (b) a timber floor on the trolleys and hobs in the stack chamber between the screen walls. The precaution should be taken to build the kiln on a well drained site, and to seal the ground of the stack chamber with an impermeable membrane. The screen kiln design, with horizontal air flow, was chosen because it has a high proportion of roof area, to maximise solar collection. The concrete block screen walls are made of either 100 mm hollow blocks laid on their side, or of 100 mm decorative screen wall blocks. The purpose of the screen walls, is to give uniform air flow along the length of the kiln. The void area of these blocks is about 25 per cent of their gross area. Timber or aluminium battens are alternative materials that could have been used for the screen walls.

All surfaces exposed to sunlight beneath the glass roof and walls were painted with flat block paint to prevent reflection of sunlight back out of the kiln and to maximise absorption of heat within the structure.

An updated estimate of the materials for the kiln is $A5000 and labour is estimated at $A2500. This amounts to a total cost of $A500 per cubic metre of capacity.

ADDITIONAL RESULTS OF DRYING TESTS

The kiln has been in operation since March 1979. The highest temperature, 59°C, was reached in the kiln during January 1980, when the ambient atmosphere temperature (Stevenson Screen) was 35°C.

Results of tests of additional species dried in the kiln since Gough's last (1979) report are as follows:

1. Sydney Blue Gum (*Eucalyptus saligna* Sm.) 38 mm thick, basic density 655 kg/cu m, dried in August and September ("dry" season). This timber dried from 27 per cent moisture content to 12.2 per cent moisture content in 62 days. A matching air drying stack dried to 17.5 per cent moisture

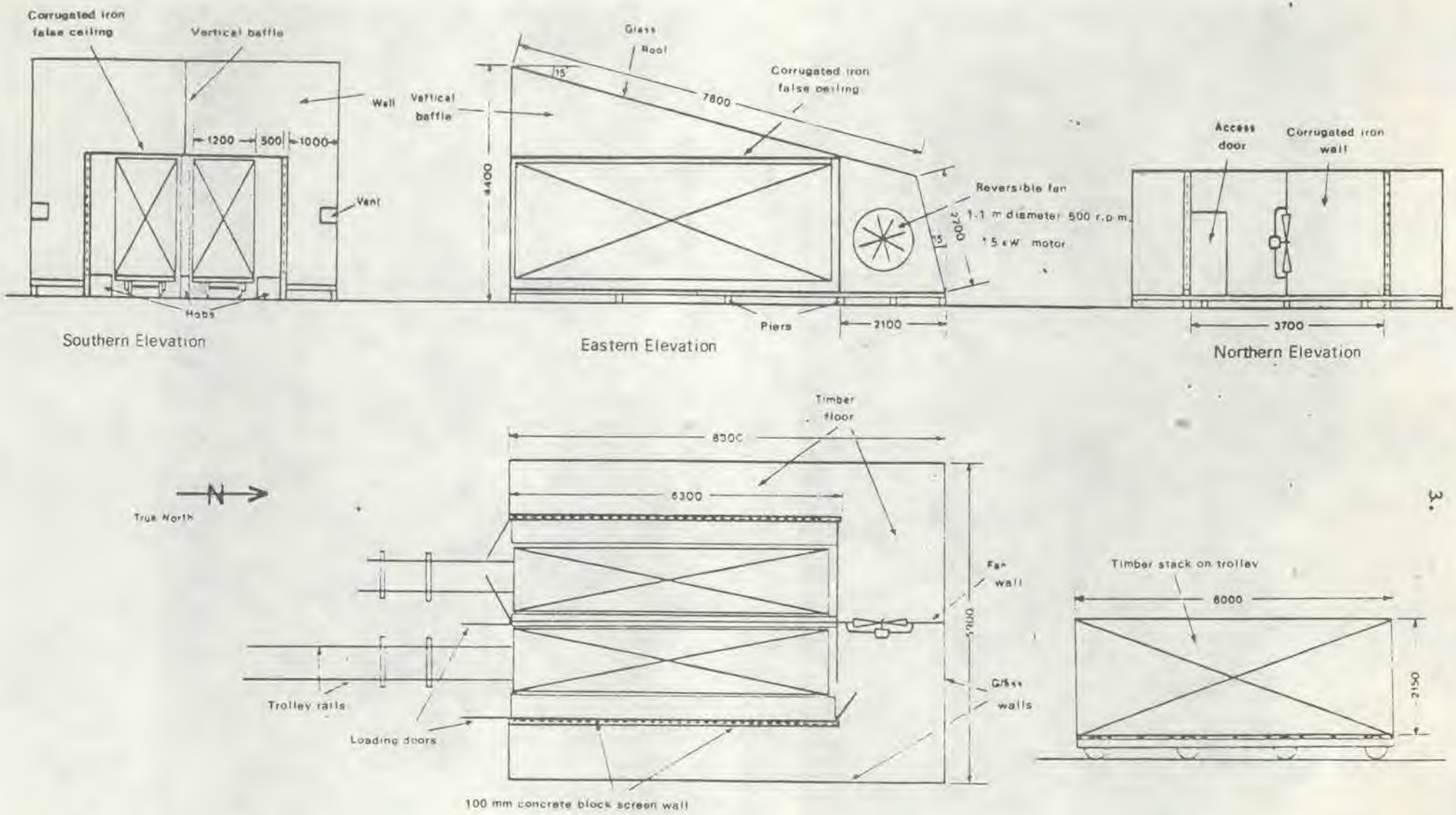



Figure 1. Design of a solar timber kiln

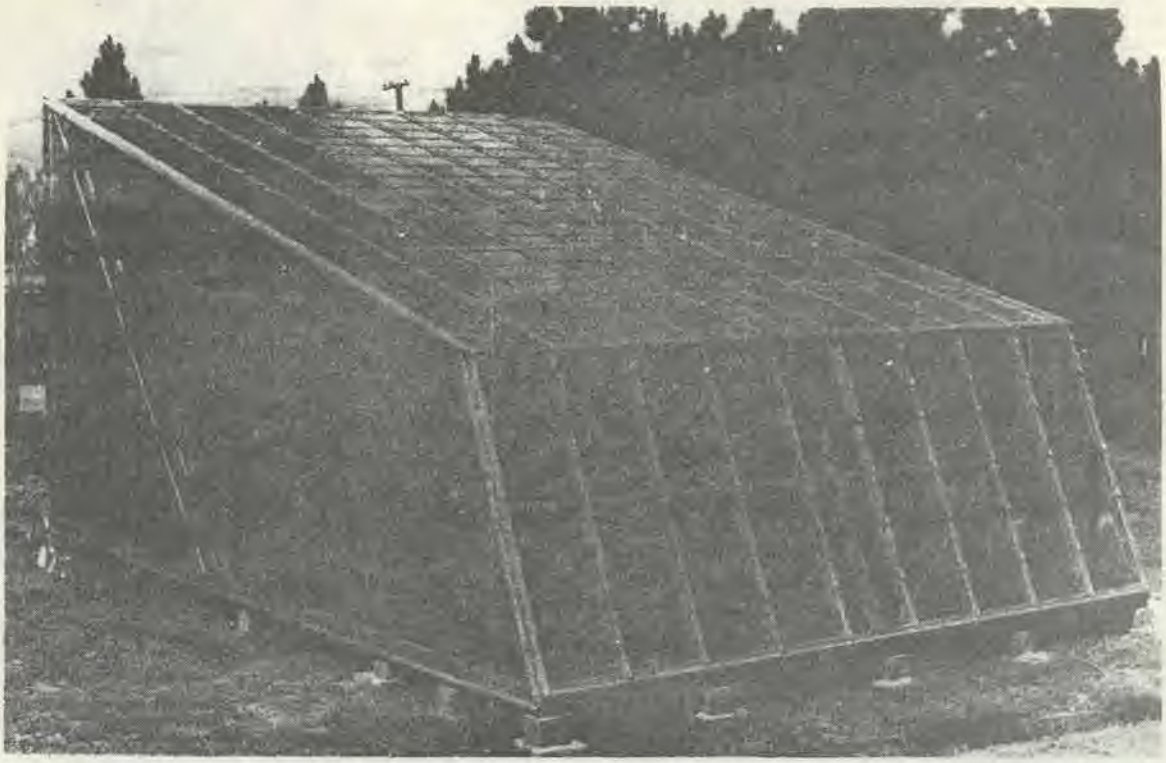


Plate 1. The Solar kiln looking at the north-eastern corner. The concrete block screen wall is visible on the left behind the eastern glass wall.

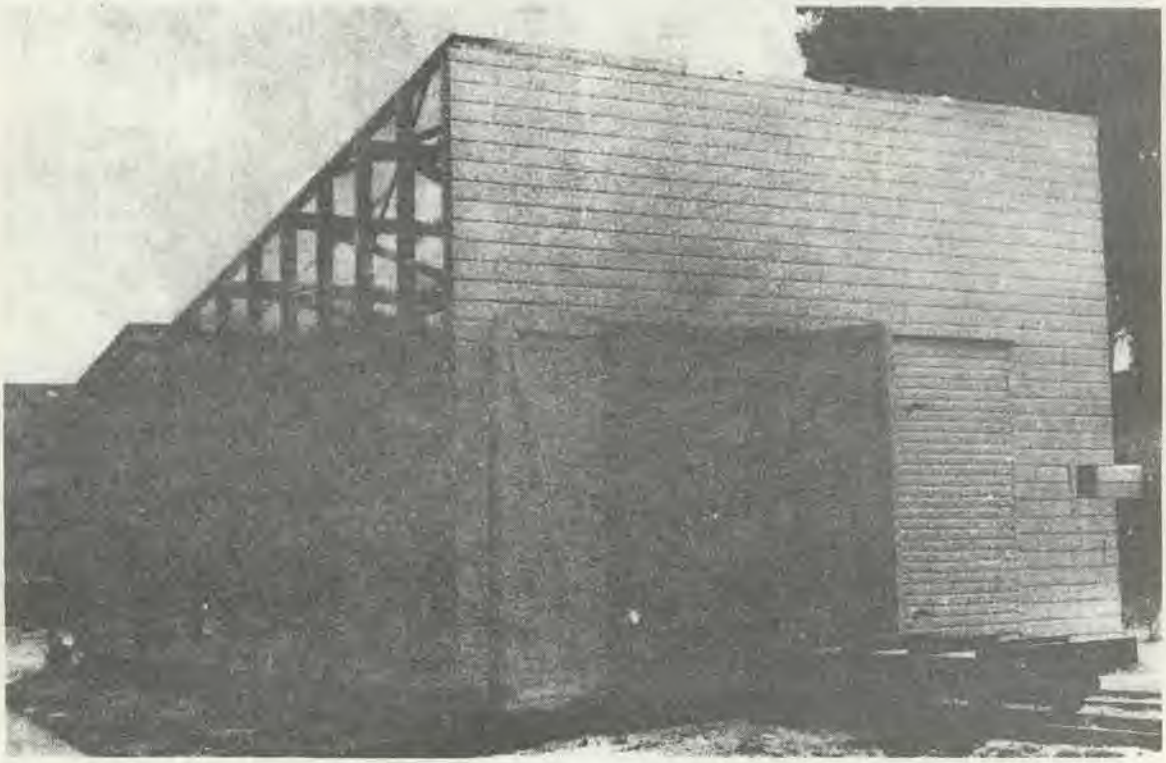


Plate 2. Rear view of the kiln, (southern wall) showing access doors and timber stack trolley

content in the same period and was only 15.7 per cent moisture content after a further 43 days. The dried quality was good but the drying time was comparatively long and this would limit annual production from the kiln. This was the first time that eucalypt timber thicker than 25 mm had been dried in the solar kiln. Previous studies had shown that 25 mm narrow-leaved red ironbark (*Eucaluptus crebra* F. Muell.) dried from 20 per cent moisture content to 12 per cent moisture content in 19 days. This 38 mm Sydney Blue Gum dried from 20 to 12.2 per cent moisture content in 38 days. In this case, a 50 per cent increase in thickness resulted in a 100 per cent increase in drying time.

2. Rose Mahogany (*Dysoxylum fraseranum*) 50 mm thick, 100-300 mm wide, basic density 591 kg/cu m, dried from December to May (mostly "wet" season). The timber in the solar kiln was dried from 37.5 per cent moisture content to 12 per cent moisture content after 72 days. It took 50 days to dry from 20 per cent moisture content to 12 per cent moisture content. A matching air drying stack dried to 18.5 per cent moisture in the 72 days and was only 17.4 per cent moisture content after a further 54 days.

Kiln temperature and the rate of drying are affected by wet and cloudy weather and by seasonal change. However, it is only under the most unfavourable weather conditions that drying is likely to cease in a solar kiln, whereas an unprotected air drying stack is affected immediately by wet weather.

## OPERATION OF THE KILN

Preliminary air drying to about 25 to 20 per cent moisture content is recommended for most economical operation. The kiln can be used for drying from green-off-saw, but the rate of release of the moisture above fibre saturation point is relatively high, and this reduces the kiln temperature. Temperature is reduced by the higher evaporative load and the need to open the vents to expel the moist kiln air. Below fibre saturation point, release of the bound moisture is slow and experience has shown that it is not necessary to open the vents. Opening the doors once a day to check the moisture content of the charge seems to be sufficient to provide an exchange of kiln air.

Direction of the air circulation should be reversed at midday, to flow firs. through the eastern screen wall in the morning, and through the western wall in the afternoon. An automatic time switch can be used to turn the fan on in the morning, reverse it at midday, and turn it off at sundown. There is nothing to gain by running the fan throughout the might. The cost of running the fan for an average of nine hours per day is about six cents per

cubic metre per day (based on the cost of electricity at six cents per kWh).

## CONCLUSIONS

It is clear that the kiln is effective. Low moisture content can be attained and the dried quality is good. On a fine day the maximum temperature in the kiln is about 18°C to 24°C above the maximum outside temperature.

Timber takes about two to three times longer to dry in a solar kiln than a conventional kiln. However, the capital cost and operation cost of a solar kiln is much less than that for conventional kilns. Naturally the efficiency of solar kilns is reduced in areas of high rainfall or heavy cloud cover. Efficiency is also reduced when drying timber greater than 25 mm thick from high density species. In general the solar kiln has been found a more attractive proposition for 25 mm material than for thicker timber particularly with the denser hardwoods.

Solar kilns should be considered as an alternative to kilns heated by an oil fired boiler or by the exhaust gases from an oil burner. They are also less expensive to install and to operate than dehumidifier kilns.

Four other solar kilns of this design are operating in a production situation. One is in Papua New Guinea and the others are in Queensland. Results achieved by all users have been very satisfactory.

## ACKNOWLEDGEMENTS

The authors wish to acknowledge the assistance given by staff at the Experimental Mill at Salisbury both during the construction and with experiments carried out in the kiln.

## REFERENCES

1. Gough, D.K. 1977. The design and operation of a solar timber kiln. Fiji Timbers and their Uses No. 67 (Dept. of Forestry: Suva, Fiji). 17 pp.

2. Gough, D.K. 1979. "Demonstration Solar Timber Kiln". Proceedings 19th Forest Products Research Conference 4A/5/C.

3. Gough, D.K. 1981. Timber Seasoning in a Solar Kiln. Technical Paper No. 24 Department of Forestry, Queensland.

# DESIGN AND CONSTRUCTION OF A LABORATORY EXPERIMENTAL KILN

S. Panow
Division of Technical Services
Queensland Department of Forestry
Brisbane

## ABSTRACT

Recognizing the necessity for more research in the drying of wood, particularly in determining the independent and interacting affect of various kiln drying parameters on the wide-ranging timber types comprising the resource, a laboratory experimental kiln will be built at the Department's premises at Salisbury, Brisbane.

The kiln is designed to:

(a) dry any material up to 1 830 mm length

(b) handle volumes of timber up to 0.34 cu m

(c) develop a temperature range from ambient to 200$^{o}$C

(d) deliver air with a velocity through the charge from 1 m/sec up to 10 m/sec; with additional pitch adjustments air velocity can reach up to 15 m/sec.

The kiln will have an electronic control system and built in safety devices.

## INTRODUCTION

Recognizing the necessity for more research in the drying of wood, a laboratory experimental kiln will be built on the Queensland Department of Forestry's premises at Salisbury, Brisbane. The design is in progress and some materials are available to commence construction.

## KILN DESIGN

The kiln is designed to perform a wide range of seasoning experiments.

The specifications of the kiln are:

1. Size (external): 2 780 mm width
   3 630 mm length
   1 000 mm height

2. Volume Capacity: the kiln is able to dry any material from 600 mm to 1 830 mm long. The maximum capacity is 0.34 cu m or 24 boards of 51 mm x 152 mm x 1 830 mm placed on 25 mm stickers.

   At 25 mm x 102 mm x 1 830 mm the capacity is 54 boards or 0.25 cu m on 25 mm stickers. At 1 830 mm length the twist of the boards can be measured.

   The charge can be reversed during drying to ensure even drying of both sides of the stack.

3. Heat Capacity: the kiln will develop temperatures in the range from ambient to 200°C.

   Electrical heaters are proposed with total capacity of 36 kw.

4. Air Delivery Rate and Air Velocity: A wide range of air delivery is provided. The axial fan is driven by variable speed drive with 6:1 ratio.

   Calculated maximum required volume of air is 540 cu m/min which should give 10 m/sec air speed through the charge.

   The air delivery system is designed to provide air speed through the charge from 1 m/sec up to 10 m/sec.

   Change in pitch angle will allow the velocity of the air to vary from 0.4 m/sec to 15 m/sec.

5. Humidity: Electrical heaters will generate the necessary steam which will be fed into the air stream as required.

6. Reconditioning of the Timber after Drying: An additional chamber adjacent to the kiln will be used for reconditioning. The steam will be generated from electrical heaters.

7. Kiln control: The kiln will have electronic control and safety devices built in the control system to provide and maintain nominated temperature, wet bulb depression and air velocity.

KILN USE

The kiln is expected to be operational by October 1981 and will be used to conduct trials of low and high temperature drying of a number of species as well as high temperature high humidity drying of other species which tend to distort or develop surface defects when conventional schedules are used.

Different air delivery rates will be tried to determine optimum rates of drying with minimum accompanying induced defects. Methods of preventing twist of the boards will be investigated using horizontal as well as vertical restraint.

New drying schedules will be established for a number of untested as well as known refractory species.

# A SYSTEM FOR MONITORING POWER CONSUMPTION

by E P Lhuede, T J Stevens and P Grusovin

Division of Building Research, CSIRO

## INTRODUCTION

The requirement to establish a basis for determining power consumption in a sawmilling operation was discussed at the 19th Forest Products Research Conference (1). As a first step in this work, it was considered that a method of concurrently recording the frequency and duration of saw cuts made by each of the benches and conversion units in a mill should be developed, without attempting to measure the actual energy usage (kilowatt hours) of the motors for the various cuts. Previous work by Cowling (2) inter alia had shown that variations in power consumption for given rates of feed and depths of cut can vary by factors of 2/1, so that in a preliminary analysis, an average power per cut might reasonably be assumed or measured separately in determining the total power consumption of a motor if frequency and cutting time could first be established.

In the course of acquiring information in this area, it was also noted that the measurement and recording of cutting frequency or "on times" of saw mill machinery is significant in the analysis of production delays, and other equipment has been reported to monitor and study such delays or breakdowns, viz "The Downtimer" (3).

The development of a system for continuously logging the frequency and duration of the non-idling periods of operation of a number of electric motors in a process could aid in establishing an energy consumption model for a particular saw mill arrangement and assist in analysing deficiencies in the process.

DESCRIPTION OF EQUIPMENT

Electric motors used in hardwood timber conversion may typically come under load up to five times per minute for periods of about five seconds (4), while in modern softwood conversion plants the number of cuts per minute and the overall utilization of plant could be higher. In either process however, there will be a considerable time for which motors are at an idling condition. There are a number of methods of monitoring the power consumption of a motor which will differentiate between the idling and higher load conditions, but for the equipment required in a sawmill investigation, it was considered that it should be a non-permanent fixture, and it would not require disconnection of permanent wiring or entry into switch board enclosures. Apart from cost considerations, power measurement transducers with associated recording equipment were considered unsuitable for the work and a simpler system was sought. One proposal was to place a small magnetic induction coil (as used in a telephone pick-up coil) against the three phase p.v.c. covered supply cable to a motor and monitor the output. These devices, when used with a suitable amplifier, have been reported as being capable of detecting a current in hidden electrical cables (5); due to the harmonics and noise associated with the current flow, and the loose electrical coupling of the coil and cable, a satisfactory discrimination of the load and no load currents could not be obtained in this work simply by amplifying the signal. Differences in the noise pattern between a load and no load current were observed however, and by incorporating a 50 Hz band pass filter in the circuit, thereby eliminating the electrical noise, an effective measure of a phase current was obtained for a suitable location of the pick-up coil on the cable. The circuit developed for the work is shown in Figure 1. The upper section is the 50 Hz filter and was designed to have a 4 Hz band width with a "flat top" characteristic, with the signal passing to a 100/1 gain control, thence to a comparator circuit.

The gain control serves the dual function of compensating for the variable coupling that exists for different locations of the pick-up coil on the cable, and secondly enables the current range of the motor (from idle to full load) to be accommodated on the scale of the level meter in the comparator circuit.

The comparator has a 1% hysteresis and is set up to change state when the level meter in the circuit passes through the centre point of its scale. A relay (with output to pins 2, 5) closes for this movement corresponding to a rise in current detected by the pick-up coil. Having taped the sensor to the power cable, the system is operated by adjusting the gain control to have the

level meter pass through the half scale deflection as the line current rises marginally above the idle current, or above some current associated with a minor production task, e.g. a short length or shallow depth of cut. As the motor load decreases, the relay opens when the current drops back through the mid-scale position of the meter. It was anticipated that at a later stage of the project, a measure of phase current could be required and a signal, linearly related to current for a given cable-pick up configuration, was made available at terminal 3.

The components were mounted on a printed circuit board and enclosed in a 70 mm x 90 mm x 600 mm plastic case with the controls exposed on a front cover. A number of units have been built at a cost of approx. $80 each inclusive of parts and labour.

A 60 kw induction motor driving a 1 m diameter saw on a power feed saw bench was used to test the equipment and it was possible to differentiate between the power inputs for cuts on hardwood of approx. 20 mm thickness at slow feed rates and at idling conditions.

## RECORDING OF DATA

While the detection system has been designed and tested, the data recording and interpretation is at a proposal stage. The concept is to log the status of the comparator circuit at an arbitrary 0.5 sec. interval either by stepping a paper tape punch at this rate or by storing the signals in a micro-computer where the sampling rate would be initiated as part of the programme. Conveniently the status of up to eight transducers could be logged on tape or as an 8 bit byte on the computer. It is considered that the logging of the status of eight motors on the main production saws would be adequate, at least in an initial evaluation and would produce managable quantities of data. The information necessary to determine average power consumption for a given saw milling system would be determined from the on times of individual benches and from the overlap of operation of the various components.

## CONCLUSION

Equipment has been designed and tested that will provide an electrical signal indicating whether an electric motor is operating under load or is at an idling, or low power consumption state. The signal is obtained without direct electric contact with supply cables. It is proposed to use this device to

establish a power consumption model for a sawmilling operation, or it may be used in analysing the power use of a multi-motor system where the loads on individual units is continually changing.

REFERENCES

1. Lhuede, E.P. (1979). "Energy and Sawmilling", 19th Forest Products Research Conference, Topic 4A/7. CSIRO Division of Building Research, Melbourne.

2. Cowling, R. (1956). "Sawing Research - Field Investigations, Review of Field Tests and Suggestions for Future Work". Forests Prod. Lab. Rep. No. 6. Sub-Project U11-10. CSIRO Division of Forest Products, Melbourne*.

3. Bryan, E.L., and Nutt, M. (1978). Modern Sawmilling Techniques. Proc. 8th Sawmill Clinic. Sawmill Clinic Library Vol. 9. Portland Oregon. 73, 80. Miller Freeman Publication.

4. Lhuede, E.P., and Waugh, G. (1980). "Productivity of Sawmills Utilizing Small Diameter Eucalypts". CSIRO Division of Building Research, Melbourne.

5. Wait, P. (1980). "Mains Cable Seeker". Electronics Today International, May, p.47-49.

*Copy held at CSIRO Division of Building Research, Melbourne.

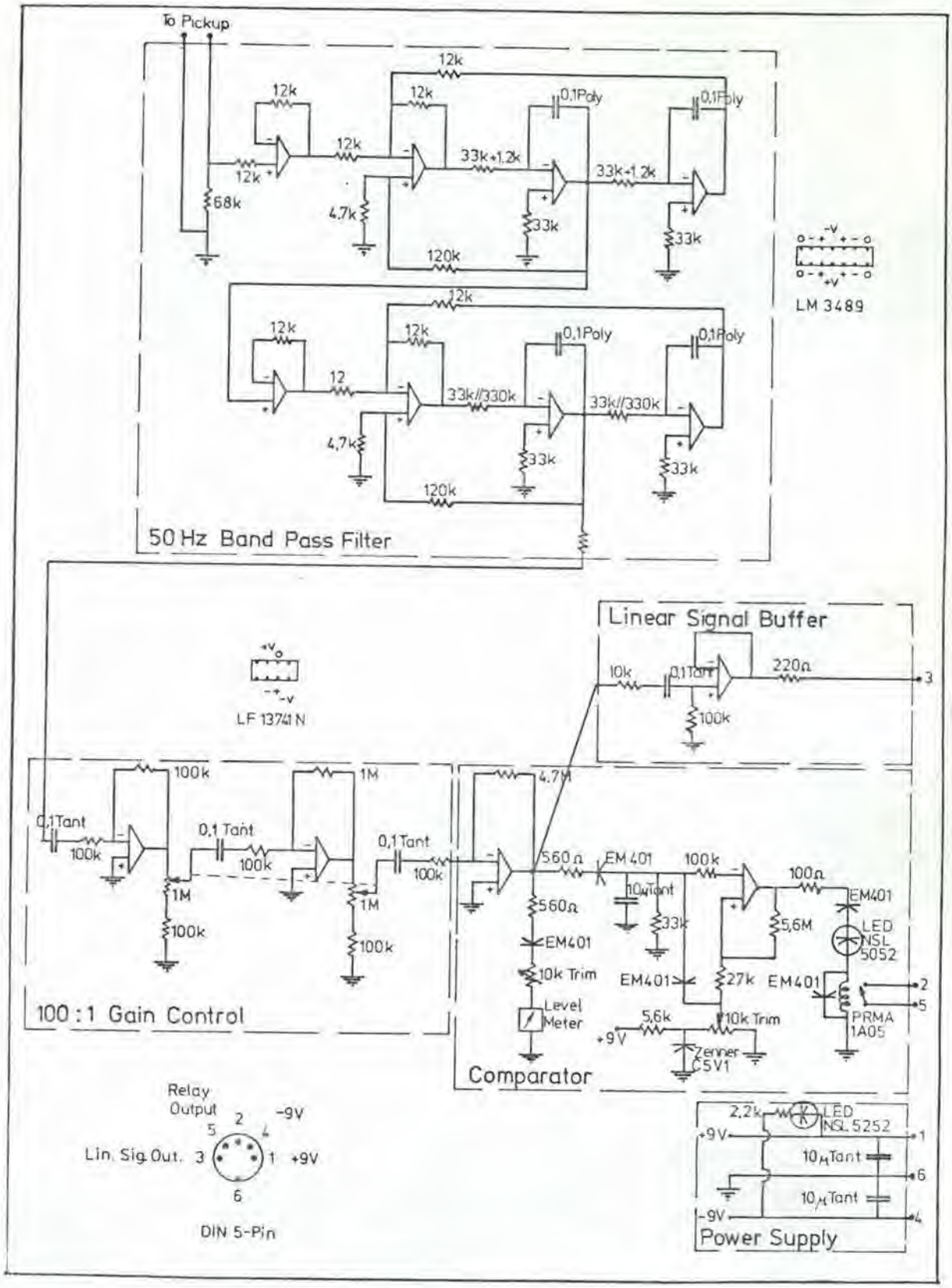

To Pickup
12k
68k
4.7k
33k+1.2k
33k-1.2k
0.1Poly
33k
120k
50 Hz Band Pass Filter
LM 3489
12
33k//330k
4,7k
LF 13741 N
Linear Signal Buffer
10k
0,1Tant
220Ω
100k
100 : 1 Gain Control
1M
0,1 Tant
4.7M
560Ω
EM 401
10µTant
5,6M
LED NSL 5052
10k Trim
Level Meter
27k
5,6k
Zenner 5V1
PRMA 1A05
Comparator
Relay Output
-9V
+9V
Lin. Sig. Out.
DIN 5-Pin
2,2k
Power Supply

FIGURE 1

# DIMENSIONS OF SAWN SCANTLING

by E P Lhuede

CSIRO Division of Building Research

## INTRODUCTION

The lateral vibration of saw blades is one of a number of factors that can be regarded as causing variability in the dimensions of timber sawn on circular saw benches, and methods of controlling such vibration have, and continue to be, the subject of research in overseas laboratories. Various aspects of the topic were discussed at the 19th Forest Products Research Conference (1) and the possibility of using alternative designs of saw guides on existing circular saw benches converting hardwoods was suggested as a means of improving stability. Such saw guides may enable either a higher sawing accuracy to be achieved with existing saw kerfs, or even thinner saws to be used with acceptable cutting accuracy but with reduced kerf loss.

As a preliminary to considering any development work in this area, a knowledge of the levels of accuracy and the variability of sawn dimensions produced on a range of commercial equipment would be necessary as a basis against which modifications could be assessed.

Some previous published and unpublished work has been available on the subject of sawing accuracy (2,3) and has formed, in part, the basis for dimensional tolerances specified in relevant standards (4); this data, however, would probably be inadequate when evaluating detailed variation of dimensions along the length of sawn scantling. In collaboration with sawmilling companies, where information on percentage overcutting was required, a series of measurements was made on scantling sawn on a number of benches in different mills and on edgers and bandsaws. Some aspects of the measurements taken on the circular saws are discussed in this paper.

DETAILS OF MEASUREMENTS

The investigation was concerned with measuring the dimensions of green hardwood produced from circular saw benches before docking in sizes ranging from 25 mm to 50 mm nominal thickness and in widths from 75 mm to 150 mm. The more common form of cutting pattern used in mills visited was for the depth or greater dimensions to be cut on benches from flitches milled (approximately on the quarter) to about the required thickness. Measurements were also taken on pieces from wide back sawn boards of a required thickness (38-50 mm) with the board being cut at the widths either on a multi-circular saw edger or on a bench. The measurements were taken with vernier calipers.

In a preliminary study, it became apparent that there could be significant differences in the thickness (lesser piece dimension) between the two edges of a sawn piece and measurements for taper should therefore be taken. Direct observation also indicated that a degree of saw vibration could occur at the start of cutting and significant differences in thickness were found to occur over at least the first metre length of pieces. Subsequently, six stations along the length were measured; two values of thickness and one of width were measured at 25 cm from the infeed end, at 50 cm from the infeed and outfeed ends, and at the centre and quarter points. Where possible, 10-12 boards were measured, although it was necessary, on occasions, to accept a lesser number. Surface finishes were also measured using equipment specified in AS 1728-1975 (5).

The measurements were analysed by an analysis of variance and mean values for each station are tabulated for the thickness data together with an overall mean and standard deviation for the six values (Tables 1 and 2). The standard error of the difference (S.E.D.) between the means for each station is listed. For the number of boards used in most of the assessments (6 to 12), and the six stations per board, the significant value of the "t" statistic for comparison of station means at the 5% level of probability is approximately 2. Where the variance ratio test indicated a level of statistical difference along the board, differences between mean values for the stations can therefore be assessed. The standard error of the overall mean can be calculated from the standard deviation and the number of boards measured, where this data may be required for establishing production control limits.

For the width (greater dimension) and taper, the mean values only are tabulated with the relevant statistics. From the production viewpoint, sawing

inaccuracies on the deeper face were considered to be the more relevant measurement and details of variation in width and taper along the board have not be listed.

Differences in means between two tests can be assessed by comparing the value of

$$\frac{\text{Mean 1} - \text{Mean 2}}{\sqrt{S_1^2/n_1 + S_2^2/n_2}}$$

with the "t" statistic for the required confidence level and the relevant degrees of freedom given (conservatively) by the lesser of $(n_1-1)$, and $(n_2-1)$. $S_1$, $S_2$ are the standard deviations of means 1 and 2 respectively, and $n_1$ and $n_2$ are the numbers of boards in the two tests. This test is applicable whether or not the variances in the two tests are equal, but is less sensitive than standard tests which assume equal variances.

## DISCUSSION OF RESULTS

### Lateral Vibrations

The detailed measurements of piece thickness as shown in Tables 1 and 2 indicate that there are significant differences along the piece with the three measurements taken from the quarter to three-quarter stations being, in general, not significantly different. It has been observed that as timber first contacts the saw a slight lateral perturbation can be observed; this is rapidly damped as the saw fully enters the cut, so that at some distance from the infeed end stable cutting occurs. There is a smaller deviation from the mean at the outfeed end which may be related to a lack of restraint of the blade (which is about 1 metre diameter) as it leaves the cut.

The standard deviation (S.D.) of the mean value provides an estimate of the range of measurements that may be obtained on a piece, and for an average value (of the S.D.) taken as 0.7 mm for 38 mm scantling a range of 2.8 mm (4 x S.D.) could be regarded as typical. This is well below the ±3 mm currently allowed in standards. It indicates that the main inaccuracies observed on circular saw benches, which may be associated with lateral vibration, occur over about one metre length of the piece (as indicated from measurements on 4.8-5 m long scantling). This level of inaccuracy is small by current standards.

Taper measurements are generally not significantly different along the length, although in some tests measurements showed that the values (of the order of 0.3 mm) reversed along the length from positive to negative. This behaviour would be compatible with a wave travelling with the blade at some relatively low rotational speed. The existence of such waves is well recognized and understood (6). The level of inaccuracy caused by such a vibration, if it exists, is less than the inaccuracy measured at the infeed end.

## Production Considerations

A number of comparative tests were carried out to determine the affect of newly sharpened and worn sawns on the accuracy of sawing and whether progressive changes in accuracy could be determined over a production period. The data presented for the power feed benches in mills G and K and for the breast bench in mill B indicated changes in accuracy between new and worn saws. The order of the change as indicated by the standard error of the difference of the means would be 0.2-0.4 mm, which may (or may not) be of practical significance.

The performance of the two breast benches of mill D, each processing an identical infeed and product indicates the importance of operator control on accuracy. The "east" bench in this mill produced approximately 15% more sawn material per hour than its counter-part with less variation and closer to an optimum size.

Correct adjustment of saw guides and frequent checking and correction for changes away from optimum sizes may have a more important influence on sawing accuracy than other possible modifications to the saw bench. It is worth noting that the standard deviation of mean values and the standard error of the difference of means are not greatly different between power feed benches and the traditional breast benches with simple feed and sizing systems.

## Dimensional Overcut

A proportion of material measured in these tests was in excess of nominal size. Where mills were converting collapse prone species the "aimed at" size was intentionally 2 mm above the nominal dimension, but for the greater proportion of pieces, the required production size was the nominal dimension.

Where a 3 mm under cut is allowable under the relevant code, some consideration might be given to selecting a production size less than the nominal size. The data presented suggests that tighter production controls may permit a 0.5 mm reduction in an "aimed at" dimension of 38 mm without causing any piece to be liable to rejection. While not all of the 1.5% potential saving may be realized, some gains could result. The alternative proposal, that the limits on the nominal dimension could be reduced, may assist in reducing possible overcut and also lead to more efficient structural use of the material.

Some sawmill managers currently use control techniques based on mean values and standard errors to monitor production and a read-out device indicating a representative sawn dimension could be a useful tool for production control.

## CONCLUSIONS

Measurements taken on sawn scantling have indicated variations in dimensions which may be related to saw blade vibration. Values of mean thickness based on six site or station measurements, standard deviations of the mean and the standard error of the difference between the six site means are listed. The data can be used as a basis for assessing possible changes in sawing accuracy as may result from alterations to saw benches or changes in saw thickness.

The variability of sawn dimensions was less than allowed for in relevant codes, and the changes in mean dimensions due to loss of saw sharpness, spring prone logs, etc., appear to be less than 0.5 mm for 38 mm thick material.

Regular maintenance and adjustment of sizing gauges and saw guides with a continuous read out for the sawyer of the average size cut, could reduce dimensional variation more effectively than major changes to the saw or bench design.

## REFERENCES

1. Lhuede, E.P. (1979). "Current Activities and Future Needs in Sawing Research". 19th Forest Products Research Conference, Topic 4A/3. CSIRO Division of Building Research, Melbourne.

2. Page, M.W. (1968). "Latest Developments in Sawmilling Equipment and Techniques for Small Logs". The Australian Timber Journal, 34 (10); 90-99.

3. Jones, D.S. "Improving the Work Balance Between Breaking-Down and Benching". The Australian Timber Journal 1958, 24 (6); 64-94.

4. Standards Association of Australia (1977). "Visually Stress Graded Hardwood for Structural Purposes". AS 2082-1977.

5. Standards Association of Australia (1975). "Types of Timber Surfaces". AS 1728-1975.

6. Mote C.D., and Szymani, R. (1977). Principal Development in thin circular saw vibration and control research. Part 1 - Vibration of Circular Saws. Holz als Roh-und Werkstoff (35) 1977, 189-196.

ACKNOWLEDGEMENTS

The author thanks Dr I Saunders and Mrs E Longmore of the CSIRO Division of Mathematical Statistics for their assistance on the statistical analyses and Mr A C Hogarth and Mr O J M Conoley of Allen Taylor and Company Limited for the arrangements made at various saw mills.

TABLE 1

PERFORMANCE OF 4 MAN BREAST BENCHES

Saw Gauge B,D: 4 mm; C: 3.5 mm; Set 0.56 mm per side
Diameters - Typical: 965-1040 mm
Tooth Velocity - Typical: 2800-3000 m/min.
Feed Speed - Typical: 50-80 m/min.

| Mill Ident. | Details of Tests | | Infeed End | | Average of UPPER and LOWER Edges (mm) | | | | Average Thickness pf Piece (mm) | | | | Average Width (mm) | | | | Average Taper Upper Minus Lower (mm) | | | | Number of Pieces |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 25 cm from end | 50 cm from end | $L/4$ | $L/2$ | $3/4L$ | 50 cm from end | mean | std. devn. | stat. sig. | S.E.D. | mean | std. devn. | stat. sig. | S.E.D. | mean | std. devn. | stat. sig. | S.E.D. | |
| B NSW | Compare NEW and WORN saws - brush box 5.0 m (a27 x 108 mm nominal size) | new saw | 51.6 | 51.9 | 52.4 | 52.3 | 52.4 | 52.4 | 52.2 | 1.15 | *** | 0.38 | 75.6 | 0.53 | *** | 0.30 | 0.07 | - | n.s. | - | 10 |
| | | anew saw | 28.6 | 28.9 | 29.6 | 29.7 | 29.7 | 30.0 | 29.4 | 0.52 | *** | 0.54 | 107.5 | 0.52 | *** | 0.40 | 0.3 | - | n.s. | - | 10 |
| | | worn | 52.6 | 52.9 | 53.6 | 53.5 | 53.2 | 53.2 | 53.2 | 0.47 | ** | 0.58 | 74.7 | 0.64 | n.s. | - | 0.01 | - | n.s. | - | 10 |
| D NSW | Compare accuracy of two identical benches (east & west) 4.0 - 6.2 m | both benches | 51.1 | 51.2 | 50.1 | 51.2 | 51.2 | 51.2 | 51.2 | 1.96 | n.s. | - | 102.9 | 1.2 | ** | 0.76 | 0.13 | - | n.s. | - | 10 |
| | | off west | 39.0 | 39.4 | 39.9 | 40.0 | 39.9 | 40.1 | 39.7 | 0.77 | *** | 0.34 | 102.9 | 1.2 | *** | 0.48 | 0.21 | 0.38 | n.s. | - | 10 |
| | | off east | 36.8 | 37.1 | 37.5 | 37.8 | 37.8 | 37.7 | 37.4 | 0.66 | *** | 0.36 | 100.5 | 0.59 | n.s. | - | 0.51 | 0.66 | n.s. | - | 10 |
| C NSW | Compare NEW and WORN saws, spring prone logs 6.5-7.0 m (Asome 38 mm cut on head saw) | anew saw | 37.6 | 38.2 | 38.6 | 39.3 | 39.2 | 37.4 | 38.4 | 0.81 | ** | 0.52 | 125.9 | 0.65 | ** | 0.20 | 0.22 | 0.53 | n.s. | - | 9 |
| | | worn saw | 36.9 | 37.6 | 38.3 | 38.5 | 38.8 | 38.4 | 38.1 | 0.32 | *** | 0.33 | 125.7 | 0.73 | n.s. | - | 0.45 | 0.49 | *** | 0.22 | 9 |
| | | springy log (1 hr after saw cut) | 36.5 | 37.2 | 37.8 | 38.0 | 38.1 | 37.3 | 37.5 | 0.31 | ** | 0.74 | 125.5 | 0.95 | ** | 1.14 | 0.20 | 0.30 | n.s. | - | 8 |
| | | new saw | 37.2 | 37.6 | 38.2 | 38.2 | 38.6 | 37.1 | 37.8 | 0.56 | *** | 0.72 | 125.8 | 0.36 | ** | 0.52 | 0.27 | 0.37 | ** | 0.80 | 9 |

n.s. signifies no difference
*, **, *** indicates differences at 5%, 1%, 0.1% levels of probability

TABLE 2

PERFORMANCE OF POWER FEED BENCHES

Saw Gauge G: 3.5 mm; K: 4 mm; BF: 3.5mm
Diameters - Typical: 960-1000 mm
Tooth Velocity - Typical: 2800-3000 m/min.
Feed Speed - Typical: 60-100 m/min.

| Mill Ident. | Details of tests | | Infeed End | | Average of Upper and Lower Edges (mm) | | | | Average Thickness of Piece (mm) | | | | Average Width (mm) | | | | Average Taper Upper Minus Lower (mm) | | | | Number of Pieces |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 25 cm from end | 50 cm from end | $L/4$ | $L/2$ | $3/4L$ | 50 cm from end | mean | std. devn. | stat. sig. | S.E.D. | mean | std. devn. | stat. sig. | S.E.D. | mean | std. devn. | stat. sig. | S.E.D. | |
| G NSW | Evaluate progressive wear of saw Ironbark & Blackbutt 4.0-4.9 m | 0-1 hr | 37.6 | 37.7 | 38.1 | 38.3 | 38.5 | 38.2 | 38.1 | 0.54 | ** | 0.44 | 101.4 | 0.93 | ** | 0.38 | 0.4 | 0.56 | n.s. | - | 5+6 |
| | | 0-½ hr | 37.7 | 37.4 | 37.5 | 37.7 | 38.1 | 38.0 | 37.7 | 0.56 | * | 0.48 | 100.8 | 0.3 | n.s. | - | 0.3 | 0.56 | n.s. | - | 5 |
| | | ½-1 hr | 38.1 | 37.8 | 38.7 | 38.6 | 38.8 | 38.4 | 38.4 | 0.49 | *** | 0.48 | 102.2 | 0.81 | *** | 0.60 | 0.6 | - | n.s. | - | 6 |
| G NSW | Compare new and worn saws Mixed Species 4.0-4.8 m | new saw | 38.6 | 38.5 | 38.6 | 38.8 | 38.6 | 38.5 | 38.6 | 0.67 | n.s. | - | 77.0 | 1.42 | *** | 0.86 | 0.4 | 0.25 | n.s. | - | 8 |
| | | worn | 38.1 | 38.3 | 38.5 | 38.5 | 38.7 | 38.4 | 38.4 | 0.67 | ** | 0.14 | 77.2 | 0.49 | n.s. | - | 0.13 | 0.22 | n.s. | - | 9 |
| K NSW | Compare new and worn saws Mature Blackbutt 4.8-6.3 m | new saw | 37.3 | 37.6 | 37.6 | 37.8 | 37.8 | 37.7 | 37.8 | 0.74 | n.s. | - | 99.2 | 0.58 | n.s. | - | 0.2 | 0.6 | n.s. | - | 12 |
| | | worn | 37.3 | 37.3 | 37.9 | 38.0 | 38.4 | 38.2 | 37.9 | 0.72 | *** | 0.23 | 999.5 | 0.93 | ** | 0.70 | -.17 | 0.5 | n.s. | - | 12 |
| BF VIC | Evaluate progressive wear over 3 hr Auto saw sharpening Messmate 5 m | 0-1½ hr | 38.6 | 38.7 | 38.5 | 38.3 | 38.1 | 38.0 | 38.4 | 1.10 | n.s. | - | 100.5 | 0.46 | n.s. | - | -.03 | 0.42 | n.s. | - | 7 |
| | | 1½-3 hr | 38.7 | 38.9 | 38.6 | 38.3 | 38.4 | 38.3 | 38.5 | 0.47 | * | 0.46 | 101.6 | 0.45 | n.s. | - | 0.3 | 0.42 | n.s. | - | 11 |
| | | 0-3 hr | 38.6 | 38.8 | 38.6 | 38.3 | 38.2 | 38.2 | 38.5 | 0.74 | n.s. | - | 101.1 | 0.71 | n.s. | - | -.19 | 0.42 | ** | 0.18 | 7+11 |
| BG VIC | One test Single ash log 5 m | - | 49.9 | 50.4 | 50.9 | 50.5 | 50.8 | 50.2 | 50.5 | 0.62 | ** | 0.28 | 75.8 | 0.75 | * | 0.45 | 0.49 | 0.60 | n.s. | - | 11 |

n.s. signifies no difference
*, **, *** indicates difference at 5%, 1%, 0.1% levels of probability

# ANOTHER LOOK AT SAWDUST-CONCRETE

E. McARTHUR
Division of Building Research, CSIRO

## INTRODUCTION

Sawdust-concrete has been used to a limited extent throughout the world for more than 50 years, particularly for interior floors but also for some pre-cast products including building blocks. In Australia, usage has been minimal despite the attraction of using a low-cost waste material and the positive advantages of the sawdust-concrete itself.

In the last decade, cement-bonded particle board has become a highly successful product for exterior use in West Germany and Japan. Apart from lower strength, one would expect sawdust-concrete to have somewhat similar favourable properties to cement-bonded particle board in regard to stability, durability, fire-resistance and thermal insulation.

Some potential users of sawdust-concrete may have been deterred by earlier publications (1,2) which reported extremely low compressive strengths and cautioned against exterior use. However, the densities reported were also unusually low (Fig. 1), suggesting that compaction was inadequate or water content too high. Short & Kinniburgh (3) quote slightly higher compressive strengths but very similar densities to the above.

By contrast, the present work tends to show that, at low sawdust contents, reasonably strong sawdust-concrete can be produced with simple equipment, provided that ingredients are weighed, minimum water content is used and good compaction is obtained.

EXPERIMENTAL

Almost all the present work involved circular-saw sawdust from mountain ash (Eucalyptus regnans) timber, typically at 100% moisture content. No drying, sieving or pre-treatment was practised, apart from screening out the coarse slivers.

All ingredients were weighed before mixing, with appropriate allowance being made for sawdust moisture content. Accurate proportions are difficult to achieve without weighing because of the highly variable bulk densities of the sawdust, cement and lime ingredients. Nominal volumetric mixes (sawdust:binder) of 2:1, 4:1, 6:1 and 12:1 contained 12, 22, 29 and 46% respectively of sawdust on an oven dry (O.D.) mass of ingredients basis. The cement-lime ratio of the binder was 5:1.

Ingredients were mixed in a pan-type mixer, using a pre-determined minimum quantity of water. (Water:binder ratios were 0.25, 0.38 and 0.58 for 2:1, 4:1 and 6:1 mixes respectively). The mixture was then placed in various types of moulds:

1. Highway guide posts 100 x 100 x 1500 mm, cast horizontally in wooden moulds and compacted by an electric hammer with a 100 x 100 mm pad. Typically, compaction occurred in three layers with about 20-30 seconds compaction per layer.

2. Shrinkage specimens approx. 133 x 66 x 66 mm, compacted in two layers for about 10 seconds each using a metal-faced wooden mould, top platten and electric hammer. Removed from mould before setting.

3. Compressive strength specimens, formed as for shrinkage specimens, but later sawn to form cubes of approx. 66 mm per side.

4. Small panels approx. 400 x 150 x 20 mm, pressed in wooden mould at 1000 KPa. Pressure maintained during setting.

Specimens were cured for 28 days in a fog room before testing. Shrinkage specimens were cured as above and then placed in an air-conditioned room at 23 ± 2°C, 50% ± 5% relative humidity for a period of 560 days.

RESULTS AND DISCUSSION

1. Density and compressive strength

Fig. 1 shows that both density and compressive strength were very much greater for the present work than those reported in previous Australian tests (1). When compared with recent results by Prestemon (4), there is reasonably good agreement on the trends at high wood content values although there were very considerable differences in procedure (notably specimen size, species, pre-treatment and moisture content at testing).

2. Modulus of rupture and Modulus of elasticity

Fig. 2 gives some indication of bending strength and stiffness of guide post specimens (100 x 100 mm) over 1400 mm span (centre point bending). Prestemon's M of R results are obviously much better, considering the higher wood content, but, as noted above, considerable differences existed in the procedures used.

M of R for two panels pressed at 1000 kPa was 3 MPa, compared with 12-18 MPa quoted for commercial cement-bonded particle board (of similar binder content). Thus, on this very tentative indication, sawdust-concrete boards would need to be at least twice the thickness of cement-bonded particle board to achieve equivalent bending strength.

3. Shrinkage and swelling

Fig. 3 shows shrinkage and swelling characteristics observed for specimens of 12-29% O.D. wood content. Mean shrinkage varied from 0.2-0.4% at 130 days air drying after curing, and increased to 0.3-0.6% at 560 days. This degree of shrinkage is approximately 5-10 times greater than for ordinary concrete, but up to 30 times less than for some timbers and wood-based panels. The above values may be much lower than expected, but Short & Kinniburgh (3) quote values (ex Parker) that are only slightly higher, despite the presence of calcium chloride additive (which increases shrinkage).

A preliminary test of swelling after a 24-hour soak gave less than 0.1% swelling, although Prestemon's results (Fig. 3) indicate that a steep increase can occur at high wood contents. Cement-bonded particle board values, quoted by Simon (5), are 0.6-1.2% for a 24-hour soaking test.

## 4. Other tests

Indicative tests on termite resistance, fungal resistance and fire resistance have been favourable. For these properties, one would expect sawdust-concrete to be at least the equal of cement-bonded particle board, which exhibits good durability and fire resistance properties. The alkaline cement matrix and the small particle size of the sawdust are believed to promote durability, even for non-durable sawdusts.

## 5. Cost

Considering a 22% wood content mix, which is probably the most practical one, the present cost of cement-lime binder is approximately \$70/$m^3$ of sawdust-concrete product (Fig. 4). Consider this in relation to a few materials with which sawdust-concrete could possibly compete in special cases:

| | |
|---|---|
| Hardwood scantling | \$310/$m^3$ |
| Red gum timber | \$390/$m^3$ |
| Sawn treated pine | \$680/$m^3$ |
| A-C flat sheets | \$710-1800/$m^3$ |
| Structural pine | \$470/$m^3$ |
| Ready mix concrete | \$50-60/$m^3$ |

Even allowing for manufacturing costs, and thicker sections to compensate for low strength, it seems quite probable that sawdust- concrete would be very competitive in selected applications.

SOME POSSIBLE USES FOR SAWDUST-CONCRETE

1. Interior floors

The most common traditional use of sawdust-concrete has been for overlaying interior concrete floors. There are now increased possibilities here with the wider use of concrete-slab floors and the greater emphasis on better thermal insulation. However, because of the relatively high shrinkages involved, the major problems would be adhesion, shrinkage and control joints. A safer approach would be the use of fairly thick sawdust-concrete floor tiles bonded to the concrete floor.

2. Panels

Pressed panels for exterior application are a distinct possibility provided one fully considers the inherently low bending strength of the material and compensates for this by surface lamination or simply by adequate thickness.

However, one must pay some heed to the opinion that numerous attempts to produce a commercial panel board from sawdust have failed because of the low strength obtainable. In commercial production, it would be desirable to give some pre-cast products a long air-drying period in order to minimize shrinkage problems.

3. Guide Posts

Mr R.M. Liversidge (CSIRO) suggested the possibility of making low-cost sawdust-concrete guide posts, and initiated the present work. This is a use where reasonably low strength can be an advantage as it is obviously better to collide with a low-strength post rather than a strong one. However, the strength should be sufficient to withstand handling and vandalism.

A number of guide posts were produced but only the 12% wood content mix seemed to offer sufficient strength, with a mean M of R of 3 MPa (Fig. 2). (The maximum test load recorded over 1400 mm span was 240 kg).

## FURTHER WORK

In the event of any commercial interest in sawdust-concrete, investigation of such areas as timber species, particle size, pre-treatment and experimental applications could be extremely useful.

## CONCLUSIONS

The present work on sawdust-concrete has been exploratory in character and insufficient to allow any definite recommendations for use in the ways suggested.

However, these limited tests have shown that a product with reasonable strength and some attractive qualities can be produced, when adequate care is taken.

## REFERENCES

1. Anon. Notes on the utilization of sawdust. CSIRO Div. For. Prod., Australia (available Div. Bldg Res, CSIRO).

2. Anon. Sawdust concrete. Concrete Information C1-2 (leaflet). Cement & Concrete Association of Australia.

3. Short, A. and Kinniburgh, W. (1963). "Lightweight Concrete", London, C.R. Books Ltd., John Wiley & Sons, New York (106-107).

4. Prestemon, D.R. (1976). Preliminary evaluation of a wood- cement composite. For. Prod. J. 26(2), 43-45.

5. Simon, R. (1980). Applications and properties of cement-bonded wood chipboard. Wood based panels in the 1980s (Proceedings of Symposium, Timber Committee UNECE, Helsinki).

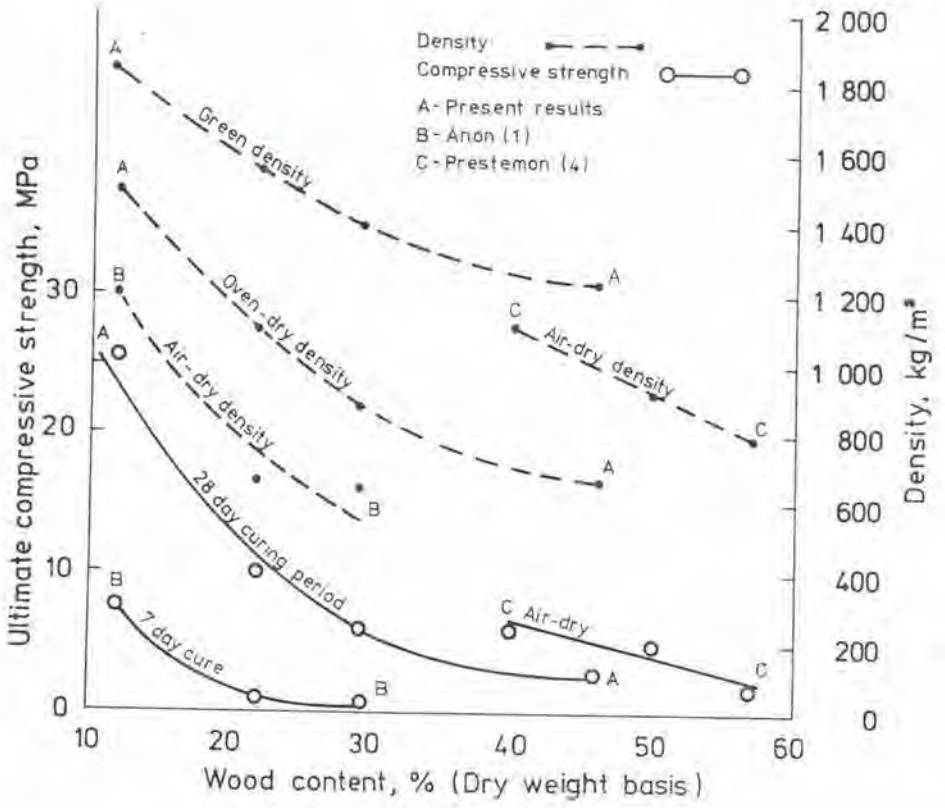



FIG. 1. COMPRESSIVE STRENGTH AND DENSITY OF SAWDUST-CONCRETE

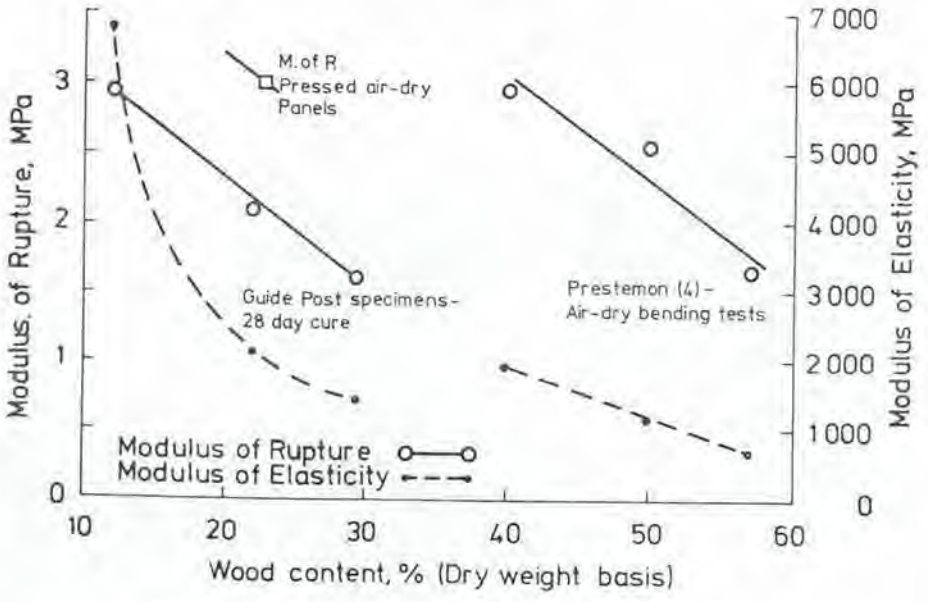



FIG. 2. BENDING STRENGTH AND STIFFNESS OF SAWDUST-CONCRETE

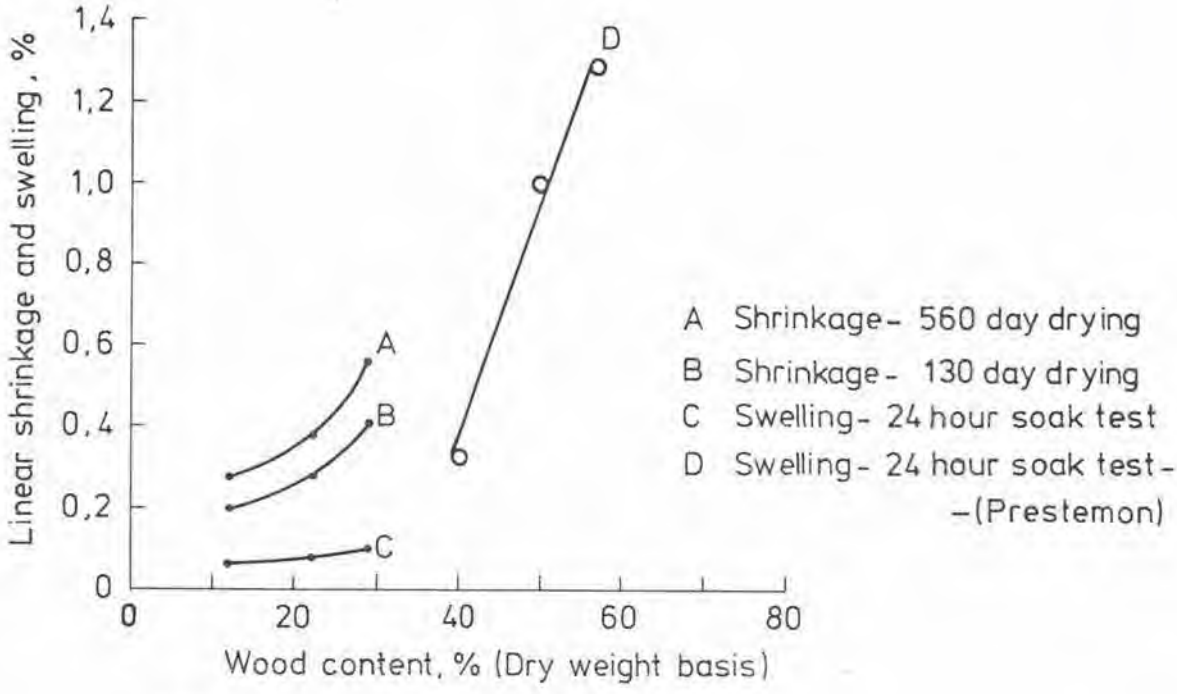



FIG. 3. SHRINKAGE AND SWELLING OF SAWDUST-CONCRETE

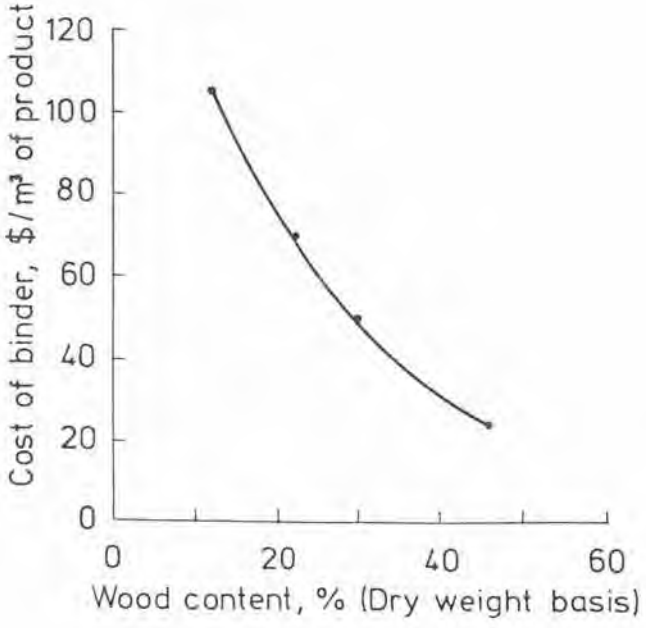



FIG. 4. COST OF BINDER IN SAWDUST-CONCRETE

# DERIVATION OF A RELATIONSHIP BETWEEN VENEER YIELD AND RAW MATERIAL VARIABLES

Topic C4

B. McCombe
Division of Building Research, CSIRO

ABSTRACT

An expression for veneer yield, in terms of the raw material variables diameter, form quality and shrinkage, was developed for the production of structural grade veneer from Pinus radiata.

## INTRODUCTION

The yield relationship that will be established is intended for the conversion of structural grade veneer of a quality equal to or better than the minimum allowed in Australian Standard AS 2269-1979 (1). As such it will have qualified application, but the logic used in its development should hold for the derivation of veneer yield relationships for other species and products.

The circumstances of equipment and production practice that are assumed to apply for the exercise are those pertaining to a modern and popular approach to the conversion of small diameter logs employing high-performance peeling, clipping and salvage equipment.

## RAW MATERIAL VARIABLES

Pinus radiata has been the Australian plywood industry's main source of structural grade veneer for over ten years and its processing characteristics and quality bounds are now well understood. With this knowledge, raw material variables can be limited to diameter, form quality and shrinkage. For another species or much higher grade of product, severity of internal defect probably would have to be included as a variable. However, for P. radiata, occasions of defect failing to comply with the Standard's requirement are rare.

Having decided on form quality as a variable, it was necessary to devise a way to evaluate it. The ideal billet form for production of rotary veneer indisputably is cylindrical. Form

defect such as sweep and taper are significant only in that they detract from cylindrical form. The measure of form quality chosen was an index reflecting deviation from cylindrical form, and is defined as the ratio of the largest diameter cylinder that can be fitted within the surface bounds of the billet, to the volume of the billet or, alternatively:

$$\text{Form index, } f = D_1^2/D^2 \qquad (1)$$

where $D_1$ is the diameter of the enclosed cylinder defined previously and
D is the mean diameter of the billet at mid-length, as calculated from a measurement of girth.

Referring to Fig. 1, diameter $D_2$ corresponds to the diameter of the partly peeled billet at the important stage in peeling when all wane has been peeled off and the veneer ribbon becomes continuous, i.e. the actual round-up diameter. The diameters $D_1$ and $D_2$ would be identical if no centring error was made. For small centring errors, $D_1$ and $D_2$ are nearly equal and a close approximation, f', of the form index is obtained by making:

$$f' = D_2^2/D^2 \qquad (2)$$

If the ratio $D_2^2/D_1^2$ is designated as CC, the coefficient of centring accuracy, then it can be shown that:

$$f' = CC.f \qquad (3)$$

and

$$CC = D_2^2/(D_2+2E)^2 \qquad (4)$$

where E is the centring error.

## THE NATURE OF PROCESSING LOSSES

The various individual processing losses are indicated on the residue lines of the flowchart (Fig. 2).

In Australia *P. radiata* peeler logs are usually supplied in lengths that coincide with multiples of billet length, in which case docking loss in crosscutting is minimal. Occasionally, there may be need to dock out felling damage or traumatic faults, but even

so, a loss of more than 2% is exceptional.

At the veneer lathe, the peeler core tends to be constant in diameter and therefore becomes an increasingly significant loss as log diameter decreases. Scribing loss arises from the need to dimension and impart straight edges to the veneer ribbon. A scribing margin of 2-3 cm is required at each end of the billet regardless of its length.

The largest component of loss in veneer production is usually the round-up veneer generated in reducing the billet to cylindrical form. This can reach 25% or more. Salvage of 10-20% of round-up is feasible provided billets are about 35 cm or more in diameter, but is rarely practised in Australia because of claims that scale of operation is usually too small to justify the high cost of the specialised facilities needed.

Losses at the green clipper comprise mostly clipper off-cuts produced in eliminating natural defect such as any residual wane or traumatic faults and also various manufacturing faults. Veneer lost to the lathe's waste conveyor as a result of operator error and that rejected for defect before it reaches the clipper are debited against green-clipping. Overall loss for the process is usually less than 5% but can reach 10% if billets are very small in diameter.

Unacceptable defect that passes unnoticed at the clipper will later be detected by veneer graders and ultimately eliminated in salvage operations together with drying degrade such as severe splitting in zones of reaction wood. Salvage losses also include narrow off-cuts produced when jointing or squaring the sides of sound narrow pieces. Depending on the specification of salvage equipment, losses will vary from about 7-10%.

The only loss accorded to the drying process is width shrinkage, which for P. radiata is 4-6%. Thickness shrinkage of between 1% and 2% is ignored because it is acceptable within product thickness tolerances.

The loss in 'correct to invoice dimension' of surplus width in dimensioned sheets is unavoidable when sheets are clipped to width before drying but can be contained within 2% if a well-adjusted high performance clipper is used.

## YIELD AS A FUNCTION OF PRODUCTION PARAMETERS

Material flow and accumulation of residue for the production system depicted in Fig. 2 is fully described by the nine network parameters shown. To illustrate the action of these parameters, the system has been supplied with an arbitrary input of 100 cubic metres of logs. The parameter values that are used were determined experimentally at a local veneer

mill and characterise the performance of a small batch of P. radiata billets.

The 'R' parameters ascribed to each process denote recovery for the process, i.e. the ratio of output volume to input volume. The parameter CF3, which discounts for excess sheet width, acts in the same way as an 'R' parameter. Residue, or loss for a process, the difference between input and output, is directed to a common waste line.

The three 'B' parameters are used to show breakdown of product into categories. By convention, they denote the proportion of product flowing on in the mainstream. The balance of the product, or the proportion one minus the value of the parameter, is diverted to a branch line.

The exact relationship between yield and the network parameters is as follows:

$$\text{Yield (\%)} = (R1.R2.B1.R3.R4(B2.B3(CF3-R5)+R5)) \times 100 \qquad (5)$$

All the parameters can be determined from measurements of input and output. However, in the cases of R2, B1 and R4, it is more convenient to use different but equally valid methods as given below.

With reference to Fig. 1:

$$R2 \text{ (recovery in peeling)} = (L_2/L_1)\,(1-d^2/D^2) \qquad (6)$$

$$B1 \text{ (branching parameter)} = (D_2^2-d^2)/(D^2-d^2) \qquad (7)$$

$$R4 \text{ (recovery in drying)} = 1 - S/100 \qquad (8)$$

where $L_1$ and $L_2$ are billet length and scribed length respectively, and S is percent shrinkage in drying.

Using equations (2), (3) and (7) it can be shown that B1 is related to form index, f, as follows:

$$B1 = (CC.f-d^2/D^2)/(1-d^2/D^2) \qquad (9)$$

YIELD AS A FUNCTION OF RAW MATERIAL VARIABLES

The raw material variables: diameter D, form index f, and shrinkage S, can be introduced into equation (5) by substituting R2, R4 and B1 by their respective definitions as given in

equations (6), (8) and (9):

$$\text{Yield} = (R3(CC.f-d^2/D^2)).(1-S/100).((L_2/L_1)R1((B2.B3)(CF3-R5)+R5)) \quad (10)$$

For an efficient modern operation, parameters R1, R5, CF3 and the ratio $L_2/L_1$ can be taken as processing constants, hence the yield relationship can be reduced to:

$$\text{Yield} = (R3(CC.f-d^2/D^2)).(1-S/100).C_1(C_2B2.B3+C_3) \quad (11)$$

where $C_1$ and $C_2$ are processing constants characterising equipment performance and production practice.

Elimination of the remaining parameters R3, B2 and B3 is not so easily accomplished because all can be expected to vary with diameter. For example, the proportion of dried veneer not requiring salvage work, as denoted by the term B2.B3, tends to be lower for small diameter billets than for larger diameter ones. R3 is similarly affected. Nevertheless, with reference to equation (10) it can be concluded that if CF3 and R5 are close in value, such as applies for an efficient modern operation, variation in the value of B2.B3 would have little bearing on yield. Hence, equation (11) can be transformed into a close approximate relationship by using a mean value for B2.B2 over the diameter range being considered. This would allow the term $C_1(C_2B2.B3+C_3)$ to be reduced to a constant, $C_4$. Thus, equations (10) and (11) become:

$$\text{Yield (approx.)} = C_4R3(CC.f-d^2/D^2).(1-S/100) \quad (12)$$

where $C_4$ is a constant characterising equipment performance and production practice.

The yield relationship is now left with one network parameter, R3: recovery in green-clipping, which because of its dependence on diameter, D, would best be replaced by an appropriate function of diameter. In field studies, R3 has been observed to increase with increase in diameter, rising to about 0.97 when a diameter of 35 cm is reached and thereafter converging slowly to a value a little below the limiting value of 1.0. This behaviour is consistent with a component of green clipping residue being independent of input volume. Residue of this kind would include veneer that is occasionally and accidentally lost to the lathe's waste conveyor before it reaches the clipper, and also 30 cm or so of width from the end of the ribbon that is usually discarded because of suspected thickness variation. Other residue, such as defect off-cuts, could be expected to accumulate in proportion to veneer input to the clipper.

The effect of both fixed and proportional components of residue on R3 can be

characterised as follows:

$$R3 = R3' (1-(wC_5/(CC.fD^2-d^2))) \quad (13)$$

where R3' is the recovery rate in green-clipping taking into account only residue which is accumulated in proportion to input volume to the clipper; w is average width per billet of fixed component of veneer residue and $C_5$ is the constant 4 x veneer thickness/3.14.

Subject to R3' being close to unity and w being no more than 40 cm (as would apply for a modern veneer manufacturing operation) and $d^2$ being small compared with $D^2$, (13) can be closely approximated to:

$$R3 = R3'-(wC_5/CC.f(D^2-d^2)) \text{ (approx.)} \quad (14)$$

Substituting equation (14) for R3 in equation (12) and eliminating insignificant terms gives:

$$\text{Yield \%} = [C_4\ R3'(CC.f-d^2/D^2-wC_5/(D^2-d^2)).(1-S/100)] \times 100 \text{ (approx.)} \quad (15)$$

R3' which accounts mainly for those losses attributable to internal defect could, for the conditions of this exercise, be taken as a constant of value 0.98. The limiting value of R3' of 1.0 would apply if veneer was entirely free from unacceptable internal and manufacturing defect.

The value of the constant $C_4$ is determined from:

$$C_4 = R1.(L_2/L_1).(B2.B3(CF3-R5) + R5) \quad (16)$$

Using this relationship, $C_4$ was calculated for the arbitrary log input in the flowsheet shown in Fig. 2 and found to be 0.94.

Four of the six variables in equation (15): d, D, w and S can be readily measured. Calculation of the form index f, as in equation (1), requires knowledge of the surface geometry of the billet, especially deformity from sweep or bend, which can be obtained with elementary surface scanning apparatus. The value of CC can be readily calculated knowing f and the actual round-up diameter $d_2$.

APPLICATION

The yield relationship was developed specifically for use as a tool for facilitating the analysis of data from yield studies. Its usefulness in this application is demonstrated in Topic 5C: Veneer yield from *Pinus radiata*.

This research has also served to establish relationships between yield and the variables: form quality and centring accuracy, which until now had not been defined in a comprehensive yield relationship.

REFERENCE

(1) Standards Association of Australia (1979). Structural plywood. AS2269-1979. Sydney, Australia.

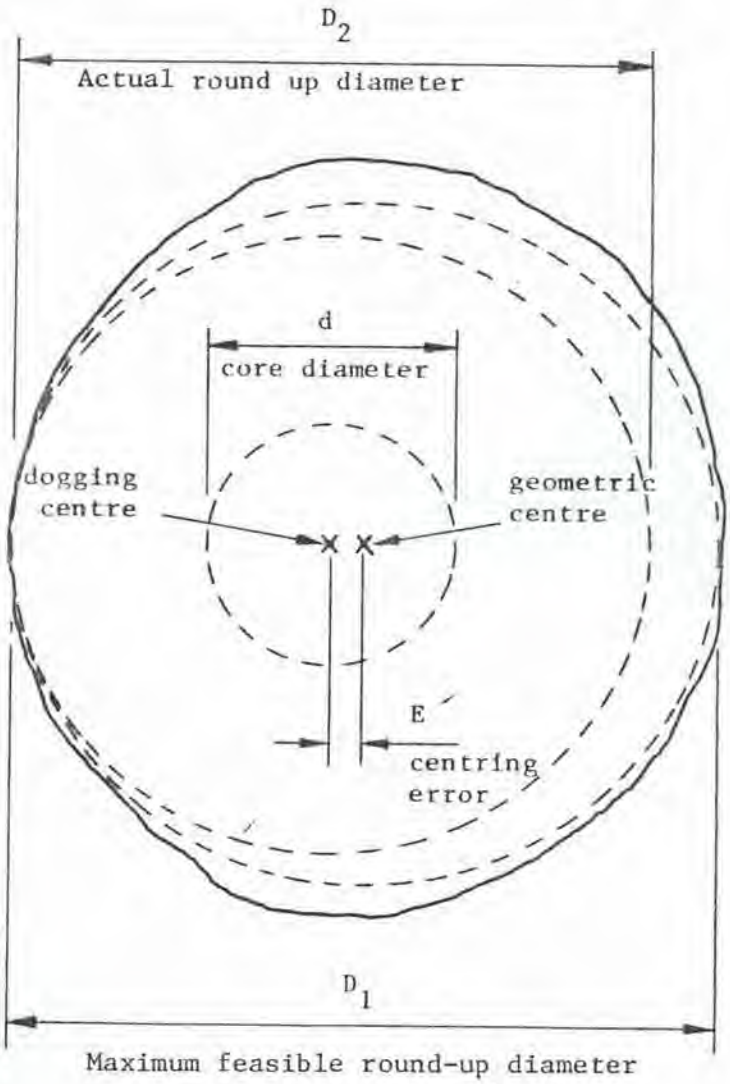



Fig. 1. Billet cross-section showing the effect of centring error on actual round-up diameter

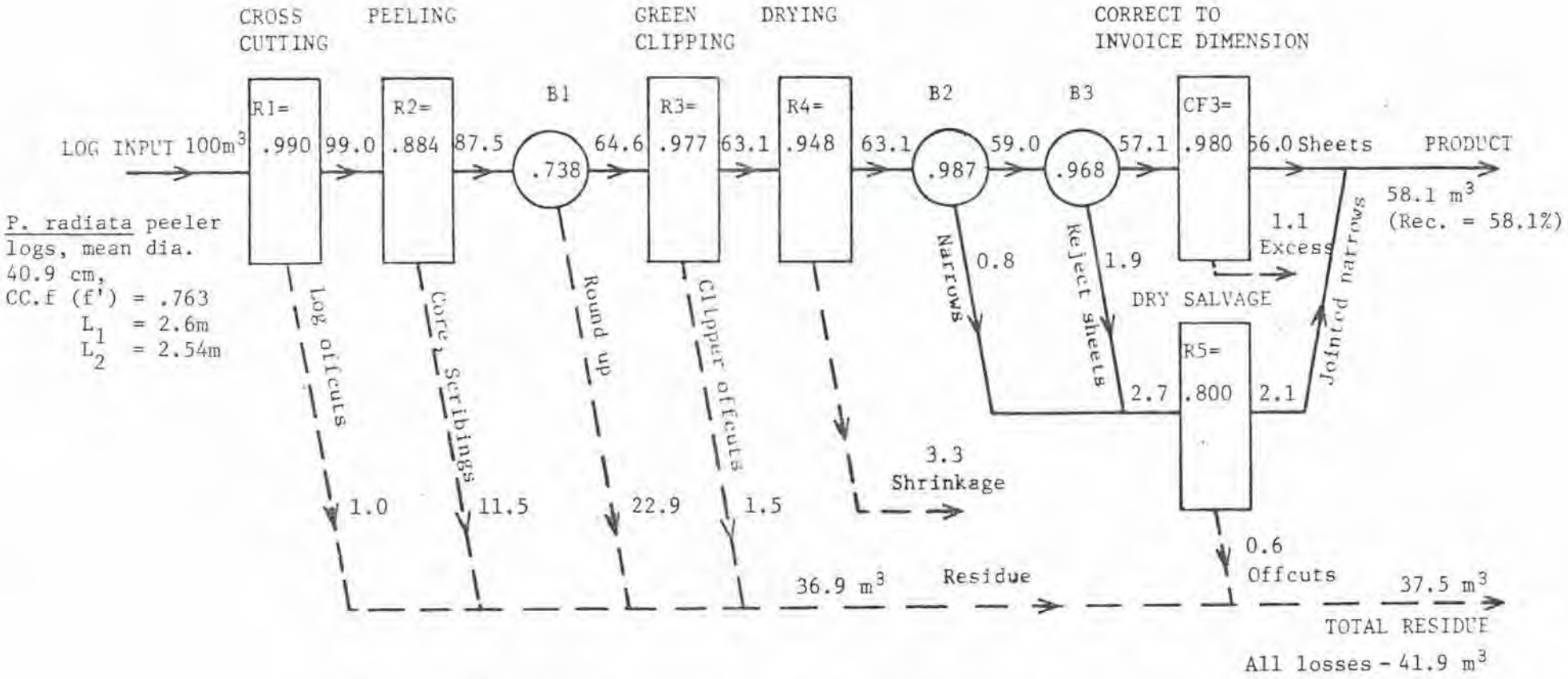



Fig. 2. Flowchart of recovery model illustrating action of network parameters on material flow for a P. radiata log input.

# VENEER YIELD FROM PINUS RADIATA

B. McCOMBE*, A. McNAUGHT** and D. ATKINS***
*Division of Building Research, CSIRO
**ANU Forestry Dept, formerly of Savaco Pty. Ltd., Benalla
***Plywood Association of Australia

## ABSTRACT

In this first comprehensive study of veneer yield from Pinus radiata conducted at a commercial plant in Australia, the effects of diameter, form quality and conversion length are clarified.

## SCOPE OF STUDY

Variables subjected to systematic study and their range/gradation were as follows:

| | |
|---|---|
| Diameter | - 20 cm to 60 cm |
| Origin of raw material | - two plantation areas in central Victoria designated as 'Myrtleford' and 'Bright' |
| Position in stem | - butt, second billet from the butt and third or further billet from the butt. These positions correspond to distances from the top of the stump of 0 m, 2.0 m and 4.6 m or more |
| Conversion lengths | - 2.0 m, 2.6 m |

End product was 2.5 mm and 3.25 mm thick mill-run structural veneer of a quality equal to or better than the minimum prescribed in Australian Standard AS2269 (1). The various combinations of end product with conversion length and origin were as follows:

| Conversion length | Product | Origin: Myrtleford | Origin: Bright |
|---|---|---|---|
| 2.6 m | 2540 x 1270 mm longband | x | |
| | 1270 x 2540 mm crossband* | x | x |
| 2.0 m | 1930 x 965 mm longband | x | x |
| | 965 x 1930 mm crossband* | x | |

*Obtained by centre scribing

The system of data collection and method of yield analysis used followed those proposed previously (2).

Production of P. radiata structural veneer is depicted in the flow chart given in Fig. 1. 'R' parameters shown in each process block denote recovery for the process, while 'B' parameters at junctions in the network indicate proportion of product flowing on in the main stream. The block labelled 'correct to invoice dimension' is not a process but its parameter CF3 discounts for any excess in average sheet width over that prescribed in the production order: surplus width in sheets is equivalent to waste.

A form index, devised for rating quality of log form, is defined as the ratio of the volume of a billet left after rounding up in the lathe to its initial volume.

## EXPERIMENTAL

The study was conducted at the factory of Savaco Pty. Ltd., Benalla, Victoria by a team of eight and covered 3 days' production. Over this period, 460 billets were processed.

A factorial experiment design, with raw material types allocated in prescribed quantities to each production treatment, was preferred but was not practicable because intensive log sorting required ahead of the lathe would have disrupted production. The only practical alternative was to leave the management to program production to orders in its accustomed way and to run the experiment for sufficient time to cover adequately the range of variables being examined.

Under the factory conditions, it was not possible to exercise control over extraneous influences on yield, such as damage to logs during felling and

debarking, and damage to veneer through mishandling and machine malfunction. However, occurrences of mistreatment were recorded so that grossly biased results could be excluded from the analysis. Felling damage was mainly in the form of 'butt pull' and, presumably, could have been avoided by better field practice. Debarking damage was the result of exceeding the debarker's diameter capacity.

The factory's lathe was also a source of bias. Like many other lathes in industry, it did not have dual telescopic spindles and a back roll: consequently, it could not peel down to a very small core diameter. Average core diameter over the study period was close to 170 mm, compared to the 125 mm that would otherwise be readily achievable with more modern equipment. By not having dual spindles, the lathe was also prone to lose grip when turning some large diameter logs. This phenomenon, known as 'spinout', was a further cause of wastage.

TREATMENT OF RESULTS

Two sets of results were derived from the experimental data. One set applied to the operation as observed, and the other, hereafter designated 'attainable', to a hypothetical and more modern operation for which:-

- the lathe would be fitted with telescopic chucks and back roll, which would enable it to peel down to an average core diameter of 125 mm without spinout

- more efficient equipment would be used in the dry salvage operations (R5) to enable recovery for this process to be increased from less than 60% to 80%.

- a high-performance green clipper would be used. Greater precision in clipped width would then allow average excess sheet width dimension to be reduced from around 4% of the sheet width to 2%, thus increasing the parameter CF3 to 98%

- the incidence of felling and debarking damage would be reduced to nil.

In arriving at a result for the hypothetical modern operation the additional quantity of green veneer obtainable by peeling down to a 125 mm core was

calculated for each billet and, after discounting by 5% for clipping loss and 5.2% for shrinkage, it was added to the experimental dry veneer tally. The latter was then 'worked' through to the finished product by applying the experimentally determined values for B2 and B3, and 80% and 98% for R5 and CF3 respectively. Effects of spinout and log damage were eliminated by culling the affected results.

## RESULTS AND DISCUSSION ON FACTORS AFFECTING YIELD

### Log Diameter and Form Quality

Yields for all of the 252 billets converted in 2.6 m lengths are plotted against diameter in Fig. 2. Notable features of this data are the variability of yield for any given diameter and the unfavourable effects of spinout and log damage on yield from larger diameter billets.

Because of the considerable spread of the plot points, yield data for the sample were subjected to multiple regression analysis taking into account other variables besides diameter. Various regression models, including the relationship given below, were used:

$$\text{Yield} = C_3.R3.(\text{Form index}) - C_4.R3/(\text{diameter})^2 \qquad (1)$$

Where $C_3$ and $C_4$ are constants and R3 is recovery for green clipping.

This regression model fitted the data best with a correlation coefficient of 0.995 and residual standard deviation of 4.8%. Most of the variability in Fig. 2 could then be explained as being due to the interactions of form quality and spinout with the latter having effect through the variable R3.

An investigation of possible correlation between the variables diameter, form index and R3 was also carried out and showed that although form index varied considerably from billet to billet there was no evidence of it being dependent on diameter. On the other hand, significant positive correlation was found between diameter and R3, whereas R3 was independent of form index.

It became clear from these analyses that the dominant influences on yield were diameter and form quality. Analyses given below will show that conversion length, origin and position in stem also had an important bearing on yield but mainly through their influence on form quality.

Actual and Attainable Yield

A curve was fitted to the data of Fig. 2 and is shown in Fig. 3 together with a similarly derived curve for attainable yield.

The downturn in the experimental curve for large diameter billets reflects a disproportionately high rate of spinout and felling and debarking damage for these billets. When the influences of spinout and log damage are removed, as for the attainable curve, yield shows very little change beyond 50 cm diameter. This flat rather than convergent response would be due at least partly to the increasing representation of butt billets towards the large diameter end of the scale. A subsequent analysis will show that butt logs generally gave inferior yields.

The appreciable difference between actual and attainable yields over the diameter range considered testifies to the importance of using specialised equipment for converting small diameter Pinus. The 6.5% yield advantage shown for 40 cm billets corresponds to 13% more product from a given log volume while 25% more product would be obtained from 30 cm billets.

The attainable yield curve is not necessarily optimum. It applies to a standard of billet centring accuracy considered to be typical for the industry, but one which could be improved. Furthermore, under special circumstances, 2.6 m billets can be peeled down to a core diameter smaller than the 125 mm nominated for attainable yield. For instance, if logs are generally small and mostly less than 40 cm in diameter, a core diameter of 110 m or less would most likely be feasible.

A further gain in yield would certainly result if usable veneer was salvaged from round-up. This practice becomes worthwhile when log diameter is greater than about 35 cm and has been found to boost yield for Pinus species by 1%-3% thus giving approximately 2% to 6% more product from a given log volume. Most Pinus mills in Australia don't practice round-up salvage because they claim it is too costly and slows production. However, given proper facilities it can be profitable, as has been demonstrated widely overseas.

Conversion Length

The samples of 2.0 and 2.6 m long material were taken from Myrtleford material. Each contained 63 billets from 2nd and higher positions in the stem. All were converted into 3.25 mm thick longband veneer.

The regression model given in equation (1) was fitted to each of the two sets of data, obtaining a correlation coefficient of better than 0,999 and a residual standard deviation of less than 2%. Furthermore, the resulting regression equations had virtually identical coefficients and hence any observed effect of conversion length on yield could be attributed to differences in either or both R3 and the form index.

Comparison of the sample means for R3 and the form index showed conversion length made little difference to R3 (95.2 c.f. 97.2%), whereas the form index was clearly better for the 2.0 m conversion (0.794 c.f. 0.762), by a margin sufficient to provide a 2% yield advantage. Yield curves for the two conversion lengths are given in Fig. 4. They were derived from the respective regression equations by substituting sample means for R3 and the form index.

Improvement of log form following a reduction in conversion length is well recognised and usually attributed to reduced effects from sweep and taper. Yield could be expected to improve further by converting in 1.3 m lengths, which would be applicable to the production of 1270 x 2540 mm crossband veneer. Practice at the mill was to obtain this product by centre scribing of 2.6 m long billets.

Origin of Raw Material

The best-matched samples available for comparison were billets from second and higher stem positions converted into 3.25 mm thick by 1270 x 2540 mm crossband veneer.

Equation (1) could again be fitted to the test data with high precision, thus showing that if there was an effect of origin it would be manifested as differences in either R3 or the form index, or both. Sample means for the two localities did indeed show marked differences in both R3 and form index. R3 for Myrtleford was 92.5% as compared with 98.5% for Bright while the respective form indices were 0.755 and 0.805.

The difference in the values for R3 suggested the influence of an unknown production or raw material variable and, therefore, needed clarification. Further investigation of a previously noted positive correlation of R3 with diameter showed that it applied for all material, especially that converted into crossband veneer, and reflected inadequacy of the veneer transfer system coupling the clipper to the lathe rather than difference in processing characteristics. The effect on R3 was such that it was barely evident for large diameter material and it could be characterised as follows:

$$R3 = C_5 - C_6/(\text{diameter})^3 \qquad (2)$$

where $C_5$ and $C_6$ are constants.

The Myrtleford billets were smaller in diameter, having a mean of 34.5 cm compared with 46.6 cm for Bright. When diameter was taken into account, the respective R3 values proved to be consistent with the above relationship. Hence, the lower recovery in green clipping for Myrtleford billets was more an effect of equipment deficiencies and product choice.

Yield curves for Myrtleford and Bright billets, as derived by using equations (1) and (2) and using sample means for form index, are given in Fig. 5. The yield advantage shown for Bright billets reflects mainly their superior form quality.

Position in Stem

Over the three days of the study, the input of 7.2 m long 1st and 2nd logs yielded billets from butt, 2nd and 3rd and higher positions in the ratio of 1:1:3. This distribution is considered to be more or less normal for P. radiata veneer operations in Australia.

The yields for test material from 2nd and from 3rd and higher positions in the stem were compared for 2.6 m conversion to an end-product of crossband veneer, but no apparent difference was found. The sample size of 2nd logs was too small to allow comparisons to be made for other products.

On the other hand, butt billets gave consistently lower yields than billets from the higher stem positions over the full product range, mainly as a result of their inferior form quality. Indices for butt and 3rd billets are given in

Table 1 together with predicted yields from 40 cm diameter billets. The latter were derived with the regression equations used for constructing the attainable yield curves of Fig. 4.

TABLE 1

Variation in Form Index and Predicted Yield with position in stem

| | Myrtleford | | Bright | |
|---|---|---|---|---|
| | Form index | Predicted yield (%)** | Form index | Predicted yield (%)** |
| 2.6 m conversion, butt | .713 (27)* | 52.4 | .741 (10)* | 54.8 |
| 3rd billets | .765 (92) | 56.9 | .813 (48) | 61.1 |
| 2.0 m conversion, butt | .704 (15) | 51.6 | .745 (15) | 55.2 |
| 3rd billets | .793 (92) | 59.4 | .820 (27) | 61.7 |

* Sample size

** Estimated yield for 40 cm diameter billets taking recovery in green clipping (R3) to be 98%

## CONCLUSION

The main objective of obtaining a better than qualitative appreciation of the effects of billet diameter, form quality and conversion length on veneer yield was achieved.

Knowledge provided on the yield-diameter relationship may prove useful to planners of new veneer manufacturing operations who, knowing diameter distribution for a given radiata pine resource, require an estimate of overall yield. Assuming that modern and specialised equipment is to be used, then the approximate yield for a 2540 x 1270 x 3.2 mm structural product for billet diameters in the range 30-60 cm would be as follows:-

$$\text{Yield \% (approx.)} = 0.87\ R3.(\text{form index}) - 140\ (R3/d^2)$$

where R3 is % recovery in green clipping and d is diameter in centimetres.

The above relationship applies for a constant core diameter of 125 mm and no salvage of round up veneer. If yield for another core diameter was required the second constant (140) would be adjusted as follows:-

$$C_2' = C_2 \times ((\text{new core diameter})^2/125^2)$$

An estimate of form quality in terms of the form index will be required and can be obtained by rounding up a sample of, say, sixty 2.6 m long billets on any 2.7 m veneer lathe. For P. radiata, a mean form index greater than 0.85 or less than 0.7 can be considered exceptional.

A value of 98% for R3 would apply to most Victorian radiata pine; however, if an unduly high incidence of very large dead branches or resin pockets was observed, then a value as low as 94% would be used.

ACKNOWLEDGEMENTS

The writers wish to thank the management of Savaco Pty. Ltd. for making their Benalla factory available for the study and for providing three members of the research team.

Thanks is also due to team members B. Rundle and W. Krieg of CSIRO and Julie McNaught and Jennifer Brims of Savaco for their endurance and reliability as observers over a 90-hr working week.

REFERENCES

(1) Standards Association of Australia (1979). Structural plywood. AS2269-1979. Sydney, Australia.

(2) McCombe, B. (1975). Analysis of yield in veneer and plywood manufacture. 17th For. Prod. Res. Conf., Highett, Australia.

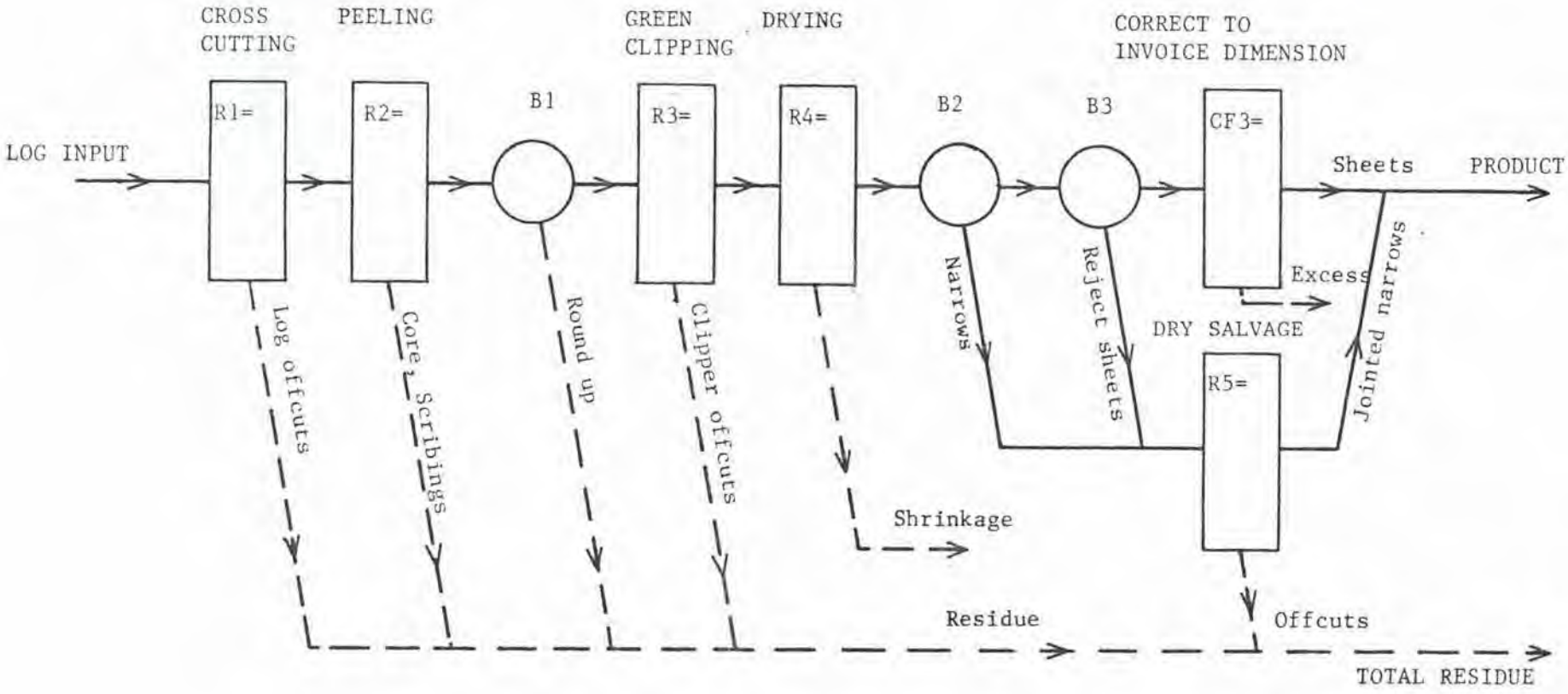



Fig. 1. Flowchart of recovery model for conversion of P. radiata into structural grade veneer.

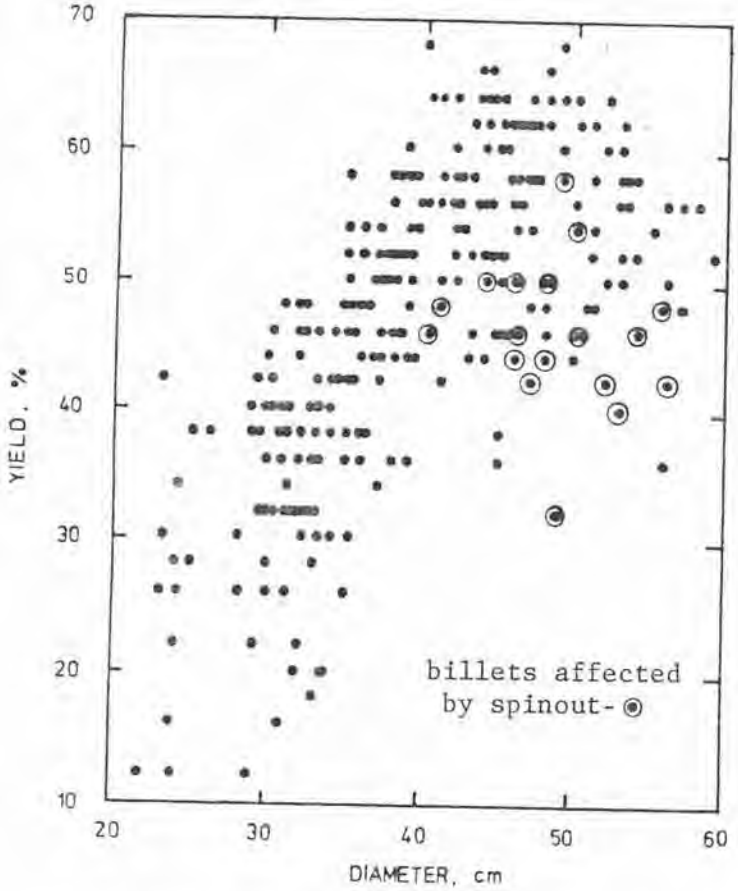



Fig. 2. Experimental yields for 252 billets converted in 2.6 m lengths - Myrtleford and Bright P. radiata, longband and crossband product.

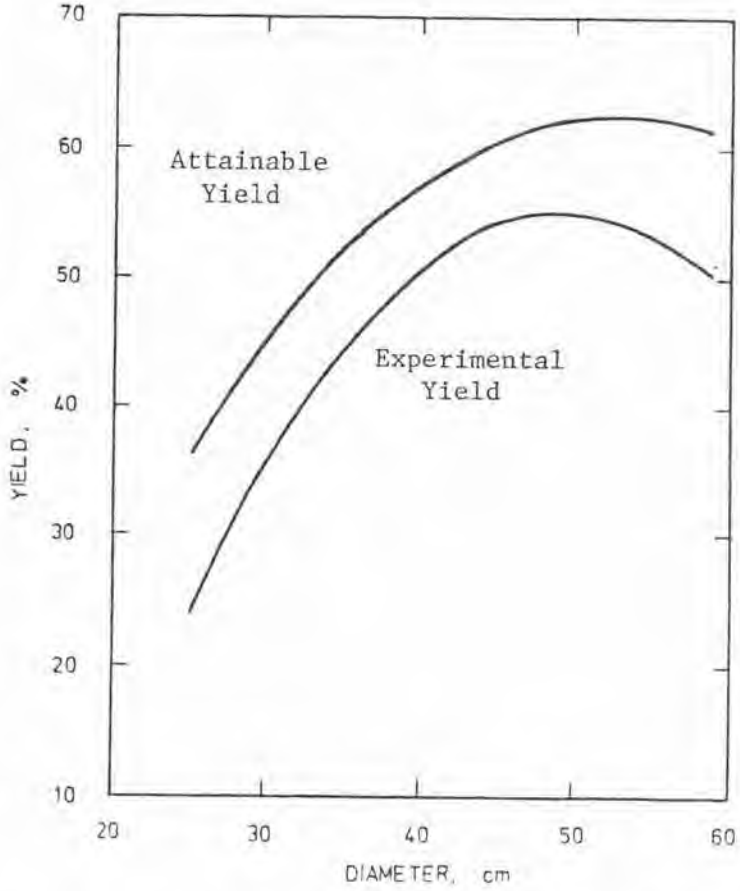



Fig. 3. Comparison of experimental yield with "attainable' yield for 2.6 m conversion - Myrtleford and Bright P. radiata, longband and crossband product.

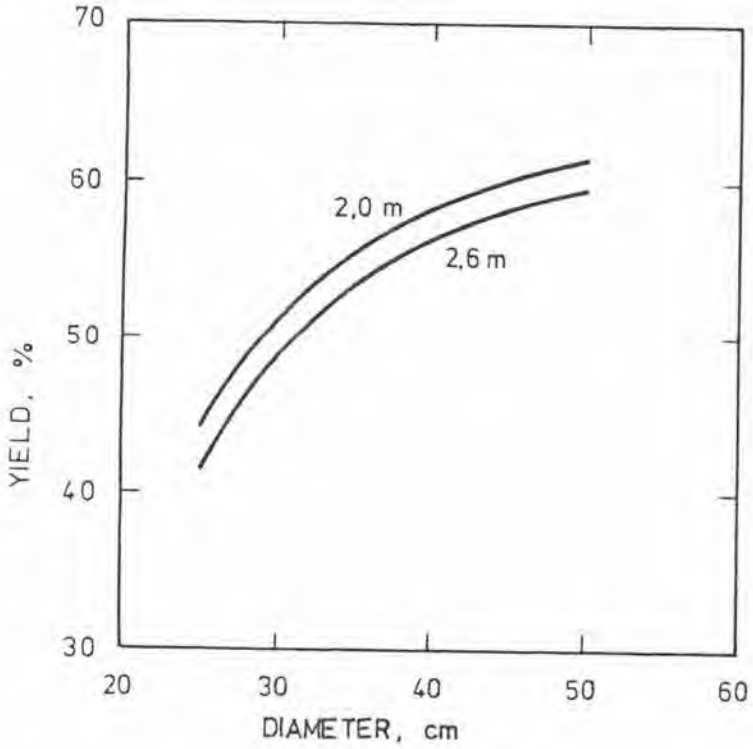



Fig. 4. Attainable yield curves for 2.0 m and 2.6 m conversion lengths - Myrtleford P. radiata longband product.

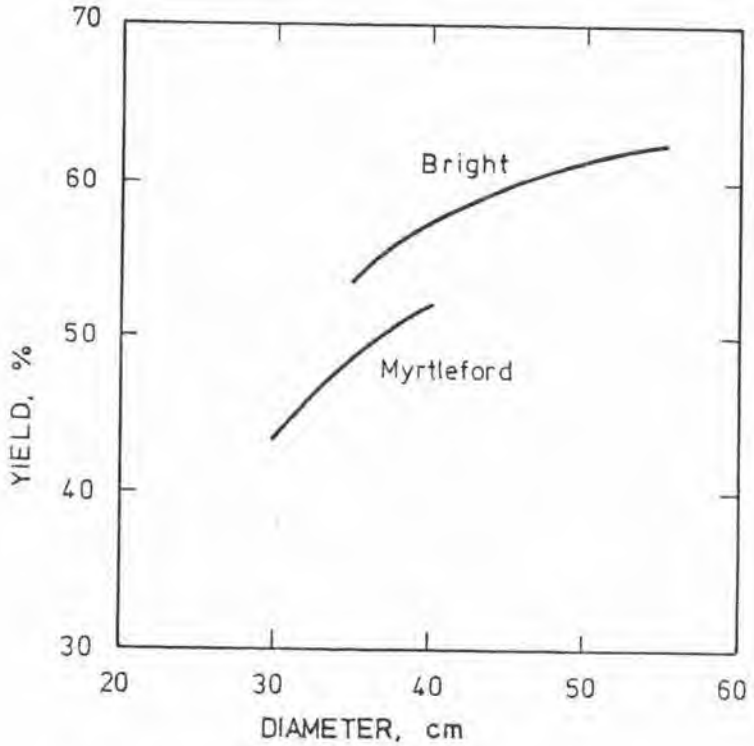



Fig. 5. Attainable yield curves for Myrtleford and Bright P. radiata - 2.6 m conversion length, crossband product.

# NEW PRODUCT FROM P. RADIATA AND EUCALYPT WASTES

A. Krilov

Wood Technology and Forest Research Division,

Forestry Commission of N.S.W.

## SUMMARY

A series of experiments recently carried out at the Lignex Products Research Station (Vancouver), have shown that an attractive looking waferboard suitable for various structural and decorative uses can be manufactured either from small diameter *P. radiata* tops, or the residue of the conventional CNS conversion process. Comparative assessment of the physical properties of this new product is very encouraging, and could provide a better way to utilize various residues from *P. radiata* thinnings in Australia. The material from eucalypt thinnings can be successfully used in mixtures with softwood wafers, to produce a better quality board.

## INTRODUCTION

Waferboard is a versatile wood panel product developed by Dr. James d'A. Clark in 1950. The unique feature of the waferboard process is its ability to utilize low value indigenous forest stands of round wood or solid wood waste from sawmills, to produce a weatherproof exterior grade board with controlled properties and with less than 3 percent of phenolic resin. The characteristics of waferboard are comparable with, and in some respects even superior to, exterior grade plywood. The board can be made fire, insect, fungus or mould resistant, from almost every species of wood, including bamboo. The board can be made in one or several plies, each of which can be aligned or treated to give it any special properties that may be desired.

The first commercial mill to manufacture 50 tonnes per day, using a 1.2 x 4.9 m 12 opening press, opened at Sandpoint, Idaho in 1953 (d'A. Clark, 1955). Since then, a number of waferboard plants have been erected, particularly in Canada and U.S.A., whilst the process itself has been considerably improved. To-day, an increasing share of the panel market, where the traditional plywood still enjoys a leading position, is being gradually filled by waferboard.

Waferboard is often classified, quite erroneously, as a particleboard. In

TABLE 1

Comparative Properties of Various Board Types

| Properties \ Type of board | Units-SI | Lignex sugar cane rind board | Commercial aspen waferboard | Industrial particle-board | Medium density fibreboard (Bagasse) | Rice husk board | Douglas fir plywood |
|---|---|---|---|---|---|---|---|
| Grade | | Exterior, structural | Exterior, structural | Interior | Interior | Exterior, | Exterior, structural |
| Board density | ($kg/m^3$) | 681 | 641-673 | 600-800 | 600-900 | 800-960 | 550 |
| Resin content | (%) | 4 | 3 | 6-10 | 6-10 | 8 | - |
| Internal bonds | (kPa) | 421 | 414 | 280-1000 | 280-1000 | 410-830 | 800 |
| Modulus of elasticity | (MPa) | 4070 | 3450-4140 | 1500-4500 | 3500 | 2760-3310 | 6900 : 4400 (face grain) |
| Modulus of rupture | (MPa) | 24.4 | 19.3 | 15-30 | 15-35 | 15-20 | 50 : 46 (face grain) |
| MOR after accelerated aging (2 hr boil test) | (MPa) | 11.0 | 9.6 | - | - | 4.8-5.5 | - |

fact, it is an entirely new category of product, fitting into neither plywood nor particleboard descriptions (Tab. 1); nor is it a flakeboard, chipboard or fibreboard. It is a unique product with specific basic properties (Tab. 2), attractive in appearance, which is accepted to-day as interchangeable in many instances with exterior plywood.

TABLE 2

Basic Properties of Waferboard(*)

| | Units-SI | Typical range | |
|---|---|---|---|
| | | Minimum | Maximum |
| Internal bonds | (kPa) | 414 | 690 |
| Modulus of elasticity | (MPa) | 2760 | 7521 |
| Modulus of rupture | (MPa) | 20.7 | 41.4 |
| MOR after accelerated aging (2 hr boil test) | (MPa) | 10.3 | 20 |

* Standard properties at a density of 640 kg/m$^3$ and a resin level of 2.5%.

Indeed, while waferboard has many uses ranging from furniture stock to decorative panels, its major and bulk market is as a competitor and alternative to exterior plywood for sheathing, underlayment, roof and floor decking.

## DEVELOPMENTS

Waferboard manufacture usually includes the operations of debarking, waferizing, drying, mixing, blending, felting and pressing, but the object of this paper is not to describe these processes in detail. Instead, it aims at directing attention to recent developments in wafer production, progress in the use of new species and improvements in the mixing of available raw materials.

### 1. WAFERIZING

One of the more significant recent developments is a semi-automatic waferizer (Fig. 1 and 2), fully patented and built by Canadian Car (Pacific) Div. of Hawker Siddeley Canada Inc., the makers of well-known CNS equipment. The new machine produces wafers of controlled thickness from 0.5 to 0.9 mm, 63 mm long, with tapered ends and restricted in width to about 25 mm. The wafers may be made from pieces of solid waste or other wood of any shape or cross-section. Unusable are thick, short pieces, such as lily-pads, which do not tend naturally to lie with their grain horizontal. This new drum-type waferizer, requires timber to be loaded into a charge bucket, holding approximately 760 x 760 x 810 mm of wood. The charge is pushed into the interior of a large drum; whilst a ram presses the shell of the drum, a series of veneer strips are cut from the charge. As these veneers leave the drum, they pass through a series of vanes clipping them into precise widths.

The main advantage of this concept is that length, width and thickness are controlled more accurately, as each charge is held parallel to the knives. This new approach results in stronger wafers, even from sawmill waste, which is acceptable to the new waferizer. The pulp and paper industry is showing a great deal of interest in these wafers because their uniform thickness is expected to give better yields of pulp. If this expectation is fulfilled the chips in current use may be superseded by wafers.

2. MIXING

To ensure sufficient contact and satisfactory bonding of the wafers, the wafer mat must be compressed to about 25 percent higher density than the original unwaferized wood. Depending on the terms of reference, this density factor can be higher or lower than 1.25. This rule is applicable regardless of the base density of the wood source.

However, another general rule is that there is almost a direct relationship between density and strength. Indeed, the strength of a waferboard produced from low density timber species can be increased by simple compacting of light-weight wafers. Dense and light woods can be combined in a homogenous mixture to produce a board of acceptable strength. It is possible also to make waferboard from heavy hardwood, if light woods are available to bring the average density down to the required level.

Such an approach is valid, providing that the waferboard plant can control the proportion of each species that is used in the process and vary hot soaking and drying times according to different wood characteristics.

All these variables can be controlled and scheduled, if provision is made in the system for segregated storage by species of the dry wafers. Retrieval from this segregated storage can be on a volume or weight basis, as dictated by the "recipe" that will give the proper proportions of each species for a required average overall density of the board.

Research workers of the Lignex Products Research Station in Vancouver have waferized and made board out of hundreds of different tropical and temperate, soft and hard, low and high density species. When used separately, not all of these were suitable for waferboard manufacture because of extreme density, poor cutting characteristics or abrasiveness, resulting in a low wafer knife life. With appropriate mixes, however, good quality boards have been made.

The most recent development in this respect was an attempt to utilize logs from small *P. radiata* trees (100-250 mm DBH), shipped to Lignex from Australia for waferboard manufacturing trials.

Normally unusable, small radiata pine tops (100 mm dia.) were transformed into wafers by means of a conventional waferizer; concurrently, it was established that a slightly modified CNS system is capable of producing material of the same type from somewhat larger pieces of timber. Presently, Hawker Siddeley Canada Inc. are actively investigating the economics of producing wafers rather than chips, as a normal by-product of a standard CNS conversion. To achieve this, only a relatively simple re-design of the existing chipping heads is required. Although this new process is still in the early stages of development, it is already obvious that it holds some exciting possibilities, both for the waferboard and pulp industries.

Tests on strips cut out from the sample boards prepared in the Lignex laboratory using Australian radiata pine wafers, yielded satisfactory results. The mechanical properties of the new board were assessed and in general compare favourably with those from other waferboards, manufactured from different species (Tab. 3). Indeed, from the data shown in Tab. 3, it can be observed that the critical MOE and MOR values of the radiata pine waferboard are well above code agency requirements, and in some cases even superior to the strength properties relative to a number of other species. Also, these figures show clearly that resin usage could be cut from 4% to the 2-3% range, resulting in a considerable saving.

## CONCLUSIONS

On the basis of these preliminary investigations, the following observations can be made:

(a) A strong and attractive waferboard can be manufactured either from *P. radiata* tops and thinnings of small diameter, or the residue of the conventional CNS conversion process involving somewhat larger stems.

(b) Exterior structural grade board made by the waferboard process compares favourably not only with the same type of product manufactured from different timber species, but also with many other traditional panels.

(c) Lignex have already demonstrated that an excellent waferboard can be produced from various Eucalypts. With both radiata pine and eucalypt thinnings available in Australia, it is clear that an adequate mix of different density wafers will result in even better board quality.

(d) Preliminary assessments indicate that this process offers a new way of utilising the problem thinnings from Australian *P. radiata* plantations, as well as small diameter Eucalypts, both of which are currently residues from silvicultural treatments.

TABLE 3

Typical Properties of Waferboard Manufactured from Various Species

| COUNTRY - species | | Board density ($kg/m^3$) | Phenolic resin content (%) | Internal bond (kPa) | Modulus of elasticity (MPa) | Modulus of rupture (MPa) | Modulus of rupture after accelerated aging (MPa) |
|---|---|---|---|---|---|---|---|
| AUSTRALIA | | | | | | | |
| -Radiata pine | A | 701 | 4 | 690 | 6008 | 45.3 | 26.6 |
| | B | 660 | 4 | 690 | 5796 | 43.5 | 18.6 |
| S. AFRICA | | | | | | | |
| -Eucalyptus | | 672 | 3 | 669 | 4879 | 31.8 | 19.6 |
| NORTH AMERICA | | | | | | | |
| -Aspen | | 672 | 3 | 731 | 5610 | 42.5 | 21.6 |
| 40% Aspen<br>- 30% W. Birch<br>30% R. Maple | | 672 | 3 | 793 | 4278 | 28.4 | 19.3 |
| 30% Sweetgum<br>22% Hackberry<br>- 6% Elm<br>17% Red Oak<br>25% Ash | | 704 | 3 | 986 | 4623 | 30.7 | 13.3 |
| -Southern Pine | | 624 | 3 | 600 | 2884 | 17.4 | - |
| PHILIPPINES | | | | | | | |
| -Almon | | 672 | 3 | 690 | 5438 | 37.1 | 25.9 |
| -Red Lauan | | 672 | 3 | 862 | 5866 | 45.8 | - |
| -Mixed Lauan<br>51% Almon<br>- 40% R. Lauan<br>9% Apitong | | 688<br>656 | 3<br>3 | 448<br>627 | 4554<br>5376 | 28.3<br>37.7 | -<br>17.7 |
| PANAMA | | | | | | | |
| -Carbonero | | 736 | 3 | 731 | - | 38.6 | - |
| -Espave | | 672 | 3 | 448 | - | 26.2 | - |
| -Cedro Macho | | 672 | 3 | 800 | - | 25.1 | - |
| -Cuajado | | 656 | 3 | 1035 | - | 40.1 | - |
| -Sangre | | 704 | 3 | 648 | - | 49.2 | - |
| CANADIAN WAFERBOARD STANDARDS (minimum values) | | - | - | 276 | 2760 | 13.8 | 6.9 |

The future potential of this new product on the Australian market seems to be worthwhile investigating.

LITERATURE:

d'A. Clark, J. (1955). "A new dry process, multi-ply board". *Tappi* 38(11): 183-187.

NOTE: The basic data for this paper has been provided by Lignex Products Group of Hawker Siddeley Canada Inc. (Vancouver), where the above testing has taken place.

ILLUSTRATIONS:

Fig. 1 - Lignex waferizer - overall perspective view.

Fig. 2 - Lignex waferizer in operation.

# GRADE YIELDS FOR SCANTLING TIMBER SAWN FROM RADIATA PINE TREES SAMPLED FROM STANDS OF VARIOUS AGES AND SITE QUALITIES

D.J. GRANT* and K. GROVES+

* Forestry Commission of New South Wales

\+ Department of Forestry, Australian National University

## INTRODUCTION

In 1977 an opportunity arose to assist in the completion of a lapsed post-graduate student project for which a considerable amount of work had been expended in investigating the grade yield of radiata pine timber from stands of various ages and silvicultural treatments. This is a topic of considerable interest and importance to forestry authorities because it was a rare attempt to marry silviculture and forest management with the engineering products derived from the forest.

Trees were sampled from radiata pine stands in the A.C.T., the logs converted to board and scantling timber which was kiln dried, machined and visually and mechanically graded. The diameter of the branches along the trunks of many of the trees were measured as well as the diameters of the ends of the logs. The data permitted a detailed study of grade yield patterns and log values for various age classes, site qualities and initial spacings for both visual and mechanical grading. The effect of spacing on various branching characteristics was also studied as well as the effect of branch size on log value (Grant, 1980). The air-dry density of scantling timber recovered from trees of various ages was also determined (Grant, 1981).

## GRADE YIELD RESULTS

Grade yield results for trees sampled from 36 year old thinned stands with three different site qualities (low (3), average (2), high (1)) and single 19 and 23 year old unthinned stands are given in Table 1. Sample sizes were unfortunately small and were sometimes unequal for the various log position classes (generally between 3 to 10 logs per log position class) and therefore the yields are termed apparent whole tree grade yields.

TOPIC C8

Table 1. Apparent whole tree percentage yields in the mechanical and visual grades for thinned 36 year old stands of 3 site qualities and for unthinned stands of 19 and 23 years of age. Scantling timber only.

(a) Machine grade percentage yield

| Age (yr.) | S.Q. | Grade | | | | | | Approximate % of total yield sawn to boards |
|---|---|---|---|---|---|---|---|---|
| | | F11 | F8 | F7 | F5 | F4 | Reject | |
| 19 | 2 | 0 | 2 | 18 | 42 | 22 | 16 | 21-49 |
| 23 | 2 | 0 | 7 | 16 | 32 | 18 | 28 | 10-45 |
| 36 | 1 | 19 | 39 | 17 | 21 | 4 | 0 | 13-20 |
| 36 | 2 | 20 | 35 | 16 | 26 | 3 | 0 | 10-15 |
| 36 | 3 | 21 | 27 | 23 | 22 | 6 | 1 | 14-23 |

(b) Visual grade percentage yield

| Age (yr.) | S.Q. | Grade | | | | | |
|---|---|---|---|---|---|---|---|
| | | F11 | F8 | F7 | F5 | F5HI | Reject |
| 19 | 2 | 0 | 5 | 3 | 10 | 67 | 16 |
| 23 | 2 | 3 | 6 | 8 | 19 | 43 | 22 |
| 36 | 1 | 9 | 28 | 17 | 23 | 12 | 11 |
| 36 | 2 | 5 | 21 | 18 | 33 | 10 | 12 |
| 36 | 3 | 10 | 21 | 11 | 16 | 27 | 15 |

## DISCUSSION

The dramatic effect of tree age on grade yield was reflected by both methods of grading. For machine grading, the 36 year old trees produced over 70% of total scantling yield in the valuable F7 and higher machine grades for all three site qualities whereas the 19 and 23 year old stands produced only about 20% in those grades and negligible amounts above F7. Results for visual grading were 54%, 45% and 42% for the high, average and low site quality areas of the 36 year old stands respectively.

Site quality did not significantly effect machine grade yields. For visual grading there was a much larger percentage of timber yield in the F5 HI grade from the low site quality area, possibly due to the larger percentage of juvenile wood in the smaller trees from that site when compared to the percentage of juvenile wood in the larger trees from the higher site qualities (Grant, 1980).

Generally, visual grading produced inferior grade yields than did machine grading, especially for the mature thinned stands. This was reflected in the lower yields of higher grades and the higher yields of lower grades when using visual as opposed to mechanical grading.

## REFERENCES

Grant, D.J. (1980). The influence of age, site and stocking density of plantations on grade and monetary recovery of radiata pine scantlings and boards. M.Sc. Thesis, Australian National University.

Grant, D.J. (1981). Density of scantling timber sawn from radiata pine trees of various ages. N.S.W. Forestry Commission Report (Unpublished).

# A FLUIDIZED BED CARBONIZER-BOILER PILOT PLANT

P.Y.H. FUNG
Division of Building Research, CSIRO

## ABSTRACT

Studies on the carbonization of timber industry residues and the recovery of heat from the combustion of the volatile components in a continuous experimental unit have led to the design and construction of a pilot plant. The proposed stages of development of the plant are described and the potential of the technology is discussed.

## INTRODUCTION

The wasteful disposal of wood residues represents a loss to the timber industry of a potentially valuable resource. The disposal costs by incineration or landfill dumping in an environmentally acceptable manner are high, with many sawmillers incurring annual expenditures in the order of $20,000-$80,000 for this non-productive practice. Where heat is required for seasoning kilns, capital costs for wood-fired heat units currently available run at a quarter to almost one million dollars, depending on the type and size, the heat recovery system employed and degree of sophistication. These units are usually highly automated and generally meet emission standards. In many cases, particularly for the hardwood sector, considerably more residues are produced than are required for energy purposes and these must be disposed of. A materials and energy balance study showed that by burning only one fifth of the total residue production from a hardwood mill in a conventional thermal power system, the total electricity and heat requirements of the mill could be met. Even if the mill chipped its slabs and edgings for sale, then half its unused residue production could supply its total energy needs (1).

The fluidized bed process has the threefold purpose of residue disposal, supplying the

energy requirements of the mill and producing charcoal, a valuable byproduct which can be sold to non forest-based industries. By combining these functions into the one plant, the economics become more attractive and the logistics of transportation of a higher value product are vastly improved. These factors are important in many of the decentralized mills far removed from the potential market centres. Although the process is based on mill residues, it could be adapted to other wood resources such as forest residues or tree-cropping ventures.

The process of charcoal production is basically simple. One of the earliest methods still in use today, particularly in developing countries, is the primitive stack where a smouldering pile of dried wood is covered with earth except for chimney and draught holes (2). A later development was the batch operated charcoal kilns which gave better quality control although a high degree of operator skill was still required. Energy utilization in these systems is very poor since over half the energy content of the wood is lost as smoke. Automated, continuous operating carbonization retorts and furnaces have also been developed; these require less labour and produce a more uniform grade product. Examples of such units are: the Lambiotte retort (3) which was, until recently, in operation at Wundowie, Western Australia, and had a capacity to produce 20,000 tonnes/y of charcoal from dried wood blocks; and also the Herreschoff multiple hearth furnace (4) used overseas. These continuous units are highly mechanized and capital intensive.

## FLUIDIZED BED CARBONIZATION

The fluidized bed carbonization work at the CSIRO Division of Building Research began in 1975 with the construction of an experimental scale unit for the continuous production of charcoal from sawdust. The objectives were to utilize sawmill wastes in the form of sawdust, chipped solid wastes and bark, convert them to charcoal and in the same process, burn the volatile matter and recover the heat in the form of steam to supply the power and steam requirements of the timber industry.

Fluidized bed technology was chosen because:

1. The principle was well established in the petroleum industry for the catalytic cracking of crude oil and the mining industry for the roasting of mineral ores.

2. It was a developing technology for such applications as coal fired boilers and gas turbine power generation.

Wood fired fluidized bed furnaces for steam raising have since been installed at sawmills in the North America and more recently, in New Zealand. These installations have shown their effectiveness and reliability.

The advantages of fluidized bed systems are:

1. They are basically simple since no mechanical moving parts are involved in the fluidization, and therefore have lower capital costs as compared with, say, the Herreschoff furnace.

2. They can handle the whole range of moisture contents encountered in practice varying from in excess of 120% moisture content to oven dry.

3. They permit a high degree of heat recovery to be tapped directly from the fluidized bed, therefore resulting in a compact unit.

4. They require no external source of heat once the system is operating.

PRINCIPLE OF OPERATION

The experimental unit consists of a steel combustor which contains a sand bed in its lower section. This bed is initially heated with gas and is kept fluidized by air injection. The material to be carbonized is fed into the hot sand where the volatile constituents are released and burnt, leaving charcoal which can be removed from the unit by a means suited to the type of particles being carbonized. The heat released by the combustion of the volatiles is sufficient to maintain the required temperature in the bed, the unit then being self-sustaining without any external heat. By fitting a heat exchanger in the sand bed, heat is extracted by circulated oil used to generate steam in an unfired boiler.

PILOT PLANT

Data obtained from the experimental unit were incorporated in the design of a pilot

plant now under construction. This is expected to carbonize half a tonne per hour of sawdust and chipped wood to produce both lump charcoal and charcoal fines. The pilot plant is being developed in following four stages:-

Stage 1: Construction of the plant to a cold operating stage for testing the fluidization, circulation and conveying of the bed of sand and wood particle mixtures.

Stage 2: Installation of feed hoppers for hogged wood and sawdust, preheat burners and a lump charcoal recovery unit for actual charcoal production.

Stage 3: Installation of heat exchangers to recover heat and generate steam.

Stage 4: Installation of a steam turbine alternator and the generation of electricity.

The carbonization unit is essentially of steel construction. Because of the relatively low design operating temperature of around 500°C, and the reducing environment of the charcoal, expensive refractory lining is not required. This is expected to reduce capital and maintenance costs of a commercial unit. The heat recovery system could be based either on hot oil or steam. The advantages of a hot oil system are: comparatively high temperature heat at 180-260°C can be obtained for kiln heating; any steam required can be generated by an unfired boiler; and a certificated boiler attendant is not needed. For a plant with power generation facilities, a pressurized steam system would be used to run a steam engine or turbine alternator. Where applicable, a cogeneration system would offer very efficient production of both heat and electricity.

With the difficulties public power generating authorities are currently facing in meeting demands, there are increasing possibilities for private power generation both to supply the timber industry's own electricity requirements as well as for exporting surplus power. The high capital costs of large scale power stations, coal exports, competition for the coal resource for liquefaction and projected electricity demands by the aluminium industry are factors which lead to uncertainties in power supplies and electricity prices. A number of timber mills have power generating facilities and some have recently installed either wood-fired or diesel alternators.

It has been estimated that, from the national annual production of sawmill residues, there is a potential production of some 900,000 tonnes of charcoal, $9.4 \times 10^2$ GWh of electricity and $0.8 \times 10^7$ GJ of process heat available through the fluidized bed carbonization method of processing these residues (5).

## CONCLUSIONS

Carbonization offers an excellent means of upgrading wood from sawmill residues into a valuable product. If energy is also recovered from the volatile products, maximum utilization of the original wood is possible. The fluidized bed carbonization process has the potential of handling the wide range of mill waste over the whole spectrum of moisture contents to produce charcoal and usable heat. This is an important consideration since the added capital and operating costs of drying wood residues before carbonization, as generally required by many systems, could be considerable.

There is scope for power generation by the process which, in the case of sawmills, could make them completely self-sufficient in energy. There is further scope for selling excess power when the current restrictive policies and disincentives placed by the electricity supply authorities are changed.

The pilot combustor-boiler plant now under construction is an imporant step in evaluating the technical and economic viability of the carbonization process.

## REFERENCES

1. Fung, P.Y.H., Liversidge, R.M. and Lhuede, E.P.(1978). Timber industry residues as an energy source. 6th Aust. Chem. Eng. Conf., Surfers Paradise, 6-8 Nov., 1978, p.182-189. (CSIRO, Div. Bldg. Res. Rept. 862).

2. Humphreys, F.R. and Ironside, G.E.(1977). Charcoal from NSW timber. Forestry Commission of NSW, Tech. Paper 23.

3. Lambiotte, A.(1942). A process of continuous carbonization of cellulosic materials. US Pat. 2 289 917.

4. Goose, A.W., Trepanier, M.A. and Johnston, M.K.(1948). Some experiments in sawdust carbonization. For. Prod. Res. Soc., National meeting, Chicago, Mar.

5. Fung, P.Y.H.(1979). Carbonization of timber industry waste and heat recovery in a fluidized bed. 7th Australian Conf. on Chem. Eng., Newcastle, 22-24 Aug., 130-134. (CSIRO, Div. Bldg. Res. Rept. 896).

Topic C10

# A STUDY OF WOODCHIP CARBONIZATION IN A FLUIDIZED BED

by

P.Y.H. FUNG and B. SINGH*
Division of Building Research, CSIRO, Highett, Vic.
*BHP Central Reseach Laboratories, Shortland, N.S.W.

## ABSTRACT

A series of batch carbonization experiments on commercial Eucalyptus regnans chips in a 0.6 m x 0.6m fluidized bed have shown that the green chips could be completely carbonized within 4 minutes at temperatures of 500-530°C. A charcoal recovery of 22% of the oven-dried weight of wood was obtained under these conditions. Oxygen concentrations of up to 13.3% by volume in the fluidizing gas, with other conditions remaining the same was found to reduce the charcoal recovery only slightly. The low residence time in the fluidized bed was insufficient for combustion of the charcoal to advance to a significant degree.

## INTRODUCTION

One approach to the utilization of wood residues generated by the forest-based industries is through carbonization. Within the Australian timber industry alone, it has been estimated that some $5.6 \times 10^6$ $m^3$ of wood residues are produced annually, equivalent to $3.4 \times 10^6$ tonnes of oven-dried wood. Considerably more residues than these are either burned or left to decay in the forest which could be potentially converted into charcoal provided factors such as nutrient depletion and soil erosion are taken into account in the utilization of this resource.

At the Division of Building Research, CSIRO, the production of charcoal and the recovery of heat from sawdust carbonized in a fluidized bed have been developed on an experimental scale in a continuous operation plant. Charcoal fines have been produced from sawdust at the entire range of moisture contents encountered in practice. A heat recovery system based on circulating heat transfer oil through the fluidized bed and extracting heat from it by the generation of steam in an unfired boiler has shown the viability of the system for heat production (1).

Similarly, the Fuel Research Group at the Central Research Laboratories of Broken Hill Proprietry Company Ltd. (BHP) has developed the fluidized bed technology used in the Auscoke pilot plant for the carbonization of coal briquettes. This unit was built at Port Kembla in 1971. It consists of a two-stage, continuous process for the production of strong, large, metallurgical grade coke briquettes from medium or low volatile, poorly caking coals (2).

There is much in common between coal and wood, since the former is really fossilized wood and other lignocellulosic materials. Both will readily carbonize in a hot fluidized bed of sand with coal producing coke and wood producing charcoal. A joint study between BHP and CSIRO was conducted in May 1979 at the BHP Central Reseach Laboratories, Shortland, N.S.W., to investigate the carbonization of woodchips and obtain preliminary data for pilot plant development. Of main interest were the residence time required for chip carbonization and the percentage recovery of charcoal at various oxygen concentrations in the fluidized gas.

## EXPERIMENTAL METHOD

### Source and properties of woodchips

Woodchips were obtained from a Victorian hardwood sawmill where slabs and edgings from regrowth *Eucalyptus regnans* were chipped for the manufacture of pulp. Four batches of chips were obtained from the mill and combined into one single batch, sealed in a 200 litre drum. Moisture samples were taken from each of the four batches and one from the combined batch. Moisture contents were measured by oven drying. The average moisture content of the values shown in Table 1 was 104 $\pm$ 13% (oven dry basis) or 50.9 $\pm$ 3.2% (wet basis).

TABLE 1

Moisture content of woodchips

| Sample | Moisture content (%) Dry basis | Wet basis |
|---|---|---|
| Batch 1 | 85 | 45.9 |
| 2 | 92 | 47.8 |
| 3 | 123 | 55.2 |
| 4 | 110 | 52.6 |
| Combined | 112 | 52.9 |
| Av. | 104 | 50.9 |

A representative sample of the four batches of chips were taken, combined together into a pile and divided into four sectors. One sector, comprising a 5.03 kg sample, was then screened through 25 mm, 19 mm and 12 mm sieves. A size analysis of this sample is shown in Table 2.

TABLE 2

Size analysis of woodchips

| Size (mm) | Mass % |
|---|---|
| +25 | 2 |
| -25+19 | 9 |
| -19+12 | 33 |
| -12 | 56 |

Carbonizing equipment and experimental procedure

The woodchip carbonizing tests were carried out in an experimental fluidized bed rig of square cross section 0.6 m x 0.6 m, containing silica sand as the fluidizing medium. The bed was fluidized by a set of BHP designed "pneudistributors" located at the base of the bed. The gas distributor, which consisted of sets of perforated concentric pipes, is more fully described elsewhere (3). Fluidizing gas comprised of a mixture of air and LPG combustion gases which were used to heat the sand bed. The proportion of air and gas could be controlled. A paramagnetic oxygen meter monitored the oxygen concentration in the off-gases above the bed while infra-red gas analysers recorded the CO and $CO_2$ content. The bed temperature was also monitored by a thermocouple and was manually controlled by varying the quantity of LPG used in the fluidizing gas.

The carbonization trials were conducted in batch runs. Samples of wood chips were contained in a stainless steel basket 200 mm long and 80 mm diameter with a mesh aperture of 2 mm. The basket allowed the free flow of sand through the mesh but retained the larger lump material. At the commencement of the run, the basket containing the chips was lowered into the heated fluidized bed. After the selected period, the charred material was withdrawn from the bed and plunged into water to quench the reaction. The charred material was inspected and then dried in an oven.

By varying the heating time for different batches of woodchips inserted into the fluidized bed, the optimum residence time for carbonization was determined. The cooled, charred material from each batch was visually examined by selecting the largest lump, dissecting it and noting whether or not a core of wood not completely carbonized remained. Having determined the period for complete carbonization, other test runs were conducted over this fixed interval. The fluidized bed temperature for the various runs was maintained between 500-530°C.

The charcoal produced from the runs was washed to eliminate as much adhering sand as possible, oven dried and weighed to determine the recovery of charcoal. Charcoal recoveries as recorded are based on the ratio of the oven-dried, sand-washed mass of charcoal to the oven-dried mass of wood used in the charge. The latter was calculated from the green weight of the chips and their moisture content.

RESULTS

Determination of residence time for carbonization

Carbonization runs to determine residence time were conducted over various heating intervals of from 2 minutes to 5 minutes. Observations are shown in Table 3 in chronological order.

TABLE 3

Effect of residence time on degree of carbonization

| Run time (min) | Temp. °C | Material charged | Observations |
|---|---|---|---|
| 2 | 500 | sample chips | not completely carbonized |
| 5 | 508 | " " | completely carbonized |
| 5 | 530 | select large chips | " " |
| 4 | 522 | sample chips | " " |

It was found that a heating time of 2 minutes was insufficient to completely carbonize the chips. However, after 5 minutes, the largest chip in the sample was completely charred. This heating time interval was repeated using a charge of selected, large wood chips and the product was found to be completely carbonized. A further sample of chips was carbonized for 4 minutes and the largest chip in the batch was fully charred. It was decided then to adopt 4 minutes as the residence time for carbonization in the subsequent tests.

The residence time depends on a number of factors, the main ones being temperature, particle size and shape, moisture content of the wood and species of timber. If these are varied significantly, the residence time for wood carbonization could also change.

Effect of oxygen concentration on charcoal recovery

The presence of oxygen in the fluidizing gas results in combustion of the volatile products of carbonization. It also burns the charcoal product formed, although at a much slower rate than the volatiles which would reduce the overall recovery of the charcoal. Batch runs were carried out with oxygen concentrations varying between 0% to 13.3%. Higher concentrations approaching that in air (21%), were not possible since LPG was burned with the fluidizing air to raise its temperature. The results of these tests are shown in Table 4.

TABLE 4

Effect of oxygen concentration on charcoal recovery

| $O_2$ (% by Vol.) Before run | $O_2$ (% by Vol.) Min value during run | Temp. (°C) | % Recovery of charcoal |
|---|---|---|---|
| 0 | 0 | 523 | 22 |
| 6.0 | 2 | 525 | 21 |
| 11.0 | 4 | 515 | 19 |
| 13.3 | 4 | 509 | 21 |

In the course of the runs with oxygen, the concentration fell to a minimum value due partly to the combustion reactions and also by its dilution with gaseous products. It can be seen from the results that any decrease in charcoal recovery is only slight and combustion of the charcoal product for the residence time of 4 minutes was not significant in the temperature range 509-525°C. Under these conditions, recoveries of charcoal were 19-22% of the oven dried mass of wood for oxygen concentrations in the fluidizing gas of between 0-13.3% by volume.

The fine charcoal particles formed by attrition or fracturing in the fluidized bed would not be retained by the wire basket and would be lost subsequently in the sand bed. Likewise, during the quenching of the hot charcoal, losses of charcoal fines could also occur. Hence, the charcoal recovery figures may be somewhat less than the true recovery values if all of the charcoal formed could be collected.

## CONCLUSION

These experiments have demonstrated that carbonization of wood chips can be readily carried out in a fluidized bed at very high rates of carbonization. The high rates of heat transfer encountered in fluidized beds results in rapid rates of drying of the wood chips, heating to carbonization temperatures and formation of charcoal. The sand bed acts as a heat transfer carrier, supplying heat for drying and heating of the wood chips and the removal of heat from the exothermic carbonization and combustion reactions.

## REFERENCES

1. Fung, P.Y.H. (1979). Carbonization of timber industry waste and heat recovery in a fluidized bed. 7th Aust. Chem. Eng. Conf., Surfers Paradise, Nov. 182-189.

2. Callcott, T.G. (1972). The Auscoke Process. Aust. Inst. Mining and Met. Proc., Newcastle Conf., May-June, 177-186.

3. Callcott, T.G., Rigby, G.R., Singh, B. (1975). Experiences in the pneumatic handling of particulate materials. BHP Tech. Bull. 19(1), 20-26.

# WOOD CHARCOAL AS A FILLER FOR RUBBER

P.Y.H. FUNG* and Z.T. NOWAK**
*Division of Building Research, CSIRO
**Australian Carbon Black Pty. Ltd., Altona

## ABSTRACT

An investigation on the use of finely ground wood charcoal as a filler for SBR-1500 rubber showed that it slightly reinforced the rubber compound. However, cure time was retarded but this could not be attributed to the pH of the charcoal or to the adsorption of accelerator by it. Moreover, dispersion of the charcoal was not homogeneous. Overcoming these factors could further improve the reinforcing properties of wood charcoal in rubber.

## INTRODUCTION

The rubber industry is a large consumer of carbon black, a well established and versatile filler which imparts desirable properties to the rubber composite for stress-demanding applications such as tyres, rubber belting etc. Australia consumes 41 000 tonnes per year of carbon black principally by the rubber tyre industry.

Carbon black and the synthetic rubber elastomers are derived from petroleum sources, the cost of which has escalated over recent years. A number of non-petroleum based fillers most of which are non-reinforcing, have therefore been investigated for use in many non-critical applications, primarily to reduce the quantity of rubber elastomer used (1,2). One group of fillers which is notably reinforcing is the precipitated and fumed silicas. These are particularly suitable for non-black applications.

Over recent years, there has been interest in the use of waste products as filler materials, and one notable example is the rice husk ash "Opal Black". Another non-petroleum derived filler is based on bituminous coal fines and is marketed under the trade name of "Austin Black" (1). Over the past years, "Micro-pulverized Delayed Petroleum Coke (MCD) has also been promoted as an alternative carbonaceous filler (3-9). Because

of the potential availability of charcoal derived from wood primarly from residues produced by the forest-based industries, and the lack of any published information known to the authors on the use of charcoal in this application, a study was made on the incorporation of this material as a rubber filler.

## EXPERIMENTAL PROCEDURES

In general, the degree of reinforcement of rubber increases with decreasing particle size. Whereas fully reinforcing fillers, such as carbon black and fumed and precipitated silicas sized below 50 nanometres (nm), are produced in special furnaces or by special preparations, wood charcoal must be ground down to size. Because of limitations in size reduction by the normal grinding process, charcoal cannot be reduced to such fine sizes and rubber reinforcement may therefore be limited.

The wood charcoal was produced by carbonizing Eucalyptus regnans sawdust at 500°C in a fluidized bed process. The charcoal was ball-milled and sized to remove the coarse fraction. Particle sizing by air- elutriation, although effective in producing a controlled range of sizes, was found to be too slow in an experimental rig built for this purpose. Wet-sieving through a 45 micron screen with ethanol was found to produce relatively fine material at a more satisfactory rate and was subsequently adopted to produce the required quantities for the rubber mixes. Electron scan microscopic examinations of the sized, ground charcoal were made to ascertain some of the particle sizes of the fines.

The charcoal was also analysed to determine its pH according to ASTM-D1512-75 (10) using an Orion 701A pH meter.

It was thought that, because the charcoal produced in the fluidized bed had high internal surface areas as shown by other studies, there was a likelihood of adsorption by the charcoal of the accelerator N-tert-butyl-2-benzothiazole sulfenamide (TBBS) from the rubber mix as has been observed with carbon blacks of high porosity. Hence, a study was conducted to determine whether or not this occurred. It would be very difficult, if not impossible, to separate the rubber from the charcoal in a compounded mix to analyse for TBBS and so a simulation study was performed where the adsorption of TBBS from a suitable solvent was investigated. Ethanol was found to be suitable.

A standard solution of recrystallized TBBS in ethanol was prepared. By mixing a portion of this solution with charcoal, standing for one hour, centrifuging and quantitatively analysing the supernatant solution in a Varian Superscan UV/Visible spectrophotometer at the wavelength 224 nm, any fall in concentration of TBBS could be determined when

compared with the original solution which was not contacted with charcoal.

The rubber polymer used in the compounded mix with charcoal was styrene butadiene rubber 1500 (SBR-1500). Three mixes were prepared and the various formulations are shown in Table 1. Compound 1 contained no filler while the second contained 50 parts by

TABLE 1

Formulation of rubber compounds

| | Quantity (parts by mass) | | | |
|---|---|---|---|---|
| | Compound 1 | Compound 2 | Compound 3 | |
| | | | Master batch | Final mix |
| SBR-1500 | 100.00 | 100.00 | 100.00 | 100.00 |
| Zinc Oxide | 3.00 | 3.00 | 0 | 3.00 |
| Sulphur | 1.75 | 1.75 | 0 | 1.70 |
| Stearic Acid | 1.00 | 1.00 | 0 | 1.00 |
| TBBS | 1.00 | 1.00 | 0 | 1.00 |
| Wood Charcoal | 0 | 50.00 | 80.00 | 50.00 |

mass of charcoal to 100 parts SBR-1500. Compound 3 consisted of a masterbatch composed of 80 parts charcoal to 100 parts SBR-1500 which was allowed to stand for 10 days before being diluted with additional SBR-1500 to give a final mix similar in composition to Compound 2. The reasons for preparing Compound 3 will be discussed later. Other components in the recipes are additives used in practical formulations of carbon black rubber compounds. TBBS is an accelerator which initiates the cross linking of the rubber polymer.

The mixing procedure was according to the ASTM test method D3191-79 (11). Mooney viscosity measurements were carried out on the compounded material according to ASTM test methods D3182-74 (12), D2230-78 (13) and D1646-80 (14). The compound was cured at 145°C for 90 minutes.

Standard stress-strain measurements were performed on dumb-bell shaped specimens of the three rubber compounds to determine the stress at 300% modulus, tensile strength and elongation according to ASTM test method D412-80 (15).

## RESULTS AND DISCUSSION

### Particle size

The ball-milled charcoal used for compounding was less than 45 micron in size. Since it was not known how finely the charcoal could be ground, a sample of elutriated charcoal fines was examined under an electron scan microscope which showed: large particles about 20 microns in size, a predominance of medium particles of 1-5 microns and a small number of particles of about 0.1 micron. In relation to the carbon blacks, the smallest ground charcoal size would correspond to the SRF, FT and MT blacks which are the most coarse in the carbon black filler range. The medium size particles would lie in the size range of the inorganic fillers such as zinc oxide and kaolin clays while the largest particles would correspond to other ground fillers such as calcium carbonates and silicates.

### Compounding with rubber elastomer

In the various mixes of ground charcoal with SBR-1500, two problems arose which were uncharacteristic of compounds with carbon black. Firstly, dispersion of the ground charcoal was not as homogeneous and secondly, cure times were markedly retarded leading to undercured material. Factors causing the latter problem were subsequently investigated but the reasons are still not known.

The pH of the charcoal extracted with water to remove soluble ash was found to be 6.3. It is well known that a low pH (below 5-6) of the filler will retard curing. However, a pH of 6.3 would be unlikely to be responsible for the degree of retardation experienced.

Adsorption of TBBS in ethanol by the charcoal was found to be negligible at TBBS to charcoal ratios of up to 1:50 which is equivalent to that in the rubber compounds.

### Rubber compound strength properties

Relevant stress-strain properties of SBR-1500 rubber compounds are compared in Table **2**. The strength properties show that wood charcoal produces a small degree of reinforcement of the rubber. Tensile strength was improved fourfold and the 300% "modulus" (i.e. tensile stress at 300% elongation) was increased threefold over that for the unfilled rubber control sample. When compared with a filler such as rice husk ash (2) in SBR-1712, wood charcoal showed an improvement in tensile strength with a value of 6.4 MPa as against 3.24 MPa for the former. On the other hand, both modulus and tensile

TABLE 2

Properties of various rubber compounds

| Compound | Filler | Mooney Viscosity ML (1+4) at 100°c | Cured time at 145°C (min) | 300% Modulus (MPa) | Ultimate Tensile Strength (MPa) | % Elongation at Break |
|---|---|---|---|---|---|---|
| 1 | None | 40 | 90 | 1.2 | 1.6 | 350 |
| 2 | Wood Charcoal | 70 | 90 | 3.6 | 6.4 | 670 |
| 3 | Wood Charcoal | 68 | 90 | 3.2 | 5.9 | 840 |
| Reference | Ind. ref. black 4 | - | - | 16.6 | 29.9 | 485 |
| (a) | Rice Husk Ash | 51 | - | - | 3.2 | 360 |
| (b) | Ground Coal | 71 | 40(c) | 3.5 | 5.2 | - |

(a) 59 parts rice husk ash to 100 parts by mass SBR-1712 (2)
(b) 56 parts ground coal to 100 parts by mass SBR-1500 (9)
(c) at 160°C.

strength values obtained for the wood charcoal compounds are similar to those reported by Seng et al. (9). for an ASTM-D3191 SBR-1500 compound (11) filled with 56 phr of commercially available ground coal (Austin Black).

Nevertheless, the degree of reinforcement with wood charcoal falls far short of that observed with carbon black.

It was reasoned that if there existed any interaction between the filler and the polymer, masterbatching would favour "bound rubber" formation and lead to improved physical properties. However, compound 3 actually shows slightly lower strength values than compound 2. This may be due to polymer breakdown (molecular weight reduction) during the additional mixing necessary for the dilution of the masterbatch. Bound rubber determinations were not carried out in view of the rather preliminary nature of the investigation.

## CONCLUSION

Finely ground wood charcoal can be used as a filler for SBR-1500 rubber with slightly reinforcing properties. However, special preparation techniques of the charcoal and rubber formulations must be devised to assist in dispersion of the charcoal and to increase the rate of vulcanization.

The retardation in rate of vulcanization was unlikely to be due to pH of the charcoal or adsorption of TBBS accelerator by the latter and the cause is still not known.

There is room for improvement of the reinforcing properties of charcoal as a filler for rubber and further work is envisaged.

## ACKNOWLEDGEMENTS

The authors wish to thank Australian Carbon Black Pty. Ltd. for permission to publish the results of the rubber compound tests.

Special thanks also to Dr C.D. Sutcliffe and Mr S.K. Gune of Australian Carbon Black Pty. Ltd. for their work in preparing the rubber compounds and subsequent tests and Mr A. Rozsa of CSIRO, Division of Building Research, for operating the UV/visible spectrophotometer.

REFERENCES

1. Mueller, W.J. 1977. Compounding with fillers from non-petroleum sources. Amer. Chem. Soc., Rubber Div. Meeting, Cleveland, Ohio. Oct. 5, Paper No. 26, 44 pp.

2. Anon. 1975. Reinforcing fillers: clays, silicas and silanes; cellulose, corn starch; rice husk ash and carbon black. European Rubber J., April, 34-42.

3. Gotshall, W.W. 1969. Carbon black replacement. Rubber Age, 101 (6), 60-62.

4. Del Gatto, J. 1968. Marathon Oil's answer to carbon black: coal. Rubber World, 160 (4), 64-66.

5. Anon. 1971. New carbon black process to start up. Rubber Age, 103 (7), 74.

6. Anon. 1971. New substitute for black. Rubber World, 164 (4), 27.

7. Gotshall, W.W., Wolf, R.F. 1973. Reinforcing carbons from petroleum coke. Amer. Chem. Soc., Rubber Div. Meeting, Denver, Colo., Oct. Paper No. 29.

8. Gotshall, W.W., Fernandes, d.p. 1976. New sources of carbon. Amer. Chem. Soc., Rubber Div. Meeting, San Fra., Cal., Oct. 5-8, Paper No. 43.

9. Seng, R.H., Padgett, W.M., Gotshall, W.W. 1980. Micro-pulverized delayed petroleum coke (MDC), an alternative carbonaceous filler. Amer. Chem. Soc., Rubber Div. Meeting, Detroit, Mich., Oct. 7-10, Paper No. 51.

10. Amer. Soc. for Testing Materials. 1975, Standard method of testing carbon black-pH value. 37, D1512-75.

11. Amer. Soc. for Testing Materials. 1979, Carbon black in SBR-Recipe and evaluation procedures, Tests for. 37, D3191-79.

12. Amer. Soc. for Testing Materials. 1974. Rubber-Materials, equipment and Procedures for mixing standard compounds and preparing standard vulcanized sheets. 37, D3182-74

13. Amer. Soc. for Testing Materials. 1978. Rubber property-Extrudability for unvulcanized compounds, Tests for. 37, D2230-78.

14. Amer. Soc. for Testing Materials. 1980. Rubber from natural or synthetic sources:- viscosity and vulcanization characteristics (Mooney Viscometer), Testing. 37, D1646-80.

15. Amer. Soc. for Testing Materials. 1980. Rubber properties in tension, Tests for. 37, D412-80.

# SOME PHYSICAL PROPERTIES OF FLUIDIZED BED CHARCOAL

P.Y.H. FUNG, T. BROWN, and D.N. CROOK
Division of Building Research, CSIRO

## ABSTRACT

Samples of sawdust residues of Pinus radiata and Eucalyptus regnans were carbonized in a fluidized bed. Determination of a number of the physical properties of the charcoal produced was made and the effect of carbonization temperature on some of these was investigated. The properties were also compared with commercial grades of charcoal namely barbecue and activated charcoal.

## INTRODUCTION

Wood charcoal is a form of carbon, the physical and chemical properties of which could be highly variable depending on the species of wood from which the charcoal was derived, the carbonizing process and the conditions under which the charcoal was produced.

The potential for charcoal production from various wood sources such as residues from the forest products industry, forestry wastes and tree-cropping operations has led to the development of a fluidized bed process of carbonization at the Division of Building Research, CSIRO.

In the fluidized bed process, charcoal is produced by the thermal decomposition of wood in a hot sand bed. Air is passed through the bed via a distributor at its base which effects the combustion of the volatile matter within the bed. The charcoal formed also burns but at a slower rate and is recovered from the bed before much combustion can take place.

This paper is concerned with the determination of some of the physical properties of the fluidized bed charcoal and compares them with commercial grades of charcoals. The effect of fluidized bed temperature on the properties of charcoal produced was examined.

## EXPERIMENTAL PROCEDURES

Sawdust samples were obtained from two sawmills in Victoria, one converting Pinus radiata and the other, regrowth Eucalyptus regnans. The samples were carbonized in a fluidized ilmenite sand bed at three bed temperatures, namely: 500, 550 and 600°C. Some of the physical properties of the charcoal samples obtained were then examined by current analytical methods. The properties determined were also compared with those of activated charcoal representing a refined form of charcoal and barbecue charcoal representing another form produced under entirely different conditions. The activated charcoal, obtained through a commercial source, was manufactured by the activation of wood with phosphoric acid. Likewise, the barbecue charcoal was also obtained commercially but no details of its manufacture were available.

The properties determined and the analytical methods used are described in the following paragraphs, with many of the procedures being similar to those used in the determination of the properties of fly ash (1).

Particle size distributions were determined by wet-sieving the charcoal in ethanol using standard B.S. sieves of size ranging between 45 to 599 microns.

Bulk densities were determined by measuring the volume of a weighed quantity of charcoal in a 100 ml measuring cylinder after being compacted by tapping.

True specific gravities were determined by a pycnomemeter using vacuum impregnation of the charcoal with absolute alcohol which served as the replacement fluid.

Specific surface areas were determined by nitrogen adsorption using the B.E.T. method. A Carlo Erba Sorptomatic 1800 absorption equipment was used for the determinations.

Pore-size distributions were determined in a Carlo Erba mercury porosimeter which measured pore volumes for pores with radii down to 3.5 nanometres (nm) in size.

Ash contents were determined on samples oven-dried at 110°C and ignited in a muffle furnace at 950°C.

X-ray powder diffraction analyses were determined using Siemens equipment fitted with a scintillation counter, Co Kα radiation source and iron filter.

## EXPERIMENTAL RESULTS AND DISCUSSION

### Particle size distribution of charcoal

Table 1 shows the particle size distribution of the fluidized bed charcoal produced at different bed temperatures. For both softwood and hardwood, the higher the temperature, the greater the proportion of fines produced. This would be due to the increase in rate of combustion of the charcoal particles both within the bed and in the disengagement space above the bed.

### Bulk density of fluidized bed charcoal

Values shown in Table 2 for the fluidized bed charcoal lie in the range 132-294 kg/m$^3$. In general, the higher the carbonization temperature, the greater the bulk density. The higher bulk density of *E. regnans* charcoal produced at 550 and 600°C compared to that for *P. radiata* at the same temperature is a reflection of the higher proportion of fines less than 45 microns in size in the former material.

### True specific gravity (SG)

This is a measure of the solid substance excluding the pore space. For fluidized bed charcoal, there was little difference between the two species which both showed similar increases with increasing carbonization temperature. Their SG values were high compared with barbecue grade charcoal, but close to that of activated charcoal. The true SG is probably related to the fixed carbon content which rises with temperature of carbonization.

### Specific surface area

Values for *P. radiata* fluidized bed charcoal dramatically decreased with the temperature of carbonization as shown in Table 3. Activated charcoal had a characteristically high specific surface area while barbecue charcoal was found to be similar to fluidized bed charcoal produced at 500-550°C.

### Pore size distribution

Both *P. radiata* and *E. regnans* showed a large volume of pores greater than 100 nm radius (Table 4). The total pore volume of barbecue charcoal was in the middle of the range of fluidized bed charcoal values while activated charcoal was significantly

higher. The latter showed a large volume of small pores of radii less than 50 nanometres which are mainly responsible for its high internal surface area.

Ash content

The ash content of charcoal depends on the species from which charcoal was derived, the presence of extraneous inorganic matter in the handling of the wood, and contamination during the carbonizing process and subsequent handling of the charcoal product.

Ash contents for the fluidized bed charcoal (Table 5) were uncharacteristically high for charcoal, particularly for that from P. radiata sawdust. Analysis of the ash in samples of sawdust showed that P. radiata had an ash content of 5.3%. This value was exceptionally high since reported ash contents for this species were heartwood: 0.28%, sapwood: 0.37% and bark: 1.21% (2,3). E. regnans sawdust showed an ash content of 0.52% which was also high since charcoal from this species (which could have an ash content of between 3-5 times higher than that of the wood) has been reported to be as low as 0.4% (4). The high ash contents of the fluidized bed charcoal was most likely due to contamination of the sawdust at the sawmill by extraneous material. A smaller degree of contamination could occur in the carbonization process by bed material.

The general increase in ash content with increasing temperature of carbonization was probably due to the lower yield of charcoal at the higher temperature due to combustion.

X-ray diffraction analyses

All of the charcoals examined exhibited an X-ray pattern with a broad peak corresponding to a d-spacing at 0.36 nm spread over the range 0.29-0.54 nm. This indicates that wood charcoal is not entirely amorphous but has some "ordering" corresponding to a poorly crystalline structure. The X-ray analyses also showed the presence of impurities in the fluidized bed charcoal with silica being the main contaminant. The presence of ilmenite which obviously came from the bed, was detected in two fluidized bed charcoal samples. These were E. regnans charcoals produced at 500 and 600°C.

## CONCLUSIONS

Wood charcoal was found to possess a poorly crystalline structure and is not entirely amorphous as normally stated in the literature.

This work has enabled the characteristics of fluidized bed charcoal to be defined.

The true specific gravities of the fluidized bed charcoal were higher than for barbecue charcoal but similar in magnitude to that of the activated charcoal. The effect of increasing carbonizing temperature from 500-600°C was to increase the true SG of charcoal from both E. regnans and P. radiata sawdusts but to reduce their specific surface areas. The proportion of fines increased with increasing carbonizing due to a greater degree of combustion of the charcoal, causing corresponding increases in bulk density. The pore size of fluidized bed charcoal was biased towards the larger end of the range in contrast to activated charcoal with a preponderance of small pores and the largest pore volume.

## ACKNOWLEDGEMENT

The authors wish to thank Mr J. Beretka of the Division of Building Research for his most helpful discussions and comments.

## REFERENCES

1. Beretka, J. and Brown, T. (1976). Properties and pozzolanic behaviour of Australian fly ash. Aust. Ceramic Soc. J. 12(1), 13-19.

2. Humphreys, F.R. and Ironside, G.E. (1977). Charcoal from N.S.W. species of timber. For. Com. N.S.W. Tech. Paper No. 23.

3. Lambert, M.J. and Cramsie, M.M. (1977). Inorganic constituents in wood and bark of some N.S.W. forest species. For. Com. N.S.W. Tech. Pap. 31.

4. Moore, D. (1940). The ash content of charcoal for use in producer gas vehicles. Qld. Dept of For. Proj. No. Q.U.18-2-1E.

TABLE 1

Particle size distribution of fluidized bed charcoal

| Particle size (microns) | % by weight in various size ranges | | | | | |
|---|---|---|---|---|---|---|
| | *P. radiata* charcoal | | | *E. regnans* charcoal | | |
| | 500°C | 550°C | 600°C | 500°C | 550°C | 600°C |
| <45 | 3.3 | 7.7 | 31.1 | 6.8 | 27.3 | 45.0 |
| 45- 53 | 2.0 | 6.0 | 7.1 | 2.1 | 8.5 | 9.5 |
| 53- 66 | 1.0 | 2.9 | 8.1 | 12.6 | 8.0 | 9.1 |
| 66- 76 | 2.3 | 4.7 | 8.7 | 10.2 | 9.6 | 10.3 |
| 76- 89 | 3.4 | 5.9 | 8.1 | 6.1 | 10.3 | 8.9 |
| 89-152 | 8.1 | 10.4 | 9.5 | 12.1 | 13.5 | 8.5 |
| 152-300 | 37.8 | 33.9 | 13.8 | 21.6 | 16.7 | 6.8 |
| 300-599 | 37.9 | 23.7 | 9.4 | 26.7 | 5.6 | 1.8 |
| >599 | 4.2 | 4.8 | 4.0 | 1.9 | 0.5 | 0.1 |

TABLE 2

Bulk density and true specific gravity of various charcoals

| Charcoal | Production temp. (°C) | Bulk density (kg/m³) | True specific gravity |
|---|---|---|---|
| *P. radiata* | 500 | 139 | 2.01 |
| | 550 | 135 | 2.11 |
| | 600 | 227 | 2.12 |
| *E. regnans* | 500 | 132 | 2.00 |
| | 550 | 227 | 2.05 |
| | 600 | 294 | 2.12 |
| Activated | - | - | 2.14 |
| Barbecue | - | - | 1.71 |

TABLE 3

Specific surface areas of various charcoals

| Charcoal | *P. radiata* | | | Activated | Barbecue |
|---|---|---|---|---|---|
| | 500°C | 550°C | 600°C | | |
| Specific Surface Area ($m^2/g$) | 312 | 115 | 67 | 1522 | 207 |

TABLE 4

Pore size distribution of various charcoals

| Pore radius (nm) | Pore volumes (ml/g) | | | | | |
|---|---|---|---|---|---|---|
| | *P. radiata* charcoal | | *E. regnans* charcoal | | Activated charcoal | Barbecue charcoal |
| | 500°C | 600°C | 500°C | 600°C | | |
| <10 | 0 | 0 | 0.01 | 0 | 0.38 | 0.04 |
| 10- 50 | 0.02 | 0.05 | 0.03 | 0.03 | 0.26 | 0.15 |
| 50- 100 | 0.03 | 0.01 | 0.01 | 0.02 | 0.08 | 0.06 |
| 100- 500 | 0.18 | 0.06 | 0.12 | 0.11 | 0.21 | 0.13 |
| 500-1000 | 0.15 | 0.11 | 0.10 | 0.09 | 0.23 | 0.10 |
| 1000-2000 | 0.27 | 0.18 | 0.19 | 0.16 | 0.17 | 0.11 |
| >2000 | 0.37 | 0.12 | 0.20 | 0.10 | - | 0.12 |
| TOTAL | 1.02 | 0.53 | 0.66 | 0.51 | 1.33 | 0.71 |

TABLE 5

Ash contents of various charcoals

| Charcoal | *P. radiata* | | | *E. regnans* | | | Activated |
|---|---|---|---|---|---|---|---|
| | 500°C | 550°C | 600°C | 500°C | 550°C | 600°C | |
| Ash content (%) | 9.3 | 18.0 | 14.5 | 5.3 | 8.3 | 10.8 | 1.4 |

# PEAT MOSS ALTERNATIVES FROM PINE RESIDUES

H. Mamers and D.J. Menz

## SUMMARY

The explosion pulping technique, when applied to *P. radiata* wood waste, was found to give a range of open textured, fluffy materials having many of the characteristics of peat moss. The properties of individual products could be adjusted by suitable selection of treatment conditions and explosion digester discharge nozzle geometry.

## INTRODUCTION

The Australian mushroom growing industry uses some 60,000 bales of peat moss each year as a casing material. This peat moss is currently imported at a price of \$15-21 per $6ft^3$ ($0.17\ m^3$) bale. The main supplier is West Germany, followed by New Zealand.

The mushroom growers have recently expressed some concern over the future availability of peat moss at a price which the industry can afford. The present investigation was undertaken to examine the possibility of producing a satisfactory alternative to peat moss from locally available wood wastes.

## EXPERIMENTAL

The wood waste used in the investigation came from the debarking operations at a pine pole treatment plant. The waste as received contained approximately 30 wt% bark and 70 wt% wood. The layout of the laboratory pilot plant explosion digester system used to process the wood waste is shown schematically in Figure 1.

The explosion digester vessel had a working volume of 6 litres. The digester contents were heated by the direct injection of 1.7 MPa steam. The system was further pressurized to a maximum pressure of 13.8 MPa by the introduction of compressed nitrogen.

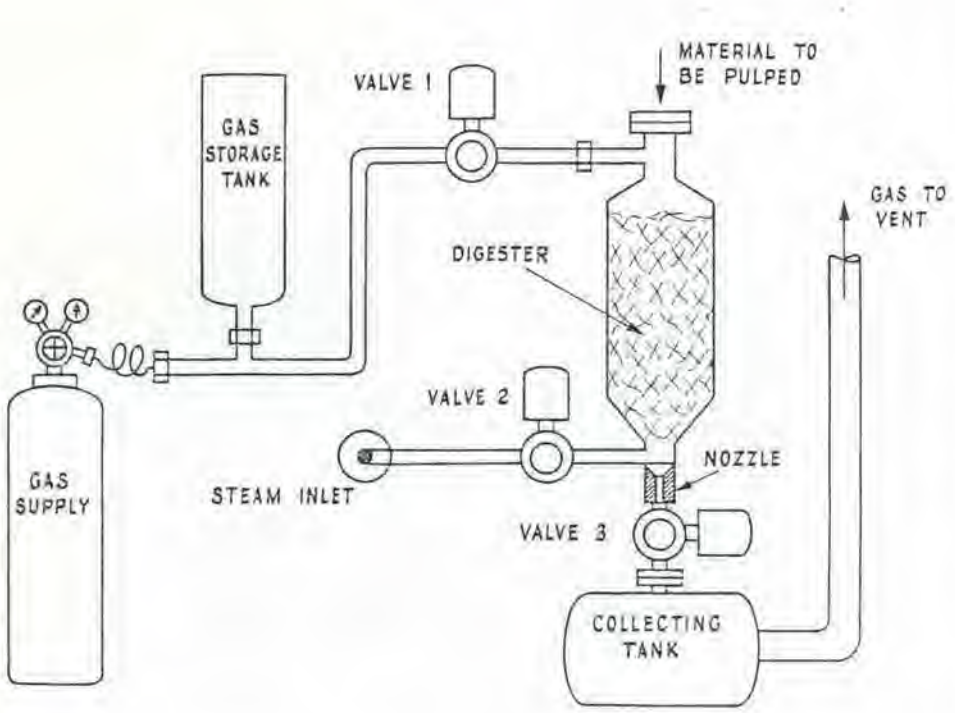



FIG. 1 Explosion digester system

The experimental variables examined in the work were:

1. Feed composition
2. Cooking temperature (186-200°C)
3. Applied digester pressure (8.3-13.8 MPa)
4. Cooking time (5-15 min)
5. Digester discharge nozzle configuration

The product from each cook was washed and weighed to determine the yield. The extent of disintegration was assessed by wet screening a sample of the washed product over a 0.25 mm slotted screen to define a Disintegration Efficiency (D.E.) as:

$$\frac{\text{Weight of screen undersize (dry basis)}}{\text{Weight of screen undersize and oversize (dry basis)}} \times 100$$

A product property of major significance to the mushroom growers was the "Dry Moisture Characteristic". This was the amount of moisture retained by the product at various levels of applied suction. The method used to measure the drying moisture characteristics has been previously described (1). To be consistent with other publications in the field, the applied suction was expressed in terms of pF units (= log (Applied suction measured in cm water) ) and the moisture content as grams water retained/100 grams dry solids (2).

## RESULTS AND DISCUSSION

Soluble metal ions, such as sodium, are known to adversely affect the growth of mushrooms (3). Consequently, the cooks in the present series were performed without the use of pulping reagents.

When the raw materials were processed at elevated temperature, some components of the furnish became water soluble and were eventually lost when the products were washed. The proportion of the furnish passing into solution became greater as the treatment conditions became more severe and hence the final yield of product decreased.

Partial solution of the feed materials made the solid residue progressively easier to disintegrate upon explosive release from the digester. Taken overall, the extent of disintegration generally increased as the product yield diminished (Figure 2).

At a given yield, the extent of disintegration was affected by:

(a) Temperature

Cooks exploded from 200°C defibrated more readily than cooks exploded from 186°C.

(b) Applied digester pressure

Increasing the digester pressure gave increased fibre release.

(c) Discharge nozzle configuration

The use of bar nozzles (described in Reference 4) promoted a more complete breakdown of the discharging furnish.

(d) Furnish type

Separate samples of bark and wood were obtained by hand sorting the original feed material. Under given processing conditions, the bark disintegrated more readily than the wood fraction.

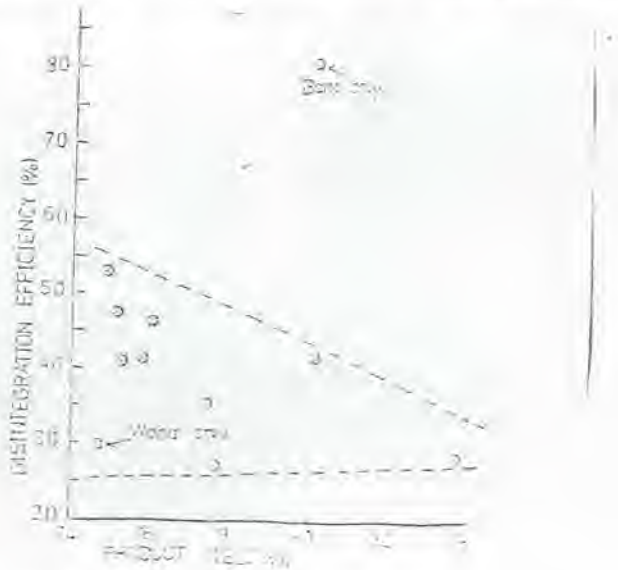



FIG. 2 Product disintegration

A requirement of casing material is to maintain an open structure during the mushroom cropping period of some 6 weeks. On this basis, the product should not contain an excess of free fibres which could mat together to form an impermeable layer. The product having the most suitable texture for a casing material was judged to be a sample obtained at 75% yield and 40% disintegration efficiency. This corresponded to a 10 min cook at 200°C under 8.3 MPa applied digester with the charge being exploded through an 8 bar discharge nozzle.

Figure 3 compares the range of drying moisture characteristics of the present products with those of New Zealand and German peat moss. At pF(0), the moisture retention of the present products was intermediate to that of the two natural peat mosses. However, on the application of suction, the drying moisture curves of the exploded wood wastes resembled the New Zealand moss more closely than the German moss.

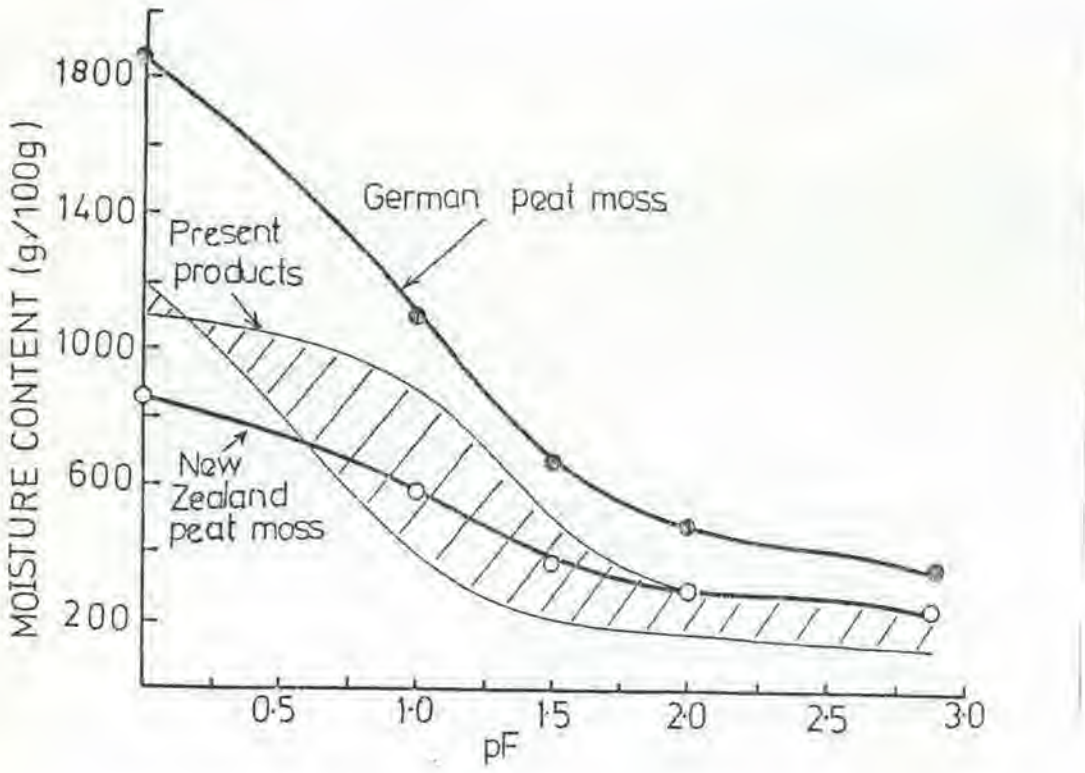



Fig. 3 Drying moisture characteristics of exploded wood wastes and natural peat mosses.

Exploded wood waste samples from the present investigation were further tested in mushroom growing trials by Dr N.G. Miar at the N.S.W. Department of Agriculture. The results were satisfactory except for those materials con-

taining a high proportion of disintegrated bark. The bark inhibited growth rates and should therefore be excluded from the feed material as far as possible.

Preliminary economic studies indicated that a plant producing 100,000 bales/annum of exploded wood waste would repay the initial capital investment in 9 to 12 months if the selling price of the product was $15 per bale.

## CONCLUSION

Explosion treatment of pine wood wastes can be used to obtain fluffy, open textured products which satisfactorily substitite for peat moss as a casing material in the cultivation of mushrooms.

## REFERENCES

(1) Mamers, H., Menz, D.J.
"Explosion treatment of pine wood wastes for the production of mushroom casing materials", Proceedings of the Eleventh Scientific Congress on the Cultivation of Edible Fungi, 13-19th August, 1981, Sydney (In Press).

(2) Griffin, D.M.
Trans. Brit. Mycol. Soc., 46, 273-80 (1963).

(3) Atkins, F.C.
"Guide to Mushroom Growing", Page 59, (Faber and Faber, London, 1974).

(4) Mamers, H., Rowney, J.E.
U.S. Pat. 4,163,687 (Aug 7, 1979).

# RESOURCE EVALUATION BY SAWMILL STUDIES OF QUEENSLAND-GROWN EXOTIC PINES

D.K. Gough and D.G. Hiley
Division of Technical Services
Queensland Department of Forestry
Brisbane

## ABSTRACT

Sawing studies carried out in Queensland in 1980/81 to determine graded sawn recovery data for *Pinus caribaea* var. *hondurensis* showed that recoveries were comparable with those obtained for slash and hoop pine. Pruning gave greater recoveries than O.T.S. stems as well as a higher valued product. As a result of mechanical strength testing of material produced during the studies, the strength group of *P. caribaea* var. *hondurensis* was upgraded one classification to SD6, equivalent to radiata and loblolly pines. Techniques for drying both boards and framing sizes were also developed.

Similar recovery studies carried out on high altitude, inland slash and loblolly pine showed recoveries similar to those obtained for these species on the coast. Heart shake and resin streak did cause some loss in recovery in the lower diameter breast height (d.b.h.) classes and also a drop in board grade. Pruning was effective in reducing the amount of degrade caused by these defects, giving a greater recovery in the production of boards and framing and in producing a higher valued product.

## INTRODUCTION

Sawmill studies were used to determine in the case of Caribbean pine, graded sawn recovery data for the anticipated resource of *P. caribaea* var. *hondurensis* and to investigate the seasoning and mechanical strength properties of this material.

For high altitude, inland slash and loblolly pine material the aim was to determine the affect on recovery of heart shake and resin streak in slash pine and bark encased knots in loblolly pine.

EXPERIMENTAL PROCEDURE

CARIBBEAN PINE MATERIAL

A total of 60 stems of Caribbean pine varying in d.b.h. from 23.5 cm to 42.5 cm was thinned from a 25 year old basal area plot (Exp. 67 Bowenia) Cpts. 18 and 20 Stringybark, State Forest 20 Maryvale, Rockhampton District. Logs were processed at our Salisbury mill and the products graded into batches based on d.b.h. class and classification into select (i.e. pruned) or other than select (O.T.S.) (i.e. unpruned) stems. Framing sizes after seasoning were both visually and mechanically stress graded to obtain comparisons of both methods.

Results

1. Recoveries obtained in this study were comparable with those obtained for studies on slash pine and hoop pine. (Figure 1).
2. Recoveries from select stems were higher than those obtained from O.T.S. stems and stems cut to framing sizes gave higher recoveries than those cut to boards. (Figure 1).
3. Pruning gave a higher proportion of material represented in the top grades for both framing and board production. (Figure 2).

   Fig. 2 was prepared from the average distribution of grades from all logs sawn in the study irrespective of d.b.h.
4. Figure 2 shows the difference in grade distribution from stress grading the framing sizes both visually and mechanically. For F8 and better, mechanical stress grading increased the percentage by volume of framing from 26 per cent when visually graded to 40 per cent.
5. Using material from this and other studies, Caribbean pine was upgraded from strength group SD7 to SD6 which is the same as for radiata pine and loblolly pine.

Seasoning

Boards produced during the study were air dried to 25-30 per cent moisture content then dried in the solar kiln. Concrete blocks were used to weight the stacks, a procedure used for all plantation grown pines. The amount of degrade due to drying distortion was virtually nil.

Framing sizes were 'high temperature dried' under our recognised procedure for drying slash pine framing sizes. Kiln conditions of 120°C dry bulb and 70°C wet bulb were used. Air flow through the stacks was measured at about 5 metres per second. Stacks were weighted with concrete blocks but were not reverse twisted. Results were extremely good and none of the timber was rejected due

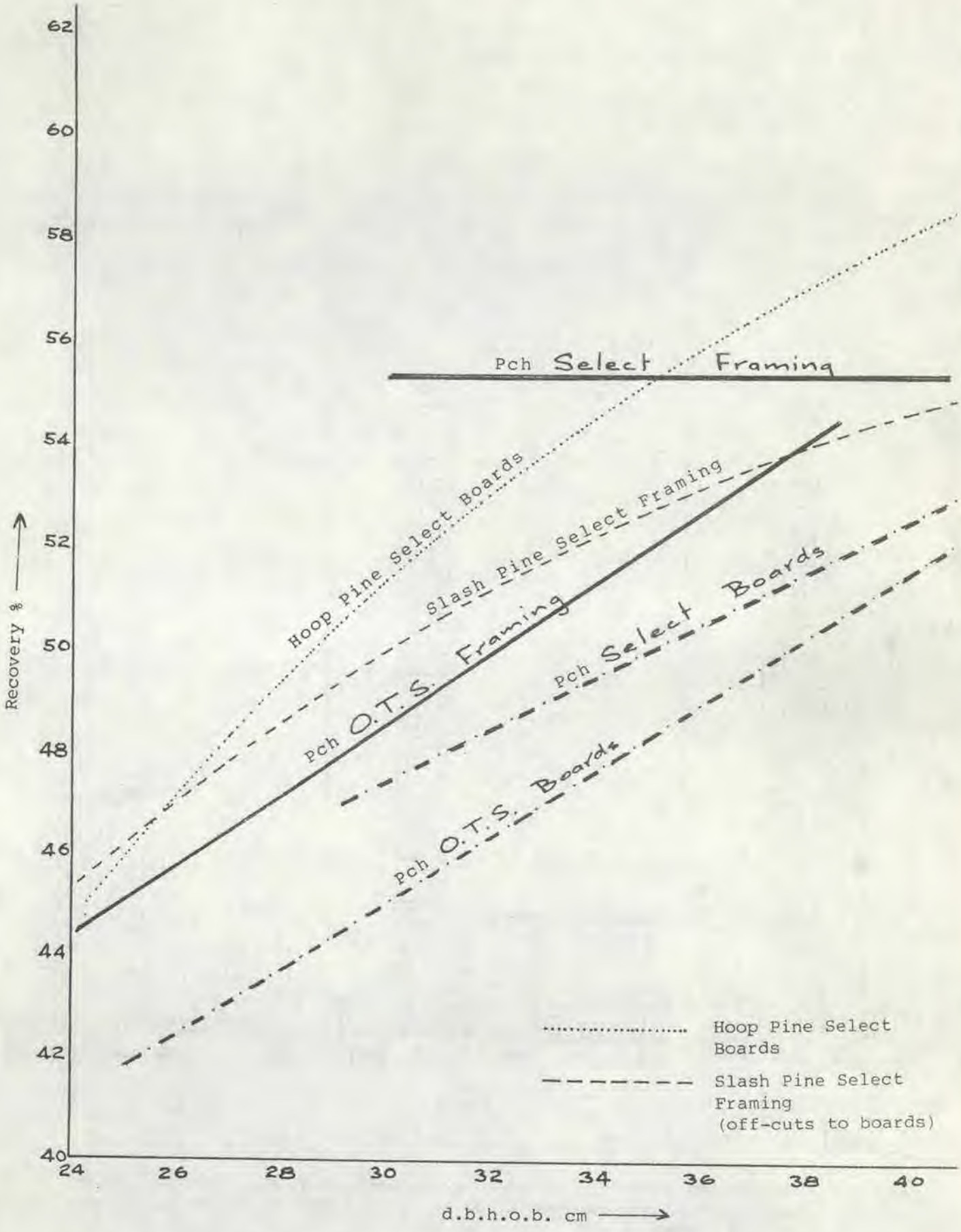



Figure 1. Percentage recovery plotted against d.b.h.o.b.

Pch = Caribbean Pine

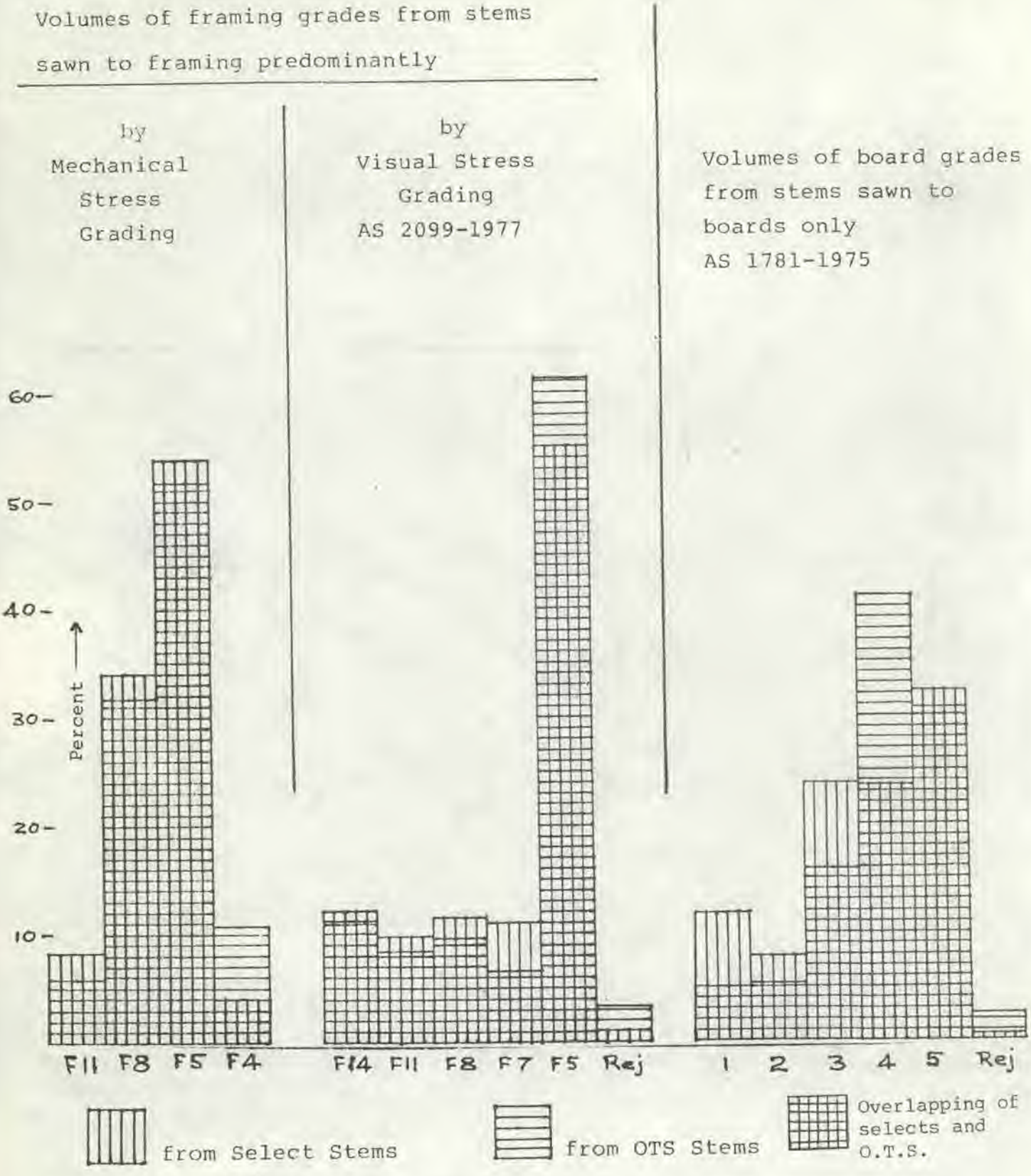



Figure 2. Histograms comparing volumes of the various grades (expressed as percentages) obtained from the select and OTS Caribbean pine stems sawn in the study.

to drying distortion. High temperature drying under positive restraint must therefore be recommended to achieve satisfactory results in drying framing sizes of Caribbean pine.

SLASH PINE MATERIAL

A total of 150 stems of final crop slash pine and 50 stems of loblolly pine (some of the slash pine being pruned) ranging in d.b.h. from 30.0 to 65.8 cm was thinned from compartments at Passchendaele in Warwick District. Logs were processed at a local mill after being classified into eight batches on species, d.b.h. class and select or O.T.S. classification.

Results

1. Recoveries for board production obtained in this study were comparable with those obtained for coastal slash pine of equivalent predominant height class. (Table 1)

TABLE 1

Percentage recoveries from slash pine board production - coast and inland

| Area Inland | Percentage Recovery (gross vol) Board Production | | Area Coast |
|---|---|---|---|
| Passchendaele (pruned) (1970)† | 45.7% P. Ht.‡ = 20 m | 49.6% P. Ht. = 24.4 m | Beerburrum (pruned) (1970) |
| Passchendaele (unpruned) (1970) | 48.9% P. Ht. = 21.9 m | 50.3% P. Ht. - 24.4 m | Beerburrum (unpruned) (1970) |
| Passchendaele (unpruned) (1980) | 44.2% P. Ht. = 21.9 m | 40.3% + seasoning loss 43.3% P. Ht. = 25.8 m | Toolara (mixed) (1975) |
| Passchendaele (pruned) (1980) | 47.5% P. Ht. = 21.9 m | 41% + seasoning loss 44% P. Ht. = 21.9 m | Tuan (mixed) (1975) |

† Year in which study carried out

‡ Predominant Height, mean height of tallest 50 stems/ha

2. Resin streak and heart shake in slash pine and bark encased knots in loblolly have had no detected major effect on higher diameter class or total sample recovery. In the lower diameter classes however these defects were the major causes of losses in recovery.

3. There was a reduction in board quality of 1-2 grades in slash pine compared with coastal material because of larger and more numerous knots and associated defects (including pitch streaks) i.e. from Table 2 the high percentage of boards in grade 5 batches 1, 3 and 7 (64.8 per cent) is in direct contrast to a study for slash pine ex Tuan and Toolara which showed the higher percentage of boards to be classified into grades 3 (55 per cent) and 4 (25 per cent).

4. Pruning was found to improve both the recovery and quality of both framing and boards i.e. Table 2 shows the following:-

   (a) There was a larger proportion of grade 1 boards and F17 framing in batches 5 and 6 (from pruned Compartment 16) than in the batches from the unpruned Compartments.

   (b) For the production of grades 1-2 boards pruned slash pine (batch 5) had more than twice the recovery of unpruned batches 1 and 3.

   (c) Pruning in slash pine (batches 5 and 6) apparently reduced the amount of reject material in boards and framing production (because of the reduction in knots and shakes) as compared with the unpruned slash pine batches.

   (d) The distribution in grades for boards and framing recovery for unpruned loblolly pine (batches 7 and 8) was similar to that from unpruned slash pine (batches 1-4).

5. There was found to be a greater recovery in sawing to framing (with offcuts to boards) than for sawing to boards only (Table 3).

TABLE 2

Distribution of the various grades of sawn timber from each batch at Passchendaele expressed as percentages of total sawn product

| Batch No. | Board Grades | | | | | | Framing Grades | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | Rej. | F17 | F14 | F11 | F8 | F7 | F5 | Rej. |
| 1 Slash Cpt. 2 | 4.6 | 3.2 | 4.9 | 14.9 | 65.8 | 6.6 | | | | | | | |
| 3 Slash Cpt. 11 | 5.4 | 2.6 | 4.3 | 11.6 | 65.2 | 10.9 | | | | | | | |
| *5 Slash Cpt. 16 | 14.3 | 5.4 | 8.0 | 20.9 | 50.0 | 1.4 | | | | | | | |
| 7 Loblolly Cpt. 10 | 4.0 | 2.4 | 5.8 | 13.8 | 63.3 | 10.7 | | | | | | | |
| 2 Slash Cpt. 2 | 1.6 | 0.8 | 2.4 | 4.0 | 6.6 | 0.9 | 4.2 | 5.5 | 13.0 | 10.6 | - | 50.1 | 0.3 |
| 4 Slash Cpt. 11 | 2.0 | 0.9 | 2.2 | 2.9 | 8.8 | 2.6 | 5.4 | 6.0 | 11.3 | 8.0 | - | 48.2 | 1.7 |
| *6 Slash Cpt. 16 | 6.4 | 0.6 | 2.1 | 2.4 | 4.6 | 0.7 | 7.1 | 3.9 | 10.3 | 9.9 | - | 49.6 | 2.4 |
| 8 Loblolly Cpt. 10 | 1.6 | 0.7 | 2.4 | 1.7 | 6.2 | 1.4 | 5.9 | 4.9 | 13.4 | 8.3 | - | 53.3 | 0.2 |

* Pruned Compartments

Percentage of volume recorded as boards obtained in the 'framing' batches were as follows:

No. 2 - 16.3%

4 - 19.4%

6 - 16.5%

8 - 14.0%

TABLE 3

Average recovery for each batch expressed as a percentage of gross log volume

| Batch number | Percentage recovery (gross volume) |
|---|---|
| 1 Slash | 44.1 |
| 2 Slash | 44.0 |
| * 5 Slash | 47.6 |
| 7 Loblolly | 44.8 |
| Average for logs cut to boards | 45.0 |
| 2 Slash | 51.2 |
| 4 Slash | 49.6 |
| * 6 Slash | 51.5 |
| 8 Loblolly | 47.6 |
| Average for logs cut to framing | 49.1 |

* Pruned compartments

REFERENCES

1. Gough, D.K. Pinus Caribaea Sawing Studies, Internal Report. Qld. Dept. of Forestry, December 1980.

2. Hiley, D.G. Final Crop Pinus Taeda Pinus Elliottii Sawing Studies Passchendaele. Internal Report Qld. Dept. of Forestry, June 1981.

# THE EFFECT OF SULPHITE TREATMENT ON VISCOSITY, ON GELATION AND BOND QUALITY OF *PINUS RADIATA* BARK EXTRACT

K.F. Plomley and P.J. Collins
Division of Building Research, CSIRO

## INTRODUCTION

Excessively high viscosity and low solubility can cause difficulties in the formulation of *Pinus radiata* bark extract and other tannin adhesives. Various methods are available for reducing the viscosity, one of the most effective being treatment with sodium sulphite.

Sulphite treatment has been used for many years for the production of more soluble forms of commercial quebracho extract for the leather industry. At the same time it was observed that solutions of these sulphited extracts were lower in viscosity than untreated extract (2). The sulphite treatment of radiata bark extract and other extracts with the aim of reducing viscosity to a level suitable for the preparation of adhesives was the subject of a paper by Dalton (1).

In the course of our work on the properties of radiata bark extract, variability in the results of adhesion tests raised the question of possible adverse effects of sulphite treatment. This report examines the effect of treatment with sodium metabisulphite on the viscosity of a hot (100°C) water extract of radiata butt bark, on gelation with paraformaldehyde and on adhesion.

## 1. THE EFFECT OF SULPHITE TREATMENT ON VISCOSITY

An aqueous solution containing 40% of extract solid was treated with 2.5, 5.0 and 7.5 percent of sodium metabisulphite at 80°C for up to 6 h. Samples were taken at intervals for viscosity determination.

The results (Figure 1) show that treatment with 5.0% sodium metabisulphite at 80°C for 2 to 6 h produced a viscosity suitable for adhesive formulation, i.e. 0.8 to 0.4 Pa.s. Increasing the sulphite concentration to 7.5% gave little further reduction in viscosity. A concentration of 2.5% was less effective than 5.0% and 7.5%.

The pH has a large effect on the viscosity of untreated extract, but the effect is modified considerably by the sulphite treatment. Figure 2 shows the viscosity of 35% solutions of untreated 60°C water extract and sulphited

100°C extract between pH 3.5 and 10. Untreated 60°C extract was used for comparison with sulphited 100°C extract because of difficulty in determining the viscosity of untreated 100°C extract. The viscosity measurements were made at 25°C on solutions which had been kept at room temperature for 1 h and 23 h after pH adjustment. Not only was the viscosity of the sulphited extract lower and relatively uniform over almost the whole pH range, but also there was little or no increase in viscosity between 1 h and 23 h. This is in contrast with the untreated extract which showed a marked peak at about pH 7 and also a significant increase in viscosity at 23 h.

## 2. THE EFFECT OF SULPHITE TREATMENT ON GELATION WITH PARAFORMALDEHYDE

Important effects of sulphite treatment were an increase in gelation time and in the proportion of paraformaldehyde required for gelation. Although the gelation times for the 60°C extract and the untreated 100°C extract were the same between pH 3.5 and 7, the gelation time for the sulphited extract at pH 4 was 3 to 4 times longer. This difference was not eliminated by increasing the proportion of paraformaldehyde (Figure 3).

## 3. THE EFFECT OF SULPHITE TREATMENT ON ADHESION

Under certain conditions differences were observed in the bond quality of untreated and sulphited extracts. Adhesion tests were conducted with 100°C extract treated with 2.5, 5.0 and 7.5% of sodium metabisulphite at 80°C for up to 6 h using coachwood veneers at 12% moisture content. With this species there was a large decrease in wood failure at the highest (7.5%) sulphite concentration and longest heating time (6 h). The decrease in wood failure was limited to the shortest assembly time (30 min) i.e. highest glue line moisture content. Wood failure was high for 60 min and 120 min assmebly times (Table 1).

In tests with tulip oak veneers at 12% mc there was a decrease in bond quality under less severe treatment conditions, i.e. 5% sulphite at 80°C for 5 h. In this case also the decrease was limited to the 30 min assembly time and at the longer assembly times the bond quality was equal to that of untreated extract.

TABLE 1

Bond Quality of Sulphite Treated
100°C Extract with Coachwood Veneers

| Sodium meta-bisulphite (%) | Assembly time (min) | Bond Quality* Duration of sulphite treatment (h) 2 | 6 |
|---|---|---|---|
| 2.5 | 30 | 3.05-96+ | 2.94-84 |
| | 60 | 2.92-96 | 3.14-89 |
| | 120 | 3.23-95 | 3.26-82 |
| 5.0 | 30 | 2.42-99 | 2.35-84 |
| | 60 | 2.48-93 | 2.69-97 |
| | 120 | 2.18-100 | 2.70-96 |
| 7.5 | 30 | 2.42-100 | 2.66-17 |
| | 60 | 2.58-92 | 2.60-100 |
| | 120 | 2.76-95 | 2.73-89 |
| Untreated 60°C extract | 30 | 2.84-97 | |
| | 60 | 3.25-85 | |
| | 120 | 2.58-99 | |

* Tested wet after 72 h in boiling water.
\+ Failing stress (MPa) and wood failure (%).

## CONCLUSIONS

In addition to reducing the viscosity of radiata bark extract to a uniformly low value suitable for adhesives, sulphite has a stabilizing effect and delays the increase in viscosity which occurs in solutions of untreated extracts even at room temperature.

The longer gelation time for sulphite treated extract probably results at least in part from the splitting of polyphenol molecules. This is supported by the associated increased formaldehyde requirement.

The adverse effect on bond quality, which occurred under different sulphite treatment conditions for the two veneer species used in the experiments, is shown only at high glue line moisture conditions and is apparently the result of the increased solubility and lower viscosity of the treated extract. The high bond quality obtained at longer assembly times indicates that resistance to hydrolysis in boiling water is not impaired to any significant extent.

REFERENCES

1. Dalton, L.K. (1953). Resins from sulphited tannins as adhesives for wood. Aust. J. Appl. Sci. 4, 136-145.

2. Mezey, Ernesto (1947). El quebracho colorado y su extracto tanico. Buenos Aires, Editorial Labor.

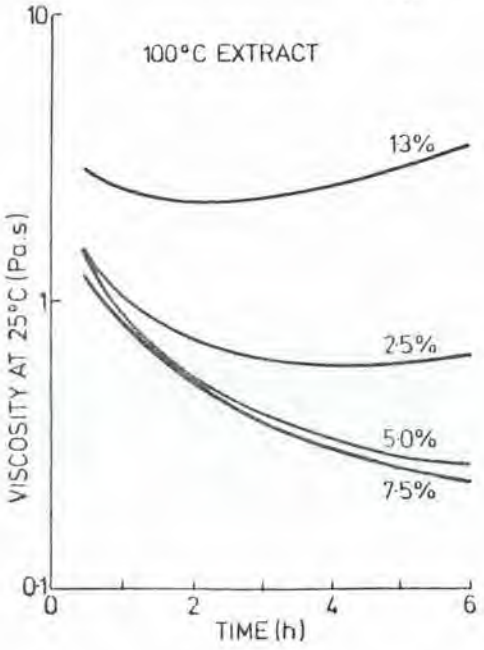



FIG. 1. Effect on viscosity of concentration of sodium metabisulphite and duration of treatment at 80°C.

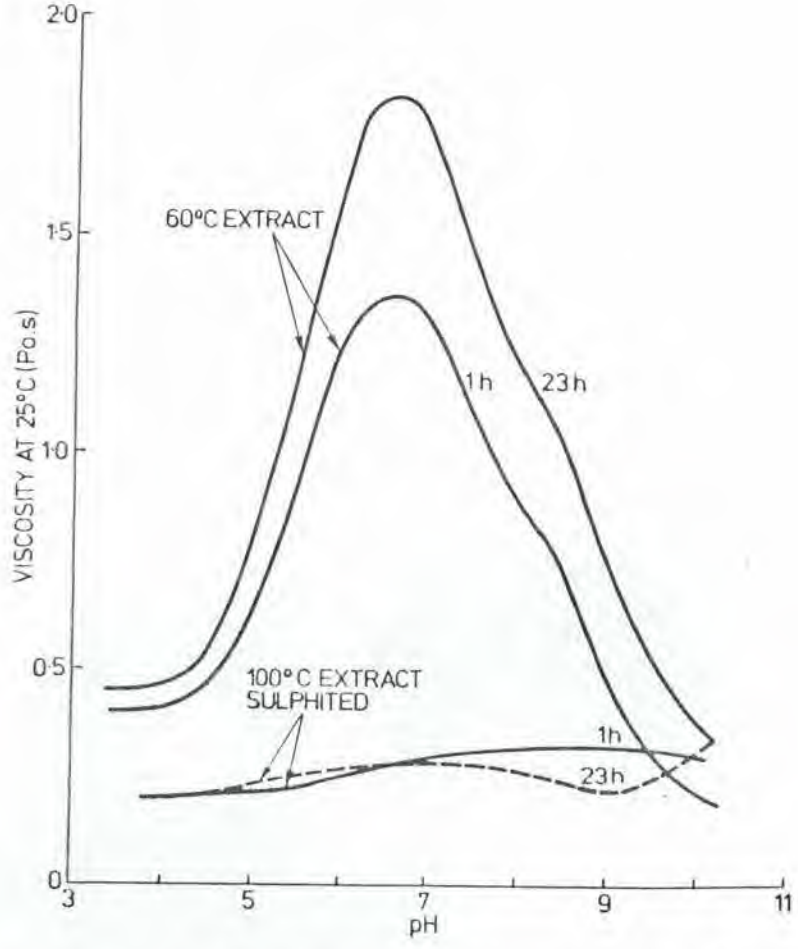



FIG. 2. Effect of pH on viscosity of untreated 60°C extract and sulphited 100°C extract.

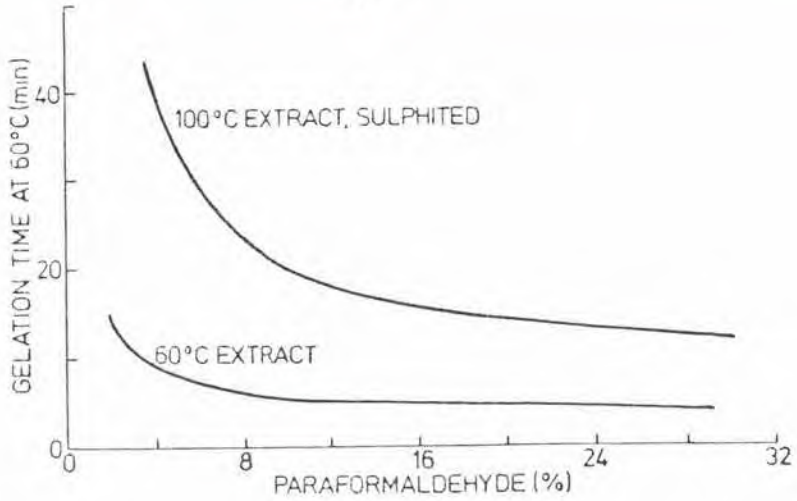



FIG. 3. Effect of sulphite treatment on gelation.

# COLD SETTING ADHESIVES BASED ON MIXTURES OF WATTLE TANNIN WITH A COMMERCIAL PHENOL-RESORCINOL-FORMALDEHYDE ADHESIVE

K.F. Plomley and P.J. Collins
Division of Building Research, CSIRO

## INTRODUCTION

With the present (1981) price differential between resorcinol and other wood adhesive raw materials, there is potentially a large saving in glue cost to be made by the partial replacement of resorcinol. Commercial resin adhesives are available which incorporate a proportion of cheaper phenol (phenol-resorcinol-formaldehyde or PRF resin adhesives), but the extent to which this substitution is possible is limited by its effect on low temperature curing; 50% replacement is usually the maximum for cold (ambient temperature) setting adhesives.

Some tannins, such as wattle and *Pinus radiata* bark extracts, form gels with paraformaldehyde at ambient temperatures. At the same pH wattle tannin gels a little more slowly than resorcinol-formaldehyde (RF) resin adhesives and more rapidly than PRF adhesives. Although the adhesion of wattle tannin alone is not adequate at this temperature, wattle tannin has potential for incorporation with resorcinol resins. The cost of wattle tannin is now about 13% of the cost of RF resin on a dry solid weight basis, and about 20% of the cost of PRF resin. A significant cost reduction could accrue if a substantial amount of the tannin could be incorporated in a PRF resin without harmful effect on its properties

Studies of the adhesive properties of some commercial RF and PRF adhesives (1) have shown that a large improvement in bond quality results from an increase in the air temperature at curing from 20°C to 60°C.

This paper reports results of adhesion tests with mixtures of a commercial PRF resin adhesive and wattle tannin with medium and relatively high density wood species. The effect of increasing the air temperature at curing from 20°C to 40°C has been studied also.

## THE BONDING EFFICIENCY OF MIXTURES OF A COMMERCIAL PRF RESIN WITH WATTLE TANNIN WHEN CURED AT 20°C

The experimental adhesives were tested according to Australian Standard 1321.3-1976, Bond Strength of Cured Wood-to-Wood Adhesives in Shear, Clause 2.1.2.

Two-ply assemblies of veneers of coachwood (a medium density wood species) blush tulip oak, and silvertop ash (two relatively high density wood species) were spread with adhesives based on mixtures of a commercial PRF resin adhesive with 25%, 50% and 75% of wattle tannin on a dry solid weight basis, with PRF resin adhesive alone and with wattle tannin adhesives alone for comparison. The assemblies were pressed at 20°C air temperature.

Tensile shear specimens from the panels were tested dry and wet after soaking in cold water for 24 h. Tests were also made on wet specimens after immersion in boiling water for 72 h. The testing of specimens after soaking in cold water gives an indication of the degree of cure of the adhesive, and this test is especially valuable in the case of structural adhesives. Typically, cured phenol- and resorcinol-formaldehyde resins are resistant to the boiling water treatment, whereas other less durable resins deteriorate.

The wood failures and failure stresses for coachwood specimens bonded with different percentages of wattle tannin are shown in Figures 1A and 1B. Mixtures of PRF resin adhesive with up to 50% of wattle tannin gave bond qualities equivalent to those for the PRF resin adhesive alone. For the adhesive containing 75% of wattle tannin (Figure 1B) the somewhat lower wood failure in the dry test suggests that the concentration of wattle tannin was critically high.

In dry and wet tests of blush tulip oak and silvertop ash specimens (not reported here), mixtures of PRF adhesive with up to 50% of tannin gave bond qualities equivalent to PRF adhesive alone. As with coachwood, the wet tests indicated that cure was adequate and that those adhesive mixtures were not more susceptible to hydrolysis by boiling water than was the PRF resin.

At 50% PRF resin and 50% tannin the mixture contained about 25% of resorcinol-formaldehyde on a dry solid weight basis.

THE INFLUENCE OF CURING TEMPERATURE ON BOND QUALITY

Two-ply coachwood panels prepared as above were pressed at air temperatures of 20°C and 40°C. Tensile shear specimens cut from the panels were tested dry and wet after 24 h in cold water.

The results for specimens tested wet (Figures 2A and 2B) show that increasing the curing temperature from 20°C to 40°C resulted in a marked increase in wood failure. When cured at 40°C bond qualities equal to those for the PRF adhesive control were obtained at tannin concentrations up to 75% and PRF resin as low as 25%. This contrasted with a maximum concentration of 50% tannin for acceptable bond quality when cured at 20°C.

The dry tests showed the same trend.

## CONCLUSIONS

When cured at 20°C, adhesives based on mixtures of a commercial PRF resin adhesive with up to 50% of wattle tannin on a dry solid weight basis produced bonds equivalent to those made with PRF resin alone with medium density and relatively high density wood species.

By increasing the curing temperature from 20°C to 40°C the bond quality with coachwood was improved considerably, and bond quality equal to that for the PRF resin alone was obtained with an adhesive consisting of 25% PRF resin and 75% of wattle tannin.

The results indicate that large savings in the use of imported resorcinol and adhesive cost can be achieved without decrease in bond quality. The adhesive mixtures can be prepared by the user, which enables the maximum cost advantage to be obtained.

## REFERENCE

1. Plomley, K.F. (1980). Studies by CSIRO on the adhesive bonding of high density wood species. CSIRO Division of Building Research Report.

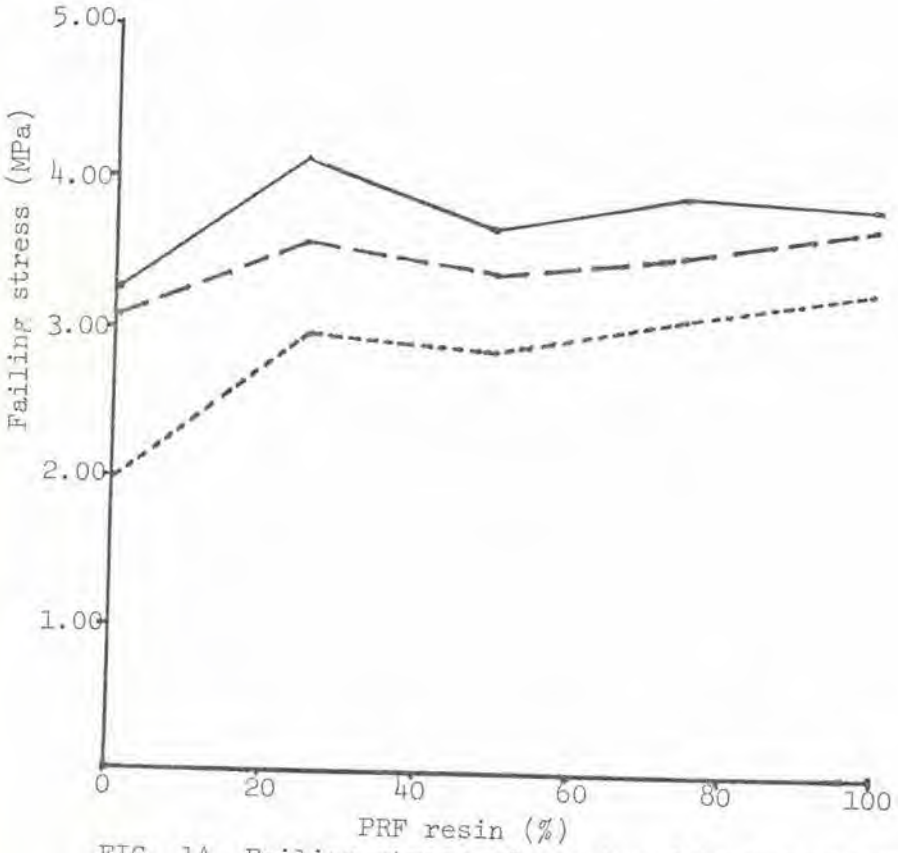



FIG. 1A. Failing stress of coachwood test specimens bonded at 20°C:
Dry test ————
24 h cold soak — — — —
72 h boil ---------

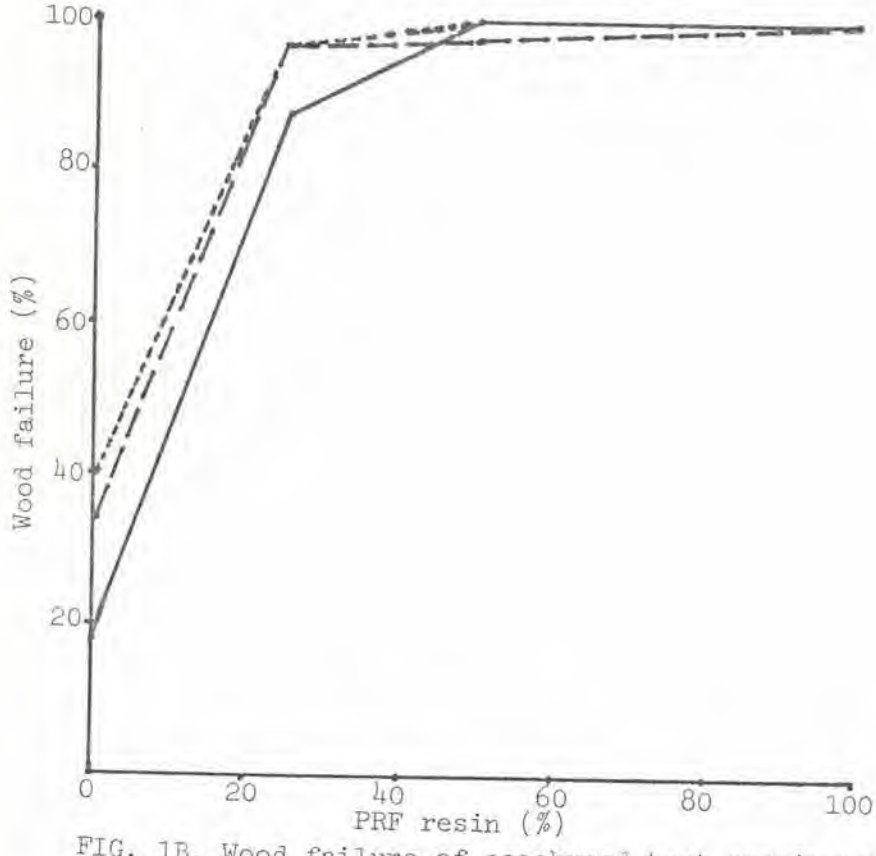



FIG. 1B. Wood failure of coachwood test specimens bonded at 20°C:
Dry test ————
24 h cold soak — — — —
72 h boil ---------

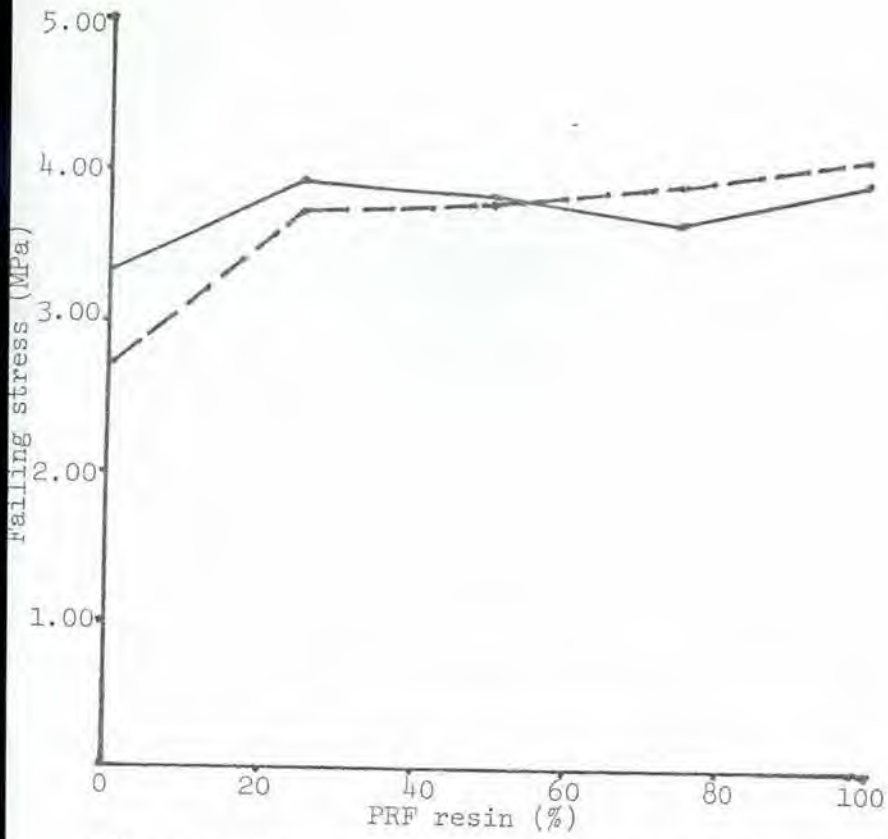



FIG. 2A. Failing stress of coachwood specimens tested wet after 24 h in cold water.
Air temperature at curing 20°C. — — — — —
Air temperature at curing 40°C. ————————

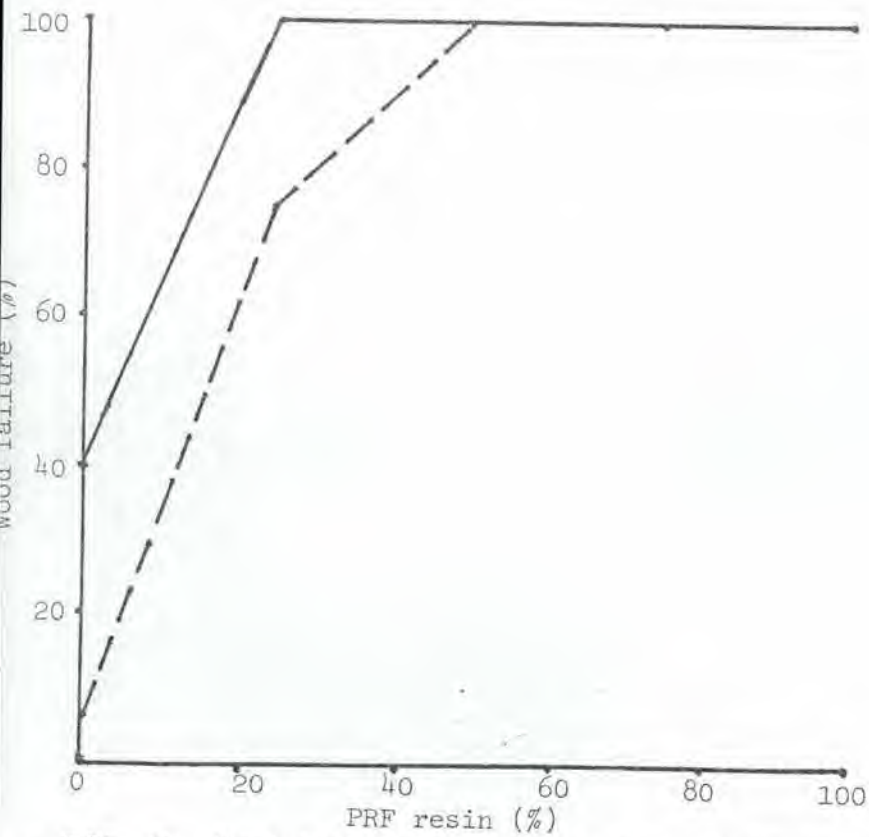



FIG. 2B. Wood failure of coachwood specimens tested wet after 24 h in cold water.
Air temperature at curing 20°C. — — — — —
Air temperature at curing 40°C. ————————

# RESPONSE OF MELAMINE-BONDED PARTICLEBOARD FLOORING TO HUMIDITY CYCLING

G.N. Christensen, Division of Building Research, CSIRO

## INTRODUCTION

Australian Standard 1859 - 1976 requires that Class I Flooring Grade particleboard be "manufactured with an adhesive that does not deteriorate in the presence of water". The Standard therefore includes the so-called "bond durability" test, in reality an adhesive hydrolysability test based on retention of bending strength after 72 hours in boiling water, and intended originally to discriminate against urea-formaldehyde adhesives in favour of phenolic and tannin adhesives which are known to be much more stable.

Cost increases have made phenolic adhesives less attractive to the particleboard makers, and one solution has been to use adhesives based on melamine which, although hydrolysable, are more resistant than urea resins, and then to improve board properties by other manufacturing techniques to the point where they are claimed to be able to pass the requirements of the bond durability test. What is not known is whether this 72 hour boil test on particleboard does in fact denote adequate in-service performance of particleboard floors over the lifetime of a building, or how well it correlates with other more realistic ageing tests.

## FIRST EXPERIMENT

In 1979, Palmer and Stashevski (1) reported results of humidity cycling tests on urea-, phenol- and tannin-bonded particleboard flooring in which an attempt was made to accelerate breakdown by mechanisms that were more likely to operate in normal use. Panels 500 by 300 mm were submitted to humidity cycles consisting of one week of 5% and one week of 17% emc conditions at 38 deg C for 65 complete cycles (2 ½ years), during which time their deterioration was monitored. The cycling test has been described in the Palmer and Stashevski report. The actual variation in moisture content was approximately 8%.

It was decided to test similar 500 by 300 mm panels from sheets of commercial melamine-bonded flooring under exactly the same conditions. Two sheets numbered 2 and 5 were chosen, 2 having been shown by previous tests to perform much better than 5 in the bond durability test. At the date of preparing the present paper, 50 cycles have been completed, and the results to this stage are presented below. Data after another 10 cycles should be available by the Conference date.

The changes in thickness, modulus of rupture (MOR), modulus of elasticity (MOE) and internal bond (IB) were measured at intervals during cycling and are shown in Figures 1 to 4 together with the trend lines for the results from the material tested earlier by Palmer and Stashevski. In both investigations scatter of results allows only major differences in performance to be recognised. Nevertheless some conclusions can be drawn.

In Figs 1-3, it is apparent that the response of the melamine board to cycling is somewhat inferior in swelling behaviour, MOR and IB to that of the tannin and phenolic boards, but considerably better than that of any of the urea boards. In the present test, the fourth property of the melamine board affected by cycling was the MOE (Fig 4) which deteriorated a little more than either MOR or IB. Comparable results for this property were not available for the phenolic and tannin boards tested earlier. The second observation is that melamine sheet 5 performed consistently worse than sheet 2, and this is in agreement with the results of the 72 hour boil test.

## SECOND EXPERIMENT

In an attempt to obtain more information and to accelerate still further the breakdown due to humidity cycling, smaller specimens, 40 by 40 mm as used for the internal bond (IB) test, were prepared and exposed to 48 hour cycles of humidity between 5 and 17% emc except that over weekends samples were held at high and low humidity alternately. Specimens were removed and tested after every ten cycles (= 4 weeks), the testing being confined of necessity to measurements of the increase in thickness and decrease in internal bond. At the same time, one group of specimens was exposed without cycling, first at 17% and then at 5% emc conditions, for periods equivalent to the cumulative exposure of the cycles specimens to each of these same conditions, namely 10 weeks. In all cases the specimens were brought back to 12% emc before testing. The experiment was stopped after 50 cycles.

For this small specimen exposure test, 6 sheets of commercial melamine-based flooring were used, all of which had been previously tested for bond durability (72 hour boil test). The 6 sheets included the two used in the first part of the experiment described above. Specimens from a sheet of commercial phenolic-bonded flooring were also included for comparison.

Figure 5 shows the progressive increase in thickness over the 50 cycles measured at the centre of the 40 by 40 mm face. There is good agreement between the results for the two sheets, namely 2 and 5, that were tested by both methods, the thickness increases reaching values of 1 and 2% respectively in both experiments. It is also of interest to compare the final swelling during the exposure test with the swelling following the 72 hour boil (unpublished results). Figure 6 shows that there was a fairly good correlation between the two swelling measurements.

The other property followed during the small specimen cycling was the internal bond, and its decline is shown in Fig. 7 for all 6 melamine-based sheets and the phenolic board. Some erratic results at 30 cycles tend to reduce the significance of the trends. Otherwise the ranking of the 7 sheets was fairly consistent, with numbers 1 and 5 behaving poorly throughout.

When the I.B. results at the end of 50 cycles are plotted against the residual MOR values after 72 hours boiling (unpublished results) for the 6 melamine boards (Fig. 8), an apparent linear relationship is spoilt by two results. Thus, in at least some sheets, these two properties are responding differently to the 72 hour boiling on the one hand and humidity cycling on the other. This is probably to be expected to some extent as the IB test is a measure of bond breakdown in the core, whereas the change in MOR after boiling reflects more strongly changes in the surface layers. The quality of these two layers may be varied independently of each other during manufacture and may respond differently to the different exposure hazards, namely boiling and humidity cycling.

The specimens that were exposed to the limiting emc conditions for the duration of 50 cycles but without cycling were all from sheet 5, namely one of the two sheets that were expected to behave poorly. The mean thickness increase of 1.57% (Fig. 5) was the same as the value for the cycled specimens from the same sheet after 40 cycles, so that cycling appears to have had only a marginal additional effect on swelling compared with steady exposure. It is assumed that it was the exposure to 17% emc conditions (at 38 deg. C) that caused most of the change. On the other hand, as may be

seen in Fig. 7, the final decrease in IB by the uncycled specimens to 77% was already exceeded in the cycled specimens by the time they had completed 10 cycles, the initial decline in the IB of the two poor sheets being very rapid. Thereafter it was much slower, dropping to 60% after 50 cycles but still continuing.

The difference in response shown by the thickness increase on the one hand and IB decline on the other is again probably explained by the layering of the particleboard, the IB decline reflecting damage to the core only, whereas the thickness increase occurs in both core and surface layers. It is probable that the changes in the melamine boards are due mainly to the hot humid conditions accelerating hydrolysis, this process being aggravated by the internal stresses generated cyclicly by the uneven swelling and shrinking of adjacent wood particles.

Another comparison is possible from the results in Fig. 3 in which it can be seen that despite the shortening of the cycles for the small specimens from 2 weeks to 2 days, their rate of decline was faster than for the larger specimens. It appears that any effect of greater cumulative exposure in the longer cycles was more than compensated by retardation of transfer of water to and from the core of the larger specimens.

## CONCLUSIONS

In conclusion, it seems likely that MOE and MOR would be the properties most rapidly affected by humidity cycling, these properties being highly dependent on the surface layers of the boards. Whether these properties would respond to cycles of less than two weeks now needs to be determined. The IB test is probably a less useful indicator, depending as it does on the behaviour of the core. In small specimens, the thickness is the only other property easily measured. In these tests the swelling after cycling correlated well with the swelling after 72 hours boiling, but the correlation with MOE and MOR was not determined.

## ACKNOWLEDGEMENT

The author wishes to acknowledge assistance with the experimental work by Mrs M. Morehouse.

## REFERENCE

(1) Palmer, R.E. and Stashevski, A.M. (1979). "The Effect of Humidity Cycling on Commercial Particleboards", CSIRO Division of Building Research.

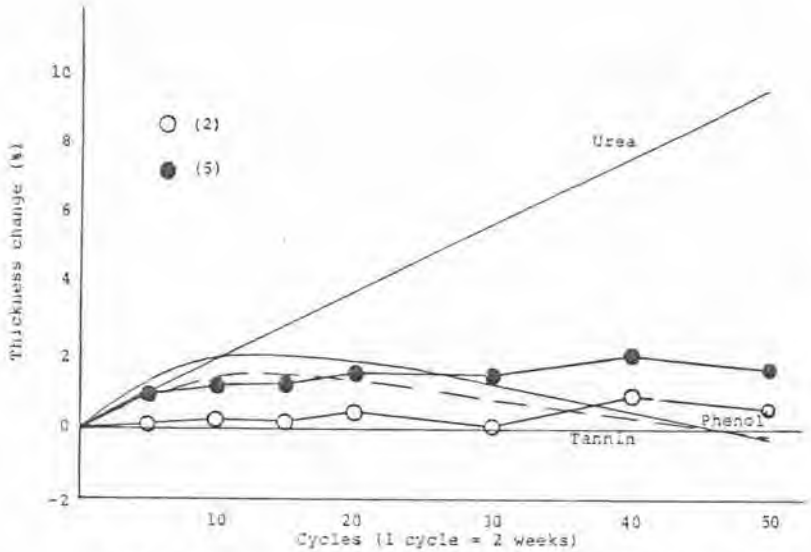



FIG 1. Progressive change in thickness with humidity cycling.

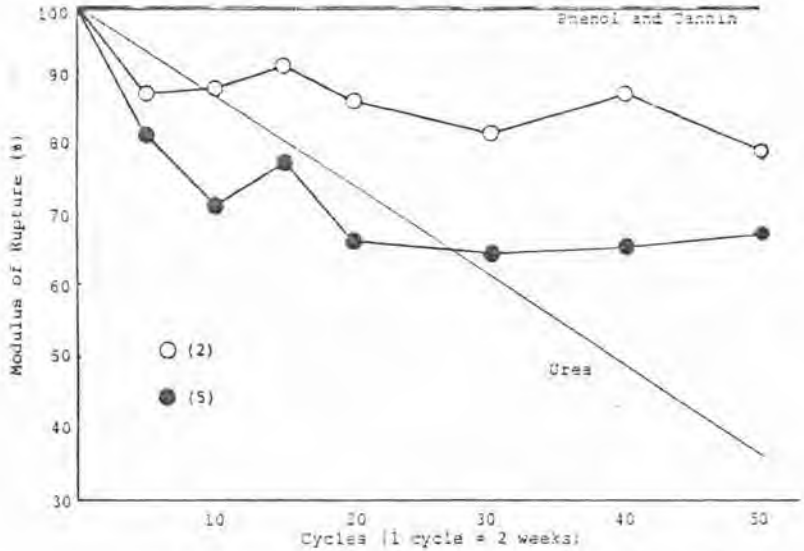



FIG 2. Progressive change in MOR with humidity cycling.

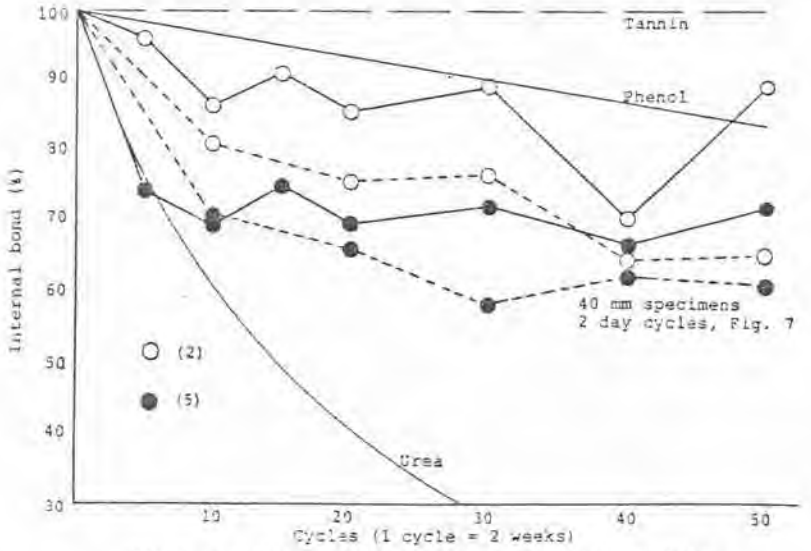



FIG 3. Progressive change in IB with humidity cycling.

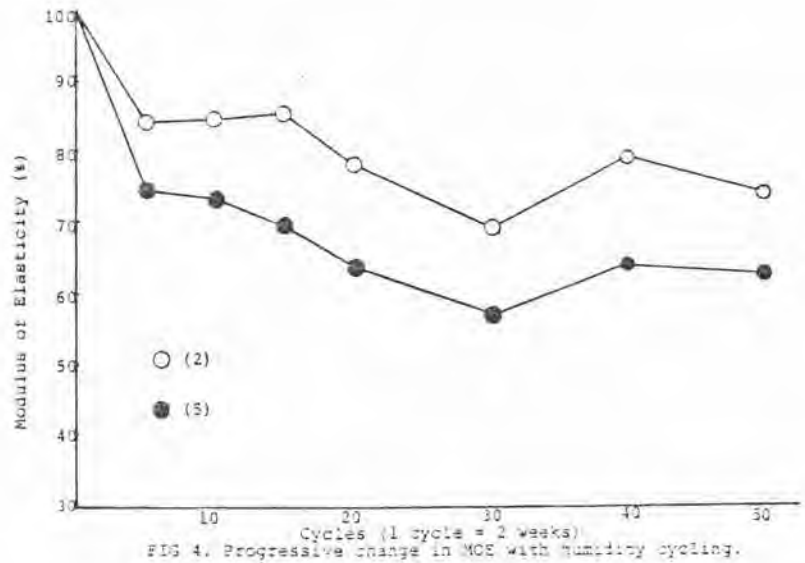



FIG 4. Progressive change in MOE with humidity cycling.

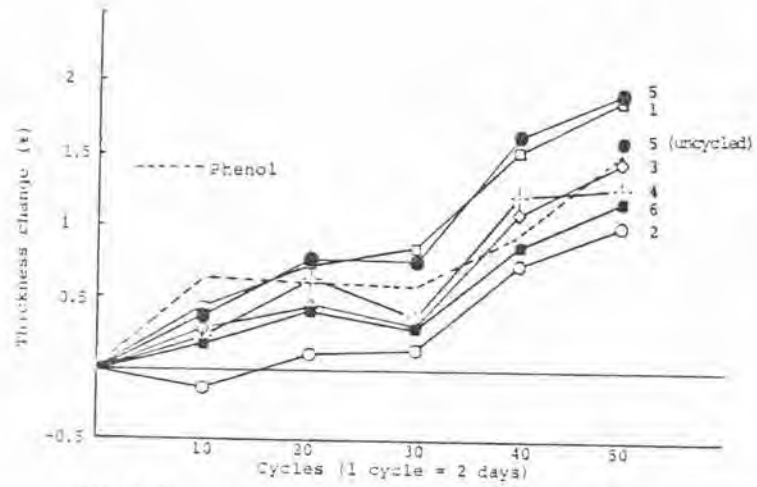



FIG 5. Progressive change in thickness, 40 x 40 mm specimens.

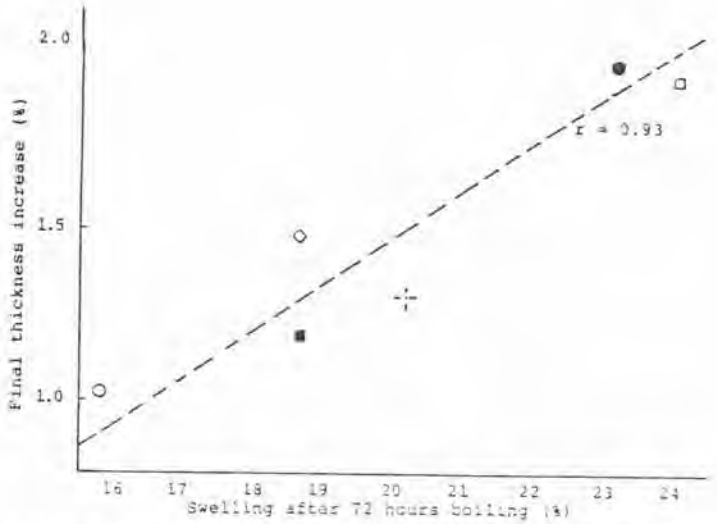



FIG 6. Relationship between swelling after cycling and after boiling

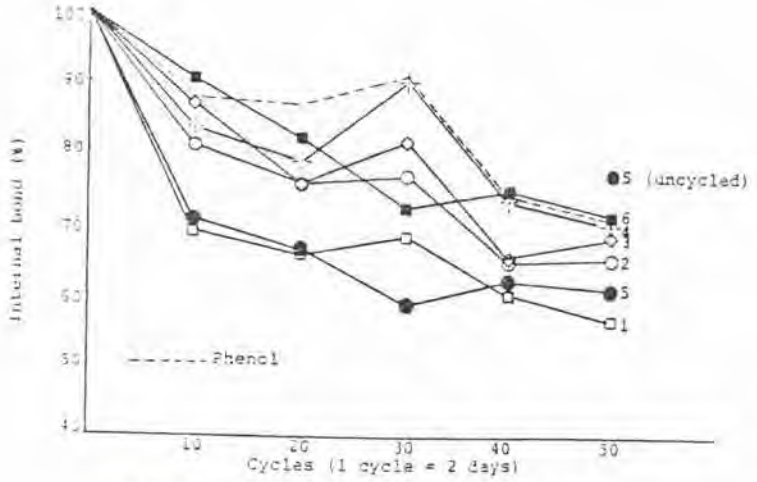



FIG 7. Progressive change in IB, 40 x 40 mm specimens

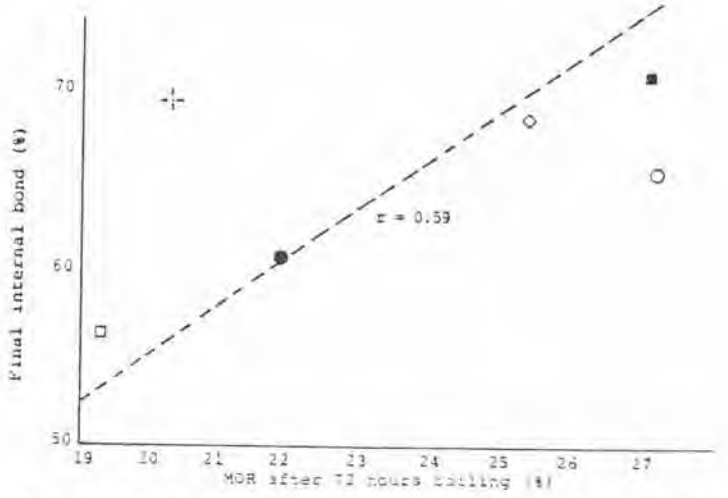



FIG 8. Relationship between IB after cycling and MOR after boiling

# CRACK PROPAGATION AND THE DURABILITY OF GLUE-LINES

G.N. Christensen and E.R. Pankevicius
Division of Building Research, CSIRO

## INTRODUCTION

Adhesives have been successfully used in structural, i.e. load-bearing, wood products such as plywood, glu-lam and particleboard for many years. At the same time there have been bonding failures, and these can usually be traced to poor gluing practice. Relatively little is known about the mechanisms of the slow breakdown in service that can occur over long periods of time. In many cases, the breakdown is not sudden or complete, but consists of progressive de-bonding by crack propagation starting from an outside surface or from some internal flaw. What are the factors that give rise to this common type of failure and how can they be studied?

A standard method for the study of crack propagation is the double cantilever beam test, well known for example in the study of bonding of metals. A sharp crack is initiated at one end of the glue-line in a longitudinally bonded beam and a tensile force is applied perpendicular to the glue-line at the cracked end until the crack starts to extend.

In a more recent development of this method, the tapered double cantilever beam (TDCB) was introduced by Mostovoy, Crosley and Ripling (1), and has now been incorporated in ASTM D 3433-75. This beam is profiled in depth in such a way that its compliance increases linearly with crack length. Its advantage is that the perpendicular force required to extend the crack should remain constant until the crack nears the end of the beam. It is possible, at least in principle, to control the rate of crack propagation by controlling the rate of separation of the two loading points, and the failure chracteristics of the glue-line can be sampled over a finite length limited only by the specimen size.

The purpose of the present study is firstly to develop the experimental technique of using TDCBs for the study of crack propagation in wood glue-lines, to determine some of the variables that affect crack propagation, and then later to explore crack propagation as a method for testing the durability of structural wood-glue bonds. This paper describes some preliminary experiments on crack propagation in wood TDCBs. Some similar experiments have recently been reported by Eberwele, River and Koutsky (2).

METHOD

If wood is glued properly with a structural adhesive, failure under stress will always occur in the wood. For the present experiments it was therefore necessary to take special steps to ensure that failure was restricted to the glueline. Firstly, the glue itself was weakened. Working with a urea-formaldehyde adhesive only at this stage, it was found that addition of 25% of urea chemical gave a bond with zero wood failure that was still moderately strong. The second method for directing bond failure along the glueline was to use specimens with slightly sloping grain in each half joined so that the grain converged in the direction of crack propagation.

The geometry of an isotropic TDCB required to give a linear change in compliance is such that the quantity m, defined as

$$m = \frac{3a^2}{h^3} + \frac{1}{h},$$

should be constant, where "h" is the half height of the double beam at any distance "a" from a line perpendicular to the glue-line through the loading points. Some of the assumptions underlying the above relationship are not true for wood, and the final shape adopted for a 250 mm long wooden beam was arrived at experimentally (Fig 1).

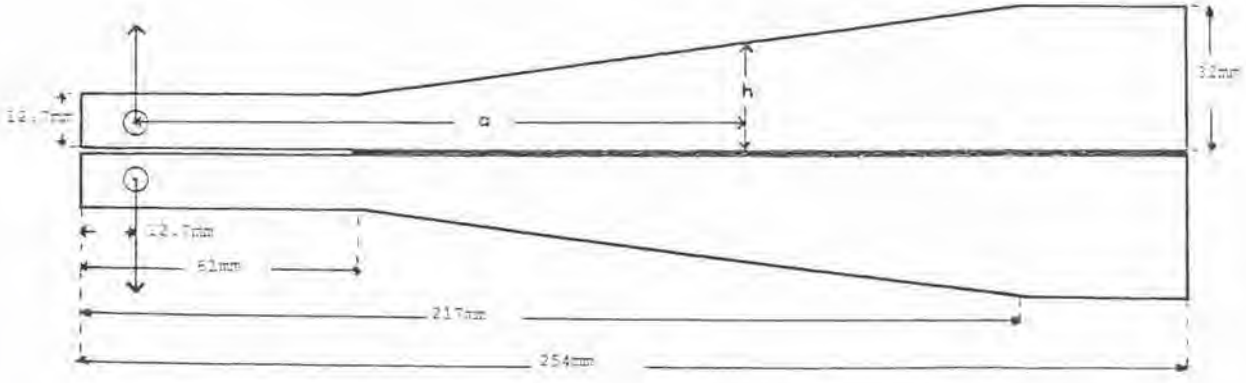



FIG. 1. Dimensions of Tapered Double Cantilever Beam

Two short experiments only are described in this paper to demonstrate the use of the technique.

FIRST EXPERIMENT - REPRODUCIBILITY AND EFFECT OF GRAIN ANGLE

In the first experiment, six TDCBs were prepared from pieces of ash eucalypt glued on their tangential faces. The angle of the grain to the surface to be glued was measured prior to gluing to enable matching of each pair of pieces. After gluing and assembly at room temperature, the specimens were kept under pressure for 16 hours in an oven at 40 deg C, then transferred to 12% emc conditioning at 38 deg C for 8 days before testing. For testing, the cross-head speed was set at 1 mm/min.

Figure 2 shows a typical graph of the measured load, during loading, crack propagation and final failure. The slope during the loading phase enables the initial compliance to be calculated. The graph shows that the crack progressed by a series of sharp jumps (which were quite audible) interspersed with relatively steady extension. After each jump, indicated by the vertical lines, the change in compliance of the specimen is evident in the slope during the next phase of elastic bending. Final catastrophic failure occurred when the crack reached to within 65 - 80 mm of the end of the specimen.

To compare specimens quantitatively, each small peak on the graph was regarded as a fresh failure of a new section of glue-line and all the peak values were averaged irrespective of their number or distribution. From Table 1 it is seen firstly that both the initial compliance and the mean failing load were fairly consistent between specimens, and that such variation as did occur was not obviously related to the grain angle.

TABLE 1

First Experiment - Reproducibility of Test Results

| Spec. No. | Grain angle (deg.) | Initial compliance (mm/500 N) | Mean failing load (N) |
|---|---|---|---|
| 13 | 4.6 | 2.02 | 266 |
| 14 | 5.8 | 2.04 | 234 |
| 15 | 6.4 | 2.15 | 236 |
| 16 | 6.8 | 2.18 | 253 |
| 17 | 6.9 | 2.04 | 249 |
| 18 | 7.3 | 2.24 | 247 |

This is at variance with the findings of Eberwele et al (2), but the range of angle in the present test was very small. An earlier test over the range 2 to 9 deg. likewise had shown no effect.

SECOND EXPERIMENT - RADIAL FACE GLUING AND EFFECT OF CURE VARIATION

In the second experiment, similar specimens were prepared except that bonding was on the radial face since this has a more uniform longitudinal distribution of early wood and late wood than the tangential face. The grain slope was more variable within each piece and was not measured, but the pieces were again glued with the slopes converging in the direction of crack propagation. Three sets of four beams were prepared, differing from each other only in the pressing and curing conditions. These are shown with the results in Table 2. Apart from the changeover to radial face gluing, the second set of the three almost replicated the first experiment.

TABLE 2

Second Experiment - Effect of Gluing Procedure

| Spec. No. | Pressing condition | Post-cure treatment | Initial compliance (mm/500 N) | Mean failing load (N) | Type of failure |
|---|---|---|---|---|---|
| 23 | 16 hours at 38°C | nil | 1.94 | 250 | Adhesive |
| 26 | | | 2.35 | 232 | Adhesive |
| 29 | | | 2.50 | 184 | Adhesive |
| 30 | | | 2.30 | 268 | Adhesive |
| 24 | 16 hours at 38°C | 6 days at 12% emc & 38°C | 2.70 | 270 | Adhesive |
| 27 | | | 2.30 | 259 | Adhesive |
| 32 | | | 2.90 | 308 | Some wood failure |
| 33 | | | 2.60 | 348 | Some wood failure |
| 25 | 21 hours at 70°C | 6 days at 12% emc & 38°C | 2.43 | 310 | Adhesive? |
| 28 | | | 2.37 | 368 | High wood failure |
| 31 | | | 2.45 | 369 | High wood failure |
| 34 | | | 2.52 | 408 | High wood failure |

The first set shows the effect of eliminating the post-cure conditioning, the third set the effect of pressing at a higher temperature.

Figure 3 shows the typical failure behaviour in a beam from the first set. It is characterised by stable crack growth, i.e. with no sudden jumps. In the second set the effects of additional storage at 38 deg C and drying out of the glueline became apparent (Fig 4), with quite large crack jumps occurring, particularly in the later stages of the test. This last

phenomenon is possibly caused by the larger amount of elastic energy stored in the strained beam at longer crack lengths.

Unfortunately, the glue cured under these conditions was still marginally too strong for the radially-glued wood. In two specimens there was considerable wood damage even though the final separation occurred at or near the glue-line, and the mean failing loads were higher. With wood damage occurring as well, there was apparently less tendency for the crack to jump (Fig 5). In the final set, cured initially at 70 deg C, the glue appears to have been even stronger, and the wood failure was much more evident after final separation.

## CONCLUSIONS

This study of the propagation of cracks in structural gluelines is at a very early stage, and the present paper is intended merely to demonstrate the technique and indicate some of the insights into gluing which it might be able to provide. Extending the technique to durability testing may be possible by observing slow crack propagation in TDCBs under a continuous or periodic load as the bond strength deteriorates due to weathering.

## REFERENCES

1. Mostovoy, S., Crosley, P.B. and Ripling, E.J. (1967). "Use of crack-line-loaded specimens for measuring plain-strain fracture toughness". J. of Materials 2 (3), 661-681.

2. Eberwele, R., River, B. and Koutsky, J. (1979). "Tapered double cantilever beam fracture tests of phenolic-wood adhesive joints - Part 1". Wood and Fibre 11 (3), 197-213.

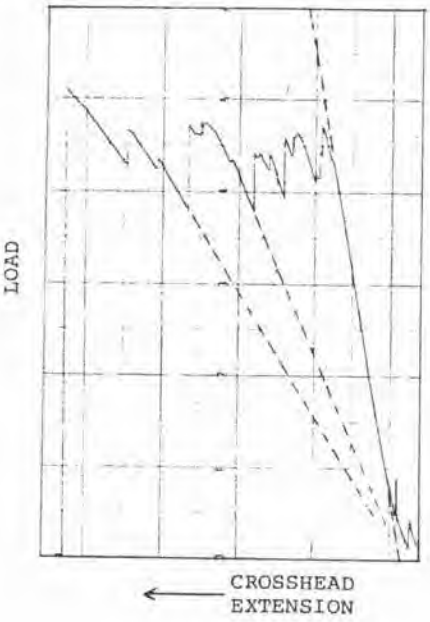



FIGURE 2

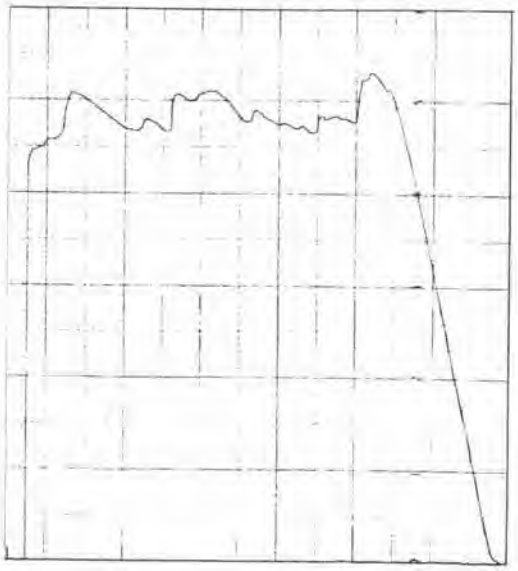


FIGURE 3

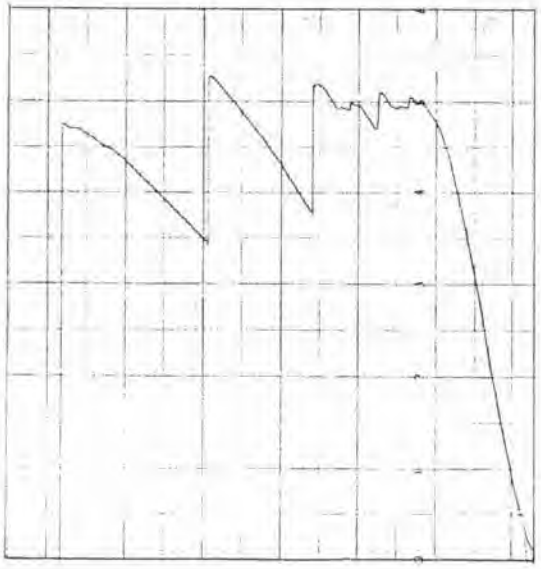


FIGURE 4

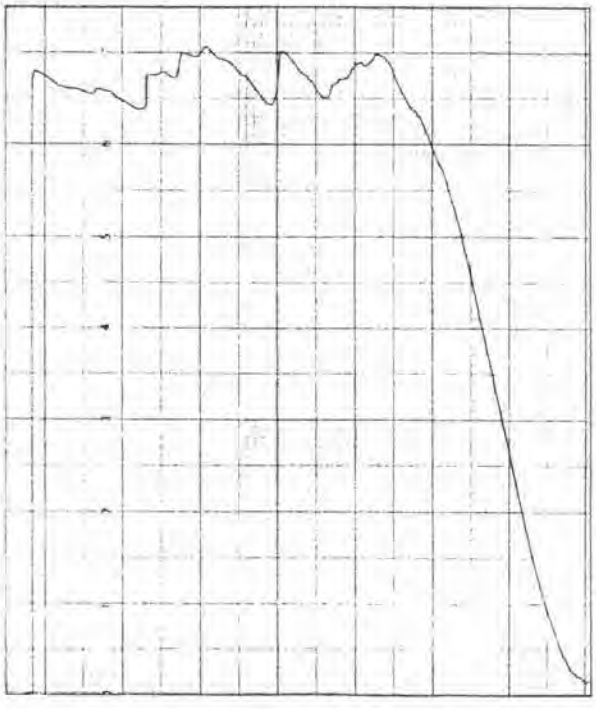


FIGURE 5

FIGS 2-5. Changes in load during crack propagation. Cross-head movement shown right to left.

# STEEL TO WOOD BONDING FOR STRUCTURAL JOINTS

H.F.A. Hergt and G.N. Christensen
Division of Building Research, CSIRO

## ABSTRACT

The feasibility of bonding steel to wood to form structural joints is explored. One application proposed is to increase the service life of softwood sleepers in railway tracks. For this purpose, joints capable of resisting exposure out of doors unprotected are needed. Preliminary studies of the behaviour of bonded joints using epoxy and phenolic adhesives, indicate that bonds which are highly resistant to water, at least in the short term, can be formed between wood and steel.

## INTRODUCTION

Techniques for bonding thin metal sheets to wood or wood-based panels have been known for many years. The adhesives used have been based on natural and synthetic rubbers and also on synthetic resins such as polyvinyl acetate, epoxies and phenolics (1). The purpose of the metal in those assemblies was to provide a decorative or protective surface or to provide a thermally reflective or moisture resistant barrier. It was seldom used as a structural component.

However, metal components are commonly used in timber structures, usually as part of a mechanical fastening. Examples are shear rings and toothed metal plate connectors. Adhesive bonding of steel components to predominantly timber structures appears to be worthy of consideration. Occasional experiments involving the adhesive bonding of steel to wood for structural purposes have been published (2), (3), (4), (5), (6), but usually these results are applicable only to situations where the bond to the metal is protected from exposure to outdoor conditions. Exceptions to this are to be found in papers by Chugg and Gray (7), and Cach (8) on the adhesive bonding of rail-plates to hardwood railway sleepers.

This paper describes research into bonding between steel and a softwood, namely radiata pine. Again the immediate application envisaged is to bond rail-plates to sleepers to protect the rail seat area of the sleeper from plate damage and thereby extend the service life. One additional requirement

of this proposed use is that the bond must be able to withstand treatment of the sleeper with a preservative such as creosote or a creosote/oil mixture.

EXPERIMENTAL

The adhesive systems under test are listed in Table 1.

TABLE 1

Adhesives Systems Tested

| Adhesive No. | Type | Form supplied | Form used | Curing schedule |
|---|---|---|---|---|
| 1 | low temp. epoxy(RTC) | 2 part pastes | combined paste | 150 KPa 16 hour 20 deg.C |
| 2 | heat resisting epoxy | 2 part pastes | combined paste | <150 KPa 16 hour 20 deg.C |
| 3 | high temp. epoxy | paste | as supplied | <150 KPa 10 min. 20 deg.C |
| 4 | PRF(resol) | liquid | liquid & filler & hardener | 700 KPa 16 hour 20 deg.C |
| 5 | PF(resol) | film | as supplied | 700 KPa 10 min. 150 deg.C |
| 6 | PF(novolac) | powder | 50% w/w in methanol | 700 KPa 10 min. 130 deg.C |
| 7 | PF(novolac) (nylon modified) | powder | 50% w/w in methanol | 700 KPa 10 min. 130 deg.C |
| 8 | Nitrile rubber/ phenolic | 2 part liquid | n.r. on wood phen. on steel | 700 KPa 45 min. 200 deg.C |
| 9 | Vinyl formal/ phenolic | liquid & powder | liquid on both parts & powder on steel | 700 KPa 30 min. 160 deg.C |
| 10 | Vinyl formal/ phenolic | liquid | liquid on both parts | 700 KPa 30 min. 160 deg.C |

The adhesives were not of course designed for the proposed purpose, but were provided by the manufacturers as possibly being suitable. They include cold and hot curing epoxies, cold and hot curing phenolics and several modified phenolics. Because of the very different natures of the surfaces to be bonded together, it was necessary sometimes to apply two component systems separately to each surface (Table 1) or to use a priming treatment (Table 3).

The initial requirement was to obtain a bond which was strong enough to give 100% wood failure on test, and then to assess the resistance of the bond to preservative treatment and to weathering. Bond quality was rated by shear tests on "small" specimens and by moisture content cycling to bond failure on "medium-sized" specimens. The small specimens were prepared from coupons of mild sheet steel 60 mm x 20 mm x 1.5 mm bonded to radiata pine pieces 50 mm (L) x 20 mm (R) x 8 mm (T). The test specimen comprised two coupons of steel and two pieces of wood assembled to give a total stressed area of 400 square mm, using a teflon spacer between the enclosed tips of the steel coupons as shown in Fig 1. Earlier work with non-symetric shear specimens generally broke the wood in tension outside the overlap region. With the present form of shear test piece failure outside the bond area was not possible.

The "medium-sized" specimen consisted of a 200 mm x 25 mm x 10 mm bar of mild steel bonded across the tangential face of a block of radiata pine 200 mm (T) x 100 mm (L) x 50 mm (R) as shown in Fig 2. The steel surfaces for both types of test specimen were prepared by degreasing in a vapour phase degreaser (VPD) using 1.1.1. Trichloroethane, followed by grit blasting with aluminium oxide abrasive (number 32 mesh), and another VPD treatment. The surface quality approximated that described by Australian Standard AS1627 (1974) Parts 4 and 9 respectively, as Class 3 and Sa3 (white metal).

In those instances where bonding was to bare steel, as soon as the steel had cooled down after the VPD treatment the joints were assembled and the adhesive cured. If a primer treatment was required, this too was given. The only delay in using the freshly prepared steel surface involved the epoxy powder coating which was done off-site at a paint factory. These pieces were sealed inside specially prepared bags for transit and storage before they were coated. Before bonding to the wood, the coated pieces were very lightly grit-blasted to give them a fine matt surface, then cleaned with acetone. The radiata pine surfaces were planed, sanded lightly along

the grain and freed of sanding dust just before they were coated with primer or adhesive.

RESULTS

The results from the small specimen shear tests are presented in Table 2. Results for adhesives 1, 2, 3 and 4 are reported for the untreated assemblies only. Observation showed that they either would not survive heating as required for the creosote preservation (adhesive 1), would not resist the ingress of water along the steel interface (adhesive 2), yielded weak, starved joints when bonded to wood (process 3), or failed in shear at the steel interface. However, results for systems using adhesives 2 and 4 on epoxy-coated steel, and designated 2A and 4A respectively, show the potential usefulness of these adhesives.

These results show that there are several possible processes or combinations that could provide strong resistant bonds. It appears that there is little difference in the initial bond strength for systems 4A to 10, all being strong enough to cause wood failure in shear. However, the subsequent vacuum/pressure water saturation (VPS) and/or creosote treatments show possible weaknesses in adhesive 8, the nitrile rubber/phenolic, and to some extent in adhesive 7, a nylon modified novolac. The former showed a decrease in cohesive strength with a consequent change in mode of bond failure, and the latter showed some decrease in water resistance.

Testing of the medium-sized specimens is still in progress and the present state is indicated in Table 3. Four test specimens were prepared for each adhesive. Cycles of VPS followed by drying at 25% relative humidity at 38°C is the only exposure treatment that has been given at this stage. The criterion for failure is some visible evidence of bond breakdown. In most instances this consisted of an obvious gap between the steel and the wood, or some shearing movement between the wood and steel because of insufficient restraint, particularly at the bar ends.

Table 3 shows that the joints which failed to survive the first VPS/drying cycle, were those bonded with adhesives 3, 4, 5, 6 and 7. Bonds formed with adhesive 2 began to separate after the second VPS/drying cycle (one bond opened up so far during drying that the mode of failure (WFS) was readily seen, but the steel bar remained attached to the wood over half of its length). The other three joints showed separation either at both ends (2 joints) or in the centre (1 joint).

Joints formed with adhesive 2A performed better than with 2 alone although one failed in the bond between the coating and the steel after the second cycle. Another failed in the bond between the adhesive and coating at the fifth cycle. The remaining two joints were broken by hammer blows and the fractured bonds on examination revealed wood failure.

The joints bonded with adhesive 8 have undergone seven cycles to date although starting to show defects after the fifth cycle. Here the defect evident was the occurrence of 1 to 1.5 mm of tangential swelling and shrinking of the wood under the joint. Although an unrestrained block would have swollen more than four times this amount, this was considered evidence of a weakened joint. Since the steel bars are still firmly attached to the wooden blocks the actual locus of failure is not known.

Three of the four joints bonded with adhesive 9 showed partial failure after three cycles, the fourth appearing to be still intact. The indication of failure was similar to that for adhesive 8 but the swelling movement was greater namely 1.5 to 2 mm.

All four joints bonded with adhesive 10 showed separation for about half of the length of the bond immediately after the first saturation. When the steel bars were levered off the wet blocks, the spontaneously failed zone was seen to consist of a layer of wood up to .5 mm thick still adhering to the steel. Clearly in this test a bond had been formed but apparently high stress concentrations led to premature wood failure. Two more series of specimens were then assembled using the same resin in slightly different ways. The first used a priming coating for the steel made from adhesive 10 with 20% by weight of talc added to increase its viscosity. After press curing at 160°C these bars were then bonded with adhesive 4 to the radiata pine blocks. In the second set, strips of 2.5 mm radiata pine veneer, were bonded to the steel bars with their grain direction parallel to the length of the bar using adhesive 10. The steel was then bonded to the pine block using adhesive 4. These new sets of joints have passed the initial VPS/drying cycles.

Those adhesive systems which formed bonds capable of withstanding several VPS/drying cycles are to be tested further using larger bond areas. Modification to some of the formulations or their method of use, to enhance bond durability, will also be considered.

## CONCLUSIONS

The results obtained so far indicate that a water resistant structural bond between wood and steel should be feasible using modified phenolic adhesives, or temperature resistant epoxy adhesives. Although some of the adhesive types tested appear to be usable alone, improved joint performance may be possible if the steel is first treated by priming or pre-coating, thus allowing the use of a simpler wood adhesive for the final bond.

## ACKNOWLEDGEMENTS

The authors wish to acknowledge the assistance of the Wattyl Paint Company for the powder coating of a large number of steel components used in this investigation.

## REFERENCES

1. Hirst, K.H. (1971). Aust. Timber J. 37 (11), 25-27.

2. Hugo, F. de V. (1977). J. Struct. Div. ASCE 103, No. ST5, 1005-1014.

3. Van Wyk, W.J., Gerischer, G. and Hugo, F. de V. (1977). Holzforschung 31 (4), 125-129.

4. Van Wyk, W.J. (1979). Holzforschung 33 (4) 103-106.

5. Eichner, H.W. (1946). USDA For. Prod. Lab. Madison, Report No. 1570.

6. Eichner, H.W., Mraz, E.A., Bruce, H.D. (1947). USDA For. Prod. Lab. Madison, Report No. 1545.

7. Chugg, W.A. and Gray, V.R. (1965). Wood 45-51.

8. Cach, E. (1963). Cross Tie Bulletin 20-26.

TABLE 2

Small Specimen Tests

| Adhesive | Steel * treatment | After bond treatment | Shear MPa; S.D. | Mode of failure |
|---|---|---|---|---|
| 1 | ABR | nil | 7.7; 1.6 | BFS |
| 2 | | nil | 10.6; 1.1 | WFS |
| 2A | EPC | nil | 11.2; 1.5 | WFS |
| 3 | ABR | nil | 0.0; 0 | CFA |
| 4 | | nil | 3.1; 1.7 | BFS |
| 4A | EPC | nil | 9.0; 1.7 | WFS |
| | | nil | 10.1; 2.3 | WFS |
| | | VPS | 11.1; 1.3 | WFS |
| | | C | 11.2; 1.0 | WFS |
| | | CVPS | 10.6; 1.4 | WFS |
| 5 | | nil | 8.3; 0.6 | WFS |
| | | nil | 10.4; 1.7 | WFS |
| | | CVPS | 11.5; 1.3 | WFS |
| 6 | | nil | 8.8; 1.1 | WFS |
| | | C | 8.3; 1.5 | WFS |
| | | CVPS | 8.6; 1.4 | WFS |
| 7 | | nil | 8.0; 0.6 | WFS |
| 8 | | nil | 10.8; 1.4 | WFS |
| | | nil | 8.7; 1.6 | WFS |
| | | VPS | 10.2; 1.5 | WFS |
| | | C | 7.4; 1.3 | CFA |
| | | CVPS | 6.2; 0.8 | CFA |
| 9 | | nil | 11.6; 1.7 | WFS |
| | | VPS | 11.5; 1.7 | WFS |
| | | C | 12.0; 2.8 | WFS |
| | | CVPS | 13.7; 1.7 | WFS |
| 10 | | nil | 11.6; 2.6 | WFS |
| | | nil | 10.4; 1.8 | WFS |
| | | VPS | 11.0; 1.4 | WFS |
| | | C | 9.3; 1.2 | WFS |
| | | CVPS | 9.5; 1.3 | WFS |

TABLE 3

Medium Specimen Tests

| Adhesive | Steel* treatment | Block No. | Cycles completed | Mode of failure |
|---|---|---|---|---|
| 2 | | 1 | 2 | WFS |
| | | 2 to 4 | 2 | P-WFS |
| 2A | EPC | 1 | 2 | BFSC |
| | | 2 & 3 | 5 | P-WFS |
| | | 4 | 5 | BFAC |
| 4 | | 1 to 4 | 1 | BFS |
| 4A | EPC | 1 | 1 | BFSC |
| | | 2 to 4 | 3 | P-WFS |
| 5 | | 1 to 4 | 1 | BFS |
| 6 | | 1 to 3 | 1 | CFA;WFS |
| | | 4 | 1 | CFA |
| 7 | | 1 to 4 | 1 | CFA;WFS |
| 8 | | 1 to 4 | 5 | P-WFS |
| 9 | | 1 to 3 | 3 | P-WFS |
| | | 4 | | (intact) |
| 10 | | 1 to 4 | 1 | WFS |
| 10 & filler | PR | 1 to 4 | 2 | (intact) |
| 10 & 4 | VEN | 1 to 4 | 1 | (intact) |

* All steel coupons were vapour degreased and all except 1 and 3 were grit blasted. 1 and 3 were abraded.

The following abbreviations are used in Tables 1 and 3:

Steel treatment: ABR = Abraded surface; EPC = Epoxy powder coating; PR = Primer coating; VEN = Wood veneer bonded to surface

After bond treatment: C = Creosote treatment; VPS = Vacuum/pressure water saturation; CVPS = C + VPS.

Mode of failure: CFA = Cohesive failure in adhesive; BFAC = Bond failure between adhesive and coating or primer; BFSC = Bond failure between steel and coating or primer; P-WFS = Partial failure in wood shear; WFS = Wood failure in shear.

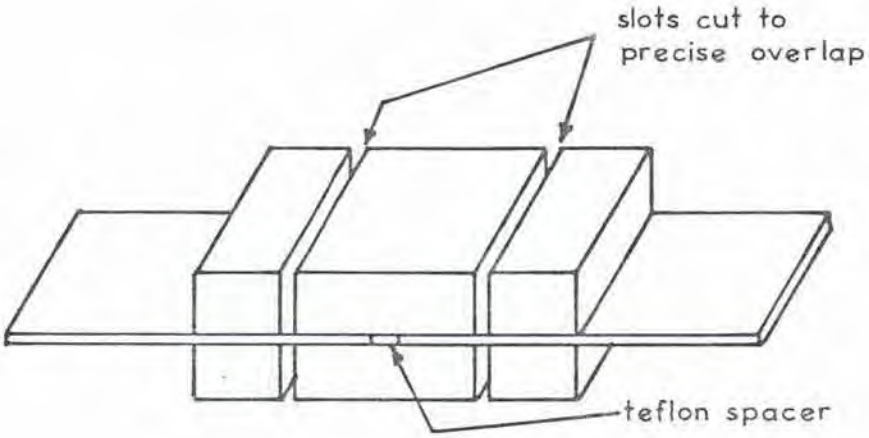



FIG. 1 Small double-shear specimen

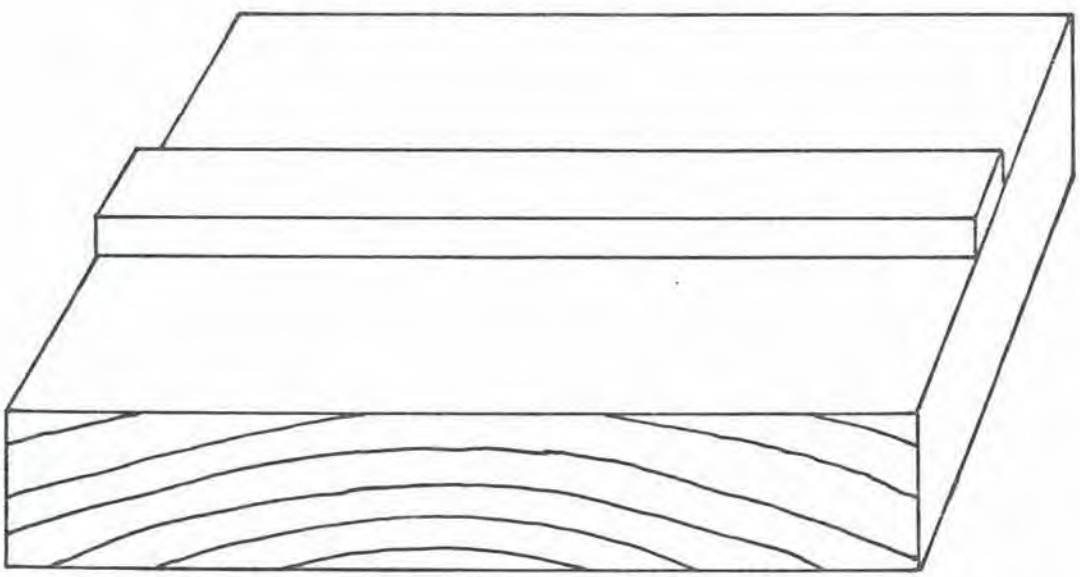


FIG. 2 Bar test specimen

# EXPOSURE TRIALS ON FINGER-JOINTED RADIATA PINE STUDS BONDED WITH MODIFIED CASEIN GLUES

H.F.A. Hergt
Division of Building Research, CSIRO

## ABSTRACT

Two separate exposure trials were conducted on finger jointed studs bonded with casein glue to which preservatives had been added. The first trial compared the performance of two preservatives to protect casein glue from micro-organism attack during exposure to daily wetting and drying cycles over a twelve month period. The joints used in that trial were cut in a wood working factory but were hand assembled in the laboratory. In the second trial the joints were cut and assembled on the factory production line, but only one of the preservatives was included. Instead a set of joints using the commercial phenol/resorcinol adhesive in use at the factory was assembled, to permit comparisons of processing to be made. The results of the two trials showed that the two preservatives were not as satisfactory as the results of an earlier screening test had suggested.

## INTRODUCTION

In recent investigations carried out at DBR two preservatives, Permapruf T and Tricidal were chosen from 40 to 50 candidates to provide a limited protection for casein glue bonds in finger-jointed house framing timber. The protection sought was against micro-organism attack on the casein during the time the framing is open to the weather before cladding. An earlier investigation had used sodium pentachlorophenate as a preservative, but this was not effective. The recent investigations first reduced the number of candidates from some 40 to 50 to 6 by a preliminary bio-assay. Permapruf T and Tricidal were then selected from the 6 by testing two-ply panels of copper-chrome-arsenic treated radiata pine, bonded with casein glue formulations containing the preservatives, by immersing them in an inoculated wet sawdust medium for up to 12 weeks using the method described in Australian Standard AS 2098 part 5, Resistance of Glue-lines in Plywood to Micro-organism Attack (1).

METHODS AND TESTING

Two separate exposure trials were conducted. The radiata pine used for the first trial was F8 grade scantling with a cross section measuring approximately 85 x 35 mm and 65 x 33 mm for the second trial and the fingers were cut in the narrow face.

The first trial used joints assembled in the laboratory from factory-cut fingers. In order to ensure that each joint was made from two pieces of similar strength a one metre length of timber had fingers machined in each end, and then was cut into equal lengths to provide the mating pair. The joints were assembled by hand and clamped using sash clamps taking care to avoid bowing. The joints were wiped clean of any excess glue squeezed out. The casein glue formulations were varied only by the preservative added and the amount of water needed to get the required viscosity for spreading. Sodium triphosphate and sodium tetra borate were used as the alkali donor. The use of these salts instead of sodium fluoride was dictated by the need to extend the pot life of the mixed adhesive which was reduced to approximately 15 minutes by the Permapruf T. The only other ingredient added was dialdehyde starch, added as a suspension in water, to provide a very slow crosslinking in the casein during subsequent wetting treatments after the joint was cured. The 'dry' glue-line bond strength of the formulation with and without addition of preservative compared with a casein formulation using sodium fluoride was determined by a block shear test using radiata pine blocks. Only wood failure in shear was found and it was concluded that there was no real change in bond strength.

Ninety joints were assembled (thirty each for formulations containing no preservative, and 10% by weight on dry casein basis of Permapruf T and Tricidal respectively). From each group five joints were selected randomly for either no exposure or exposure for 30, 90, 180, 270 or 360 cycles. The exposure consisted of a daily water spraying lasting one hour followed by 23 hours drying. The exposure rack was placed in an open shed so that the joints were shielded from direct sunlight and rain but otherwise exposed to wind and temperature changes. The joints receiving no exposure were stored in a 12% MC conditioning room until tested. At the end of each exposure period the joints concerned were removed from the rack and placed in the 12% room until they reached constant weight. Then they were tested in static three point bending over a 600 mm span with the centre load applied at the finger joint, and the specimen resting on its broad face on the supports.

The second trial was of shorter overall duration, the maximum period being limited to 180 cycles. The finger joints for this trial were cut and glued on a factory production line using timber in approximately 1 metre lengths which was selected for similarity of appearance and relative freedom from knots. Apart from the selection of the timber input and the complete cleaning of the glue spreader for each of the glues used, the operation was treated as a normal production run. Unlike the first trial, the assembly time for each joint was about 20 seconds and the long stick of jointed timber coming off the line had to be carefully stacked for several hours before handling.

The glues used in this trial were a casein glue without preservative, one with preservative Permapruf T, and a phenol-resorcinol adhesive used for glulam production in this factory. This latter adhesive was included to obtain a direct comparison with the casein glue's performance.

The exposure procedure was the same as in the first trial. Specimens were randomly selected for length of exposure and randomly allocated a position on the exposure rack. The treatment of specimens after exposure was the same as for the first trial, with reconditioning to 12% MC followed by testing in static three point bending over a span of 600 mm with the specimen supported on it flat side.

RESULTS

The results of the first exposure trial are presented in Table 1. It will be seen that from the very beginning the addition of Permapruf T to the casein glue reduced the bond strength by about 40% compared to the untreated and Tricidal treated glues. During the first 30 exposure cycles the joints protected by Permapruf T lost further strength (a total loss of 60%) but no further change occurred for the duration of the trial. The ranges for the five specimens tested at each exposure period, are also presented in the table. The Tricidal series appear to have lasted better than the Permapruf series although an unusually low M of R for one specimen was obtained at the 90 cycle point. Without that value the results using Tricidal preservative may have shown a steady decline over the 360 cycles. For the first 30 cycles the untreated glue showed no significant loss in strength but then fell away to the level of the Permapruf series at 180 cycles.

TABLE 1

Glue-bond Strengths after Exposure Trial No. 1

| Glue system | Exposure cycles | Modulus of Rupture (MPa) | | |
|---|---|---|---|---|
| | | Mean | Standard deviation | Range |
| Untreated casein | 0 | 51.1 | 7.9 | 40.1-61.9 |
| | 30 | 48.8 | 6.3 | 40.3-56.0 |
| | 90 | 29.7 | 19.0 | 8.7-47.2 |
| | 180 | 22.1 | 10.5 | 9.3-37.3 |
| | 270 | 25.5 | 16.5 | 8.5-48.6 |
| | 360 | 16.2 | 7.8 | 7.6-25.5 |
| Casein plus 10% Tricidal | 0 | 49.6 | 7.7 | 41.3-62.0 |
| | 30 | 39.7 | 3.8 | 35.8-44.4 |
| | 90 | 31.1 | 12.1 | 10.0-38.8 |
| | 180 | 35.3 | 10.5 | 21.4-45.9 |
| | 270 | 32.6 | 10.0 | 24.1-46.5 |
| | 360 | 31.5 | 5.9 | 21.7-36.9 |
| Casein plus 10% Permapruf T | 0 | 28.9 | 2.6 | 25.6-31.5 |
| | 30 | 22.1 | 6.3 | 13.6-27.9 |
| | 90 | 24.2 | 6.6 | 16.0-33.9 |
| | 180 | 21.1 | 3.8 | 17.2-26.7 |
| | 270 | 20.7 | 6.5 | 9.7-26.7 |
| | 360 | 20.4 | 3.5 | 14.8-23.2 |

The relatively poor performance of the Permapruf T protected bonds was a reversal of the findings of the earlier panel tests (1) and it was resolved to repeat the trials using this preservative for confirmation of the current result and to have the assembly done by machine to see if method of assembly had any influence on joint strength.

Table 2 shows that in the second trial the behaviour of the Permapruf treated glue bonds was almost identical with that in the first trial. The behaviour of the untreated casein glue was also reproduced up to the 30 cycle point but thereafter the strength declined rather faster than in trial 1.

TABLE 2

Glue-bond Strengths after Exposure Trial No. 2

| Glue system | Exposure cycles | Modulus of Rupture (MPa) | | |
|---|---|---|---|---|
| | | Mean | Standard deviation | Range |
| Untreated casein | 0 | 41.0 | 6.7 | 32.1-49.8 |
| | 30 | 37.4 | 9.6 | 23.5-50.0 |
| | 90 | 15.3 | 8.9 | 6.3-33.0 |
| | 180 | 9.7 | 2.3 | 7.4-14.1 |
| Casein plus 10% Permapruf T | 0 | 32.3 | 4.9 | 26.1-40.4 |
| | 30 | 23.8 | 4.1 | 18.3-32.6 |
| | 90 | 18.5 | 3.1 | 12.8-22.1 |
| | 180 | 18.1 | 5.6 | 8.1-25.3 |
| Phenol/ resorcinol | 0 | 42.4 | 6.0 | 30.2-50.8 |
| | 30 | 41.7 | 5.6 | 32.7-51.4 |
| | 90 | 41.7 | 4.9 | 33.9-46.1 |
| | 180 | 39.1 | 5.3 | 31.4-45.8 |

The results for the phenol/resorcinol adhesive show the superiority of that system in this type of test, where no significant loss in strength was observed for 180 cycles.

## CONCLUSIONS

The preservative, Tricidal, is more likely to provide protection to a finger joint bonded with a casein glue in which it is an additive than is Permapruf T. The extent of the protection provided may not be sufficient to be relied on with safety after six months exposure to weather. The loss in strength when compared with unexposed bonds and with bonds using a resorcinol type adhesive was approximately 40% when using Tricidal and 60% when using Permapruf T.

## ACKNOWLEDGEMENTS

The author wishes to acknowledge the very great contribution of Mr K.B. Schuster who supervised all the mechanical testing and storage of the test joints and collated the data for statistical analysis. The experimental assistance of Mr S. Lunn is also acknowledged.

## REFERENCES

1. Thornton, J.D. and Hergt, H.F.A. (1981). Laboratory assessment of potential preservatives for short-term protection of exposed casein-glued joints. (To be presented at 20th Forest Products Research Conference, November 1981).

# GLUE-LINE TEMPERATURE - ITS EFFECT ON SETTING TIME AND BOND QUALITY OF RESORCINOL TYPE ADHESIVES

P.J. Collins

## INTRODUCTION

Of some concern to both producers and users of glued laminated timber is the number of reported delaminations in service. These are usually associated with exposure to either direct weathering or to conditions of high humidity and frequently are traceable to production carried out during the winter months. Long term durability studies show that only the resorcinol type of laminating adhesives (1) have the durability required for use in structural applications and for severe exposure conditions. These include resorcinol-formaldehyde (RF), phenol-resorcinol-formaldehyde (PRF) and blends of wattle tannin and PRF (WRF). Most laminated beam production is carried out at ambient or slightly above ambient temperatures and most complies with the block shear test requirements of AS1328 - 1972 Glued Laminated Structural Timber.

Both the rate and extent of the adhesive crosslinking reaction are temperature dependent and a high degree of crosslinking is required to produce bonds of high durability. The Vacuum-Pressure Cycle Test (VPC) in AS1328 is an accelerated ageing test and gives a prediction of long term durability. However, this test is not mandatory and it is possible to have satisfactory dry bonds that would fail a VPC test, therefore little information has been gained of the production conditions necessary to provide a level of crosslinking for long term durability.

This paper describes a study into the relationships between curing conditions and bond quality assessed after a vacuum-pressure cycle.

## EXPERIMENTAL

### LAMINATING STOCK

Freshly dressed radiata pine conditioned at 12% emc cooled to approximately 12$^{o}$C to simulate winter conditions.

### BEAM DIMENSIONS

140 x 100 x 450 mm

140 x 75 x 450 mm

The test beams consisted of 4 laminates, 35 mm thick. Two beams of each size were produced under each condition.

ADHESIVES

A Straight resorcinol

B Phenol-resorcinol containing approximately 50% phenol

Both are widely used commercial adhesives and all gluing was done within the range of conditions allowed by the manufacturer.

GLUING CONDITIONS

Spread - 35 Kg/100 $m^2$ spread equally over both surfaces

Open assembly time - 5 minutes

Closed assembly time - 10 minutes

Pressure - 1.0 MPa

Air temperature - at time of spread, 20°C

- during pressing 20, 30, 40, 50, 60°C

Pressing time - 120 Degree Hours. (Degree hours = glueline temperature x pressing time in hours (from manufacturer's data)).

Glueline temperature was recorded at the centre of the laminates using copper-constantan thermocouples. Figs 1 and 2 show glueline temperature over the period required to attain 120 degree hours of cure at relevant air temperature.

POST TREATMENT CONDITIONS

1. 20°C for 7 days (immediate).
2. -10°C for 7 days, 20°C for 7 days (delayed).

Immediately after removal from the press, 50 mm was docked from each end of the beams and discarded. 4 x 50 mm blocks were cut, 2 each of which were subjected to each post treatment.

After post treatment all blocks were subjected to a VPC according to AS1328 and then cleaved in the wet condition using a bricklayers bolster. This test is likely to replace the current end grain delamination test as described in AS1328. The blocks were dried and wood failure assessed. The results of these tests are plotted in Figs 3 and 4. Each point is the average of 12 glueline assessments. Results for the 100 mm blocks were virtually identical to those for the 75 mm.

RESULTS AND DISCUSSION

These results indicate that for the attainment of a durable bond, i.e. high wood failure, a minimum cure temperature of at least 30°C should be used and that higher temperatures afford a greater margin of safety especially if there is to be little or no post curing. Also, it should be noted that beams cured

post curing. Also, it should be noted that beams cured at the lower air temperatures required immediate post-curing for bond improvement, delayed post-curing did not give this improvement. It appears that the PRF requires a somewhat higher minimum curing temperature than the RF. This trend is consistent with the known lower reactivity of PRF. Bond quality at the higher air temperatures was better for PRF than RF probably because of less tendency for over penetration.

REFERENCES

1. Knight, R.A.G. (1968). The efficiency of adhesives for wood. Ministry of Technology Bulletin No. 38, HMSO London.

# HYGROSCOPIC MOVEMENTS IN RADIATA PINE STRUCTURAL PLYWOOD

E.R. Pankevicius and M. Spicer
Division of Building Research, CSIRO

## INTRODUCTION

In the past two decades the wood-based panel industry has experienced rapid growth and its products, namely plywood, particleboard and hardboard, have found many applications in building construction. With the emergence of plantation pine in Australia, the plywood industry has an ideal species for the production of structural plywood, which is useful for all constructional applications where face appearance is not important. As plywood is hygroscopic, any environmental humidity changes cause its physical and mechanical properties to change. The user must, therefore, take into consideration the moisture content of the material at the time of application and allow for changes which are likely to occur in service. As there is very little information available on the dimensional stability of structural plywood, a systematic study of dimensional movements of structural *P. radiata* plywood of various thicknesses was undertaken.

A study has been completed on commercial structural *P. radiata* plywood, in which the hygroscopic movements in all directions were investigated when the moisture content (MC) varied between 5% and saturated conditions.

## EXPERIMENTAL PROCEDURE

Six plywood sheets of each of the six thicknesses consisting of 3, 5, 7 and 9-ply assemblies, were obtained from one plywood mill. From each sheet, 50 mm wide and 350 mm long specimens were cut with the face grain parallel (X - direction) and perpendicular (Y - direction) to the longitudinal axis of the specimens. They were exposed successively to 5, 12 and 17% equilibrium moisture content (EMC) conditions and finally subjected to a vacuum-pressure-soak (VPS) treatment.

Measurements of weight and dimensions (length and thickness) were made at each equilibrium condition. From these measurements the following quantities were calculated:

(i) actual moisture content at each equilibrium condition,

(ii) interval movement (IM), defined as the dimension change for the interval between two successive EMC conditions expressed as a percentage of the dimension at 12% EMC,

(iii) total movement (TM), defined as the dimension change for the total moisture content change 5% to VPS condition expressed as a percentage of the dimension at 12% EMC,

(iv) unit movement (UM), the dimensional change per unit moisture content change over an interval,

$$\text{i.e. } UM = \frac{\text{interval movement}}{\text{interval moisture content change}}$$

RESULTS AND DISCUSSION

Tables 1 and 2 summarize the mean values of IM, UM and TM in length and in thickness respectively.

TABLE 1

Dimensional Increases in Length

| Type | Face grain direction | Interval 5 - 12% IM | 5 - 12% UM | 12 - 17% IM | 12 - 17% UM | 17 - VPS IM | 17 - VPS UM | TM |
|---|---|---|---|---|---|---|---|---|
| 3 ply 8 mm | X | .098 | .014 | .030 | .006 | .065 | .005 | .193 |
| | Y | .133 | .019 | .045 | .009 | .091 | .007 | .269 |
| 3 ply 9 mm | X | .098 | .014 | .035 | .007 | .052 | .004 | .185 |
| | Y | .147 | .021 | .060 | .012 | .130 | .010 | .337 |
| 5 ply 13 mm | X | .112 | .016 | .045 | .009 | .078 | .006 | .235 |
| | Y | .112 | .016 | .020 | .004 | .039 | .003 | .171 |
| 5 ply 15 mm | X | .112 | .016 | .040 | .008 | .052 | .004 | .204 |
| | Y | .119 | .017 | .030 | .006 | .039 | .003 | .188 |
| 7 ply 18 mm | X | .119 | .017 | .045 | .009 | .065 | .005 | .229 |
| | Y | .126 | .018 | .040 | .008 | .065 | .005 | .231 |
| 9 ply 23 mm | X | .119 | .017 | .060 | .012 | .052 | .004 | .231 |
| | Y | .126 | .018 | .050 | .010 | .104 | .008 | .280 |

TABLE 2

Dimensional Increases in Thickness

| Type | Face grain direction | Interval 5 - 12% IM | 5 - 12% UM | 12 - 17% IM | 12 - 17% UM | 17% - VPS IM | 17% - VPS UM | TM |
|---|---|---|---|---|---|---|---|---|
| 3 ply 8 mm | X | 2.17 | .31 | 2.70 | .54 | 3.90 | .30 | 8.77 |
| | Y | 1.96 | .28 | 2.85 | .57 | 3.64 | .28 | 8.45 |
| 3 ply 9 mm | X | 2.38 | .34 | 3.10 | .62 | 4.16 | .32 | 9.64 |
| | Y | 2.17 | .31 | 2.85 | .57 | 3.64 | .28 | 8.66 |
| 5 ply 13 mm | X | 2.17 | .31 | 2.65 | .53 | 3.51 | .27 | 8.33 |
| | Y | 1.89 | .27 | 2.75 | .55 | 3.25 | .25 | 7.89 |
| 5 ply 15 mm | X | 1.89 | .27 | 2.45 | .49 | 3.12 | .24 | 7.46 |
| | Y | 1.96 | .28 | 2.50 | .50 | 3.25 | .25 | 7.71 |
| 7 ply 18 mm | X | 1.96 | .28 | 2.40 | .48 | 3.38 | .26 | 7.74 |
| | Y | 1.96 | .28 | 2.55 | .51 | 3.38 | .26 | 7.89 |
| 9 ply 23 mm | X | 1.89 | .27 | 2.35 | .47 | 3.51 | .27 | 7.79 |
| | Y | 1.96 | .28 | 2.45 | .49 | 3.51 | .27 | 7.92 |

The data was statistically analysed, but it proved to be difficult to see any overall pattern in the results.

As can be seen from Table 1, the longitudinal UM between 5% and 12% was generally greater than between 12% and 17%. Also the movement in the X-direction specimens was less than in the Y-direction ones, this effect disappeared with larger number of plies.

In three ply there is twice as much wood oriented in one direction as in the other. As movement due to MC change is vastly different in the longitudinal compared with the transverse grain direction, the movement of the pair of veneers oriented in one direction should tend to dominate. As the number of plies increases, the proportion of wood in each direction approaches one half.

It was expected that no differences in thickness movement would be found between X and Y directions, since the samples were closely matched and since expansion was being measured perpendicular to the surface. However, as can be seen from Table 2, differences were found to exist. The UM was generally lower between 5% and 12% than between 12% and 17%. In general, the three thinnest types have a significantly higher variance than the remaining three types.

A detailed account of this work is being prepared. Further work on mixed hardwood structural plywood and particleboard is in progress.

# THE DEVELOPMENT OF PRE-PRESS ADHESION IN GLUED VENEER ASSEMBLIES

E.R. Pankevicius
Division of Building Research, CSIRO

## INTRODUCTION

Pre-pressing can be defined as the preliminary application of pressure to a glued assembly, not to produce final cure, but primarily to ensure transfer of glue from a spread to an unspread surface. Pre-pressing is an additional operation in the manufacture of plywood and consequently an additional cost. In spite of this, it is widely adopted by the industry because it has a number of advantages related to bond quality and productivity. This paper is a general summary of recent work done by the Adhesives Group on the investigation of a range of factors involved in pre-pressing. A comprehensive report is to be issued in due course.

## EXPERIMENTAL PROCEDURE

Strips of coachwood (*Ceratopetalum apetalum*), Karri (*Eucalyptus diversicolor*) and radiata pine (*Pinus radiata*), each 203 mm x 63 mm x 2.5 mm, were conditioned to a moisture content of either 5 and 12 percent. They were then weighed and spread with glue on the loose side by brushing with a commercial phenol formaldehyde resin of 43 percent solids content mixed with walnut shell flour 20 parts to 100 parts of the liquid resin. Glue was spread on veneers at the rate of 195 $gm/m^2$ on one strip. Then the strips were assembled in a jig loose side to loose side with their grain directions parallel. The area of overlap was 152 mm x 63 mm.

After open assembly times of 0, 10, 20 or 30 min the strips were pre-pressed cold for 10 min at ambient temperature. The coachwood and karri specimens at either 0.69 MPa or 1.38 MPa, and radiata pine at 0.52 MPa or 0.86 MPa. They were then removed from the press and blockstacked. After various closed assembly times (10 min, 1 and 24 hrs) the bond strength (grip) of the uncured glue was evaluated by tensile shear testing. A visual evaluation of transfer of glue from spread to unspread veneer was also made.

## RESULTS

The effects of the following variables were examined:-

(i) open assembly time,
(ii) platen pressure,
(iii) closed assembly time,
(iv) veneer moisture content,
(v) glue transfer, and
(vi) species.

Results in Fig. 1-3 show that there is strong interaction of variables and that it is very difficult to single out and discuss the effect of each variable separately. Three species were investigated, but to keep this paper within the required length, graphed results will be presented for radiata pine only.

Fig. 1 shows the effects of pressure and open assembly times on grip at two levels of pressure.

The effects of open assembly time and moisture content of veneers on grip development are shown in Fig. 2.

In Fig. 3 the effect of pressure and veneer moisture content on glue transfer is shown.

## DISCUSSION

### OPEN ASSEMBLY TIME

Having a suitable open assembly time is an important requirement for success in pre-pressing. During the assembly time, moisture is lost from the glue line. This increases tackiness of the glue to the point where even the uncured glue develops an adhesive capability. But the loss of moisture depends largely on the veneer moisture content. If the veneer moisture content is too low, poor glue transfer will result because of rapid drying of the glue line before pressure is applied. However, if the veneer moisture content is high, the loss of water is slow and the development of tackiness will be slow. It appears that to obtain maximum grip, veneers at 5 percent moisture content should be pressed immediately after spreading. In contrast, 12 percent veneers developed maximum grip after a short open assembly time. In addition, the application of pressure whilst the glue moisture content is still high usually causes a reduction in bond strength due to excessive glue penetration or squeeze out. Results show that for the wood-glue combination studied an open assembly time of 10-20 minutes is required.

GLUE TRANSFER AND GRIP

Glue transfer is known to depend on veneer moisture content, species, glue spread, glue viscosity, open assembly time and pre-press pressure. It was found that glue transfer improved with increase in moisture content of the veneers and decreased with increasing assembly times. With veneers at low moisture content, the glue line moisture content tends to fall rapidly with time and this usually leads to poor glue transfer during pre-pressing. Grip of pre-pressed assemblies is a function of glue transfer and cohesive strength development of the adhesive at the time of pre-pressing. It appears, however, that it is more dependent on dehydration of the resin than onset of cure.

PRESSURE

One of the most important variables in pre-pressing is pressure. Its important functions are:-

(i) to assist transfer of glue from spread veneer to unspread veneer,
(ii) to facilitate partial penetration of glue into the voids of the veneer,
(iii) to remove air bubbles from the glue line, and
(iv) to attain a good grip with the proviso that the optimum quantity of resin solids remains in the glue line.

It is claimed that best results from pre-pressing are obtained when the pressure applied is above that used in the hot press. Fig. 3 shows that higher pressures have produced higher glue transfers and, therefore, better grip could have been expected. However, each of the three species used responded differently with regard to pressure applied, most likely as a result of the wide range of specific density of the species used. In radiata pine best results were obtained with .52 MPa pressures, with coachwood .69 MPa and with karri 1.38 MPa.

CONCLUSIONS

From the results presented it can be concluded that to obtain optimum grip of uncured glue:-

(i) higher pressures are required for higher density species,
(ii) assemblies of lower moisture content (approx. 5%0 should be pre-pressed immediately, while higher moisture content (approx. 12%) material requires an open assembly time of at least 10 minutes.

At present further work is in progress using larger panels and evaluating bond strength after hot pressing, main variables being open and closed assembly times and veneer moisture contents.

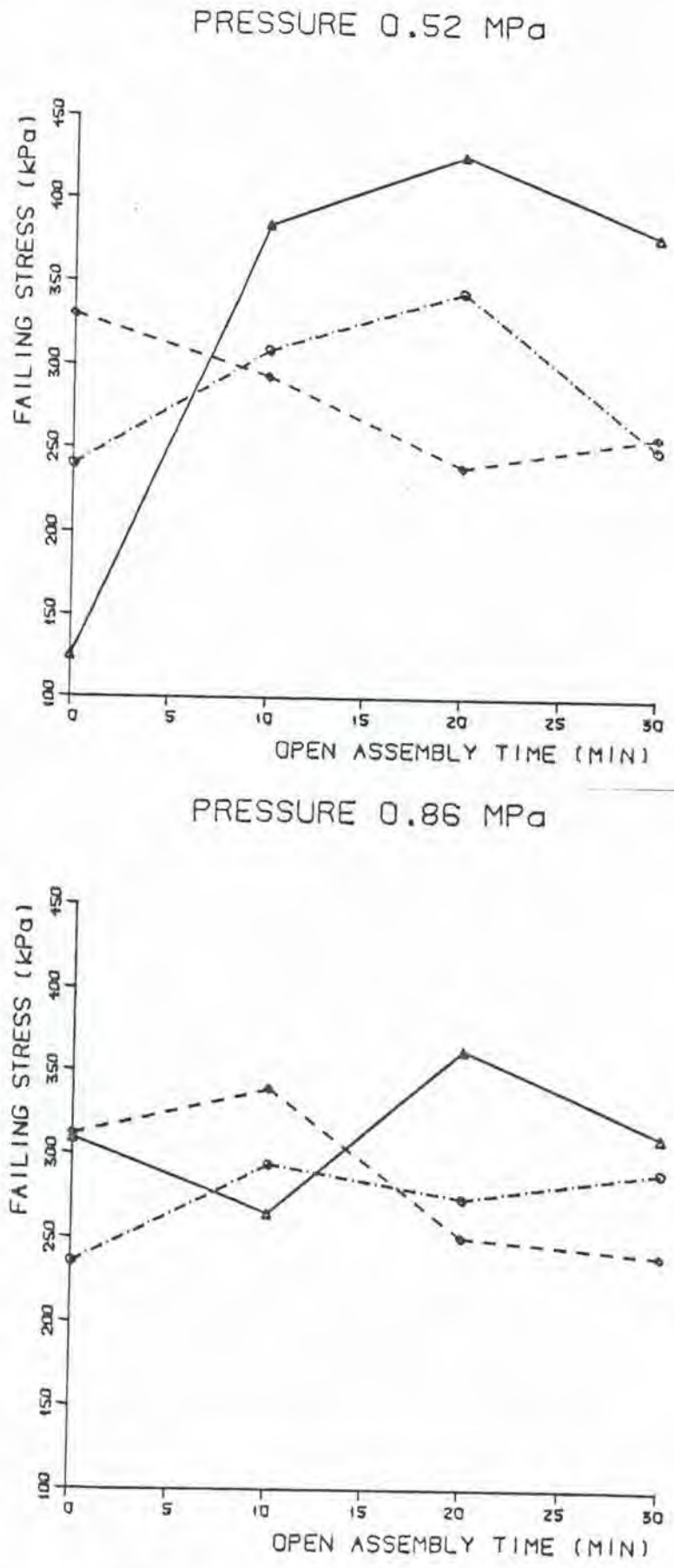



FIG. 1. Effect of pressure and open assembly times on grip.
(after pre-pressing: —10 min, -·-60 min, --24 hr)

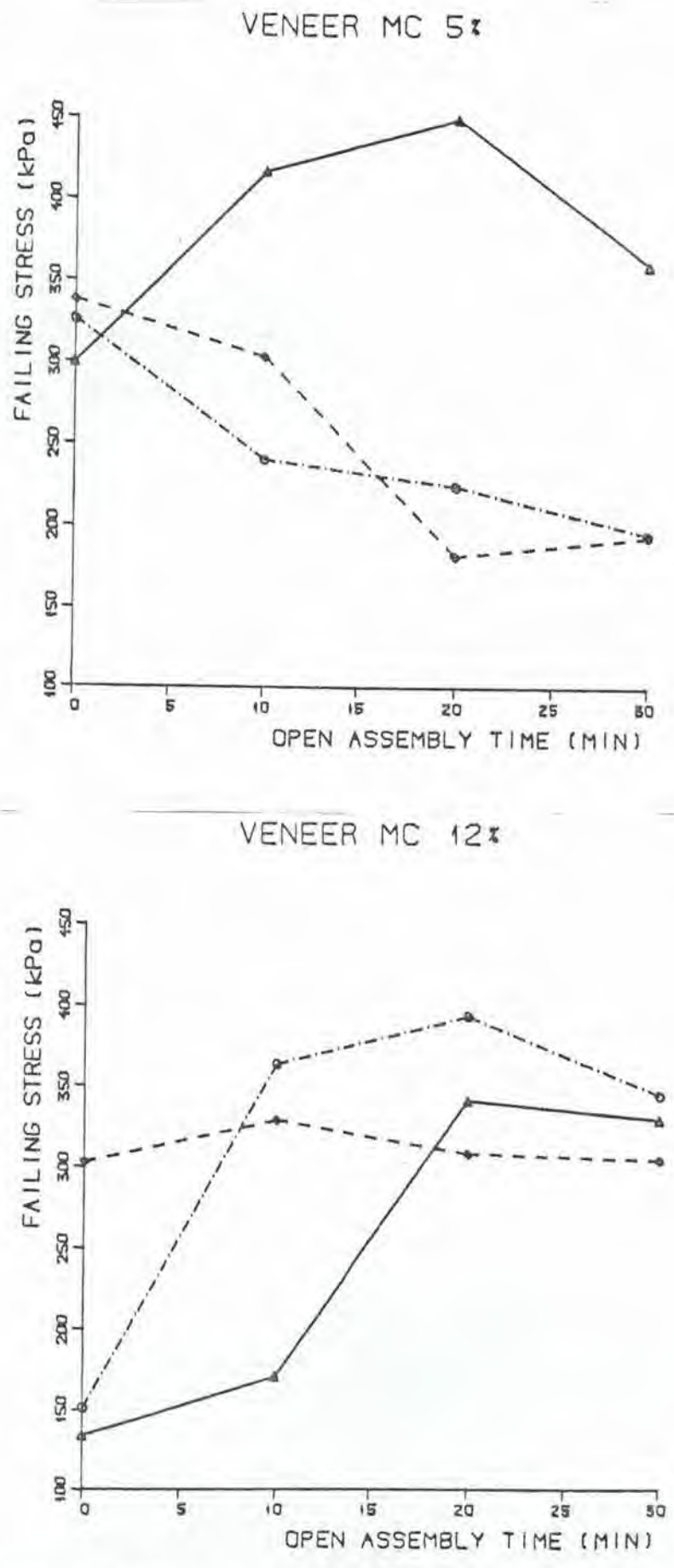



FIG. 2. Effect of open assembly times and moisture content of veneers on grip. (after pre-pressing: — 10 min, —·—60 min, - - 24 hr).

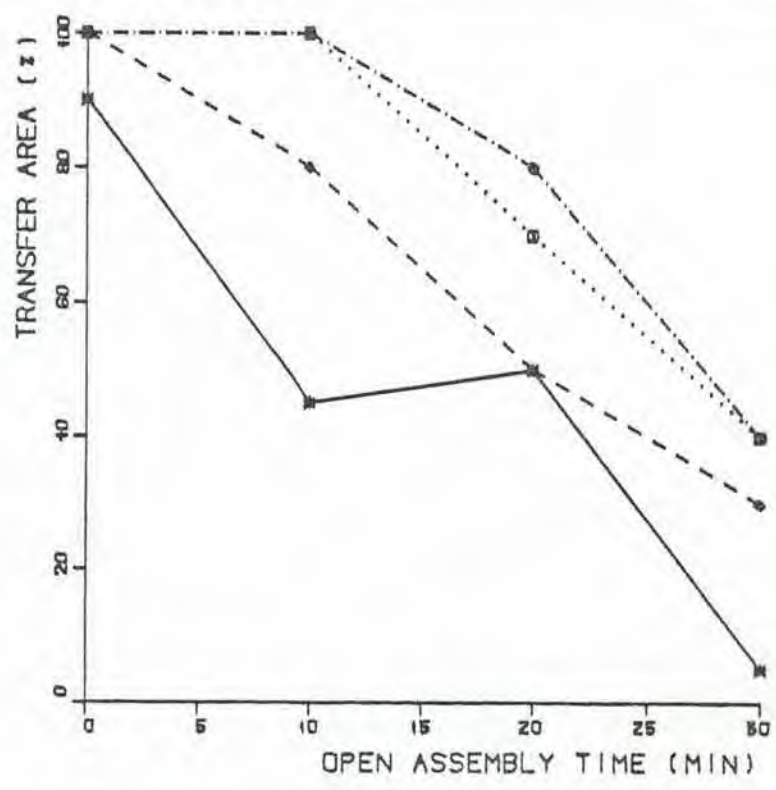



FIG. 3. Effects of pressure and veneer moisture content on glue transfer.

LEGEND

0.52 MPa Pressure

—— 5% veneer mc

—·— 12% veneer mc

0.86 MPa Pressure

···· 5% veneer mc

— — 12% veneer mc

# LABORATORY ASSESSMENT OF POTENTIAL PRESERVATIVES FOR SHORT-TERM PROTECTION OF EXPOSED CASEIN-GLUED JOINTS

J.D. Thornton and H.F.A. Hergt
Division of Building Research, CSIRO

## ABSTRACT

Some house stud timber is produced by finger jointing short pieces sawn from defect containing material, into longer pieces. Casein would be a most suitable glue for this purpose if casein-glued joints were not susceptible to the risk of microbiological attack which could arise when they are exposed to rain-wetting during house frame construction. However, the comparatively low cost of casein is such that the addition of a preservative might be economically feasible if a suitable one could be found.

In preliminary work, some 40 to 50 preservative chemicals were tested for their compatibilities with casein and wood but only six of them showed promise. Formulations incorporating these preservatives at concentrations of both 5% and 10% by mass of dry casein were used to glue two-ply panels of CCA-treated veneers. Specimens from these panels were exposed according to Australian Draft Standard DR 76047, Part 5 - Resistance of Glue-line in Plywood to Micro-organism Attack. At the conclusion of the exposure and drying, the specimens were cut into lap-shear test pieces and tested. Results showed that only two of the preservatives, "Tricidal" and "Permapruf T" both at 10% concentration, gave a protection better than 50% of the original bond strength, the criterion proposed for evaluating the strength requirements of casein-glued finger joints exposed to the weather in the short term.

## INTRODUCTION

Casein, being a protein, would normally be considered a "microbial food"; but because of the low cost of the glue it might still be economic to add a relatively high concentration of a compatible preservative to make this glue suitable for short term exterior use. Casein-bonded finger-joints in house studs would need preservative protection for the period from erection to cladding of the structure.

The present study is not the first attempt at this Division to preserve casein glue. Timber glued with casein incorporating 5% sodium pentachlorophenate failed after three weeks' exposure (N. Tamblyn, personal communication).

MATERIALS AND METHODS

Some 40 to 50 preservative chemicals were screened in the laboratory for compatibility of mixing with the casein glue formulations: Casein, HCℓ precipitated, 100 g; $Ca(OH)_2$, 30 g; NaF, 9.4 g; water 240 mℓ. A quantity of each mixture was also placed on pieces of untreated plywood which after allowing time for the glue to set, were placed on the Division's outdoor exposure racks and left for 48 hours. During this time some rain fell and many of the formulations showed bond failure. The preservatives contained in them were excluded from further consideration. Space does not permit here a listing of all the chemicals suggested as potential preservatives. Both inorganic and organic preservatives were included, with paint preservatives, wood preservatives and agrochemicals being represented. From this preliminary work only six potential formulations were found to be promising: the solid "Busan II M1", and the liquid formulations "Proxel PL", "Tricidal", "Busan 30", "Permapruf T", and phenyl mercury dodecyl succinate.

For ease of handling and strength testing and in order to have sizes suitable for the laboratory testing of many specimens against biodeterioration, plywood was used rather than finger-jointed offcuts. *Pinus radiata* D. Don veneer sheets 2.5 mm thick, were treated with copper-chrome-arsenic to an average retention of 5.6 Kg $m^{-3}$. This treatment was given so that the glue, rather than the wood, was the only component under test against biodeterioration. Two-ply panels 300 mm square were made up in pairs, using casein glue containing either 5% or 10%, of active ingredient, for each of the six candidate preservatives (the 5% or 10% being the percentage of mass of dry casein content in the glue). A control treatment, using water instead of preservative, was also included. These panels were cut into pieces a little larger than 100 mm x 50 mm. Two sets of replicate specimens were produced, one for exposure to 6 weeks' micro-organism attack and the other for 12 weeks' exposure. For each concentration of preservative, 6 replicate specimens (3 from each of 2 CCA-treated panels) were exposed for each period. Controls were also provided at the level of four for each preservative at each concentration. These unexposed specimens were kept in the 12% MC room during the exposure tests.

The microbial susceptibility test was carried out largely in accordance with Australian Draft Standard DR 76047, Part 5 Resistance of Glue-lines in Plywood to Micro-organism Attack. Two large galvanised metal tanks each 1300 x 900 x 200 mm deep were used for this purpose. In each tank *P. radiata* sawdust was mixed with 36 ℓ of tap water containing 2% glucose and 0.2% bacteriological peptone. The moist sawdust was then loosely compacted to a depth of 50 mm in the tanks.

The six and 12 weeks tests were carried out in two separate tanks. Specimens from all treatments were randomised before placing each specimen (at 12% moisture content) into the appropriate tank with its upper surfaces level with the top of the sawdust. Specimens were placed 30 mm apart and a handful of garden loam was sprinkled over the surface of the sawdust in each tank before covering the tank with a plastic sheet. Tanks were then incubated at 25° C for either 6 or 12 weeks. At the end of these periods specimens were removed and individually weighed before conditioning to 12% MC and reweighing. The moisture content of each specimen at the end of the exposure period was then calculated.

Two lap-shear specimens 100 x 20 mm with a 20 x 20 mm overlap were then cut from each 100 x 50 mm piece. They were taken as close as possible to the edges of the exposed specimens to ensure that the glue to be tested had received the maximum exposure to attack.

## RESULTS

The results of both exposure trials are combined in Table 1. The shear test values expressed in megapascals (MPa) are the means of all specimens for each preservative according to the amount of preservative added and the exposure time. The bonds of some specimens were so little protected by their preservative that the shear pieces were too fragile to load. For these, zero values were allotted in the calculations of the means, but if there were more than five zero values in any group of twelve (6 replications x 2 shear values) the standard deviation is not listed in Table 1. The moisture content of the specimens at the conclusion of exposure show that the conditions in the 'six weeks' exposure' tank were considerably wetter than in the '12 weeks' exposure' tank. The specimens which were too fragile to be tested in shear were visually examined under strong light and it was seen that very little glue was left to provide a bond. It was concluded

that it had been consumed by the microbial attack.

TABLE 1

Lap-shear Strength of Two-ply Radiata Pine Panels Bonded with Preservative Treated Casein, after Exposure to Microbial Attack and Conditioning to 12% Moisture Content

| Preservative and level | | Exposure time | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 0 | | 6 weeks | | | | 0 | | 12 weeks | | | |
| | | Mean MPa | SD | Mean MPa | SD | Ch% | MC% | Mean MPa | SD | Mean MPa | SD | Ch% | MC% |
| Control | 0 | 2.5 | 0.52 | 2.2 | 0.54 | 13 | 170 | 2.5 | 0.52 | 0 | - | 100 | 93 |
| Proxel PL | 5 | 2.3 | 0.24 | 1.4 | 0.45 | 38 | 155 | 2.1 | 0.28 | 0.1 | - | 94 | 46 |
| | 10 | 2.3 | 0.48 | 1.5 | 0.8 | 35 | 170 | 2.1 | 0.2 | 0 | | 100 | 96 |
| Busan II M1 | 5 | 3.0 | 0.18 | 2.4 | 0.77 | 21 | 182 | 2.7 | 0.27 | 0.1 | - | 97 | 100 |
| | 10 | 2.9 | 0.27 | 2.7 | 0.39 | 6 | 163 | 2.6 | 0.26 | 0.2 | - | 93 | 93 |
| Tricidal | 5 | 2.7 | 0.41 | 2.6 | 0.31 | 4 | 184 | 2.6 | 0.37 | 0.8 | 0.59 | 70 | 74 |
| | 10 | 2.7 | 0.60 | 2.7 | 0.32 | 0 | 165 | 2.6 | 0.31 | 1.5 | 0.98 | 40 | 70 |
| Busan 30 | 5 | 2.6 | 0.33 | 0.6 | 0.54 | 75 | 175 | 2.7 | 0.54 | 0 | - | 100 | 130 |
| | 10 | 3.3 | 0.32 | 0 | - | 100 | 165 | 2.8 | 0.31 | 0 | - | 100 | 105 |
| Permapruf T | 5 | 3.0 | 0.51 | 2.0 | 0.71 | 34 | 164 | 2.6 | 0.3 | 1.3 | 1.02 | 50 | 68 |
| | 10 | 2.6 | 0.44 | 2.7 | 0.49 | +5 | 155 | 3.0 | 0.29 | 2.6 | 0.53 | 11 | 57 |
| Phenyl Hg dodecyl succinate | 5 | 2.9 | 0.47 | 2.5 | 0.56 | 15 | 145 | 2.9 | 0.30 | 0.9 | - | 68 | 42 |
| | 10 | 2.8 | 0.25 | 2.7 | 0.45 | 6 | 149 | 2.5 | 0.26 | 0.5 | - | 79 | 83 |

In Table 1, the column headed Ch% lists the changes in bond strength of the exposed specimens when compared with eight unexposed specimens cut from the same panels. Except for "Permapruf T" at 10% level and 6 weeks' exposure, these are all decreases. The "Permapruf T" result shows a 5% increase which was not significant. It will be seen that at the end of the six weeks' trial, the only system to fail to meet the proposed requirement of a loss in strength not exceeding 50% (H. Kloot, personal communication), was the "Busan 30" series, although its controls at 10% concentration had the highest lap-shear strengths.

After the 12 weeks' exposure, the only system clearly able to meet the 50% strength requirement was the "Permapruf T" at 10% concentration. None of the systems at a level of 5% addition met the requirement although "Permapruf T" may have been close. However, an acknowledged wide variation in individual values for bond strength with this chemical casts doubt on the protection it provided at that level. Similarly, the "Tricidal" system at

10% addition after 12 weeks exposure might be considered to provide only marginal protection for the same reason.

Based on the losses in bond strength shown in Table 1, the preservatives were ranked in decreasing order of effectiveness and this information is shown in Table 2.

TABLE 2

Rankings of Modified Adhesives
(Based on Table 1 Results)

| Preservative | 6 weeks exposure | | 12 weeks exposure | | Total score | Rank |
|---|---|---|---|---|---|---|
| | 5% score | 10% score | 5% score | 10% score | | |
| Control | 2 | =6 | 5 | =5 | 21 | =5 |
| Proxel PR | 6 | 4 | 6 | =5 | 21 | =5 |
| Busan II M1 | 4 | 5 | =3 | 4 | 16 | 4 |
| Tricidal | 1 | 3 | 2 | 2 | 8 | =1 |
| Busan 30 | 7 | =6 | 7 | =5 | 25 | 7 |
| Permapruf T | 5 | 1 | 1 | 1 | 8 | =1 |
| Phenyl Hg dodecyl succinate | 3 | 2 | =3 | 3 | 11 | 3 |

The generally better performance of "Permapruf T" and "Tricidal" can be seen. Additionally, when the rankings were summed for the two levels of addition and the two exposure times, the results confirmed the superior ranking of these two preservatives.

## CONCLUSIONS

According to the test and assessment criteria employed in the results reported, only two of the six preservatives tested appear to be worth further consideration as additives to a casein adhesive for finger joints in house studs which may be exposed for limited periods of time to rain wetting. These were "Permapruf T" and "Tricidal" when added to the glue at a level of 10% active ingredient by mass based on the dry casein content of the glue. Long term tests on finger joints glued with casein protected by these two preservatives would be worthwhile.

## ACKNOWLEDGEMENTS

The authors are grateful to Mr Dan McCarthy, a research chemist of this Division, for his assistance with the compilation of the list of candidate chemicals.

REFERENCE

Standards Association of Australia: DR 76047 (1976) Draft Standard for Sampling and Testing Veneer and Plywood. (Now issued as AS2098-1977).

# DAMAGE DUE TO PROOF LOADING

by

R H Leicester, H O Breitinger, R McNamara

## ABSTRACT

Methods for the quantitative measurement of damage due to proof loading are described. These include laboratory tests carried out on conventional testing machines, and mill studies undertaken with the aid of proof grading machines. Some results are presented.

## INTRODUCTION

In Australia there has recently been introduced a method of grading timber based on proof testing (1,2). In grading timber in this manner, an allowance must be made for the fact that the applied proof load may cause damage to the timber before it is put into service. The following describes methods that have been used for measuring the characteristics of this damage.

## METHODS OF MEASUREMENT

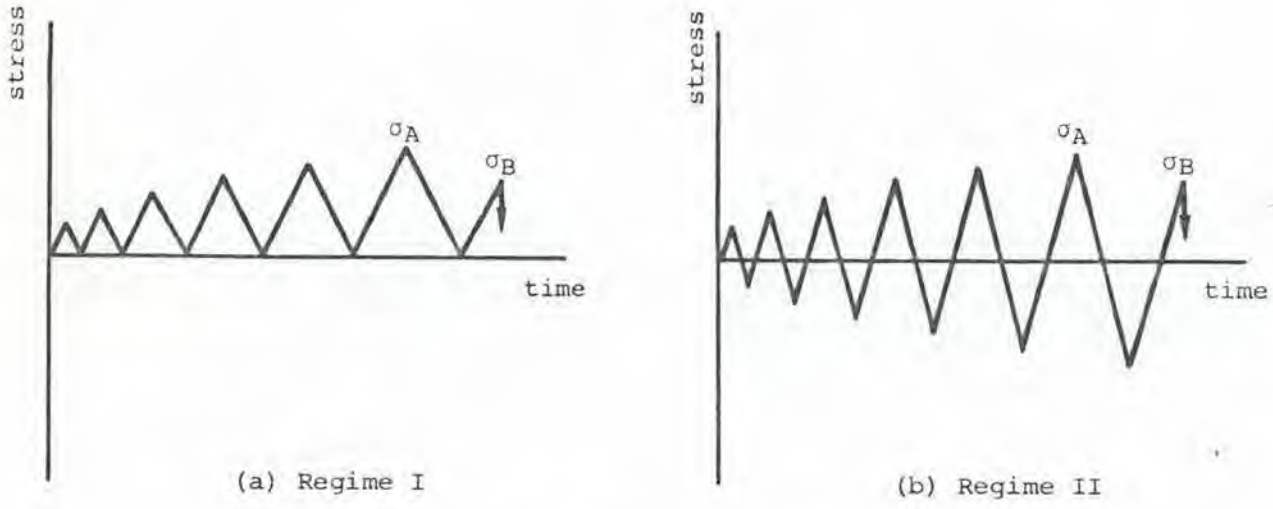
### LABORATORY MEASUREMENTS

In the laboratory test, timber scantlings of dimensions 90 x 35 mm were tested either in bending over a span of 1300 mm or in tension over a length of some 2500 mm between grips. In these tests, the maximum defects were located at the centre of the test specimens.

The two loading regimes used involved applying loads of increasing magnitude as shown in Fig. 1. The load increments were chosen so that typically 5-10 cycles of loading were required to cause failure. If the failure stress $\sigma_B$ was less than $\sigma_A$, the value of the previous loading, then the stick was considered to have been damaged due to proof loading. An estimate of the undamaged

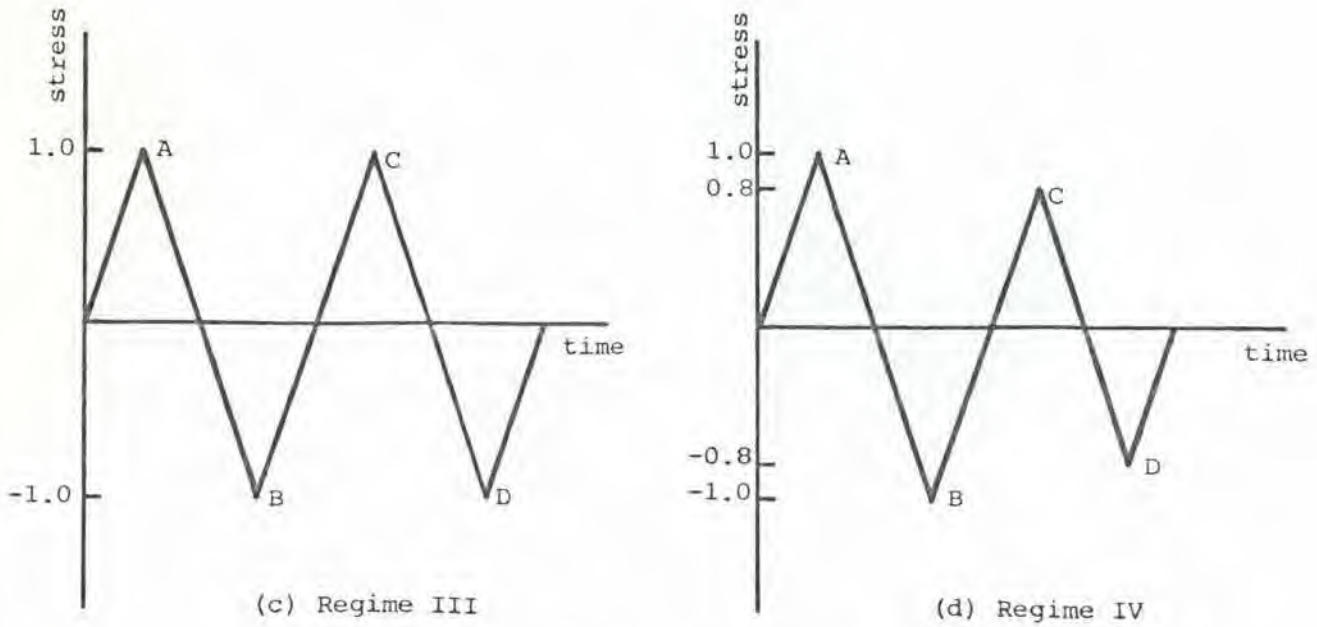
strength was taken to be given by $\sigma_A$, and the severity of the damage was specified in terms of a parameter H defined by

$$H = \frac{\sigma_A - \sigma_B}{\sigma_A} \qquad (1)$$




(a) Regime I (b) Regime II

Fig. 1 Loading regimes for laboratory tests




(c) Regime III (d) Regime IV

Fig. 2 Loading regimes for mill studies

MILL STUDIES

In mill studies, large samples of 200-1000 sticks of scantling were passed four times through a stress grader. The stress history for each stick during these passes was either that of regime III or IV shown in Fig. 2. The number of failures during the third and fourth passes, denoted C and D in Fig. 2, provided an indication of the proportion of timber damaged in the case of loading regime III, and the severity of the damage in the case of loading regime IV.

RESULTS

A summary of the laboratory test data is given in Table 1. Usually 100-150 sticks comprised the sample sizes used for each test. Damage due to proof loading was found to occur in 5-15 per cent of the timber sample. The 50 percentile value of the severity of this damage, denoted by $H_{a,5}$, was typically in the range 0.05-0.10. In addition, the measured values of the ratio $R_a/R_u$ (defined in Table 1) indicates that the stronger grades of timber tend to be more damage susceptible.

Figs 3 and 4 show the probability density function $f_H(x)$ and complementary distribution function $G_H(x) = Pr\{H>x\}$ of the measured damage severity. Also shown are the following ideal functions that have been used previously in developing mathematical models of proof grading (3)

$$f_H(x) = (1/\delta)[1 + \cos(\pi x/\delta)] \quad (2)$$

$$G_H(x) = 1 - (x/\delta) + (1/\pi) \sin(\pi x/\delta) \quad (3)$$

where $\delta$ is a constant that defines the non-zero range $0 < x < \delta$ of the functions $f_H(x)$ and $G_H(x)$.

Due to space limitations, information obtained in mill studies cannot be presented herein. However, it is worth mentioning one result noted in the application of loading regime III shown in Fig. 2a. It was found that if the load was set so that a 5 per cent failure rate was obtained during the first two passes A and B, then a failure rate of about 0.5 per cent was obtained during the subsequent passes C and D. This indication of damage due to proof loading is about the amount that would be expected from a consideration of the data obtained in the laboratory tests.

ACKNOWLEDGEMENTS

The authors are indebted to RPAA, TRADAC (Queensland) and TPC (Victoria) for the supply of test material, for undertaking the mill studies mentioned, and for their keen interest in the development of proof grading.

REFERENCES

1. Anon. (1981). Proof grader a success. Australian Forest Industries Journal. February, p.62.

2. Wooster, R. (1981). The TRADAC proof grader. Australian Forest Industries Journal. April, pp.30-32.

3. Leicester, R.H. (1981). Unpublished, CSIRO Division of Building Research.

TABLE 1
DATA FROM LABORATORY TESTS

| Timber | Test method | Diameter of loading head (mm) | Loading regime | No. of damaged sticks (%) | Damage severity $H_{0.5}$ | Strength of damage susceptible timber $R_d/R_u$ |
|---|---|---|---|---|---|---|
| Dry *Pinus radiata* | cp | 50 | II | 11 | 0.17 | 1.08 |
| " | cp | 300 | II | 9 | 0.06 | 1.22 |
| " | cp | 600 | II | 11 | 0.09 | 1.12 |
| " | 4p | - | II | 9 | 0.08 | 1.35 |
| " | 4p | - | Ic | 7 | 0.06 | 1.29 |
| " | 4p | - | It | 3 | 0.03 | 0.77 |
| " (finger joints) | cp | 300 | II | 17 | 0.04 | 1.04 |
| " | tension | - | II | 10 | 0.04 | 1.29 |
| Green *Eucalyptus obliqua* | cp | 300 | II | 8 | 0.11 | 1.34 |
| " | cp | 600 | II | 12 | 0.12 | 1.27 |
| " (borer infested) | cp | 300 | II | 25 | 0.06 | 1.21 |
| Green *Callitris glauca* | cp | 300 | II | 11 | 0.08 | 0.93 |

Notation used

cp = centre point loading
4p = four point loading , loading heads spaced at 300 mm
Ic = loading regime I, defect on compression edge
It = loading regime I, defect on tension edge
$R_d$ = mean undamaged strength of damage susceptible timber
$R_u$ = mean strength of timber not susceptible to damage

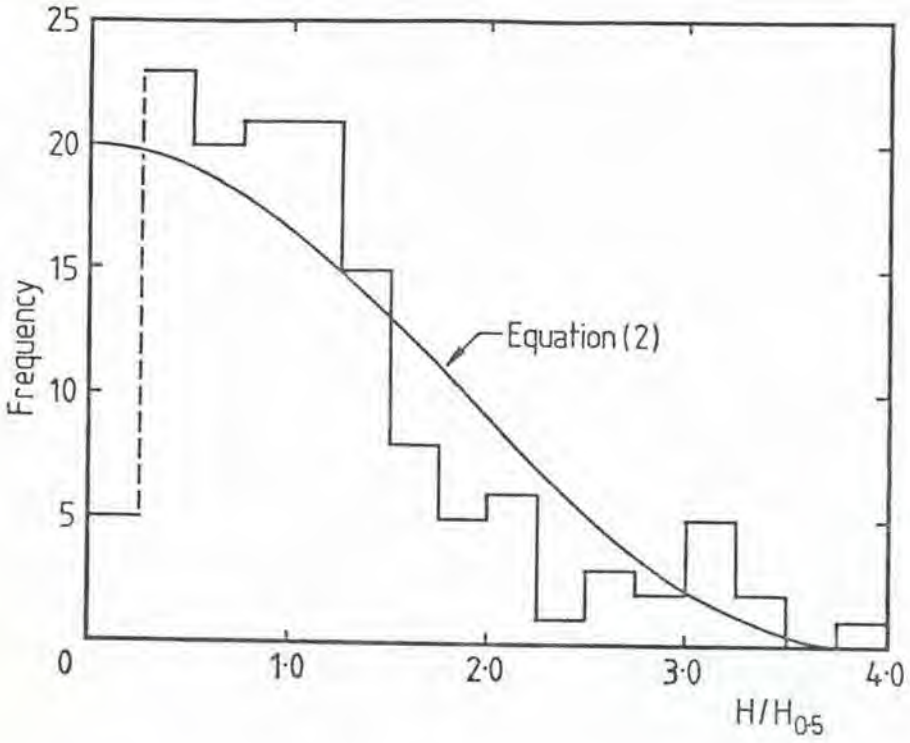



Fig. 3 Histogram of all laboratory data on damage severity

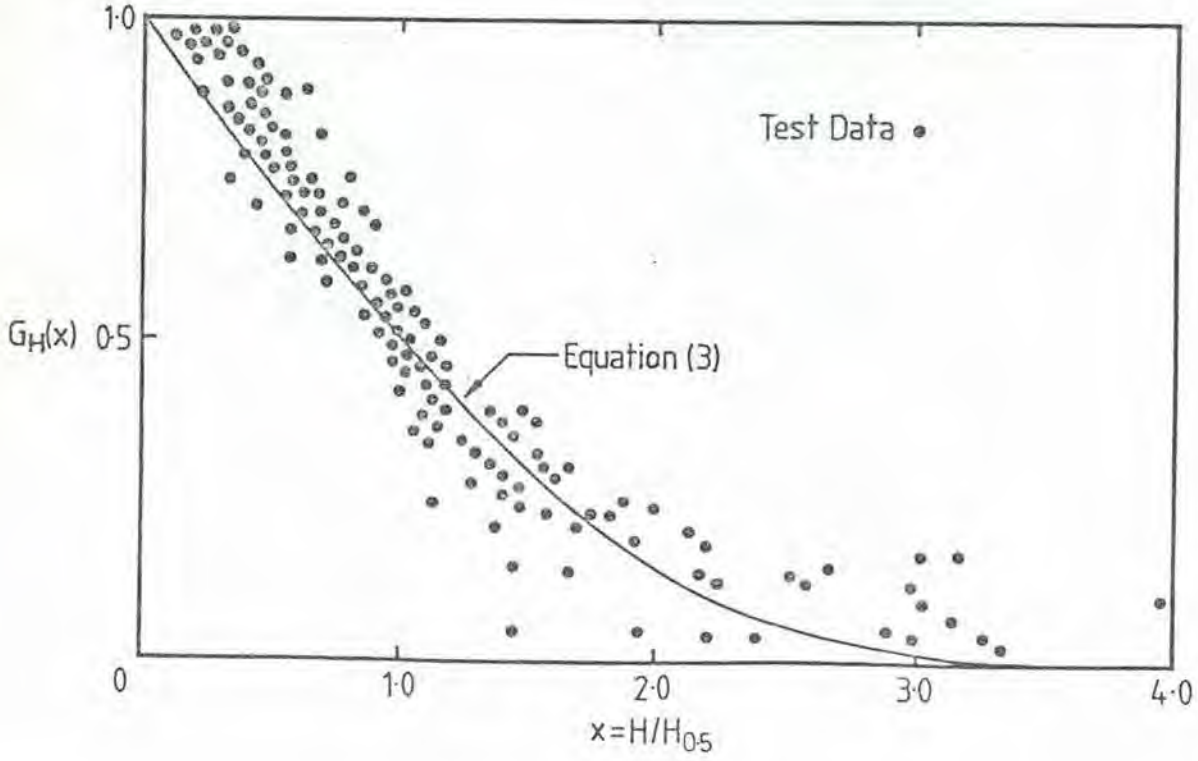



Fig. 4 Complementary distribution function of all laboratory data on damage severity

# STRENGTH OF SLENDER PLYWOOD WEBS IN SHEAR

L. Pham and R.H. Leicester
Division of Building Research, CSIRO

ABSTRACT

Slender plywood webs in shear have low buckling strength but possess considerable post-buckling strength from diagonal tension effects. This paper outlines a method of computing the ultimate strength of slender plywood webs loaded in shear. The results are compared with experimental data.

## INTRODUCTION

Consider a slender plywood panel loaded in shear (Fig.1), prior to buckling the web panel develops both tensile and compressive direct stresses. After buckling has developed, the web has no further capacity to carry extra compressive stresses but further load can still be carried by diagonal tension. Many models for this diagonal tension have been developed to predict the post-buckling load capacity but are not suitable for application to plywood web beams. For example, the partial diagonal tension model (Porter et al. 1975) currently being used for steel plate girders has been found not to be suitable because plywood webs do not display the required ductile yield plateau, and because timber flanges are relatively speaking too thick to form plastic hinges. Of the various models available, the complete diagonal tension model (Kuhn 1956) appear to fit best the experimental behaviour observed in tests on plywood-web beams, and this model will be used in this paper for the ultimate shear strength of plywood webs.

## METHOD OF CALCULATION

The ultimate strength $V_u$ of a plywood-web beam will be taken to be the lesser of the following :

$$V_{u1} = V_e + V_d + V_f$$

$$V_{u2} = V_s + V_f$$

where $V_e$ is the elastic shear buckling load of the plywood web,

$V_d$ is the shear carrying capacity resulting from diagonal tension strength of the plywood web,

$V_f$ is the contribution of the flanges and web stiffeners to the shear carrying capacity of the beam,

$V_s$ is the panel shear strength of a stable plywood web.

The method of obtaining the elastic buckling load $V_e$, is well known and has been described by Leicester(1975). The stable shear strength $V_s$, which is the ultimate panel shear strength in the absence of buckling, is obtained from measured material properties (Curry and Hearmon 1967).

The interaction between the web and the flanges is complex, particularly in the post-buckling region and will not be discussed in detail herein. Roughly, the contribution of the flanges to the shear carrying capacity for the test beams, denoted by $V_f$, is estimated by assuming that the flanges act as simply-supported beams with deflection matching those of the plywood web under shear.

Finally the shear force $V_d$ carried by a diagonal tension field $N_d$ inclined at an angle $\theta$ to the flanges is given by

$$V_d = 1/2a.N_d \sin\theta.\cos\theta \qquad (1)$$

where $N_d$ is the tension membrane force per unit length, Fig.1.

The tension membrane force $N_d$ has a maximum possible value given by

$$N_d = N_{t\theta} - N_{tE} \qquad (2)$$

where $N_{t\theta}$ is the membrane force of the plywood in the direction $\theta$, and $N_{tE}$ is the membrane buckling force $N_E$ resolved in the direction $\theta$, ie.

$$N_{tE} = 2N_E \sin\theta\cos\theta \qquad (3)$$

The membrane force $N_{t\theta}$ can be obtained by fitting a curve to the following three points of known tensile strengths (Fig.2):

$$\theta = 0 \qquad N_{t\theta} = k.t_w.F_{tu}$$

$$\theta = \Pi/4 \qquad N_{t\theta} = t_w.F_{tu}/G$$

$$\theta = \Pi/2 \qquad N_{t\theta} = (1-k)t_w.F_{tu}$$

where $F_{tu}$ is the ultimate tensile stress of the timber along the grain, k is the ratio of areas of effective plies to the gross area and $t_w$ is the plywood web thickness.

The expression for $V_d$ is taken so as to give the highest possible shear capacity. This is achieved when $\theta$ is approximately equal 15°. For this case equations (1), (2) and (3) lead to

$$V_d = 1/4a\ (N_{t\theta} - N_e/2)$$

COMPARISION WITH EXPERIMENTAL DATA

The plywood web panel geometry and the basic components of the calculation of the ultimate loads are summarized in Table 1.

TABLE 1
Calculation of the basic components
of the beam ultimate shear load capacity

| BEAM NUMBER | PANEL SIZE a x b x t (mm) | CALCULATION | | | |
|---|---|---|---|---|---|
| | | $V_\epsilon$ (kN) | $V_d$ (kN) | $V_f$ (kN) | $V_s$ (kN) |
| DBR1 | 410x550x7 | 37.2 | - | 2.5 | 28.4 |
| DBR2 | 410x535x7 | 37.2 | - | 2.5 | 28.4 |
| DBR3 | 300x485x7 | 19.3 | 8.6 | 3.7 | 20.8 |
| DBR4 | 300x510x7 | 19.3 | 8.6 | 3.7 | 20.8 |
| DBR5 | 150x460x7 | 26.5 | - | 1.8 | 10.4 |
| DBR6 | 150x460x7 | 26.5 | - | 1.8 | 10.4 |
| DBR7 | 150x540x7 | 104.3 | - | 1.3 | 10.4 |
| DBR8 | 300x520x7 | 19.3 | 8.6 | 1.3 | 20.8 |
| DBR9 | 1000x2230x7 | 4.9 | 38.6 | 4.6 | 69.3 |
| DBR10 | 905x2250x7 | 5.1 | 37.3 | 1.3 | 62.7 |
| DBR11 | 460x460x7 | 33.1 | - | 22.3 | 31.9 |
| DBR12 | 460x460x7 | 33.1 | - | 22.3 | 31.9 |
| PIT5 | 770x770x11 | 82.6 | 34.4 | 90.8 | 85.6 |
| PIT6 | 770x770x7 | 19.8 | 26.0 | 66.7 | 53.4 |
| PIT7 | 770x1925x7 | 5.7 | 29.4 | 9.6 | 53.4 |

Table 2 compares the computed and measured values of buckling and ultimate loads. The computed buckling loads agree fairly well with the experimental values obtained from the Southwell plots for small panels (less than 770x770 mm) and tend to be conservative for larger panels. It has also been observed that the lateral deflection of the web is approximately equal to the web thickness at the buckling load. The results of the ultimate load calculation show that the proposed method gives close but conservative values for the ultimate loads.

In Table 3 the ratio of the ultimate to the buckling load of the web is tabulated. It is seen that for panels of high slenderness, the ultimate load can be as high as ten times the buckling load.

## CONCLUSION

Experimental data confirm that the buckling and ultimate strength of a plywood web loaded in shear can be reliably predicted by the above proposed method of calculation. The difference between the buckling and ultimate loads of a slender plywood web in shear is considerable and should not be ignored in the formulation of the design rules.

## REFERENCES

Curry, W.T., and Hearmon, R.F.S. (1967). "The strength properties of plywood, Part 2 - The effect of the geometry of construction." Bulletin No.33, Forest Product Research, Ministry of Technology, HMSO, London.

Kuhn, P. (1956). "Stresses in aircraft and shell structures". McGraw-Hill.

Leicester, R.H. (1975). "Buckling Strength of Plywood Webs". 17th Forest Products Research Conference, Melbourne.

Porter, D.M., Rockey, K.C., and Evans, H.R. (1975). "The collapse behaviour of plate girders loaded in shear". The Structural Engineer, No.8, Vol.53, August.

TABLE 2
Comparision of the computed and measured values of buckling and ultimate loads

| BEAM NUMBER | BUCKLING LOAD COMPUTED (kN) | BUCKLING LOAD MEASURED (kN) | ULTIMATE LOAD COMPUTED (kN) | ULTIMATE LOAD MEASURED (kN) |
|---|---|---|---|---|
| DBR1 | - | - | 30.9 | 32.5 |
| DBR2 | - | - | 30.9 | 33.0 |
| DBR3 | 21.7 | 16.8 | 24.5 | 23.3 |
| DBR4 | 21.7 | 22.2 | 28.3 | 25.1 |
| DBR5 | - | - | 12.2 | 14.0 |
| DBR6 | - | - | 12.2 | 13.9 |
| DBR7 | - | - | 11.7 | 15.0 |
| DBR8 | 20.3 | 20.0 | 22.1 | 18.8 |
| DBR9 | 5.1 | 13.0 | 48.1 | 52.5 |
| DBR10 | 5.2 | 9.0 | 44.2 | 35.0 |
| DBR11 | - | - | 54.2 | 73.5 |
| DBR12 | - | - | 54.2 | 63.7 |
| PIT5 | 171.2 | 181.8 | 176.4 | 204.5 |
| PIT6 | 52.0 | 65.0 | 112.5 | 161.5 |
| PIT7 | 7.4 | 12.5 | 44.7 | 73.5 |

TABLE 3
Ratio of ultimate to buckling load of plywood webs.

| BEAM NUMBER | SLENDERNESS FACTOR $\sqrt{V_s/V_e}$ | LOAD RATIO $(V_u-V_f)/V_e$ COMPUTED | LOAD RATIO $(V_u-V_f)/V_e$ MEASURED |
|---|---|---|---|
| DBR7 | .31 | .10 | .13 |
| DBR5 | .63 | .39 | .46 |
| DBR6 | .63 | .39 | .46 |
| DBR1 | .87 | .76 | .81 |
| DBR2 | .87 | .76 | .82 |
| DBR11 | .98 | .96 | 1.54 |
| DBR12 | .98 | .96 | 1.25 |
| PIT5 | 1.02 | 1.04 | 1.38 |
| DBR3 | 1.04 | 1.08 | 1.02 |
| DBR4 | 1.04 | 1.08 | 1.11 |
| DBR8 | 1.04 | 1.08 | .91 |
| PIT6 | 1.64 | 2.31 | 4.79 |
| PIT7 | 3.06 | 6.15 | 11.20 |
| DBR10 | 3.51 | 8.41 | 6.60 |
| DBR9 | 3.76 | 8.88 | 9.78 |

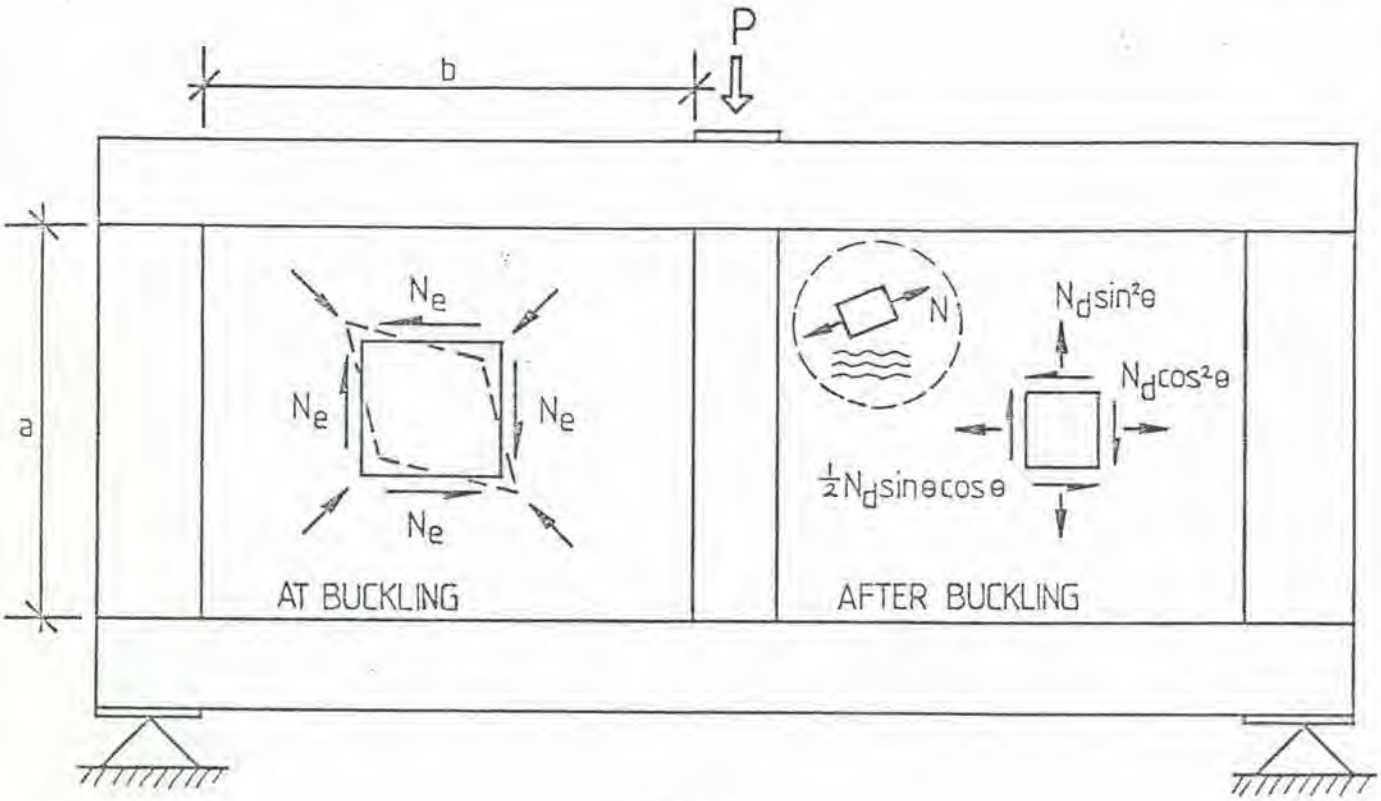



FIGURE 1.

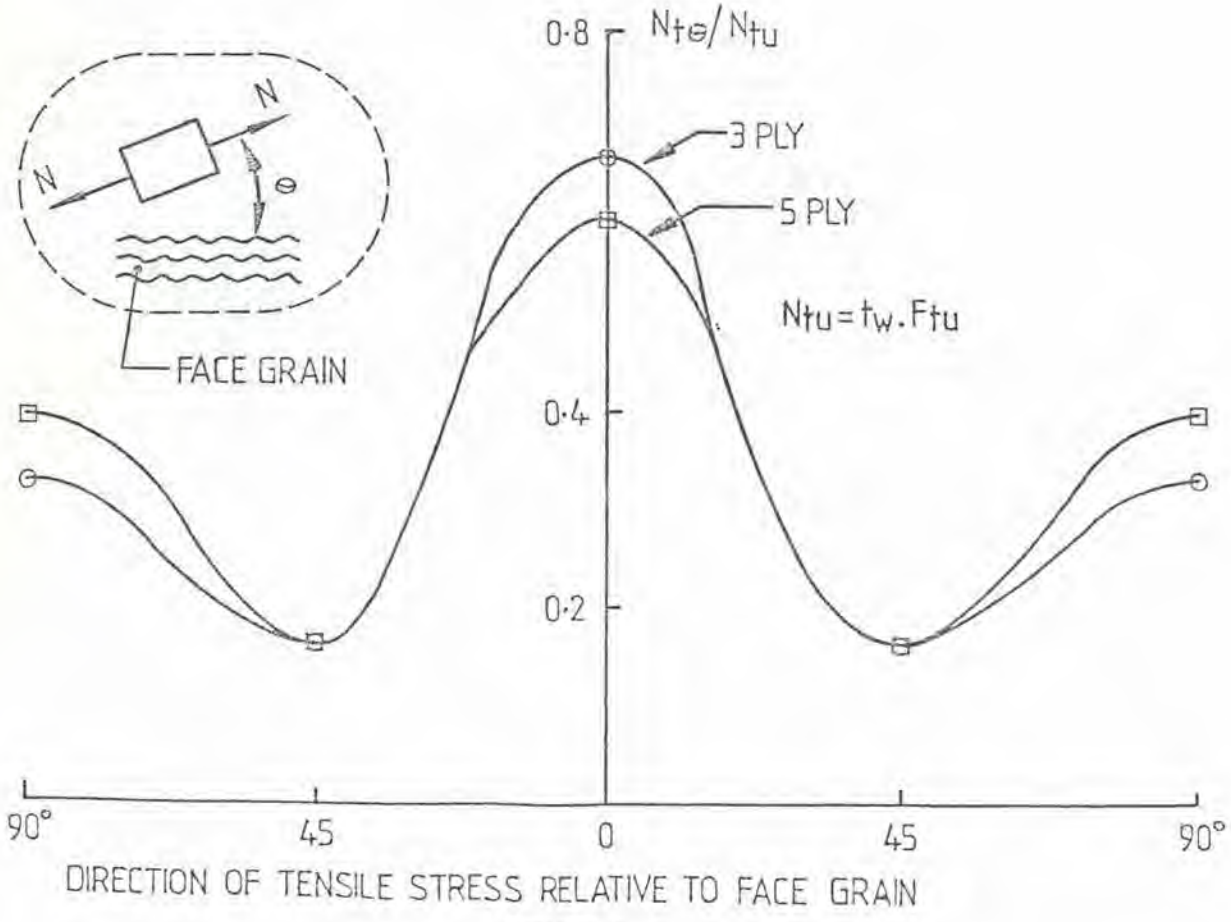



FIGURE 2.

# MODELS FOR EVALUATING STRESS GRADING

by

R H Leicester and B T Hawkins
Division of Building Research, CSIRO

## ABSTRACT

This paper describes two statistical models for evaluating the effects of grading procedures on the design properties of stress graded material. One model concerns the grading of a single species, the other concerns the grading of a mixture of species. The models involve the variability of the parent population, the correlation between structural and grading parameters, and sample sizes employed in the measurement of statistical parameters.

## INTRODUCTION

The models to be described are intended to show the relationships between grading procedures and the design properties of stress graded timber. When combined with information on the cost and value of graded timber, these models are useful for evaluating the effectiveness of various specific grading operations.

Through the use of realistic approximations, closed form solutions of these statistical models have been obtained. Such closed form solutions are useful for displaying the essential characteristics of grading procedures. If required for cases of specific interest, Monte Carlo simulation methods may be used to obtain exact solutions. Due to space limitations, only a few aspects of the grading models will be described in the following.

## DESIGN VALUES

The structural property R of graded timber will be denoted by $R_g$. The design value $R_g^*$ will be defined by

$$R_g^* = \bar{R}_g \exp [-0.6\beta V_g - 1.3 V_N] \qquad (1)$$

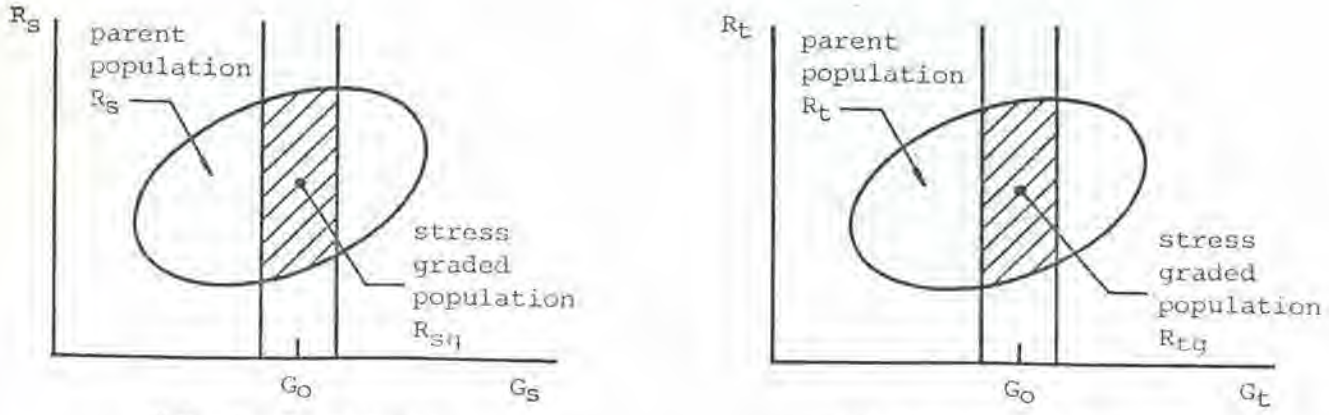
where $\bar{R}_g$ and $V_g$ are the mean and coefficient of variation of $R_g$. The parameter $\beta$ is a measure of the structural reliability. It is termed the "safety index", and typically has a value of 3.0 for strength properties and 1.0 for stiffness properties (1,2). The coefficient of variation $V_N$ refers to the variability due to limitations in the sizes of test samples, of the estimate of $\bar{R}_g \exp[-0.6\beta V_g]$, the nominal value of design strength. The constant 1.3 in equation (1) is intended to lead to a 90 percent confidence with respect to errors due to limitations in the sample size.

## GRADING PROCEDURE FOR A SINGLE SPECIES

In this grading procedure, a stress graded population $R_{sg}$ is selected from a parent population $R_s$ comprising a single species, by setting limits on the acceptable range of a grading parameter $G_s$ as indicated in Fig. 1a. It can be shown that the application of equation (1) then leads to the following estimate of the design value $R_{sg}^*$ for the stress graded population

$$R_{sg}^* = \bar{R}_s \exp\{k_s r_s V_{Rs} - 0.6\beta V_{Rs}\sqrt{1-r_s^2} - 1.3V_{Rs}\sqrt{(1+0.2\beta^2)/N_s}\} \qquad (2)$$

where $\bar{R}_s$ and $V_{Rs}$ denote the mean and coefficient of variation of $R_s$; $r_s$ denotes the correlation coefficient between $R_s$ and $G_s$; $N_s$ denotes the sample size used to measure the statistical properties of $R_s$ and $G_s$; and $k_s$ is defined by $k_s = \ln(G_o/\bar{G}_s)/V_{Gs}$, wherein $\bar{G}_s$, $V_{Gs}$ are the mean and coefficient of variation of $G_s$, and $G_o$ is the mean value of G for the graded population $R_{sg}$.




(a) single species (b) mixture of species

Fig. 1. Schematic of grading procedures

A useful reference value in assessing the effectiveness of grading is $R_{su}^*$, the design value of the ungraded parent population. From equation (1) this is given by

$$R_{su}^* = \bar{R}_s \exp\{-0.6\beta V_{Rs}\} \quad (3)$$

GRADING PROCEDURE FOR A MIXTURE OF ALL SPECIES

This grading procedure is illustrated schematically in Fig. 1b. It is similar to that of grading for a single species, except that the parent population is now all structural lumber of all species. For this case, the statistical population of the structural property and grading parameter are denoted by $R_t$ and $G_t$.

The particular value of this grading procedure is that it can be applied to species for which no structural evaluations have been made. For example, it can be applied in visually stress grading a species that has not been tested in structural sizes. In this case, the grading parameter $G_t$ is given by $F_b$.EBSR, where $F_b$ denotes the bending strength of small clear wood, and EBSR is the bending strength ratio estimated from the visual size of the natural defects.

The method chosen for deriving the relationship between $R_t$ and $G_t$ is based on the assumption that each of these two parameters is a product of two independent sets of random variables for which data will be collected. Thus for any particular stick

$$R_t = R_c R_d \quad (4a)$$

$$G_t = G_c G_d \quad (4b)$$

In equation (4), the terms $R_t$ and $G_t$ refer to the values of R and G measured on any particular stick. The terms $R_c$ and $G_c$ are reference values of R and G for the species concerned. Thus they are species constants. For example, they may be taken to refer to the values of R and G measured on clear structural lumber of the particular species. Finally, the terms $R_d$ and $G_d$ are relative values of R and G, defined by $R_d = R_t/R_c$ and $G_d = G_t/G_c$. Obviously $R_d$ and $G_d$ are dimensionless parameters and vary from stick to stick within the same species.

In the following the subscripts t, c and d refer to the properties of the parameters in equations (4). Thus, $\bar{R}_t$, $\bar{G}_t$, $V_{Rt}$, $V_{Gt}$ and $r_t$ denote the mean values, and coefficients of variation and correlation of $R_t$ and $G_t$. The parameters are taken to be related as follows

$$\bar{R}_t = \bar{R}_c\bar{R}_d \tag{5a}$$

$$\bar{G}_t = \bar{G}_c\bar{G}_d \tag{5b}$$

$$V_{Rt}^2 = V_{Rc}^2 + V_{Rd}^2 \tag{5c}$$

$$V_{Gt}^2 = V_{Gc}^2 + V_{Gd}^2 \tag{5d}$$

$$r_t = \frac{V_{Rc}V_{Gc}r_c + V_{Rd}V_{Gd}r_d}{V_{Rt}\,V_{Gt}} \tag{5e}$$

Finally, the notation $N_c$ and $N_d$ will be used to denote the sample sizes tested to measure the properties of $R_c$, $G_c$ and $R_d$, $G_d$.

In terms of these definitions, it can be shown that the design property $R_{tg}^*$ of a stress graded population is estimated by

$$R_{tg}^* = \bar{R}_t \exp\left\{k_t r_t V_{Rt} - 0.6\beta V_{Rt}\sqrt{1-r_t^2} - 1.3\sqrt{\left[\frac{V_{Rd}^2}{N_d} + \frac{V_{Rc}^2}{N_c}\right](1+0.2\beta^2)}\right\} \tag{6}$$

where the parameter $k_t$ is given by $k_t = \ln(G_o/\bar{G}_t)/V_{Gt}$, in which $G_o$ is the mean value of G for the stress graded timber, $R_{tg}$.

## EXAMPLES

### EFFECT OF IN-GRADE TESTS

The effect of in-grade tests can be examined through the use of equations (2) and (3). For example, the following may be considered typical of strength properties used in an evaluation procedure for the bending strength of mechanically stress graded timber,

$V_{Rs} = 0.4$ $\quad r_s = 0.8$ $\quad N_s = 200$ $\quad \beta = 3$ $\quad k_s = 0$

Substitution of these values into equations (2) and (3) leads to

$$R_{sg}^*/R_{su}^* = 1.25$$

Thus an average gain of 25 per cent in the design property is obtained. If the sample size $N_s$ were infinite, then the corresponding gain would be 33 per cent.

## PENALTY INCURRED IN GRADING MIXTURES OF SPECIES

This example will compare the effectiveness of two visual grading procedures applied to a particular species. In one, the grading is based on structural evaluation tests on 200 sticks of timber of that species. In the second, the grading is based on the criteria for species mixtures, assuming that 20 species have been tested structurally, each with a sample size of 50.

Typical input parameters for this problem are then as follows

$$\bar{R}_s = \bar{R}_t \qquad k_s = k_t = 0 \qquad \beta = 3$$

$$V_{Rs} = V_{Rc} = V_{Rd} = 0.4 \qquad V_{Gs} = V_{Gc} = V_{Gd} = 0.4$$

$$r_s = r_d = 0.6 \qquad r_c = 0.8$$

$$N_s = 200 \qquad N_c = 20 \qquad N_d = 20 \times 50$$

Substitution of the values into equations (5) leads to $V_{Rt} = 0.566$ and $r_t = 0.7$. Then substitution into equations (2) and (6) leads to

$$R_{sg}^*/R_{tg}^* = 1.33$$

Thus in this example a penalty of 33 per cent is indicated if the grading is to be based on a procedure for species mixtures, such as in the case of stress grades based on the properties of small clear pieces of wood. About half of this penalty is due to the small but realistic value assumed for $N_c$, the number of species in which structural size testing has been undertaken.

If for the case of mixed species the structural evaluation were undertaken on a single stick from each of 100 species, then $N_s = 200$, $N_c = 100$, $N_d = 200$ and for this case

$$R_{sg}^*/R_{tg}^* = 1.24$$

Finally it is of interest to note that if infinite size samples were used for the evaluation tests, then $N_s = N_c = N_d = \infty$ which leads to

$$R_{sg}^*/R_{tg}^* = 1.16$$

REFERENCES

1. Ravindra, M.K., and Galambos, T.V. (1978). Load and resistnce factor design for steel. Journal of the Structural Division, ASCE, Vol.104, No.ST9, Sept. pp.1377-1354.

2. Sexsmith, R.G., and Fox, S.P. (1978). Limit states design concepts for timber engineering. Forest Products Journal, Vol.28, No.5, May, pp.49-54.

# DURATION OF LOADING EFFECT ON STRUCTURAL TIMBER

H O Breitinger

Division of Building Research, CSIRO

## ABSTRACT

This paper describes the results obtained from a limited set of rapid loading tests applied to structural size scantlings. Both hardwood and softwood material were tested and their performance evaluated.

## INTRODUCTION

Rate of loading at high speeds is of interest because proof loading and wind gust conditions can be assimilated to rapid loading conditions, also there is some question as to the rate of load effects on structural sized sticks. No previously recorded full sized tests have been done on Australian timber or any hardwood to evaluate the duration of load effects.

The Australian Standard AS 1720 "duration of load" factors are based on results from small clear specimen tests. Data obtained up to date on tests for some American softwoods similar to Australian radiata pine have shown that structural size material does not behave like small clear material. The loading rate effect has less influence on bending strength, is smaller, and depends on the size of defect. The study describes some pilot tests to measure rate of loading effects on messmate (Eucalyptus obliqua), and radiata pine (Pinus radiata).

## TEST PROCEDURE

### Material

A sample of four hundred (400) sticks of messmate was obtained from the Gippsland region, Victoria. Average cross-section of timber was 100 mm x 40 mm. This sample was divided into four equally sized (based on visual grade) groups.

A sample of ninety-six (96) sticks of radiata pine was obtained from Mt Gambier, South Australia. Average cross-section was 90 mm x 35 mm. This sample was equally divided into two groups, where Group I had F11 and F8 grades and Group II had reject, F5 and F7 grades.

Procedure

All sticks were loaded in a four point bending test rig set-up, where the clear span was 1600 mm and the loads were applied at third points. All groups were divided into two sub-groups, to be denoted by A and B. Sub-group A material was loaded so as to fail in eight seconds and Sub-group B to fail in 250 seconds.

Messmate sticks had defects which were randomly orientated on the test rig, but the radiata pine was cut so that the worst defect lay on the tensile edge and in the area of maximum moment.

TEST RESULTS

For the total samples of messmate and radiata pine, the ranked bending strengths have been plotted (see Figs 1 and 2).

A summary of individual groups and total sample results have been compiled in Table 1. In this table, the ranked ratios of 5-percentile values is defined as follows:

$$\text{Ranked Ratio} = \frac{\text{M of R (A)}}{\text{M of R (B)}}$$

where Sub-group A = fast rate (8 sec. failure time)
Sub-group B = slow rate (250 sec. failure time).

DISCUSSION OF RESULTS

From literature (1,2,3) it would be expected that the ratio of bending strengths would be approximately 1.00 at the fifth percentile value, and increase for the higher percentiles. From Figures 1 and 2, messmate does hold to this theory but radiata pine does not. For radiata pine a different sample or simply a larger sample could show different trends. An estimate based on the variability of data is that the accuracy achieved in the tests was about 10 per

cent. To obtain more accurate estimates of the effect of rate of loading, larger samples would need to be tested.

## CONCLUSIONS

This limited pilot study does not disagree with the theory that at the fifth percentile, the ratio of long to short term bending strengths is approximately 1.00.

## ACKNOWLEDGEMENTS

Acknowledgement is made to the Timber Promotion Council of Victoria for supplying the messmate material and the radiata Pine Association of Australian for supplying the Radiata pine.

## REFERENCES

1. Madsen, B., and Barrett, J.D. (1976). Time-Strength Relationships for Lumber". Univ. B.C., Civil Eng. Dept, Struct. Res. Series No. 13, Vancouver, B.C.

2. de Bonis, L.A., Woeste, F.E., and McLain, T.E. (1980). Rate of Loading Influence of Southern Pine 2 by 4's in Bending". Forest Products Research Society. Forest Prod. J. 30(11):34-37. November.

3. Spencer, R. Rate of Loading Effect in Bending for Douglas Fir Lumber". Univ. B.C., Civil Eng. Dept, Vancouver, B.C.

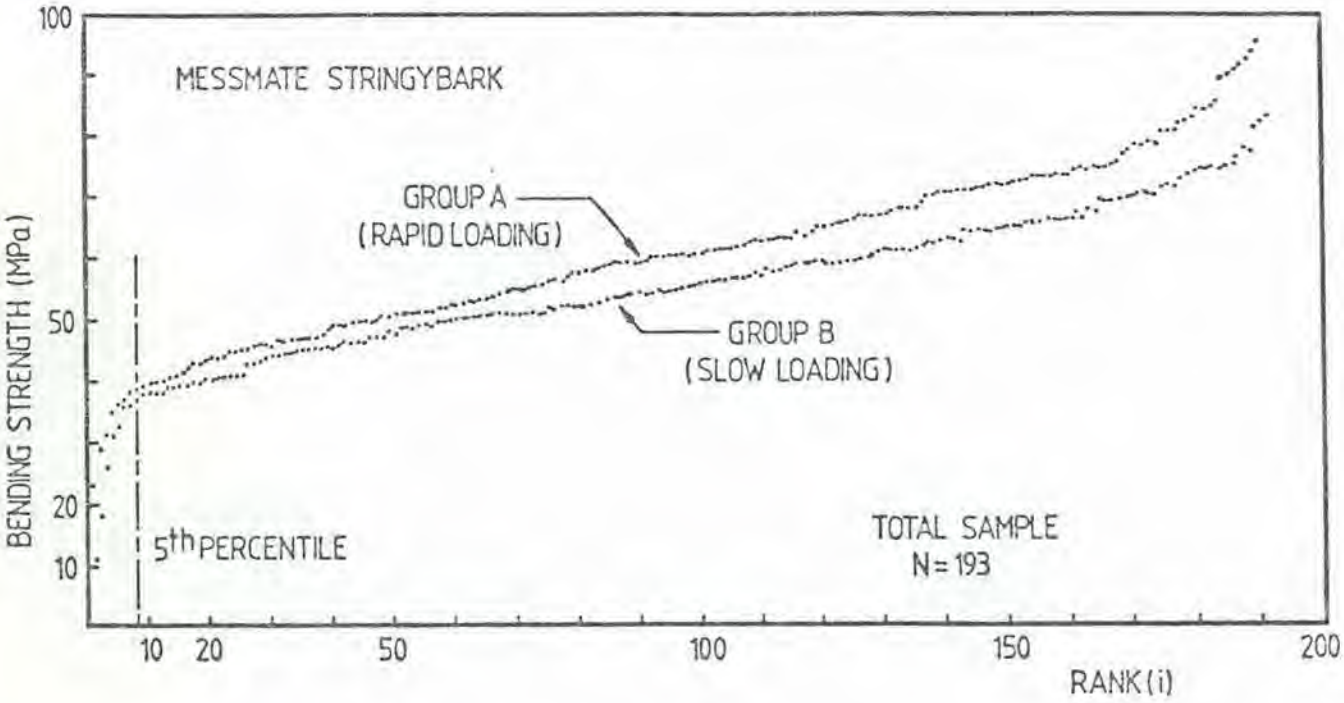



FIGURE 1: Ranked bending strengths of messmate

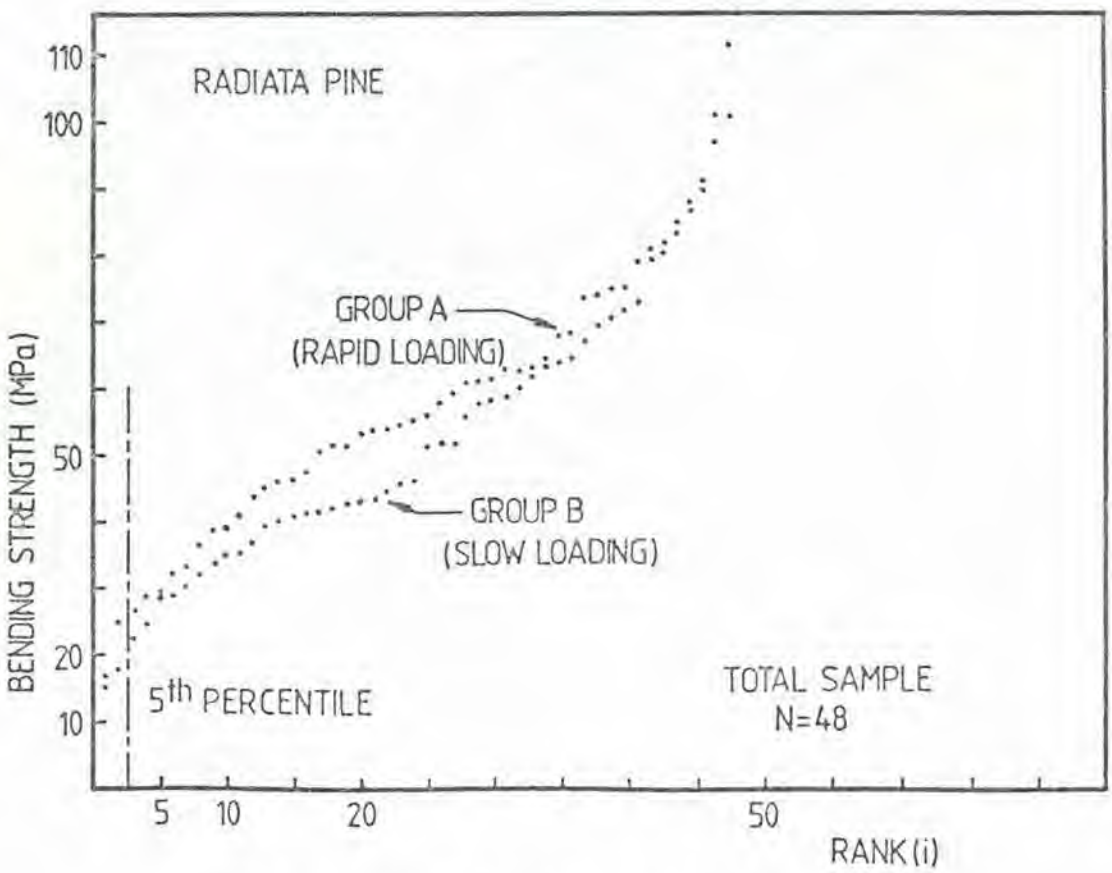



FIGURE 2: Ranked bending strengths of radiata pine

TABLE 1 TEST RESULTS

| Species | Grade* | N | Cov % | Average M of R (MPa) | | **Ranked Ratios at 5th Percentile of Strength |
|---|---|---|---|---|---|---|
| | | | | Group A | Group B | |
| Messmate | I | 50 | 17.96 | 70.51 | 63.44 | 0.95 ± 0.08 |
| | II | 49 | 16.28 | 63.38 | 52.21 | 1.23 ± 0.12 |
| | III | 48 | 21.88 | 56.56 | 53.67 | 1.05 ± 0.11 |
| | IV | 46 | 19.94 | 48.33 | 49.43 | 0.94 ± 0.07 |
| | ALL | 193 | 12.79 | 59.94 | 54.82 | 1.04 ± 0.04 |
| Radiata pine | I | 225 | 32.64 | 65.67 | 64.45 | 0.96 1 0.19 |
| | II | 223 | 27.82 | 54.30 | 45.59 | 0.99 ± 0.21 |
| | ALL | 448 | 36.69 | 58.11 | 53.91 | 1.11 ± 0.18 |

* Groups I, II, III, IV compare closely to structural grades 1 to 4

** Estimated with 85% confidence

# TIMBER PILES FOR HOUSES ON EXPANSIVE CLAYS

P F Walsh and D A Cameron

Division of Building Research, CSIRO

ABSTRACT

The paper describes the installation and performance of small diameter (0.15 m) timber piles driven into an initially dry expansive soil site. The soil of the experimental site consists of residual Quaternary basaltic clay.

In the first stage of the investigation, the effects of pile depth, load and bituminous pile coating on movements of free-standing piles were studied. It is concluded that even short timber piles of the order of 2 to 2.5 m depth are effective in resisting ground movements at this site.

The second stage of the study involved investigation of piled-footing systems as alternatives to conventional strip footings. A full-sized raised timber floor was constructed and loaded along its perimeter. Four different and independent footing systems were used to support the floor. The performance of the footing systems one year after loading is discussed.

## INTRODUCTION

Piles have frequently been used to minimize potentially severe differential movements of buildings located in areas of expansive clay soils. Concrete is particularly popular as a piling material, although timber and steel piles have been used to a lesser extent for domestic-scale structures. Within Victoria at least, timber is relatively inexpensive when compared with either steel or concrete. In particular, radiata pine (Pinus radiata D. Don) preservative treated with CCA has considerable potential.

The first stage of the investigation assesses the performance of 15 timber piles (approx. 0.15 m diameter) which were driven into an initially dry expansive soil. Parameters under investigation included depth of embedment, pile coating and

pile loading. Loads were restricted to values corresponding to residential brick veneer construction.

The second stage of the study involved the investigation of piled footing systems as alternatives to conventional strip footings. A full sized raised floor was constructed and loaded along its perimeter. Four different and independent footing systems were used to support the floor. Preliminary results of this investigation are presented.

## PILE BEHAVIOUR IN EXPANSIVE CLAYS

An expansive clay soil is one which shrinks upon drying and swells upon wetting. A pile in such soil must be designed for two possible situations. Where the pile has been installed in a dry soil, subsequent soil swelling against the pile face may cause uplift. Anchorage of the pile against uplift is achieved by both pile loading and embedment below the depth where effective soil swelling does not occur. Alternatively, uplift forces against the side of the pile may be substantially reduced by coating the pile with a low friction material such as bitumen.

Piles in initially wet expansive soil can be expected to undergo downdrag or settling frictional forces as the soil dries. The combination of downdrag forces and pile loading must be counteracted by the depth of embedment and the pile base reaction.

Finally, internal pile stresses must be resisted adequately by the pile material. The inherent strength of timber piles is of particular advantage in this regard.

## THE EXPERIMENTAL SITE

The site of the piling installation is in Sunshine, a western Melbourne suburb, and consists of residual Quaternary basaltic clay. The depth to the parent basalt varies between 3 and 4 m and floaters (boulders) are interspersed randomly throughout the soil profile. Seasonal surface soil movements have been measured at the site over the past five years, with a maximum movement of 65 mm and a depth of seasonal movement between 1.5 and 2.0 m.

## THE PILE EXPERIMENT

In all, fifteen timber piles were used for the first stage of the piling experiment. Five separate installations were designed, each consisting of three

piles of identical surface treatment and loaded with the same dead load. Piles in the one installation were driven to different embedment depths and were spaced 2 m apart. The chosen embedment depths of 1.5, 2.4 and 3.3 m varied between the depth of seasonal soil movement at the site and the depth to bedrock.

Two surface treatment conditions were considered. In an attempt to reduce the skin friction forces, the piles of two installations were coated with a class 320 bitumen over the portion of the piles to be embedded in the top 1.5 m of soil. All other piles were left uncoated.

Three loading conditions were applied to the piles. One installation of uncoated piles was not subjected to any loading, while the remaining piles were loaded to either the maximum or the minimum dead loads of a typical brick veneer house with tiled roof. Maximum and minimum loads of 21.6 and 1.7 kN per pile were estimated for piles 2.5 m apart supporting load-bearing external walls and unloaded timber floors, respectively. The piles were driven on 20 April, 1978. Loading commenced a month later.

## RESULTS OF THE PILE EXPERIMENT

After installation of the piles, the surrounding soil surface heaved a maximum of 29 mm. The subsequent shrinkage cycle realized a differential seasonal movement of 34 mm.

In Figure 1 the pile numbering legend is given and the pile movements have been plotted against time for each depth of embedment. From these results a number of observations may be made:

(a) The lightly loaded shallow piles (13 and 7) have heaved significantly. Also, the effect of subsequent soil shrinkage is not as severe as that of the initial soil swelling, possibly because soil shrinkage would diminish pile-soil contact.

(b) The bituminous coating has proved effective in reducing heave, particularly for the lightly loaded piles. A comparison of piles 7 and 4, in Figure 1, reveals that the maximum differential heave of the coated pile was only 13% of the non-coated pile.

(c) Increasing the depth of embedment significantly reduces the amount of pile uplift realized.

(d) Increasing the pile load decreases pile uplift or actually causes settlement. Small settlements were recorded for those piles loaded to 21.6 kN.

(e) Subsequent ground movement cycles have not been accompanied by any significant pile movement.

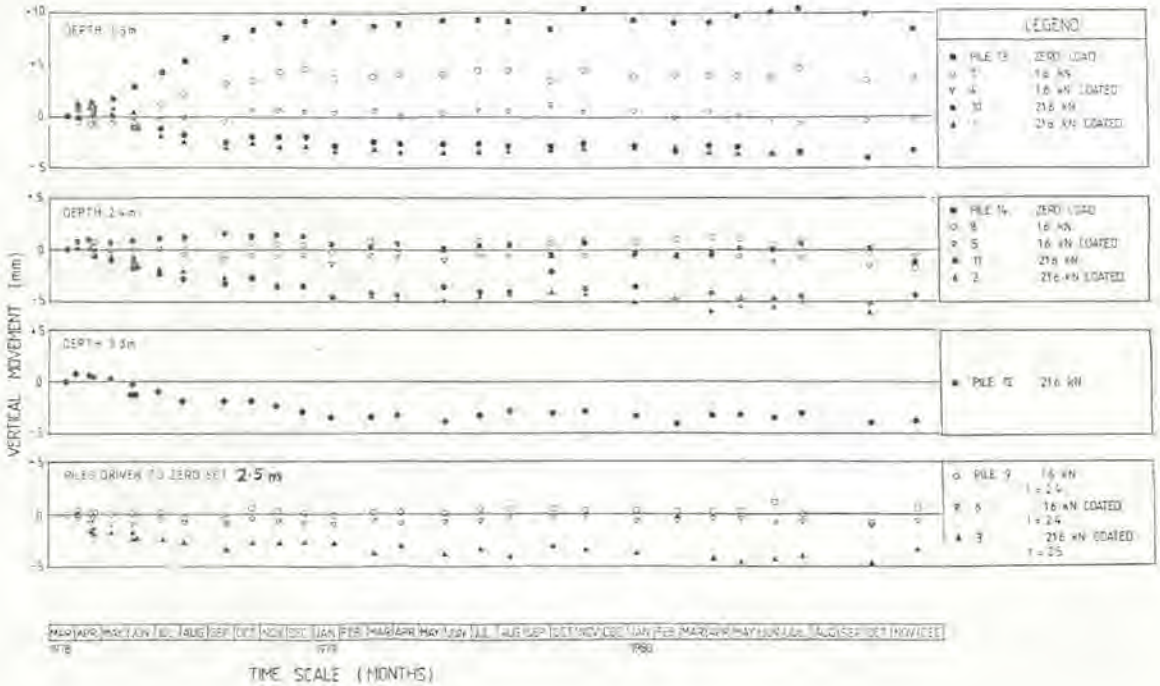



FIG.1 MOVEMENTS OF ISOLATED PILES

## PILED FOOTING SYSTEM EXPERIMENT

### GENERAL ARRANGEMENT

This experiment consisted of an evaluation of piled footings in expansive clay and a comparison with conventional strip and stump footings. The experiment was intended to represent the common Victorian method of house building, namely brick veneer and timber frame. Consequently, a full scale timber floor, 9 x 9 m, was built. Around the perimeter of the floor, loading was applied to simulate the weight of a brick wall and the roof loading. The perimeter was supported by strip or piled footing systems. Internally, the floor was unloaded to represent the potentially worst case for heave movements, and was supported by either pile or stump footings.

The footing systems were discontinuous at the mid-points of the sides to produce four independent treatments, one in each quadrant or corner of the construction. This is illustrated in Figure 2.

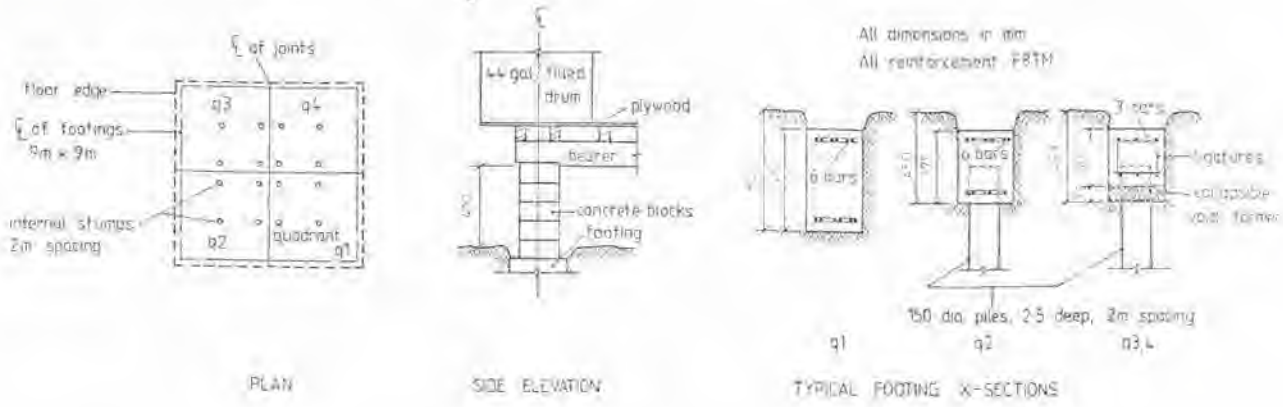



FIG.2 LAYOUT OF FOOTING SYSTEM EXPERIMENT

The various footing systems appropriate to each quadrant are shown in this figure. Typical footing cross-sections are also shown. The widths of the footings were in all cases 300 mm. The internal supports were varied for each quadrant. Four separate footing systems were investigated. These were:

Quadrant 1: Strip footing for intermediate sites consisting of a 525 x 300 mm footing founded at 600 mm depth. The internal supports were concrete stumps on pads (4500 mm²) founded at depths of 600 mm. Note that footings for this site would normally have specifications relating to the higher unstable classification. Intermediate was chosen for demonstrative purposes.

Quadrant 2: A pile anchored strip footing with piles to 2 m depths at 2.5 m spacing along the footing to anchor a double reinforced beam, 375 mm deep x 300 mm wide. The internal supports were piles driven to 1.5 m.

Quadrant 3: In this case, the footing was supported by piles of 2 m spacing and to 2.5 m depth. To reduce uplift pressures, a collapsible cardboard void-former ("Duravoid") was used below the base of the footing. This quadrant utilized piles to 1 m depth under the floor area.

Quadrant 4: A pile supported footing as for quadrant 3 but with "Formaslab" as a void former. The internal supports were piles driven to only 0.5 m.

PRELIMINARY RESULTS OF PILED FOOTING EXPERIMENT

As installation of the piles commenced late March 1980 with loading completed by mid-June, only preliminary indications of behaviour can be presently reported.

During the winter months, the ground beneath the floor became quite wet. In part, this is due to leakage through the floor but would not be atypical of the construction stage in a house. In addition, site drainage was poor and water had been allowed to drain from the floor edge to the footings. To April 1981 the surface heave of the ground under the floor was 70 mm at the floor centre and 52 mm adjacent to the footing. Over the same period the maximum seasonal movement of adjacent open grassland was only 20 mm. This result in itself indicates the importance of drainage on highly expansive soils.

The movements of the supports for the internal part of the floor are summarized in Table 1. Clearly the internal 0.5 m deep piles are not performing acceptably. The performance of the stumps and the 1 m deep piles at this stage is also not particularly good. Moreover, it is known from observation on actual houses that stumps are particularly prone to settlement during the long term drying cycle which usually occurs under houses. Only the 1.5 m deep piles have performed well. From the stage 1 experiments the performance of these piles under the subsequent shrinkage cycles is expected to be satisfactory.

The movement of the footing systems has consistently demonstrated the pattern of central heave relative to the corners. The amounts of the movements is summarized in Table 2. Note that all movements are heave movements.

The intermediate strip footing has deformed excessively. On the other hand, the pile footing systems have all performed within design tolerances despite the large ground movements. It appears from the similar results for quadrants 2, 3 and 4 that the void formers are not functioning well. This may be due in part to heave pressures on the sides of the footings.

TABLE 1
MOVEMENTS OF FLOOR SUPPORTS

| Quadrant | Type | Depth (m) | Maximum heave (mm) |
|---|---|---|---|
| q1 | concrete stumps | 0.6 | 16.1 |
| q2 | timber piles | 1.5 | 3.8 |
| q3 | timber piles | 1.0 | 12.0 |
| q4 | timber piles | 0.5 | 37.4 |

TABLE 2
FOOTING SYSTEM MOVEMENTS

| Quadrant | Type | Centre heave (mm) | Corner movement (mm) | Differential movement (mm) |
|---|---|---|---|---|
| q1 | strip footing | 12.0 | 1.0 | 11.0 |
| q2 | strip footing with anchor piles | 9.6 | 4.0 | 5.6 |
| q3 | pile supported footing, "Duravoid" void former | 10.4 | 4.9 | 5.5 |
| q4 | pile supported footing, "Formaslab" void former | 15.1 | 9.2 | 5.9 |

## CONCLUSIONS

### ISOLATED PILES

From the tests on isolated piles subjected to heave produced by seasonal moisture changes, it can be tentatively concluded that:

(1) Swelling soil causes uplift of shallow lightly loaded piles driven in a dry soil to about the depth of seasonal movement. Recorded movements ranged between 15 and 32% of the recorded surface soil heave.

(2) The ability of driven piles to resist uplift increases with either the depth of embedment or the pile load.

(3) Bituminous coating of a timber pile to approximately the depth of seasonal soil movement is effective in reducing uplift. The maximum uplift of the six coated piles was only 0.6 mm.

(4) Shrinking soil does not appear to produce significant downdrag movements over the range of residential loading conditions considered in this experiment.

## PILED FOOTING SYSTEMS

As the results for the piled footing experiment are at an early stage, it would not be prudent to attach too much significance to the results except to comment that:

(1) The performance of 0.5 m and 1 m deep piles and the stump footings, appear to be unsatisfactory.

(2) Piles driven to a minimum of 1.5 m are expected to provide satisfactory internal point supports for Melbourne basaltic clays.

(3) The pile footings systems are performing better than conventional strip footings. The use of void formers has not improved the performance of the footing systems.

## ACKNOWLEDGEMENT

This research has been sponsored by the Timber Promotion Council, whose assistance is gratefully acknowledged.

# EFFECT OF SPECIMEN SIZE ON TEST RESULTS FROM STANDARD CLEAR TIMBER SPECIMENS

by P U A Grossman* and P J Pahl**

*Division of Building Research, CSIRO
**Division of Mathematics and Statistics, CSIRO

## INTRODUCTION

Although mechanical testing of small clear timber specimens is not the subject of an Australian Standard, common practice in this country follows certain test procedures (1) which allow the option of two specimen sizes. Specimens of 50 x 50 mm cross section, referred to as the 50-mm standard, are based on the ASTM Standard and have been used in the vast majority of Australian tests. Specimens of 20 x 20 mm cross section, referred to as the 20-mm standard, are based on French practice and are widely used in Europe. The latter is useful when only a very limited volume of clear material is available for testing. The British Forest Products Research Laboratory has switched from the 50 mm (then 2-in) standard to the 20-mm standard and the smaller specimen is also recommended by ISO.

In order to make valid comparisons of results obtained from the two standard sizes, it is necessary to know the influence of specimen size and the corresponding test procedure. Knowledge of these effects or of their absence also permits a more authoritative evaluation of tests performed on non-standard sizes.

A comparison of results from the two standard-size specimens was conducted by Foord (2) on ten angiosperms and three gymnosperms. The correction factors obtained from his study have been adopted in the U.K. (3). Sallenave (4) also made some comparisons as well as deriving theoretical predictions of the ratios. The authors of these investigations consider their conclusions to be tentative and expect that their work would be supplemented by further research. The ratios of the results of the two methods are also affected by differences in rates of stress increase and since the rates of loading used in Australian tests do not always agree for the two sizes with the rates used overseas, the overseas ratios of strengths may not be exactly applicable. It was therefore

desirable to conduct further checks on the relationship between results from the two standard sizes. It may be worth noting also that the 20-mm standard will have to be used more frequently in Australia in the near future, as small logs from regrowth eucalypts and from softwood thinnings are tested.

## HISTORICAL BACKGROUND TO THE TESTS

When the mechanical properties of more than 30 species of wood from the Solomon Islands were being determined in the 1960s, the published results were based on 50-mm standards but spare material was used for the preparation of 20-mm standards which were tested for comparison. Since the pairs available for both standards were not comprehensive and the matching not as close as desirable for a comparison, the results were not considered to be a reliable indicator in their own right. However, it is now thought that they provide corroborative evidence as described below.

In 1974 an experiment was designed with the specific purpose of determining the relationship between the results from the two standard sizes and great care was taken to obtain close matching for comparison. Like the earlier tests, this experiment was planned by Mr N H Kloot and Miss N Ditchburne who have both since retired from CSIRO. Testing was initiated under the direction of Mr Kloot, but because of the time needed for drying and of priorities of other work, it was concluded only in early 1980.

## PREPARATION OF TEST MATERIAL

1. EUCALYPT SPECIES. Logs were obtained from ten trees of each of five species, namely Yellow Stringybark (Euc. muellerana Howitt), Brown Stringybark (Euc. baxteri (Benth.) Maiden et Blakely), Silvertop Ash (Euc. sieberi L. Johnson), Mountain Ash (Euc.regnans F. Muell.) and Messmate (Euc. obliqua L'Herit.). Two sticks were cut from each log, one for tests in the green state and one to be tested after drying to about 12 per cent m.c. The final dimensions of each stick after dressing were 1200 x 50 x 50 mm. This provided test pieces of both standard sizes for bending, compression parallel to the grain, shear and cleavage. The sticks were first tested as beams centrally loaded over a span of 750 mm. The centre part up to 100 mm each side of the loading point was discarded, being the zone of fracture and of high stress. The other material was used again for other tests, the 20-mm standard specimens being closely matched longitudinally to the corresponding 50-mm standards and taken from the core of the stick.

2. SOLOMON ISLAND ANGIOSPERMS. While 25 properties were measured on 50-mm standard specimens from three to five trees of each of 33 species, only spare material was used for tests on 20-mm standards. This was inadequate for all properties or even for tests on all trees. Furthermore, the 20-mm standard was not necessarily cut adjacent to the corresponding 50-mm standard and matching was thus not as close as for the species described above. Pairs of results were considered only when the same property was measured on both sizes from the same stick within a tree, so that fair matching was achieved. As there was an insufficient number of replications for individual species, the species were grouped according to anatomical features.

TEST PROCEDURE

The tests were performed on green and dry material. Where the actual moisture content differed from the nominal 12 per cent, an adjustment was made as is customary (1).

Density was obtained for all specimens except the cleavage specimens the volume of which is difficult to measure. It was assumed that the cleavage specimens had the same densities as the shear specimens which in the eucalypt logs were adjacent. In the green material, the density recorded was basic density, i.e. the ratio of mass of oven-dry material to volume of green material.

STATISTICAL ANALYSIS

The factors in the experiment on eucalypts may be summarized as follows:

| | |
|---|---|
| Properties | 10 |
| Test methods | 2 |
| Species | 5 |
| Trees per species | 10 or 11 |
| Moisture conditions | 2 |

Density was used as a co-variate. Each property was anlaysed separately but the correlations of tangential with radial directions were examined in cleavage and shear. Data from green and dry wood were analysed separately. Log-transformations were applied in order that the residuals from the linear model fitted by analysis of variance may be assumed to be normally distributed.

A similar anlaysis was conducted on the results of tests on the Solomon Islands species but the number of species and trees per species varied with property and moisture condition.

RESULTS AND DISCUSSION OF ANALYSIS

1. STATIC BENDING

(a) Modulus of rupture. The 50-mm standards tended to give marginally lower strength values than the 20-mm standards. The mean ratio of values from the larger specimens to those of the smaller specimens was 0.97 for the eucalypt species. The departure from unity is of no practical interest and indeed was only just statistically significant. The result was closely corroborated by results from the Solomon Islands species in the green state, whereas the dry material gave ratios averaging only 0.91 with an upper confidence limit of 0.94 at the 95% level. The results overall indicate that the ratio 0.95 proposed by Lavers (3) is a reasonable guide for comparisons. The reason for lower strength of the larger specimens is not obvious.

(b) Stress at limit of proportionality. There was a much wider dispersion of results and the ratio of values for 50-mm standards to those of 20-mm standards differed between green and dry material and between species. However, overall it would be reasonable to accept that the two sizes give the same result.

(c) Modulus of elasticity. Among the eucalypts the 50-mm standards tended to give slightly higher values than the smaller beams, the mean ratio being 1.03 for green material and 1.05 for dry. On the other hand, the ratios for the Solomon Island angiosperms were closely distributed around a mean of 0.99 for the dry data and very widely distributed for the green data, but centering also around unity, thus suggesting that there was no difference between the results from bigger and smaller beams. While this assumption is reasonable for most practical purposes, a ratio exceeding unity by a few per cent is likely to be more correct since more weight should be placed on the results from the closely matched tests on eucalypts. Foord (2) found a mean ratio of 1.067 for hardwoods and somewhat less for some softwoods, while Sallenave (4) lists a mean of 1.035. No reason can be advanced for the slightly higher stiffness found from larger specimens.

2. COMPRESSION PARALLEL TO THE GRAIN

(a) Maximum crushing strength. There was practically no difference between the results from the two sizes. The results did not justify the application of the ratio 0.96 recommended by Lavers (3). The British standard uses the same rate of head movement for the two specimens, thus straining the small specimen at a higher rate. This may explain the reported ratio. In Australian tests the rates of strain are the same.

(b) Stress at limit of proportionality. There were differences between species and between moisture contents, but there seems to be no cause overall to assume a ratio different from unity.

(c) Modulus of elasticity. Results from the green eucalypts indicated a lower modulus for the larger specimens with the mean ratio of 0.94 differing highly significantly from unity. However, the tests on dry material and on the other species showed no departure from a ratio 1. It would seem reasonable to assume that there is no practical difference between the results from the two sizes. The marginally smaller relative distance between gauge and loading plate for the larger specimens is the only apparent cause of discrepancies.

3. SHEAR STRENGTH

There is little difference between the results of the two sizes in either tangential-longitudinal or radial-longitudinal shear. The tendency is for somewhat lower values from the larger specimens but no corroboration of as low a ratio as 0.88 suggested by Lavers (3).

4. CLEAVAGE

Force per unit width, the measure used for cleavage strength, is not comparable for the two types of specimen. The ratio of values from the larger specimens to those of the smaller ones showed a mean of 4.6 for green timber tested radially, with 95% confidence limits of ±0.2. This ratio also reflects the behaviour in tangential cleavage of green timber except for higher scatter and in particular some much lower ratios found in one species. In dry timber, the ratios for both radial and tangential cleavage were lower, averaging 3.8. Lavers (3) lists a ratio of 4.35 and Sallenave (4) a ratio of 4.16.

Force per unit width is a meaningless quantity for determining cleavage strength. If force per unit fracture area were recorded, the 50-mm and 20-mm standard specimens would give much more comparable results, as the ratios listed above would become 1.2 for green and 1.0 for dry timber. Alternatively, a much longer cleavage specimen could be used to determine critical stress intensity factors (5).

## CONCLUSIONS

For bending, compression and shear the 50-mm and the 20-mm standard give comparable values for all practical purposes, but small correction factors may be desirable when results of tests are tabulated. Cleavage values are not

comparable; rough conversion factors can be used but it is doubtful whether the standard cleavage test provides information of sufficient value to warrant closer investigation.

REFERENCES

1. Mack, J.J. (1979). Australian Methods of Mechanically Testing Small Clear Specimens of Timber. CSIRO Div. Bldg Res. Tech. Paper (2nd Series) No. 31.

2. Foord, A.J. (1955). The Correlation of Strength Data from Matched Tests on 2-in and 2-cm Cross-section Specimens. DSIR-FPRL.

3. Lavers, G.M. (1969). The Strength Properties of Timbers. For. Prod. Res. Bull. 50 (London: H M Stationery Office).

4. Sallenave, P. (1971). [Physical and mechanical properties of Tropical Woods. 2nd Supplement]. Centre Tech. For. Trop., France, Publication 23B.

5. Walsh, P.F. (1971). Cleavage Fracture in Timber. CSIRO Div. For. Prod. Technol. Paper No. 65.

# MECHANICAL GRADING OF 1926 REGROWTH MOUNTAIN ASH

A. Anton and A. A. Garbellini
Wood Technology and Forest Research Division
Forestry Commission of N.S.W.

## ABSTRACT

Seasoned scantlings dressed all round obtained from 1926 regrowth mountain ash (*Eucalyptus regnans*) from Victoria can be sorted into defined strength grades by mechanical grading.

Laboratory test results have shown

- A high correlation (0.74) between stiffness when the scantling is loaded as a plank and strength when the scantling is loaded as a joist.
- Stiffness as a plank is highly correlated to stiffness as a joist ($r = 0.92$).
- The relationship between stiffness and strength was established in terms of modulus of elasticity and modulus of rupture.
- Modulus of elasticity ranges for a number of grades were estimated thus enabling us to prepare an experimental programme for the "Computermatic" S.G.M. to produce these grades.
- Impact resistance (IZOD) shear, compression parallel to the grain, density and rings per 20 mm were studied on 98 small, clear samples randomly selected and the results were compared with those of mature mountain ash.

## INTRODUCTION

This paper presents the results of a pilot study on scantlings produced from 1926 regrowth mountain ash (*Eucalyptus regnans*) from Victoria. The scantlings were provided by A.P.M. Limited and the aim of this investigation was to:-

- evaluate the relationship between modulus of elasticity (M.E.) and modulus of rupture (M.R.) in an endeavour to assess the possibility of using mechanical grading to produce grades below those specified in Australian Standard 2082-1977.
- Recommend an experimental programme to mechanically grade this species to produce the grades of reject, F8, F17 and F27.

- Assess other properties of importance and compare them with those obtained from mature trees.

## MATERIAL

The material for this project was sawn from top and bottom 1926 regrowth mountain ash (*Eucalyptus regnans*) logs drawn from Victorian Forest Commission areas in the Powelltown district.

The logs were stored for periods of up to 9 months before conversion to scantlings at the Powelltown mill. A combination of air and kiln drying was used to stabilize the scantling.

The sample was said to be indicative of normal production as specimen scantlings were taken at random from a series of moulder production runs and accumulated over several weeks. The specimens (960) were mechanically stress graded at Morwell using a trial programme. A sub-sample of 480 specimens was taken from the larger sample by selecting the odd numbered pieces from 1 to 959 inclusive. The nominal cross section was 85 mm x 32 mm, in lengths of 2.4 m (88%), 2.56 m (2%) and 2.71 m (10%). These specimens were sent to Wood Technology and Forest Research Division for testing.

## TESTING

### 1. MECHANICAL GRADING

The material was regraded in our laboratory with the Commission's "Computermatic" timber grading machine and deflections along the length of the graded timber were automatically recorded using a facility (3) developed for this purpose. The grading machine was programmed to produce four useful grades and a reject one. The modulus of elasticity ranges for each grade were so adjusted to embrace the range of modulus of elasticity for the species (Table 1).

TABLE 1

Programme and Grade Recovery

| Grade | Deflection range mm | Modulus of elasticity (M.E.) range GPa | Percentage recovery |
|---|---|---|---|
| 1 | 0 - 3.81 | Max - 19.30 | 2.8 |
| 2 | 3.62 - 5.33 | 20.32 - 13.79 | 43.4 |
| 3 | 5.14 - 8.00 | 14.30 - 9.20 | 48.8 |
| 4 | 7.81 - 10.67 | 9.42 - 6.90 | 5.0 |
| 5 | 10.48 - Max | 7.02 - 0 | 0 |

Details of the programme used and percentage recoveries for each grade are given below.

Setting of the "Computermatic"

Size: 31 x 85 mm dressed all round Force Applied: 975 N

Gauge Pressure: 250 kPa Cylinder 1

Deflection levels for various grades: 20, 28, 42, 56 machine units (0.1905 mm)

Extreme fibre stress in bending during grading: $F_b$ = 16.37 MPa.

2. DENSITY

A gross assessment of the average density of the sample was obtained by weighing (to the nearest 0.01 kg) each piece of 197 scantlings which were 2.4 metres long and had an average cross section of 84.5 mm x 31.1 mm. By this method the density was estimated as ranging from 870 kg/m$^3$ to 460 kg/m$^3$, with a mean of 625 kg/m$^3$. The density given by CSIRO for small clear specimens of mountain ash = 678 kg/m$^3$ (air dried at 12% m.c.).

3. VISUAL GRADING

Subsequent to machine grading the entire sample was visually graded piece by piece to AS 2082-1977 "Visually Stress-Graded Hardwood for Structural Purposes: (Table 2).

TABLE 2

Summary of Visual Grading - 1926 Regrowth Mountain Ash (Seasoned) Strength Group - SD3

| Grade description | F rating | No. | Recovery % |
|---|---|---|---|
| No. 3 Struct. | 17 | 358 | 74.7 |
| No. 4 Struct. | 14 | 59 | 12.3 |
| - | Reject* | 62 | 13.0 |
| | TOTALS | 479 | 100.0 |

* Note: The standard makes no provisions for grades below No. 4 Structural.

4. TESTING

i) Modulus of elasticity (M.E.) and modulus of rupture (M.R.). These were determined for the weakest zone found along the length of the scantlings in accordance with the requirements of appendix "A" of Australian Standard 1749-1978.

ii) Stiffness on edge

The stiffness on edge was evaluated by monitoring mid span deflections during the destructive testing to determine M.R. Only 240 pieces were tested because of the close correlation (r = 0.92) exhibited between (M.E.) on flat and (M.E.) on edge.

iii) Small Clear Specimens

Ninety eight small clear specimens were taken from the total sample of test pieces with the criteria for choice being the availability of enough clear straight grained material in the individual test piece to prepare the following test specimens.

IZOD - Density, moisture content, IZOD, and compression parallel to the grain test specimens.

SHEAR - Shear test specimens.

## PRESENTATION AND ANALYSIS OF DATA

Experimental data for M.E. and M.R. were plotted in fig. 1. The relationship between M.E. and M.R. ($r = 0.74$) is quite high and of the order reported for softwood species. The linear regression of M.R. on M.E. is

$$M.R. = 5.176\ M.E. - 1.661$$

where M.E. is in GPa and M.R. is in MPa

Although the linear regression approach may not be the best way of describing the M.E. vs M.R. relationship (1, 2), it is sufficient to establish a working stress line so the cutoff points for modulus of elasticity levels can be established for the requested grades as indicated in fig. 1.

Table 3 shows the expected grade recoveries for various ranges of M.E. derived from the basic working stress line in fig. 1 while Table 4 shows ranges for which the "Computermatic" has to be programmed to produce the grades requested by A.P.M., that is F8, F17 and F27.

TABLE 3

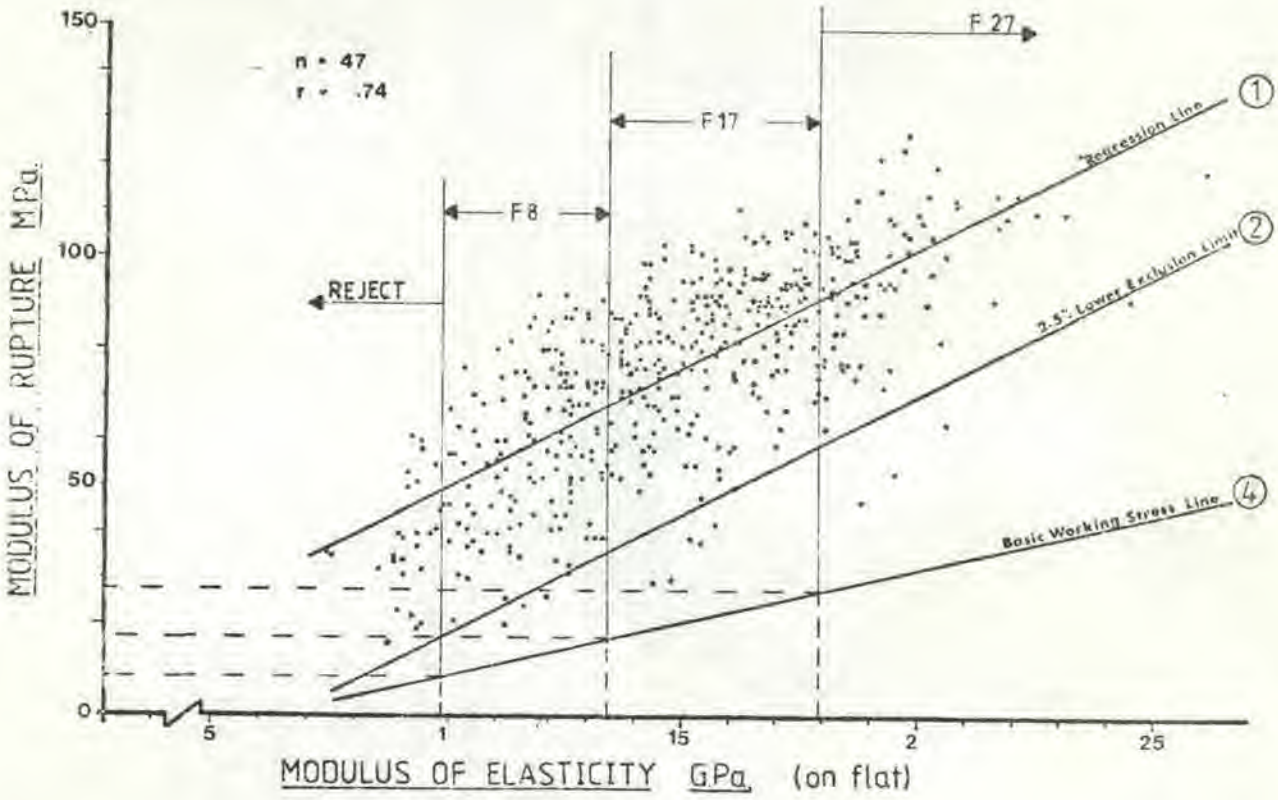
Grade Recoveries Using Basic Working Stress Line 4 Fig. 1

| Stress grade | Basic working stress in bending (MPa) | M.E. range (GPa) | No. of specimens | % |
|---|---|---|---|---|
| Below F7 | - | Min - 9.11 | 13 | 2.8 |
| F7 | 6.9 | 9.12 - 9.84 | 14 | 3.0 |
| F8 | 8.6 | 9.85 - 10.87 | 26 | 5.5 |
| F11 | 11.0 | 10.88 - 12.15 | 53 | 11.3 |
| F14 | 14.0 | 12.16 - 13.44 | 68 | 14.5 |
| F17 | 17.0 | 13.45 - 15.58 | 110 | 23.4 |
| F22 | 22.0 | 15.59 - 17.94 | 107 | 22.7 |
| F27 | 27.5 | 17.95 - 20.94 | 69 | 14.7 |
| F34 | 34.5 | 20.95 - Max | 10 | 2.1 |

TABLE 4

Basic Working Stresses for Grades Requested by A.P.M.

| Stress grade | Basic working stress in bending (MPa) | M.E. range (GPa) | No. of specimens | % |
|---|---|---|---|---|
| Reject | | Min - 9.84 | 27 | 5.7 |
| F8 | 8.6 | 9.85 - 13.44 | 147 | 31.3 |
| F17 | 17.0 | 13.45 - 17.94 | 217 | 46.2 |
| F27 | 27.5 | 17.95 - Max | 79 | 16.8 |




The Relationship between M.R. and M.E. (on flat) in Bending for 1926 Regrowth Mountain Ash. Basic Working Stress Line (4) derived from 2½ percent lower exclusion limit line (2) using 9/16 x 4/5 factor.

Results for small clear samples are presented in table 5 below. Density is important as the performance of joints using mechanical fasteners depends on this property.

TABLE 5

Comparative Table for Small Clear Specimens of 1926 Regrowth Mountain Ash and CSIRO Figures for Mountain Ash Performed in accordance with BS 373 (1957)

| Property | Rings per 20 mm | IZOD j | | Comp \|\| MPa | | Shear MPa | | Density kg/m$^3$ | | Moisture content % | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Statistical parameter | W | W | C | W | C | W (A) | C (T) | W | C | W | C |
| n | 98 | 98 | 24 | 98 | 23 | 98 | 23 | 98 | 24 | 98 | |
| Mean | 4.4 | 14.4 | 20.6 | 64.6 | 63.3 | 12.5 | 12.2 | 606 | 678 | 10.8 | |
| S.E. of Mean | 0.18 | 0.55 | 0.98 | 1.00 | 1.58 | 0.28 | 0.28 | 8.02 | 15.26 | 0.04 | |
| S.D. | 1.74 | 5.47 | 5.41 | 9.85 | 7.75 | 2.82 | 1.31 | 79.45 | 76.24 | 0.35 | |
| COV | 40.0 | 38.0 | 26.3 | 15.3 | 12.2 | 22.6 | 10.8 | 13.1 | 11 | 3.3 | |
| SKEW. | 1.21 | -0.14 | | -0.20 | | -0.54 | | 0.46 | | -0.32 | |
| KURT. | 5.59 | 2.61 | | 2.35 | | 3.89 | | 2.93 | | 3.33 | |

Adjusted to 12%

NOTE: W = WT&FRD figures for 1926 regrowth mountain ash tested for this project.

C = CSIRO figures taken from Bolza & Kloot (5)

n = No. of specimens for W.

n = No. of trees for C.

MC% = For CSIRO figures the species mean has been adjusted to the equivalent value at 12% moisture content as stated on page 4 of Bolza and Kloot (5).

A = Tangential and Radial Direction.

T = Tangential Direction.

## CONCLUSIONS

This study has shown that:-

1) Regrowth mountain ash when seasoned and reconditioned to produce good quality scantlings can be mechanically graded to produce the number of grades required ranging from F8 up to F27 where approximately 16% meets that grade. A comparison between recoveries for material above F17 indicates that both visual grading and the proposed mechanical grading programme are comparable. The grading programme recommended is experimental and will have to be verified under commercial operation before mechanically graded mountain ash can be offered for sale. This involves an intensive quality control scheme in the initial stages. The results of which would be used to prove the correctness of the proposed programme or provide sufficient data to modify it to obtain the best grade recovery.

2) Provided the quality of the material remains the same as that of the sample submitted it would be reasonable to recommend production of a one purpose grade such as an F8 by excluding only visual defects which do not meet the general pattern of the population falling by visual grading below F14 and at the same time carry out a quality control scheme by testing to destruction a reasonable number to certify the quality of the timber so produced.

## ACKNOWLEDGEMENTS

Mr. D. J. Grant for his assistance and co-operation. Dr. D. Curtin for his constructive and critical review.

## REFERENCES

(1) Anton, A. (1967). Selected topics in timber engineering. Unpublished report, For. Comm. N.S.W.

(2) Anton, A. (1977). Mechanical stress grading of timber and derivation of basic working stresses. 18th For. Prod. Res. Conf. 1977.

(3) Grant, D.J. (1977). Mnemotype - Timber grading machine defelction storage unit. For. Comm. N.S.W. Tech. Pap. 29.

(4) Garbellini, A.A. (1979). "Our investigation into Victorian regrowth Mountain ash". Unpublished report, For. Comm. N.S.W.

(5) Bolza, E. and Kloot, N.H. (1963). The mechanical properties of 174 Australian timbers. CSIRO Div. For. Prod. Tech. Pap. 25.

# GRADING TIMBER FOR STRENGTH

A. Anton
Wood Technology and Forest Research Division
Forestry Commission of N.S.W.

## ABSTRACT

This paper discusses the various methods available for grading radiata pine and other species for strength. It describes the fundamental philosophy and methodology associated with them with emphasis on mechanical grading. It recommends the need for an agreed definition as to what constitutes a grade and what strength parameters are to be considered. It proposes that all timber species when given an F rating should be of comparable quality and should be considered of equal integrity when used in engineered structures to secure the same degree of relaibility.

It proposes that the principles of mechanical grading, its methodology and way of deriving working stresses be adapted and correlated to present and possible future alternatives for grading timber.

## FUNDAMENTAL ASPECTS OF GRADING FOR STRENGTH

The main aim of grading timber for strength is to prevent material of inferior quality entering any one given grade. Hence for each grade a limiting *strength* value is specified in terms of probability or expectation. The word *strength* covers a multiplicity of properties. The main ones are strength in bending, flexural modulus of elasticity, compression, tension and density as this aspect is related to nail holding resistance.

## GRADING SYSTEMS

To achieve the abovementioned objectives the various grading systems, with the exception of proof grading, make use of a particular measurable parameter which is closely correlated to *strength*.

- Visual grading is based on the relationship which exists between visual defects and *strength*.
- The most successful system of non-destructive grading of timber is the one based on stiffness evaluation by mechanical means and under this category the Australian "Plessey Computermatic" and a number of other machines developed

in other parts of the world are classified.

The "Computermatic" is considered the best machine of its kind in terms of accuracy, repeatibility and simplicity of operation. One of its main features is that it evaluates stiffness along the length of the timber graded and colour marks the least stiffness zone found along its length. The machine is programmed for species for which stiffness and strength relationships have been determined. Its correct operation during production runs can be easily verified by passing through the machine timber of known grades, known as verification sticks. It is backed up with a well prepared standard document (S.A.A. 1748 & 1749-1978), specifying the conditions under which the machine is allowed to operate. Irrespective of the timber grading machine used the people behind it and the way they are using it is of paramount importance. We consider that the strength of a scantling is as good as its weakest zone along its length when so tested to destruction, as a joist, so to give the worst possible outcome thus providing a high reliability factor for quality.

DERIVATION OF WORKING STRESSES

For the purpose of deriving "basic working stresses" for any one grade produced using the "Computermatic" a large number of samples representing each grade is required. Strength values for the weakest zone, along the length of each sample are obtained by testing each sample to destruction as a joist (1, 2). The strength results so obtained for each mechanical grade are analysed by treating each grade as an individual population possessing specific strength characteristics.

From our experience out of the five mechanical grades produced commercially for radiata and slash pine, the upper grade F11 includes clear timber and material of high density with moderate size knots and other strength reducing growth characteristics. The lowest grade includes low density pithy material and timber containing large individual knots, clusters of knots and other severe strength reducing defects. The in between grades bridge the gap between the two extremes.

To treat each mechanical grade as an individual population for the purpose of deriving basic working stresses has considerable advantages some of which are listed below.

1. It reduces the problem into estimating for each population the LIMITING VALUE (2.5th percentile, or 1/40 low probability value for modulus of rupture (M.R.) upon which the derivation of working stresses is based.
2. It requires only elementary statistics.
3. It can be analysed graphically providing that a large number of samples are

available.

4. It is easily understood by people who have a limited knowledge of statistics, thus facilitating communication not only to the industry but to the end user.

The established practice in Australia since 1965 is to assess for each mechanical grade, from destructive tests on full size scantling samples, the LIMITING VALUE (LV) for modulus of rupture (bending strength), and to use this value to derive basic working stresses after being modified by factors related to long term loading ($f_t$) and statistical uncertainties ($f_u$).

Hence Basic Working Stress in bending $F_b = (LV) \times f_t \times f_u$

where:

(LV): is the (2.5th percentile) 1/40 low probability value for modulus of rupture obtained from quality control (Q.C.) samples sufficient in number to represent the population properties for any one given grade

$f_t$: is equal to 9/16

$f_u$: is equal to 4/5 and approaches 1 as statistical uncertainties diminish and as the number of samples tested increases. One believes that there will be a point where the samples tested will describe the properties of the population under consideration with a high degree of certainty.

Therefore the derivation of working stresses in bending ($F_b$) for a particular grade is reduced to the problem of assessing the *LIMITING VALUE* (LV). This concept should apply to all forms of grading be it mechanical, visual or proof grading so that the alternatives share the same credibility and the graded timber produced using any one method is of comparable quality and so can be safely used in engineered structures.

Tables 1 and 2 summarise the results from the 1979 analysis on quality control samples obtained from the various mechanical operations in Australia involving all sizes from 70 mm x 35 mm up to 120 mm x 45 mm.

NEED TO REVISE THE FACTORS USED IN DERIVING WORKING STRESSES

Mechanical stress grading of timber in Australia was introduced commercially in 1965 and since 1972 expanded to the extent that today the radiata pine producers have the potential of grading 80% of the total scantling production in this country. Taking into consideration the general quality of M.S.G. timber when compared with alternative grading methods, the performance of structures using M.S.G. timber, the degree of reliability associated with mechanical grading operations resulting from strict quality control and education of operators, and research findings from overseas work regarding the long term performance of timber under load, it is considered necessary and appropriate to

reconsider the values adopted for $f_t$, $f_u$ and $f_r$

($f_t$) - It is now accepted that the 9/16 factor, although it may be appropriate for clear timber, is too conservative for commercially produced scantlings and particularly so with the lower grades.

($f_u$) - The uncertainty factor (4/5) for M.S.G. timber is too severe because we are usually considering a single species and we have sufficient data to cover most possible contingencies especially when the size aspect is properly evaluated and suitable adjustments made to existing programmes.

($f_r$) - Reliability of the Mechanical Grading system with its production control using verification sticks and its quality control assurance scheme which provides a high degree of supervision makes $f_r = 1$.

Hence the 2.2 factor by which we have to multiply the working stress to obtain the "LIMITING VALUE" is considered too severe and it is proposed to select factors for the various grades to suit the Q.C. results since these grades perform satisfactorily on a commercial basis.

It is recommended that for F11, F8 and F7 which constitute the engineering grades the factor of 2 be used, a factor around 1.8 to be considered appropriate for the utility grades of F5 and F4.

Table 3 compares this proposal with actual estimates of the 1/40 low probability values obtained from the statistical analysis of test results obtained from Q.C. samples (full size scantlings) involving most of the operations in Australia for radiata and slash pine and involving all sizes from 70 mm x 35 mm up to 120 mm x 45 mm.

IN GRADE TESTING

Proposals have been put forward suggesting the need for a system to evaluate the quality of grades produced by various grading systems. This aspect was debated at the previous Forest Products Research Conference and substantial time and effort has been given by a lot of people involved in research, standards and designing practices without reaching final agreement. Having in mind what is going on in Australia and overseas with reference to standards for timber, the revision of the Timber Engineering Code and the trend towards an International Standard to serve all needs, I will put forward what I consider will meet the needs of both industry and consumer.

IN-GRADE TESTING commenced in Australia in 1965 by testing randomly selected samples (full size scantlings) of mechanically graded timber for the purpose of deriving basic working stresses for the various grades and to provide evidence of the quality of the graded timber produced. More than 30 000 tests have now

been performed covering a number of softwood and hardwood species. At the outset, after considering the then existing practices in deriving basic working stresses for scantlings, we went away from testing clear small samples and adopted the practice of testing full size specimens. In deciding how to determine modulus of rupture we took into consideration the then practices in Australia, the A.S.T.M. recommendations and the way timber members are loaded in conventional and engineered structures. To secure a high degree of reliability we decided that the bending strength of a scantling be determined by the strength of its weakest zone when tested to destruction as a joist in four point bending over a specified span related to its width and so oriented as to produce the worst possible outcome.

Since 1965 we have standardized

1 - A method of non destructively predicting the weakest zone along the length of a scantling by stiffness evaluations by developing the Microstress and Computermatic timber grading machines and a system to secure their correct operation.

2 - Procedures for determining bending strength (hee appendix A).

3 - Procedures for deriving basic working stresses, by treating each grade as an individual population, from the 1/40 low probability value for modulus of rupture (bending strength) obtained from testing to destruction a sufficient number of samples to represent the population in each grade.

4 - The use of 9/16 factor to account for long term loading aspects and the use of 4/5 factor to account for statistical uncertainties. These are the factors we multiply the 1/40 low probability value of modulus of rupture (2.5 percentile) to obtain the basic working stress for a given grade when sufficient data is available.

The outcome of all this work has shown that distinct grades are produced with well defined mean and minimum probable values at any percentile level for bending strength.

So after considering the theoretical aspects of our work, the success we enjoyed with mechanically graded timber in engineered structures for some 15 years, the benefits our industry obtained by placing our locally produced softwoods to the same reputation as that of Douglas fir, and finally the international trend to use the 5th percentile (1/20 low probability of M.R.) as the limiting value for the derivation of basic working stresses it is proposed that:

(a) The existing procedures as described in appendix A be adopted for determining the bending strength of scantlings from testing full size specimens.

(b) The results from the 1979 analysis as shown in tables 1 and 2 define the various grades for M.S.G. timber. Therefore the mathematics must be tailored to match the derivation of *the same basic working stresses* from the 5th percentile as opposed to that obtained from the 2.5 percentile.

(c) A technically competent committee be formed to look into this topic. The industry's involvement must be of great importance since altering or changing things for no reason costs the industry money and saps the confidence of the user.

ACKNOWLEDGEMENT

Dr. D. Curtin for his critical review and constructive suggestions.

REFERENCES

(1) Huddleston, E.B. and A. Anton (1967). The grading of timber into stress grades by mechanical means. Journal of Institute of Engineers, Australia. Vol. 39(b).

(2) Anton, A. (1977). Mechanical stress grading of timber and derivation of basic working stresses. 18th For. Prod. Res. Conf.

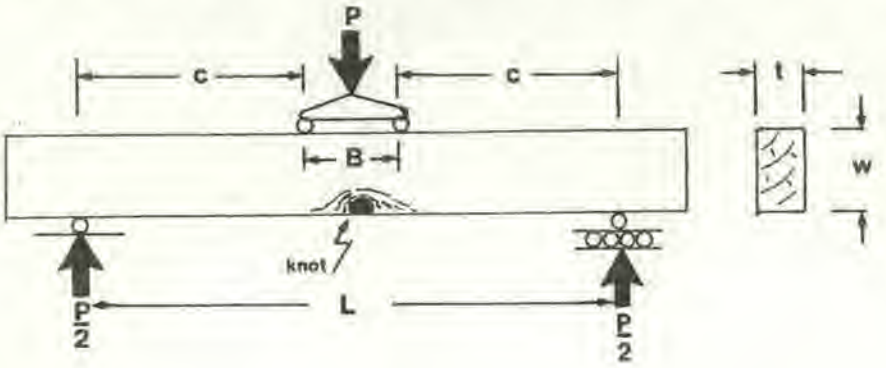
(3) Grant, D. (1979). Machine stress graded radiata and slash pine analysis of quality control data. Unpublished report.

## APPENDIX A

## DETERMINATION OF MODULUS OF RUPTURE

The method of determining modulus of rupture is arbitrary and should be so chosen as to represent the type of end use desired for the graded product.

All of our work has been done by breaking the sample as a joist on edge, (at the same point where the M.E. on the flat has been measured), by 4 point bending over a span of 12.3 times the depth with any obvious defect placed on the tension side, that is, a knot near an edge would be placed on the tension side.




Modulus of Rupture (MR) in MPa

$$MR = \frac{3Pc}{bw^2}$$

P = force N

c = distance mm

w = width mm

t = thickness mm

4 Point Bending Test

The span (L) used is a modification of A.S.T.M. specification without deviating from the principles.

The span $L = 2C + B$

where $C = \frac{14w}{3}$

$B = 3w$

w = the depth of the sample

This arrangement has the following advantages:

(a) The bending moment at section B is identical to that of third point bending with depth to span ration 1:14 as specified by A.S.T.M.

(b) The span (L) is smaller so that less timber is required for testing.

(c) Section B being smaller than the one specified in A.S.T.M. permits a particular single defect to be investigated.

(d) It is convenient for use with testing machines having a limited span table.

(e) Emphasises the tnsile properties of the sample.

TABLE 1

Analysis of Quality Control Samples for the Determination of Working Stresses for Radiata Pine

| Grade specification | | Results from Q.C. 1979 analysis | | | |
|---|---|---|---|---|---|
| M.S.G.(1) grade | Basic(2) working stress $F_b$ MPa | (3) N | Best estimate(4) of limiting value for (M.R.) 2.5 percentile MPa | Working stress ratio $\frac{(4)}{(2)}$ | Remarks |
| F11 | 11.0 | 323 | 26.0 | 2.36>2.2 | Conservative |
| F8 | 8.6 | 1566 | 17.0 | 1.98<2.2 | ? |
| F7 | 6.9 | 266 | 15.6 | 2.26>2.2 | Conservative |
| F5 | 5.5 | 2298 | 11.5 | 2.10<2.2 | ? |
| F4 | 4.3 | 1605 | 7.3 | 1.70<2.2 | ? |

TABLE 2

Analysis of Quality Control Samples for the Determination of Working Stresses for Slash Pine

| Grade specification | | Results from Q.C. 1979 analysis | | | |
|---|---|---|---|---|---|
| M.S.G.(1) grade | Basic(2) working stress $F_b$ MPa | (3) N | Best estimate(4) of limiting value for (M.R.) 2.5 percentile MPa | Working stress ratio $\frac{(4)}{(2)}$ | Remarks |
| F11 | 11.0 | 454 | 21.8 | 1.91<2.2 | ? |
| F8 | 8.6 | 1473 | 16.8 | 1.95<2.2 | ? |
| F7 | 6.9 | 247 | 13.9 | 2.00<2.2 | O.K. |
| F5 | 5.5 | 1326 | 12.1 | 2.2 = 2.2 | ? |
| F4 | 4.3 | 208 | 9.3 | 2.16<2.2 | ? |

- The expected working stress ratio is 2.2 which is the reciprocal of 9/16 x 4/5.
- Although the working stress ratio in some cases is less than 2.2 these grades have performed satisfactorily for the last 10 years in engineered structures. An extensive study is in progress (3) to evaluate the size effect as it applies to the existing mechanical programmes.

TABLE 3

Comparison of Recommended "Limiting Values" for Modulus of Rupture for Various Mechanical Grades

| Recommendations for M.S.G. timber | | | | Results from statistical analysis 1979 | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Radiata pine | | | Slash pine | | |
| (1) | (2) | (3) | | | | | | | |
| F rating | Basic working stress | Proposed working stress ratio | Expected limiting value for (M.R.) 1/40 LOR prob. (2) x (3) | N | Limiting value (MR) estimated 1/40 LOW prob. value from (M.R.) | Remarks | N | Limiting value (MR) estimated 1/40 LOW prob. value for (M.R.) | Remarks |
| | MPa | | MPa | | MPa | | | MPa | |
| F11 | 11 | 2.0 | 22.0 | 323 | 26.0 | Conservative | 454 | 21.8 | O.K. |
| F8 | 8.6 | 2.0 | 17.2 | 1566 | 17.0 | O.K. | 1473 | 16.8 | O.K. |
| F7 | 6.9 | 2.0 | 13.8 | 266 | 15.6 | O.K. small (N) | 247 | 13.9 | O.K. |
| F5 | 5.5 | 1.8 | 9.9 | 2298 | 11.5 | O.K. | 1326 | 12.1 | O.K. |
| F4 | 4.3 | 1.8 | 7.7 | 1605 | 7.3* | ? | 208 | 9.3 | O.K. small (N) |

* Altering the 70 x 35 mm programme will bring the value from 7.3 closer to 7.7 MPa.

It appears that the new proposal in general does justice to both radiata and slash pine except for the F11 grade for radiata pine which appears to be conservative. If we consider that younger radiata pine trees in the future will be converted into scantlings we have to allow some safeguards against the posibility that the strength of F11 will be depreciated.

# The Strength and Stiffness of Visually and Mechanically Graded Radiata Pine With Cross-sections of 35 mm x 150 mm and 35 mm x 200 mm

by D.J. GRANT
Forestry Commission of New South Wales

## 1. Introduction

Little information is available on the stiffness and strength of locally grown radiata pine with cross-sections of 35 mm x 150 mm and 35 mm x 200 mm. A grade recovery project carried out in the 1970's (Grant, 1980a) resulted in the sawing of a number of pieces of radiata pine timber with these cross-sections from trees of known age and silvicultural treatment thus providing the material suitable for this study.

## 2. Aim

The aim of the work was to evaluate the strength and stiffness of visually and mechanically graded radiata pine of large cross-section and to compare the results with those obtained from currently commercially produced cross-sections.

## 3. Materials and Methods

Timber used in this work was the bulk of the scantling sawn to 35 mm x 150 mm (159 pieces) and 35 mm x 200 mm (197 pieces) cross-sections during the study by Grant (1980).

The timber was mechanically graded using a Computermatic Mk.P.IVa grading machine with the N.S.W. Forestry Commission yellow program card inserted and the calculated forces applied (1485 N for 35 mm x 150 mm and 1980 N for 35 mm x 200 mm). The mnemotype recording system (Grant, 1977) was used during the grading to determine the deflection and location of the lowest stiffness zone on each piece.

TOPIC E9

This information plus visual examination of each piece enabled the lowest stiffness/likely weakest section to be identified. This section was marked and each sample docked to a convenient length for the mechanical tests.

The timber was visually graded to AS1490-1973 (SAA, 1973) before it was amended in 1977.

Modulus of elasticity was measured on the flat ($ME_f$) over a 914 mm span with the load applied at the mid point of the span and the deflection measured at the same point using a dial gauge positioned under the sample. Each sample was positioned so that the lowest stiffness/likely weakest section was situated over the mid point of the span. The load used for this test was equivalent to that applied during machine grading with the addition of a small zeroing load. This method is similar to the method of ME evaluation described in AS1749 (SAA, 1978).

Modulus of Elasticity was also evaluated when the samples were tested on edge ($ME_e$) during the Modulus of Rupture (MR) test. MR was determined using the NSW Forestry Commission reaction beam system in general accordance with the method described in AS1749 (SAA, 1978), i.e. using four point bending and with the sample loaded in such a way that its expected load carrying capacity would be a minimum (worst edge in tension). The distance between the base supports and the distance between the top loading points were 1860 mm and 460 mm respectively for the 35 mm x 150 mm size and 2470 mm and 570 mm for the 35 mm x 200 mm size. Forces were measured using load cells at the supports and beam deflection measured using a digital dial gauge positioned over the beam at the mid point of the span.

## 4. Results and Discussion

### 4.1 General

Stiffness and strength data were analysed firstly for each size group and then for the two groups pooled. Pooling of the data was justified because there was generally no statistically significant difference between the mean strength and stiffness values for either size group for any one grade.

Two methods were used for the estimation of the 2.5 percentiles, (i) the "Pearson" method as described by Johnson et al (1963) using four parameters and (ii) the "ordered array" method which follows closely the interpolation method of ASTM D2915-70T, Section 5.4.4 ASTM (1972).

ME data is in GPa units and MR data in MPa units for all results presented.

## 4.2 Modulus of Rupture Values for Timber with Various Visual and Mechanical Grades

Results of the analysis of MR values for samples with the various visual grades are given in Table 4.1 for the pooled data. Results for the theoretical machine grades based on the $ME_f$ ranges equivalent to the normally used machine grading ME ranges (Forestry Commission of N.S.W. "Yellow" and "Red" programs) are given in Table 4.2 for the pooled data.

Table 4.1 Results of the analysis of MR values for samples with particular visual grades for the 2 size groups pooled.

| | | | | | | Lower 2.5 percentile | |
|---|---|---|---|---|---|---|---|
| Grade | N | x | s.d. | skewness | kurtosis | Pearson | ordered array |
| F11 | 29 | 52.80 | 9.84 | -0.42 | 2.06 | - | - |
| F8 | 85 | 40.96 | 12.28 | 0.25 | 2.76 | 18.9 | 18.1 |
| F7 | 65 | 35.14 | 10.44 | -0.06 | 2.38 | 15.1 | 14.5 |
| F5 | 73 | 28.23 | 9.08 | 0.56 | 3.36 | 13.1 | 10.7 |
| F5HI | 47 | 33.72 | 9.99 | 1.40 | 6.07 | 21.0 | 17.3 |
| Reject | 44 | 20.93 | 9.77 | 1.89 | 7.95 | - | - |

TOPIC E9

Table 4.2 Results of the analysis of MR values for samples with various $ME_f$ ranges for the 2 size groups pooled.

| $ME_f$ range | Equivalent grade | N | $\bar{x}$ | s.d. | skewness | kurtosis | Lower 2.5 percentile | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | Pearson | ordered array |
| = > 11.59 | F11 | 80 | 48.05 | 11.66 | -0.05 | 2.35 | 25.9 | 25.7 |
| 8.28 to 12.20 | F8 | 227 | 35.06 | 11.60 | 0.49 | 2.88 | 16.2 | 16.0 |
| 5.52 to 8.59 | F5 | 81 | 24.79 | 9.07 | 0.48 | 2.88 | 9.9 | 8.5 |
| 4.14 to 5.65 | F4 | 4 | - | - | - | - | - | - |
| = < 4.21 | Reject | 4 | - | - | - | - | - | - |
| 7.73 to 9.27* | F7 | 81 | 27.81 | 9.07 | 0.23 | 2.37 | 12.2 | 11.6 |
| 5.52 to 7.99* | F5 | 50 | 22.64 | 8.14 | 0.49 | 3.38 | 8.6 | 8.0 |

* $ME_f$ ranges as proposed by Grant (1979) for sizes up to 35 mm x 120 mm.

The Modulus of Rupture values for samples with $ME_f$ within various 2 GPa ranges were analysed so they could be compared with a previous analysis of data from quality control samples taken from machine grading operations with a cross-section size of 35 mm x 120 mm (Grant, 1979). Both sets of results are given in Table 4.3.

Table 4.3 Results of an analysis of MR values for samples with various $ME_f$ ranges for the pooled data and for an analysis of 35 mm x 120 mm cross section size pieces from a previous study (Grant, 1979).

| $ME_f$ range | 35 mm x 150 mm & 35 mm x 200 mm cross-section | | | | 35 mm x 120 mm cross-section | | | |
|---|---|---|---|---|---|---|---|---|
| | N | $\bar{x}$ | 2.5 percentile | | N | $\bar{x}$ | 2.5 percentile | |
| | | | Pearson | Ordered Array | | | Pearson | Ordered Array |
| 4-6 | 5 | - | - | - | 145 | 19.31 | 7.0 | 7.0 |
| 5-7 | 24 | - | - | - | 160 | 21.53 | 8.8 | 7.1 |
| 6-8 | 49 | 22.74 | 8.5 | 8.0 | 176 | 25.50 | 11.7 | 11.5 |
| 7-9 | 84 | 26.97 | 12.5 | 11.5 | 180 | 27.84 | 13.7 | 12.4 |
| 8-10 | 122 | 30.17 | 14.2 | 13.7 | 141 | 32.44 | 15.0 | 14.3 |
| 9-11 | 128 | 33.72 | 15.4 | 15.6 | 107 | 38.77 | 16.4 | 17.8 |
| 10-12 | 113 | 37.88 | 19.0 | 17.5 | 89 | 46.33 | 18.7 | 19.5 |
| 11-13 | 89 | 43.87 | 22.8 | 21.4 | 63 | 50.94 | 22.2 | 20.3 |

4.2.1 Discussion

The visual grading statistics (Table 4.1) produced the following working stress ratios (WSR) when the 2.5 percentile estimated from Pearson curves are used. Note WSR = 2.5 percentile divided by the basic working stress in bending as defined by AS 1720(SAA, 1975).

F11 sample size too small (N=29)
F8 WSR = 2.2 (N=85)
F7 WSR = 2.2 (N=65)
F5 WSR = 2.4 (N=73)
F5HI WSR = 3.8* (N=47) *Note the small sample size

TOPIC E9

The machine grading statistics (Table 4.2) produced the following WSR's when the 2.5 percentiles estimated from Pearson curves are used.

F11 WSR = 2.4 (N=80)
F8 WSR = 1.9 (N=227)
F5 WSR = 1.8 (N=81)
F4 Sample size too small (N=4)

F7 WSR = 1.8 (N=81)
F5 WSR = 1.6* (N=50) *Note the small sample size.

The WSR normally applied in Australia is 2.22 which includes a long term loading factor of 9/16 and another factor of 4/5 which is described as an uncertainty factor (A. Anton pers. Comm.). Visual grading produced WSR's equal to or greater than 2.2 for all grades but it should be noted that the visual grading rules applied during the grading were the original ones included in AS1490 (SAA, 1973). Since this work was carried out before the new rules were introduced (they effectively upgraded all grades by one grade and eliminated F11) the results would not be applicable to the presently accepted rules (SAA, 1977). In fact if the present grading rules were used then the WSR's would be lower than those given for the F7 and F5 grades and also possibly for the F8 grade as well.

Machines grading produced WSR's below the 2.22 factor for the F8 F7 and F5 grades. Generally the WSR was 1.8 to 1.9, a ratio which would accommodate for the long term loading factor but not for the uncertainty factor.

Working stress ratios of around 1.9 to 2.1 were found to be fairly common in an extensive analysis of data from the testing of a large number of quality control samples of various cross-sections taken from machine grading operations in Australia, except for the 35 mm x 70 mm size which had generally lower WSR's and for the 45 mm x 90 mm size which had higher WSR's. (Grant, 1979) Some of the results from this earlier work were given in Table 4.3 and when the 2.5 percentiles from the present study are compared to those of the earlier study for the 35 mm x 120 mm size they appear to be quite similar for most groups i.e. in the 1.8 to 2.1 WSR range.

Mean values given in Table 4.3 are generally lower for the wider cross-section group when compared to those for the 35 mm x 120 mm group, especially as $ME_f$ increases. This however is not necessarily due to depth alone but could possibly be caused by differences in density and the type and size of defects between the two groups.

4.3 Modulus of Elasticity measured on edge for samples with various visual and theoretical machine grades.

The $ME_e$ values of samples with the various visual and mechanical grades were analysed and the results given in Tables 4.4 and 4.5.

Table 4.4 Results of an analysis of $ME_e$ for samples with various visual grades (pooled data).

| Grade | N | $\bar{x}$ | s.d. | skewness | kurtosis | min. | max. |
|---|---|---|---|---|---|---|---|
| F11 | 29 | 13.32 | 1.54 | -0.44 | 2.89 | 9.78 | 16.47 |
| F8 | 85 | 11.96 | 1.66 | 0.07 | 2.65 | 8.30 | 16.08 |
| F7 | 65 | 11.22 | 1.44 | -0.53 | 3.19 | 7.07 | 14.30 |
| F5 | 73 | 10.01 | 1.62 | -0.49 | 4.15 | 5.18 | 13.44 |
| F5HI | 47 | 10.28 | 1.51 | 0.45 | 3.40 | 7.29 | 14.40 |
| Reject | 44 | 8.98 | 1.87 | 0.74 | 3.93 | 5.14 | 14.80 |

TOPIC E9

Table 4.5 Results of an analysis of $ME_e$ for samples within various $ME_f$ ranges (pooled data).

| $ME_f$ range | Equivalent F Grade | N | $\bar{x}$ | s.d. | skewness | kurtosis | min. | max. |
|---|---|---|---|---|---|---|---|---|
| = > 11.59 | F11 | 76 | 13.26 | 1.11 | 0.11 | 2.97 | 10.47 | 16.08 |
| 8.28 to 12.20 | F8 | 227 | 11.01 | 1.42 | -0.10 | 3.34 | 5.67 | 15.04 |
| 5.52 to 8.59 | F5 | 81 | 8.85 | 1.35 | -0.51 | 3.05 | 5.14 | 11.47 |
| 4.14 to 5.65 | F4 | 4 | - | - | - | - | - | - |
| = < 4.21 | Reject | 4 | - | - | - | - | - | - |
| 7.73 to 9.27 | F7* | 81 | 9.55 | 1.07 | -0.53 | 4.23 | 5.67 | 11.95 |
| 5.25 to 7.99 | F5* | 50 | 8.50 | 1.36 | -0.24 | 2.88 | 5.14 | 11.30 |

*$ME_f$ ranges as proposed by Grant (1979) for sizes up to 35 mm x 120 mm

The relationship between $ME_e$ and $ME_f$ was found to be as follows:

$$ME_e = 0.859 \times ME_f + 2.32$$
$$\text{where } N = 344, \quad R^2 = 0.738$$

4.3.1 Discussion

The Australian Timber Engineering Design Code (SAA, 1975) gives the following modulus of elasticity values for structural timber grades:

F11 - 10.50 GPa
F8 - 9.10 GPa
F7 - 7.90 GPa
F5 - 6.90 GPa
F4 - 6.10 GPa

The average $ME_e$ for all visual and mechanical grades in this study (Tables 4.7 and 4.8) exceed the above values, especially considering that "in service" loading conditions would be generally uniformly distributed and over a wider span than the test span used here.

4.4 Relationships between Modulus of Rupture and Modulus of Elasticity

The following relationships were found when regression analyses were performed on the stiffness and strength data.

| | | | |
|---|---|---|---|
| 35 mm x 150 mm size group | : | MR = 5.11 x ME - 15.66 | N = 150, $R^2$ = 0.536 |
| 35 mm x 200 mm size group | : | MR = 3.91 x ME - 5.12 | N = 194, $R^2$ = 0.377 |
| both sizes pooled | : | MR = 4.45 x ME - 9.87 | N = 344, $R^2$ = 0.446 |

5. Final Discussion

The effect of beam depth on the bending strength of timber has been studied by research workers for many years. Most work, however, has involved the testing of clear timber or timber with small defects. Little work has been done on the effect of beam depth on strength for timber with relatively large defects which are often present in timber from fast grown trees.

Bohannan (1966) presents an analysis based on the Weibull (1939) "weakest link theory" and also a relationship between "strength ratio" and beam depth developed by Dawley and Youngquist in 1947 using beams having depths up to 400 mm. This relationship predicts that there would be a 5% and 10% reduction in bending strength for 150 mm and 200 mm deep beams respectively from the strength of a 100 mm deep beam.

Curry and Tory (1976) state that "tests have shown that the MR of graded timber (as opposed to clear timber) also exhibits a reduction when plotted against increased section depth". They also give the formula for the reduction factor used in the British Standard Code of Practice (B.S.A., 1971) This they state "is recommended for application to depths exceeding 300 mm (but) it has been shown to apply equally to shallower sections (Curry and Covington, 1969)". This formula gives reductions of 6% and 10% for 150 mm and 200 mm deep beams respectively from the strength of a 100 mm deep beam. The Australian Timber Engineering Design Code (SAA, 1975) also applies a reduction factor for beams of depth greater than 300 mm.

TOPIC E9

Walford (1979) observed that "basic working stresses for radiata pine in bending are from 14% to 34% less in 50 mm x 200 mm size than in the 50 mm x 100 mm size". Grant (1979) observed that 45 mm x 90 mm cross-section radiata pine showed a higher strength for various machine grades than did any other cross-section up to 35 mm x 120 mm which was the widest size tested.

## 6. Conclusion

This project has shown that there is little difference between working stress ratios for machine graded radiata pine in the 35 mm x 150 mm and 35 mm x 200 mm sizes and for those achieved by machine grading the 35 mm x 120 mm size. If the current machine grading programs were used for the grading of the larger sizes then WSR's similar to those currently achieved for the smaller sizes would be expected.

The 35 mm x 150 mm, 35 mm x 200 mm material had a lower mean modulus of rupture than the 35 mm x 120 mm size, especially in the higher machine grades, and this could be a result of the expected 5% - 10% decrease mentioned previously. This decrease was, however, not reflected at the lower 2.5th percentile.

Visual grading to the old AS1490-1973 rules achieved working stress ratios higher than those achieved by machine grading. Ratios significantly less than these, however, would be produced if the material had been graded to the current AS1490 rules.

Mean modulus of elasticity on edge for the various mechanical and visual grades exceeded the design values given in the Timber Engineering Design Code (SAA, 1975).

## 7. Acknowledgements

I would like to thank Mr. A. Anton, whose efforts resulted in the donation of the timber used in the study by the Forests Branch Dept. of the Capital Territory and also Mr. Edgerley, Director of the Forests Branch, for donating the timber. The assistance of Mr. Peter Webber and Mr. Michael Welsh is gratefully acknowledged.

## 8. Bibliography

American Society for Testing and Materials. (1972). D2915-70T. Tentative method for evaluating allowable properties for grades of structural lumber. U.S. A.S.T.M. Philadelphia.

British Standards Association (1971). The structural use of timber. British Standard Code of Practice CP 112:Part 2:1971.

Bohannon, B. (1966). Effect of size on bending strength of wood members. U.S. Forest Service Research Paper FPL 56.

Curry, W.T. and Covington, S.A. (1969). Grade stresses for European redwood and whitewood. U.K. Ministry of Technology, Forest Products Research, Bulletin No. 52.

Curry, W.T. and Tory, J.R. (1976). The relation between the modulus of rupture (ultimate bending stress) and modulus of elasticity of timber. U.K. Dept. of the Environment, Building Research Establishment Current Paper 30/76.

Grant, D.J. (1977). Mnemotype timber grading machine deflection reading storage unit. N.S.W. Forestry Commission, Technical Paper No. 29.

Grant, D.J. (1979). Machine stress graded radiata pine and slash pine - analysis of quality control data. N.S.W. Forestry Commission Report (Unpublished).

Grant, D.J. (1980a). The influence of age, site and stocking density of plantations on grade and monetary recovery of radiata pine scantlings and boards. M.Sc. Thesis, Australian National University.

Johnson, N.L., Nixon, Eric, Amos, D.E. (1963). Table of percentage points of Pearson curves. Biometrika, 50 (3 and 4) p 459.

Standards Association of Australia (1973). AS 1490-1973, Visually graded radiata pine scantling. Australia, Standards Association.

TOPIC E9

Standards Association of Australia (1975). AS 1720-1975, SAA Timber engineering code. Australia, Standards Association.

Standards Association of Australia (1977). AS 1490-1973, including Amendment No. 1, Visually graded radiata pine scantling. Australia, Standards Association.

Standards Association of Australia (1978). AS 1749-1978, Mechanical stress grading of timber. Australia, Standards Association.

Walford, G.B. (1979). Basic working stresses for radiata pine derived from in-grade bending tests. New Zealand Forest Service, Forest Research Institute, Timber engineering report No. 28 (Unpublished).

# METHOD FOR DERIVATION OF CORRECTION FACTORS FOR STRENGTHS WITH REFERENCE TO MOISTURE CONTENT

M. Chali
Wood Technology and Forest Research Division,
Forestry Commission of N.S.W.

## SUMMARY

When small clear specimens are tested for the purpose of estimating the various strength properties, the moisture content is often found to differ from that of 12% which is accepted as standard for comparison purposes.

This paper proposes a mathematical approach to estimate the correction factor 'α' as specified in the International Organization for Standardization (I.S.O.).

## INTRODUCTION

For most tests of the mechanical properties of small clear specimens of wood, International Organization for Standardization (I.S.O.) has specified a certain formula to be used in adjusting the test data results of the air-dry material to the 12% level of moisture content. The formula in itself is straightforward and contains only one unknown factor which has been defined as correction factor 'α'. The third F.A.O. conference on wood technology (1) had also recommended that on data presentation of small clear specimens of wood, all test results on air-dry material should be adjusted to 12% moisture content, but this conference did not specify any specific formula.

The motive of this study is to derive a formula to calculate 'α' values required by I.S.O. specifications.

## METHOD OF FORMULATION

In everyday practice it would be practically impossible to obtain air-dry material that contained precisely 12% moisture content. Laboratory experience has shown that the material moisture content varies between 8% and 16% under normal air-dry conditions.

United States Department of Agriculture (2) gave a formula known as the exponential formula for adjusting the air-dry test data to the 12% moisture content level. The implementation of this formula is not simple and required

a number of unknown factors. However, the USDA formula which is established on empirical data, can be written into the following form:

$$\sigma_{12} = \sigma_m \cdot \gamma^k \quad \ldots\ldots [1]$$

where:

$\sigma_{12}$ = strength value at 12% moisture content.
$\sigma_m$ = strength value at m% moisture content.
$\gamma$ = strength ratio of air-dry strength to green figures = $\frac{\sigma^*}{\sigma_G}$
$\sigma^*$ = mean strength value of the air-dry material with moisture content around 12%, otherwise it can be obtained from previous test data or test reference.
k = moisture ratio = $\frac{m - 12}{M - 12}$
M = intersection point on strength-moisture relationship curve.

The numerical value for the intersection point (M) can be estimated using either of the two formulae presented by Kelsey (3) and Kingston and Risdon (4)

Formula [1] can be expressed as:

$$\sigma_{12} = \sigma_m \cdot C_E \quad \ldots\ldots [2]$$

where:

$C_E$ = changing factor of the exponential formula = $\gamma^k$

Fortunately I.S.O. has adopted a simpler formula to correct the strength value of air-dry material to 12% moisture content. The I.S.O. formula was reported previously by Perelygin (5) and expressed as follows:

$$\sigma_{12} = \sigma_m \cdot C_S \quad \ldots\ldots [3]$$

where:

$C_S$ = I.S.O. changing factor = $1 + \alpha(m - 12)$
$\alpha$ = correction factor that depends on species and type of test.

To derive a procedure to estimate '$\alpha$', let us consider the changing factor ($C_E$) of the exponential formula eq. [1].

$$C_E = \gamma^{\frac{m - 12}{M - 12}} \quad \ldots\ldots [4]$$

In fact this expression [4] defines the curve for the changing factor versus moisture content (m) - see fig. 1. This purports that we are here concerned with an equation of the following form:

$$y = g(x)$$

where:

g is the defined continuous function of the changing factor for the abovementioned range of moisture content. Hence the assumption that g is differentiable is not questionable and that its first derivative

satisfies

$$| \dot{g}(x) | < = 1 \qquad \text{for } 8 < = m < = 16$$

Therefore under this circumstance

$$\dot{y} = \frac{dy}{dm} = \frac{d}{dm} g(x)$$

$$= \frac{d}{dm} \left(\gamma^{\frac{m - 12}{M - 12}}\right) \qquad \ldots\ldots [5]$$

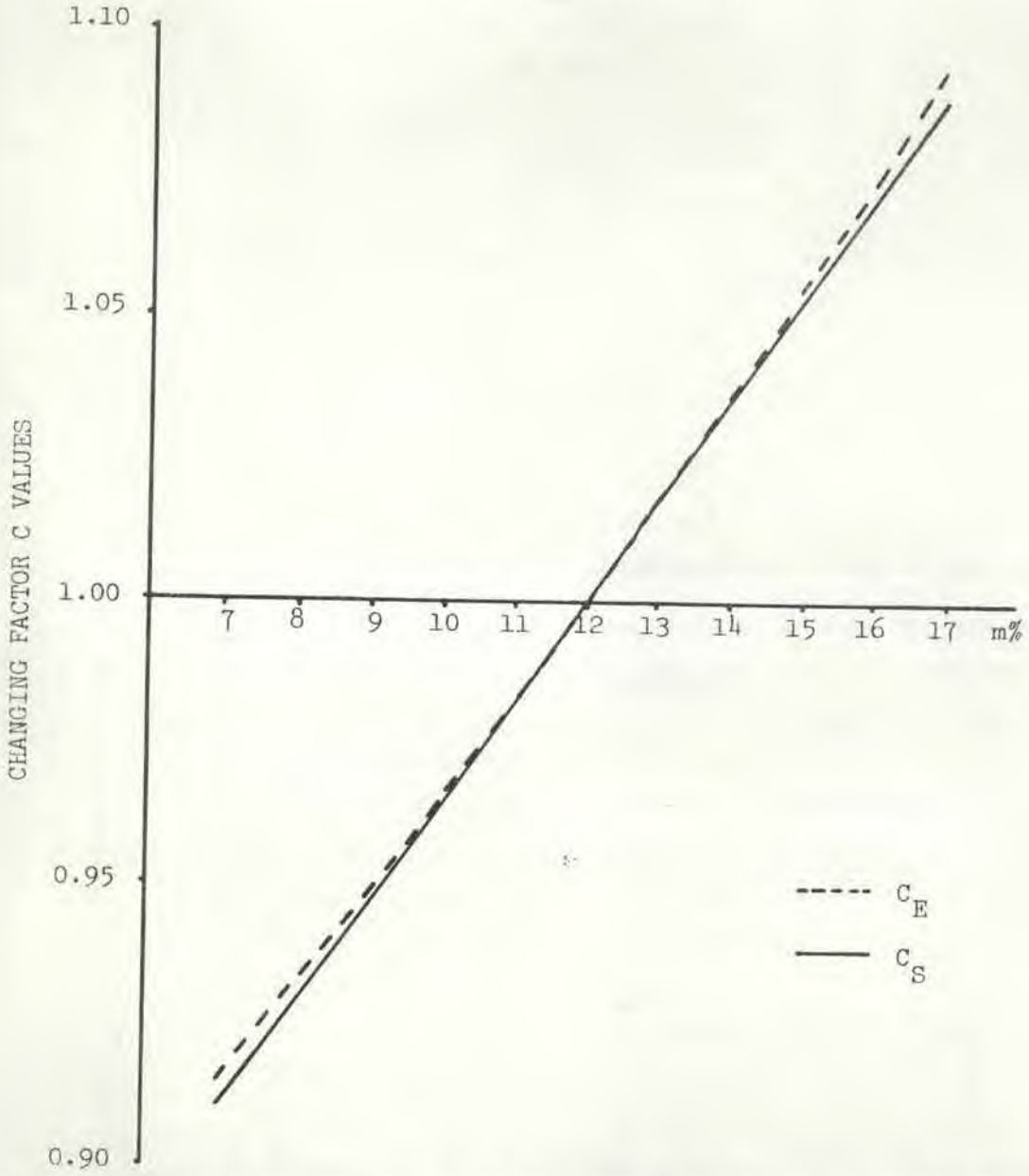



FIG. 1: Changing factors curves ($C_E$) and ($C_S$) of USDA and ISO formulae when plotted against moisture content (m).

Through differentiation we get:

$$\dot{y} = \frac{\gamma^{\frac{m - 12}{M - 12}}}{M - 12} \cdot \ln \gamma \qquad \ldots\ldots [6]$$

Proof:

Let $r = (M - 12)^{-1}$

From eq. [5]

$$\dot{y} = \frac{d}{dm} \frac{\gamma^{rm}}{\gamma^{12r}}$$

or

$$y = \frac{\gamma^{rm}}{\gamma^{12r}}$$

$$\ln y = r\,m \ln \gamma - 12r \ln \gamma$$

then

$$\frac{d}{dm} \ln y = \frac{d}{dm} (\text{r.h.s.})$$

$$\frac{1}{y} \cdot \frac{dy}{dm} = r \cdot \ln \gamma$$

$$\frac{dy}{dm} = r \cdot \gamma^{r(m-12)} \cdot \ln \gamma$$

Finally

$$\dot{y} = \frac{\gamma^{\frac{m-12}{M-12}}}{M-12} \cdot \ln \gamma \qquad \ldots\ldots [7]$$

$$= \dot{C}_E$$

Execution of equation [7] will give the slope value of the tangent to the curve of the $C_E$ function at different m values.

Estimating the arithmetic mean will give logically the optimum value for 'α'.

TABLE 1

Changing Factors for Both Exponential ($C_E$) and I.S.O. ($C_S$) Formulae

| m | Changing factor | | Error of using eq. [3] with $\alpha_{opt.}$ (percent) |
|---|---|---|---|
| | $C_E$ | $C_S$ | |
| 7 | 0.915178 | 0.911224 | 0.432 |
| 8 | 0.931546 | 0.928979 | 0.276 |
| 9 | 0.948207 | 0.946734 | 0.155 |
| 10 | 0.965167 | 0.964490 | 0.070 |
| 11 | 0.982429 | 0.982245 | 0.019 |
| 13 | 1.017885 | 1.017755 | 0.013 |
| 14 | 1.036091 | 1.035510 | 0.056 |
| 15 | 1.054622 | 1.053266 | 0.129 |
| 16 | 1.073484 | 1.071021 | 0.229 |
| 17 | 1.092683 | 1.088776 | 0.358 |

As an illustration of the two changing factors $C_E$ and $C_S$ for the exponential and I.S.O. formulae respectively, let us take M = 26.8, $\gamma$ = 1.3, $\alpha = \alpha_{opt.}$ and moisture content range $7 <= m \neq 12 <= 17$

From eq. [7] we get $\alpha_{opt.} = 0.01776$

The values of the changing factors $C_E$ and $C_S$ for each value of m are listed in Table 1. The table also shows the very small percentage differences between the two formulae. Estimation of the error was executed using the $C_E$ as a basis for the percentage.

To sum up the conclusion of this study, here is the final form of the equation which may be utilized for estimating the correction factor 'α'

$$\alpha_{opt.} = \frac{1}{n} \cdot \frac{\ln \gamma}{M-12} \sum_{i=1}^{n} \gamma^{k_i}$$

REFERENCES

(1) Food and Agriculture Organization (1955). 'Third Conference on Wood Technology.' (United Nations, Rome.)

(2) United States Department of Agriculture (1974). 'Wood Handbook.' For. Prod. Lab. Agric. Handbook No. 72. (USDA: Washington, D.C.)

(3) Kelsey, Kathleen E. (1956). 'The shrinkage intersection point its significance and the method of its determination. *For. Prod. J.* 6(10): 411-17.

(4) Kingston, R.S.T. and Risdon, C.J.E. (1961). 'Shrinkage and density of Australian and other south-west Pacific woods.' CSIRO Div. For. Prod. Tech. Pap. No. 13 (Melbourne.)

(5) Perelvgin, L.M. (1965). 'Science of Wood.' (Higher School Publishing House, Moscow.)

D. West, Government Printer, New South Wales – 1981

# IN GRADE TENSION TESTS ON 90 mm x 35 mm RADIATA PINE (F8), TO ESTABLISH THE RELATIONSHIP BETWEEN TENSILE AND BENDING STRENGTH

A. Anton and P. Chapman
Wood Technology and Forest Research Division,
Forestry Commission of New South Wales

## ABSTRACT

Tension tests were carried out on mechanically graded F8, 90 mm x 35 mm radiata pine scantlings to assess the relationship between tensile and bending strength, the latter of which is considered to be the main property to which all others are related.

The test results have shown that for the particular grade and size tested the tensile to bending strength (T/B) ratio is approximately 0.7. This value was obtained by comparing specific percentiles for 92 samples tested in tension with 728 samples of the same cross section and of the same origin of supply tested over a three year period as part of the quality control which is associated with mechanical grading.

## INTRODUCTION

In timber engineered structures each individual element is expected to carry the loads apportioned to it as opposed to conventional building practices where load sharing plays an important role.

In earlier times, with the then available mechanical fasteners, the size of tension members in engineered structures were generally determined to satisfy the joint requirements, as a result of which tension members were rarely highly stressed. This led to the practice of using the same working stress in tension as that for bending without adverse effect.

With the introduction of toothed plate metal connectors and other modern mechanical fastening systems the situation has been reached where the efficiency of the joint has improved to the extent that timber sizes can be reduced to a critical level. Hence the reliability of a tension member in a structure is dependent not only on the integrity of the joint but also to a far greater extent, on the quality of the timber used. This aspect has been recognised

internationally and the various timber design codes account for it by reducing the tensile working stress with reference to that in bending. Australian Standard 1720-1975 "S.A.A. Timber Engineering Code" provided for working stresses in tension to be 0.8 of those in bending, More recently this factor was amended to 0.6.

This amendment takes into account the limited experimental evidence available and the uncertainties resulting from lack of research in areas of concern such as, changing practices in building construction, joint efficiency, reduction in size of timber used in tension members and the variability in timber quality resulting from alternative grading systems.

With these factors in mind, this paper presents and discusses the results of an investigation (1) carried out on a parcel of commercially mechanically graded radiata pine 90 mm x 35 mm with the aim of assessing among other things the tensile to bending strength ratio of mechanically graded timber of this size which is commonly used in truss manufacture.

## MATERIAL

The material for this study comprised 159 lengths of radiata pine scantling, 90 mm x 35 mm, which had been high temperature kiln dried, dressed and mechanically graded.

The material was supplied by the Radiata Pine Association of Australia and was considered to be representative of the quality of mechanically graded radiata pine, viz. a small percentage of F5 and F11 grades with the bulk of the material being F8 (Table 1).

## TESTING

The following factors were investigated.

1) Grading

The material was regraded mechanically under well controlled laboratory conditions using the same programme as that used by the industry.

2) Density

The overall density of each sample was obtained by weighing (to the nearest 0.01 kg) each one of the 159 pieces which were 4000 mm long with an average cross-section of 90 mm x 35 mm.

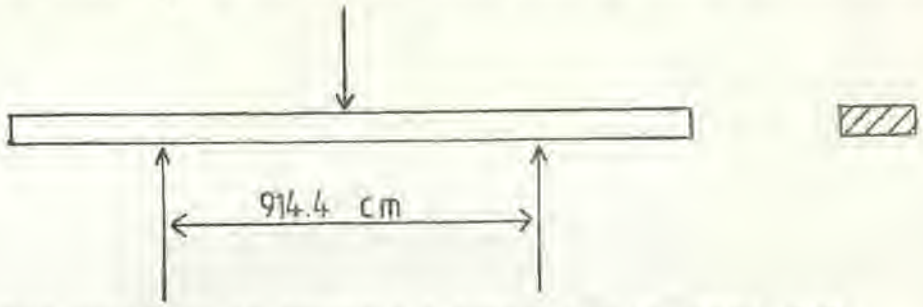
3) Moisture Content

Moisture content was determined using an electrical resistance moisture metre.

4) Modulus of Elasticity in bending ($E_b$)

The lowest stiffness zone, as indicated by the grading machine, which

contained the worst visual defect was selected for evaluation of flexural modulus of elasticity on the flat ($E_b$) under centre point load as shown in the diagram below.




This being the method specified in Appendix A Australian Standard 1748 "Mechanically stress-graded timber and rules for Mechanical Stress Grading of Timber" and 1749-1978.

5) Tensile Testing

The tensile test rig consisted essentially of two large angle brackets bolted onto a universal beam. These brackets support the articulated jaws which grip the timber as well as the force measuring load cell and the hydraulic cylinder providing the tensile force.

The timber was placed between the jaws and loaded to destruction at a constant strain rate of 0.0006 cm/cm. min. as specified in A.S.T.M. D. 198-1967. The extension was measured over a gauge length of 900 mm and the point of expected failure was situated centrally within this length. Load and extension were automatically recorded and the ultimate tensile strength ($F_t$) and modulus of elasticity in tension ($E_t$) of the weakest zone along the length of the scantling were determined.

## RESULTS AND DISCUSSION

Table 1 below presents a comparison of grades obtained using the laboratory and the mill stress grading machines. The results indicate that the mill machine graded conservatively.

TABLE 1

Comparison of Grades Obtained by Wood Technology and Forest Research Division and Mill Stress Grading Machines

| Grade | Number | |
|---|---|---|
| | Laboratory | Mill |
| F5 | 28 | 32 |
| F8 | 92 | 106 |
| F11 | 39 | 21 |

The moisture content of the timber varied from 9 - 16% with an average value

of 11% which is normal for seasoned radiata pine.

The overall density varied from 474 to 668 kg $m^{-3}$ with an average value of 565 kg $m^{-3}$. The denser timber tended to be stronger.

Table 2 summarises the test results obtained for Modulus of Elasticity in tension ($E_t$) and bending ($E_b$) and ultimate tensile strength ($F_t$).

TABLE 2

Summary of Statistical Data for the Various Grades

| Grade | No. tested | Mean Modulus of Elasticity (MPa) | | Ultimate tensile strength $F_t$ (MPa) | | | |
|---|---|---|---|---|---|---|---|
| | | $E_t$ | $E_b$ | Mean | Std. dev. | Skewness | Kurtosis |
| F5 | 28 | 9220 | 8290 | 18.0 | 9.6 | 1.76 | 6.21 |
| F8 | 92 | 12130 | 10940 | 28.4 | 12.1 | 0.97 | 3.78 |
| F11 | 39 | 15380 | 13290 | 34.2 | 14.3 | 0.94 | 3.39 |

Figure 1 shows the cumulative frequency curves of the ultimate stress in tension for the various grades. It indicates that mechanical grading provides an effective method of sorting timber according to its tensile strength as well as for its bending strength.

Table 3 gives the linear regression equations and correlation coefficients for modulus of elasticity in tension ($E_t$), modulus of elasticity in bending on the flat ($E_b$) and ultimate tensile strength ($F_t$).

TABLE 3

Linear Regressions

| x on y | Linear regression equations* | Correlation coefficient |
|---|---|---|
| $E_t$ on $F_t$ | $y = 2.28x - 2.35$ | 0.585 |
| $E_b$ on $F_t$ | $y = 2.63x - 3.26$ | 0.535 |
| $E_b$ on $E_t$ | $y = 0.972x + 1610$ | 0.771 |

* x and y are expressed in MPa

Since the bulk of the test material was F8 grade, the tensile results for this grade were compared with those of bending for the same grade and scantling size and from the same source. These latter results being obtained from quality control tests of mechanically stress graded radiata pine over a 3 year period.

This comparison is shown in Figure 2 in the form of cumulative frequency distributions and with the lower tail of the distributions magnified. There is good agreement between the various percentile levels obtained using statistical

calculations and those obtained from the curves.

Table 4 gives the ratios of the ultimate tensile strength to modulus of rupture for various percentiles of interest as obtained from the curves shown in Figure 2.

TABLE 4

Ultimate Tensile Strength and Modulus of Rupture in Bending Ratio for Various Percentiles

| Percentile | Ultimate tensile strength 'T' (MPa) | Modulus of rupture 'B' (MPa) | Ratio T/B |
|---|---|---|---|
| 2.5 | 11.7 | 16.0 | 0.73 |
| 5.0 | 12.9 | 19.0 | 0.68 |
| 50.0 | 23.5 | 39.5 | 0.59 |

## CONCLUSIONS

The elastic modulus in tnesion and the ultimate tensile strength were both successfully measured using the newly commissioned tensile testing equipment.

Because the bending strength of mechanical graded timber is determined in a manner which emphasises the properties of the scantlings in tension, mechanical grading provides an effective method of sorting timber according to its tensile strength as well as for its bending strength. Although the ratio of tensile to bending strength in this study was found to be about 0.7, consideration should be given to the number of specimens tested, the size of the cross-section, the fact that only one grade was examined in detail and the variability which could occur due to source of supply and the various methods of grading. Hence, as a result of this study, and others carried out by the C.S.I.R.O. Division of Building Research, the tensile strength of timber for design purposes has been considered as 0.6 of that in bending for all grades which, of course, may be determined by alternative methods of grading.

## ACKNOWLEDGEMENTS

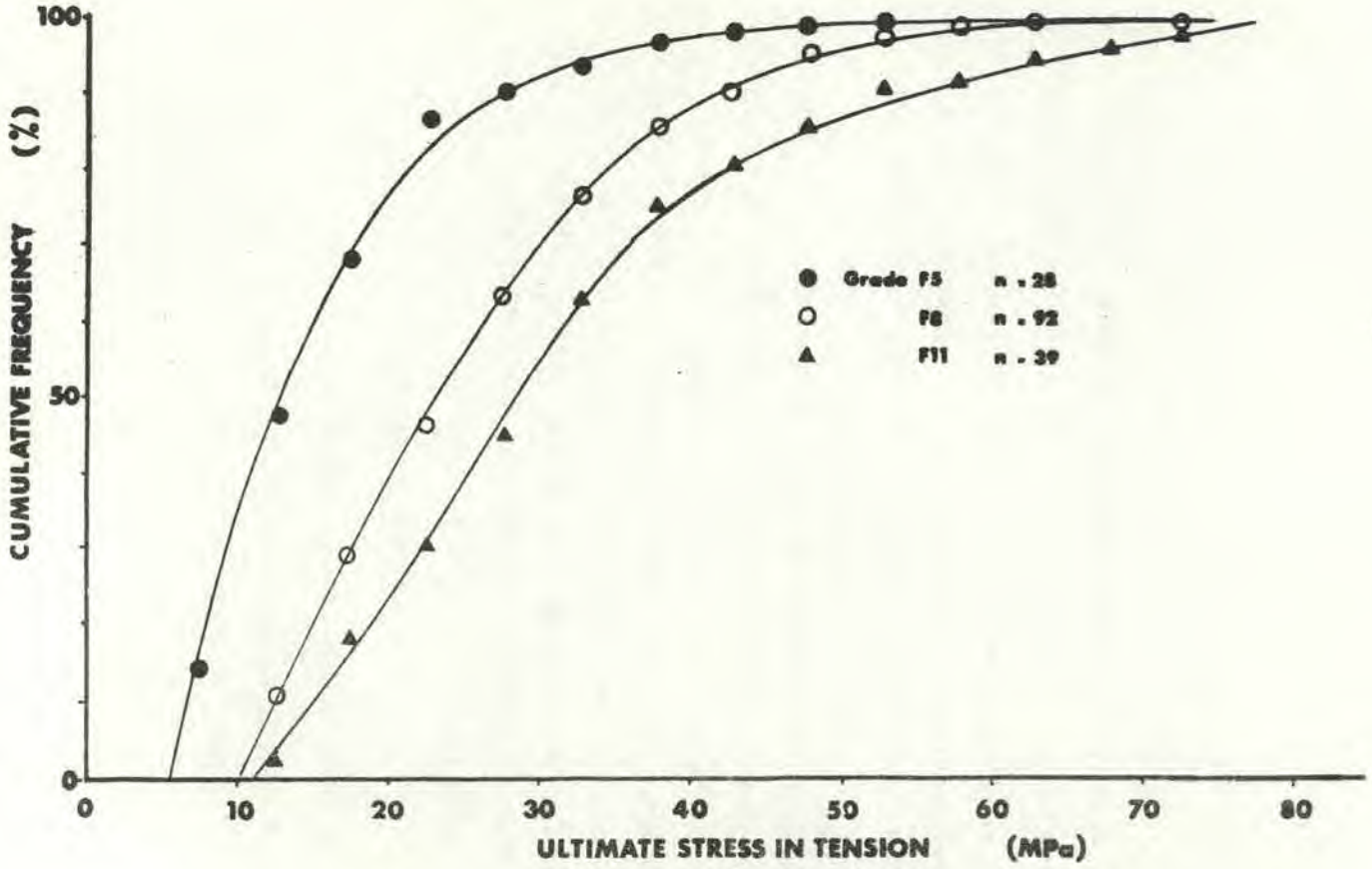
Dr. R. A. Curtin, for his critical review and constructive suggestions.

Dr. R. Leicester, Building Research Division, CSIRO, for the communication we have had over the years on this topic.

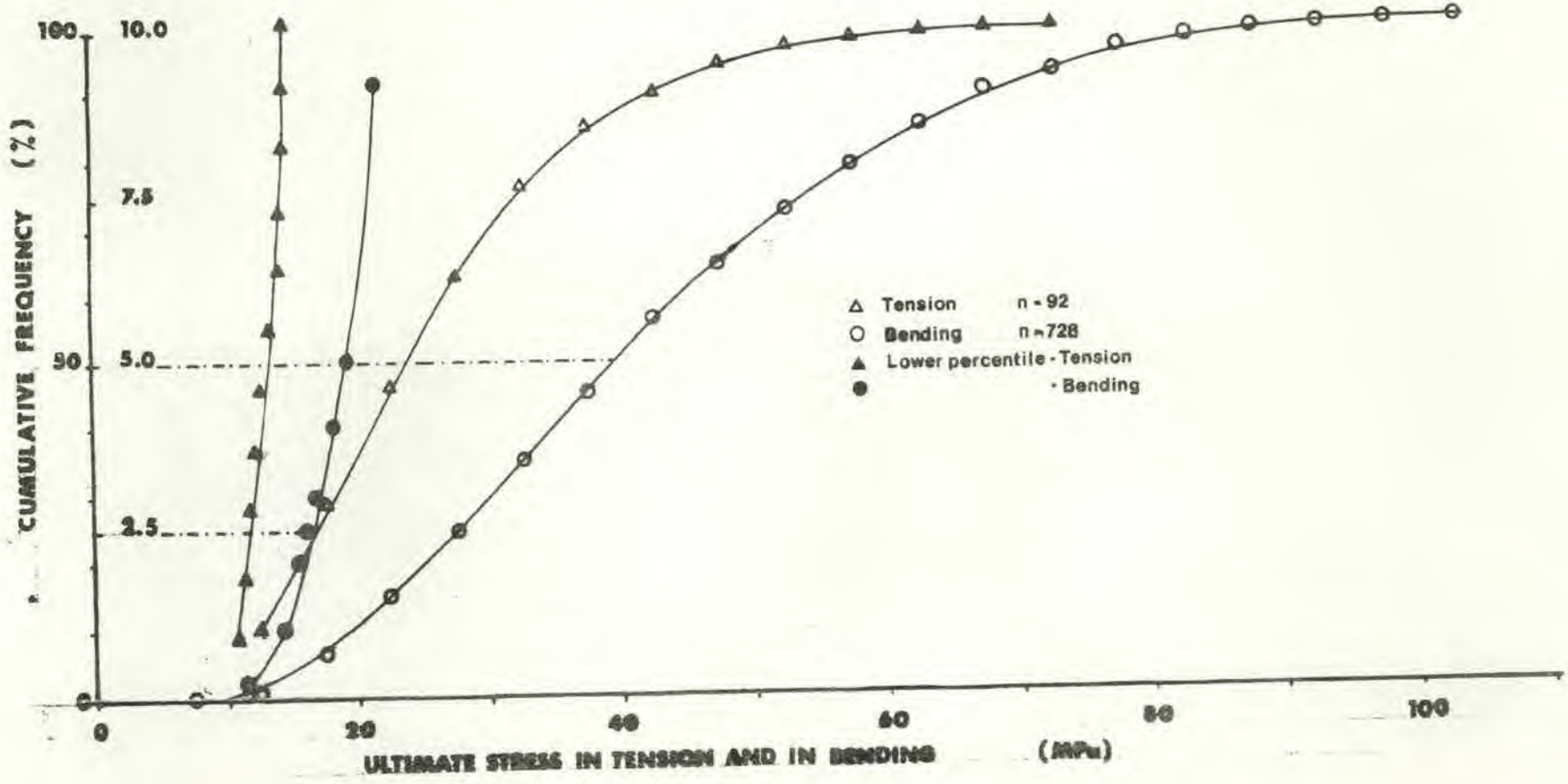
Mr. Skidmore, A. - who carried out the experimental work under the supervision of the authors as a trainee forestry student and prepared a comprehensive report (1).

## REFERENCES

(a) Skidmore, A., (1980). "Tensile properties of *Pinus radiata* scantling". F.C. Report.




Cumulative frequency curves for various mechanical grades.




Cumulative frequency distribution curves with the lower percentile tail magnified.

# EXPLORATORY STUDY INTO THE GLUABILITY OF SIX HARDWOOD TIMBER SPECIES OF NEW SOUTH WALES

M. Ghali
Wood Technology and Forest Research Division
Forestry Commission of N.S.W.

## ABSTRACT

The gluability of six New South Wales tableland and coastal hardwood species were evaluated using two commercially available room temperature setting phenolic type adhesives (resorcinol/phenol formaldehyde and resorcinol formaldehyde). The main object of this study was to assess the potential of using these species for laminated constructions. The results of close lap-joint tests indicated that the bond established by gluing any of the six species with either adhesive has satisfied the requirements needed for weatherproof applications.

The relationship between percentage wood failure and bond strength is discussed. It is concluded that wood failure and strength values when considered together will provide a better indicator for bond quality.

## INTRODUCTION

Large structural members made from timber have advantages over many other engineering materials, e.g. low energy consumption is required in production, a low weight to strength ratio, and minimum maintainance costs. However, the possibility of obtaining such large members as single pieces of solid timber is both remote and expensive, because virgin forests are becoming limited and regrowth and plantation forests are unable to meet the demand for large trees.

Structural timber of any desired shape, length or dimensions can be fabricated by end-joining, edge or face gluing. By these techniques laminated members made of low grade timber can also be produced with much more uniform strength properties than the natural solid member since the dispersion of defects may be readily controlled.

The critical part of these gluing techniques is the strength of the bond created between the timber and the glue. Glues that are excellent for bonding certain timber species and assembled within a particular environment may not be

equally well suited for others. This is due, to a large extent, to the amount of water and organic solvent type extractives present within the wood surface. These extractives may react chemically with the ingredients of the adhesives and or may create a physical barrier which prevents or restricts the adhesive penetration. The amount of the extractives also is proportional to the wood density. This paper thus depicts the gluability behaviour of typical medium to high density hardwood species with resorcinol adhesives. The ultimate intention of this study is to extend the range of hardwood utilization to include crossband and laminated constructions.

## MATERIALS AND TEST METHOD

Six New South Wales tableland and coastal hardwood species were selected on the basis of their commercial importance. They were blackbutt (*Eucalyptus pilularis* Sm.), brush box (*Tristania conferta* R. Br.), manna gum (*E. viminalis* Labill.), rose gum (*E. grandis* W. Hill ex Maiden), blue-leaved stringybark (*E. agglomerata* Maiden) and silvertop stringybark (*E. laevopinea* R. T. Bak.).

Two types of commercially available adhesives were used. Both were close-contact room temperature setting types based on resorcinol type resins used with a hardener in a dry powder form. These were CASCOPHEN (resorcinol/phenol formaldehyde RS240M) mixed with 20% (by weight) of dry powder hardener (FM-124); and RESOBOND (resorcinol-formaldehyde A-3) and hardener (P-6) mixed at the same ratio of 20%.

The procedure of the British Standard 1204 (1) was followed as closely as practicable. Slips made of coachwood (*Ceratopetalum apetalum* D. Don) were used in lieu of European beech (*Fagus sylvatica* L.) as recommended by Australian Standard 1328 (2).

Slips were cut and dressed to size 114 x 25 x 3 mm. For each test at least six close joints were assembled and conditioned at 24°C for six days in an incubator. Joints tested for resistance to hot water were boiled for six hours, while the cold water resistance joints were immersed in a waterbath at 17°C for 20 hours. Though it is not specified in either standard, sets of joints were tested in the dry condition (i.e. assembled condition) after being conditioned for six days.

## RESULTS AND DISCUSSION

Data on wood characteristics and mechanical properties of the six species used in this study are given in (3). The basic density of the species varied from 505 $kg.m^{-3}$ (rose gum) to 720 $kg.m^{-3}$ (brush box). Most species had straight grain, although some interlocked grain did occur and were pale to medium in colour, with narrow sapwood.

The mean shear failing load and the average wood failure percentage are shown in Table 1. Slip moisture contents based on oven dry weight measured before the assembly, are also shown in the table.

BS-1204 (1) states that the mean failing load for the cold soak test and the boiling water test should not be less than 2.22 kN and 1.45 kN respectively, i.e. the cold soak test load requirement having more than 50% greater than that of the boiling water test. This high percentage difference was not observed in the present series of tests. In fact blackbutt gave a high mean failing load after the boiling test (3.38 kN) than after the cold soak test (2.98 kN) for CASCOPHEN adhesive. A similar result was obtained with RESOBOND adhesive, the difference, however, being of lesser magnitude.

In the boiling-water test (Table 1), only one specimen of manna gum did not pass the minimum limit of BS-1204. Silvertop stringybark was the only species in which all specimens passed the cold-soak test minimum limit with the use of both adhesives.

Comparing the bond quality of the two glues, the dry test result shows that both silvertop and blue-leaved stringybark gave better bonding with RESOBOND than with CASCOPHEN. In the boiling-water test, there is no apparent difference between percentage wood failure for either of the two glues, although the mean failing load with CASCOPHEN was higher than that with RESOBOND for most species.

The cold-soak test is a severe test of bond strength for most species. The percentage of specimens passing the minimum limit dropped to 55% for blackbutt joints with the RESOBOND glue. Wood failure was low (13%) for blue-leaved stringybark with CASCOPHEN, though five out of six specimens gave higher shear failure load than the limit specified by the standard. However, in general with high density wood the percentage of wood failure decreases while the mean failing load increases.

Results of cold-soak and dry tests as compared to the boiling-water test indicate that the assembly environment at 24°C for a period of six days is not adequate for a good cured bond especially for CASCOPHEN with the high density species tested.

BS-1204 does not specify the need to consider wood failure as a factor in bond assessment. However in this study the percentage of wood failure was considered as an empirical index in making a complete assessment of the bond quality. This was done by making the following assumption: Taking p% as the percentage wood failure, this purports that p% of the maximum failing load is carried by the wood and that (100-p)% is the resistance of the bond established between the wood slips and the adhesive in use ($0<p<100$). To be more explicit:

TABLE 1

Slips Shear Failing Result of Some Hardwood Species With CASCOPHEN (C) and RESOBOND (R) Adhesives. The Result is Based on Testing Six or More Joints for Each Test

| Species | Air-dry density $kg.m^{-3}$ | Slips | Dry test | | Boiling water test (for 6 h) | | Cold soak test (for 20 h) | | Adhesive |
|---|---|---|---|---|---|---|---|---|---|
| | | MC[A] | MFL | WF | MFL | WF | MFL | WF | |
| Blackbutt | 895 | 10.0 | - | - | 3.38 | 65 | 2.98 | 17 | C |
| | | 12.9 | 2.21 | 2 | 2.37 | 70 | 2.30 | 55 | R |
| Box, brush | 900 | 11.2 | 2.83 | 70 | 2.74 | 80 | 3.44 | 75 | R |
| Coachwood | 620 | 11.2 | - | - | 2.70 | 93 | 2.36 | 100 | C |
| | | 11.1 | 2.61 | 95 | 2.03 | 90 | 2.37 | 90 | R |
| Gum, manna | 730 | 12.3 | 2.52 | 20 | 2.06 | 78 | 2.77 | 65 | R |
| Gum, rose | 615 | 10.2 | - | - | 2.79 | 75 | 2.76 | 55 | C |
| Stringybark | 885 | 10.8 | 2.71 | 30 | 2.48 | 75 | 2.53 | 13 | C |
| blue-leaved | | 13.4 | 2.84 | 68 | 2.35 | 73 | 3.20 | 71 | R |
| Stringybark | 860 | 10.7 | 2.69 | 52 | 2.66 | 84 | 2.79 | 53 | C |
| silvertop | | 13.5 | 3.19 | 53 | 2.90 | 56 | 3.47 | 71 | R |
| B.S. 1204 (1) minimum limits | | 12 ± 2.5 | - | - | 1.45 | - | 2.22 | - | |

A : MC = moisture content (%), MFL = mean failing load (kN) and WF = wood failure (%).

1) When the mean shear failing load is found to be higher than the BS-1204 limit then if the p value is equal to:

   a) 100%, the result can interpreted as an acceptable bond associated with low strength timber,

   b) 0%, the result can be taken as an acceptable bond associated with high strength timber.

2) When the mean failing load obtained is lower in value than the BS-1204 limit and the wood failure p is equal to:

   a) 100%, this indicates that the bond has not been assessed and then the timber strength is very weak,

   b) 0%, this means that the bond achieved is very poor and there is no indication of the wood strength.

By means of this assumption ranking the species in decreasing order according to the bond established with each type of the two adhesives became possible (Table 2). The results show that all species tested have higher bond quality-strength value than coachwood. Therefore the manufacturing of weatherproof composite members consisting of any of these species including coachwood is feasible.

TABLE 2

Adhesive - Species Relationship in Decreasing Order in Accordance With the Assumption made to Relate Bond Quality with its Strength

| Type of adhesive | Boiling-water test | Cold-soak test |
|---|---|---|
| CASCOPHEN | blackbutt | stringybark, blue-leaved |
| | gum, rose | blackbutt |
| | stringybark, silvertop | stringybark, silvertop |
| | stringybark, blue-leaved | gum, rose |
| | coachwood | coachwood |
| RESOBOND | stringybark, silvertop | blackbutt |
| | box, brush | stringybark, silvertop |
| | blackbutt | box, brush |
| | stringybark, blue-leaved | stringybark, blue-leaved |
| | gum, manna | gum, manna |
| | coachwood | coachwood |

Although tannin-type phenol resin has not been included in the present study, its importance cannot be ignored and it is intended that further work on gluability be carried out using a wider range of adhesives. The test method

will also be expanded to include the block shear test procedure.

It was concluded, under the test conditions and assumptions outlined, that close lap-joints of blackbutt, brush box, manna gum, rose gum, blue-leaved stringybark and silvertop stringybark using room-temperature setting of CASCOPHEN and RESOBOND are superior to those made of coachwood slips. Therefore these joints are expected to be resistant to weather and should withstand cold water for many years without pronounced degradation. Also the association of the wood failure with the bond strength allows a better judgement of species gluability.

## ACKNOWLEDGEMENT

Borden Chemical Company (Australia) Pty. Ltd., and N. H. Town & Co. supplied the adhesives CASCOPHEN and RESOBOND respectively.

## REFERENCES

(1) British Standards Institute (1965). Specification for synthetic resin adhesives for woods - close contact adhesives. BS-1204 - Part 2, London.

(2) Australian Standards Association (1972). Glued-laminated structural timber - AS 1328. Sydney.

(3) Ghali, M. (1977). Mechanical and physical properties of N.S.W. species of timber. For. Comm. N.S.W., Unpublished Report TE-175.

# ENGINEERING ASPECTS IN UTILISATION OF SHINING GUM TREES INFESTED BY AMBROSIA BEETLES

M.B. Ghali and D.T. d'Espaignet

Wood Technology and Forest Research Division,
Forestry Commission of N.S.W.,

## A B S T R A C T

This paper presents data on the effect of defects associated with ambrosia beetle attack on the wood properties of shining gum (Eucalyptus niteus Maiden) grown in the southern tablelands area of New South Wales. Green material was tested in scantling sizes for static and impact bending. Strength losses occurred in scantlings which had the greatest number of pin holes and/or black stain distribution density. The defective material showed a reduction in energy absorption properties, but on the other hand there was a relative increase in basic density as well as in stiffness. The defective material collapsed and shrank less than the defect-free material during air-drying.

It is concluded that the visual strength grading rules should make an appropriate allowance for black stain defect which has an adverse effect on the strength of shining gum when severe.

## INTRODUCTION

Defects caused by pinholes and black stain arising from ambrosia beetle attack, present a problems in the marketing of many species because of their effect on the appearance of the timber. While visual strength grading rules give some recognition to pinholes they do not mention anything about stain.

TOPIC E13

This study was designed to investigate the effect of ambrosia attack on timber properties with reference to shining gum

## MATERIAL AND SAMPLING

In summer 1978, we made an engineering evaluation of structural size timber from shining gum (Eucalyptus nitens Maiden) infested by ambrosia beetle. The study was requested by Bega Forestry Office, South East District in N.S.W., which is responsible for the management of Glenbog State Forest, and Tablelands Sawmills Pty Ltd., Nimmitabel, which has logging rights in the area.

Test specimens were collected in the mill from freshly rough sawn, unseasoned scantlings (nominal size 3.8 x 10.0 x 250 cm). The general procedure used for selection of the material was based on proportionate probability sampling (1). The selection of samples was spread over two full days of the mill's production and obtained from 16 logs 5-6 m long cut from 7 different trees.

## TESTING PROCEDURE

In the laboratory each sample was dressed to uniform size (34 x 94 mm) and divided into four groups according to the number of borer holes and black-stain distribution density (BSDD) as follows:

Group A 'Control': Normal, clear, defect free material without imperfection, allowing a sloping grain 1 in 15.

Group B 'Light defect': Defect free material, allowing sloping grain as in group 'A' borer holes not exceeding 10 in any 100 $cm^2$ and/or BSDD less than 1 $cm^2$ per 100 $cm^2$.

Group C 'Medium defect': Defect free material allowing sloping grain as in 'B', borer holes not exceeding 20 in any 100 $cm^2$ and/or BSDD less than 2 $cm^2$ per 100 $cm^2$.

Group D 'Heavy defect': Defect free material allowing sloping grain as in 'C' borer holes and/or BSDD in excess of 'C'.

Testing was divided into two major procedures:

1. Non-destructive mechanical test:

The specimens were loaded in static bending on flat as well as on edge in accordance with (2) and (3) respectively to determine the modulus of elasticity.

2. Destructive test:

Upon completion of the non-destructive test, the ultimate bending strength of the material was evaluated. This was accomplished by loading each scantling as a joist under 4 point bending. Loading, shear span and testing procedure were in accordance with (2). The test specimen was so positioned on the testing apparatus that the worst defect assessed by number of holes and black stain distribution density was in the area of maximum moment and therefore in the region of greatest stress.

The second phase of destructive testing was an impact test. Specimens were prepared from undamaged regions from material tested to rupture in static bending. Impact tests performed, (i.e. Izod and toughness) were as specified in Mack (4) though allowance was made for borer holes and black stain.

The final phase of testing was for physical parameters (i.e. moisture content and green density). A subjective method was used in collapse assessment as no standardised procedure is available for this purpose. The method was based on a qualitative measurement using a scale of collapse proposed by Wright (5). The collapse specimens were left to air-dry in the air-conditioned laboratory (65% RH and 21°C) for 300 days.

TOPIC E13

RESULTS AND DISCUSSION

In the forest, the infested trees did not show any obvious sign of the infestation. Within trees from which the test material was obtained, the crown foliage was normal, the trunk was straight, smooth and free from limbs or any external abnormalities.

Fig. 1: Five scantlings of shining gum vary in degree of the defect from free (bottom) to the severe (top fifth).

In the laboratory visual inspection of the selected material showed a number of scantlings with a considerable range of number of pinholes and black stained spots (Fig. 1).

The proportion of scantlings with pinholes having black stain was 99% while the corresponding portion of those free from pinholes, but containing stain was 24% (Table 1).

TABLE 1: The percentage of occurrence of the two defect factors.

| | With pinholes | No pinholes | Total |
|---|---|---|---|
| With black stain | 66.5 | 8.0 | 74.5 |
| No black stain | 0.5 | 25.0 | 25.5 |
| Total | 67.0 | 33.0 | 100.0 |

TABLE 2: Collapse distribution percentages for each of the four groups of shining gum.

| | | Degrees of collapse (5) | | | | | |
|---|---|---|---|---|---|---|---|
| Group | n[a] | 0 | 1 | 2 | 3 | 4 | 5 |
| A | 53 | 0 | 0 | 13 | 38 | 49 | 0 |
| B | 53 | 0 | 6 | 32 | 60 | 2 | 0 |
| C | 53 | 0 | 53 | 43 | 4 | 0 | 0 |
| D | 53 | 34 | 64 | 2 | 0 | 0 | 0 |

a:n = number of scantlings

TOPIC E13

One of the physical properties of the defective wood was found to be resistance to collapse as shown in Table 2. The absence of collapse observed for material of Group D "heavy defect" may be due to the presence of the dark extraneous materials. The explanation of this observation is that cell walls may be reinforced and consolidated by the deposit of these extraneous materials.

Sample mean and coefficient of variation were computed from data of each group (Table 3). The test results show that there is a consistent decrease in the moisture content, strength and impact properties as the defect changes from defect free (Group A) through the intermediate (Groups B and C) to the heavy defect (Group D), while the other properties under consideration, i.e. density and stiffness, increased with the increases in the defects (Table 3). The presence of the extraneous material is believed to be also responsible for the increases in density and stiffness.

It is known that density has an influence on the strength to a large extent. Therefore, all modulus of rupture values (MOR) were divided by the corresponding value for basic density (BD) after first being divided by water density, then raised to the power of 1.25 (6). This gives what is called specific modulus of rupture SMOR, which is not affected by density variations (Table 3). This method is used here not only to remove the effect of density but in addition, to lead to a more unbiased and precise analysis. It clearly indicates the loss in strength within Group D, while the other three groups are similar to one another. 4% and 20% of Groups C and D respectively gave a carroty type failure in static bending; i.e. short fibre as a sign of brashness, while Groups A and B were free from this blemish.

Both impact tests (Izod and toughness) gave a significant reduction (38% and 28% respectively) as the defect increases from Group A to Group D.

Basic working stresses for wood are estimated from the mean value of the failure stress after being modified by an uncertainty factor. The most common expression for the uncertainty factor in timber design is that a normal distribution for the data is assumed and a lower probability level 1:40 or 1:100 (i.e. at confidence level $\alpha$ = 0.05 and 0.01 respectively for a one tail t-table) may be used. Also as the rupture test was carried out on structural size specimens and under four point loading, its numerical value should be modified to account for size and loading effects (7) prior to deriving the basic working stress.

TABLE 3: Properties of shining gum scantlings classified in four groups according to defect limitations as specified in this study.

| Group: | | Moisture Content (%) | Basic Density ($kg.m^{-3}$) | Bending | | | | | Impact | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | SpL (MPa) | MOR (MPa) | SMOR[c] (-) | MOEE (GPa) | MOEF (GPa) | Izod (J) | Toughness (J) |
| A | $\bar{x}$[a] | 105 | 540 | 33.8 | 58.6 | 126 | 10.6 | 11.5 | 18.8 | 20.9 |
| | cv. | 11.1 | 9.3 | 18.3 | 13.8 | -- | 15.7 | 18.4 | 18.6 | 21.8 |
| B | $\bar{x}$ | 97 | 537 | 33.5 | 61.9 | 134 | 11.9 | 13.6 | 16.7 | 19.0 |
| | cv | 14.5 | 11.4 | 14.0 | 14.4 | - | 15.6 | 19.9 | 23.8 | 21.9 |
| C | $\bar{x}$ | 93 | 538 | 31.1 | 59.6 | 130 | 12.2 | 14.3 | 16.0 | 18.2 |
| | cv | 12.4 | 8.1 | 20.2 | 18.6 | - | 16.6 | 18.1 | 26.6 | 31.2 |
| D | $\bar{x}$ | 84 | 568 | 28.9 | 53.0 | 108 | 12.4 | 14.6 | 13.6 | 16.3 |
| | cv | 10.4 | 7.8 | 20.1 | 28.4 | - | 16.8 | 18.3 | 37.5 | 34.8 |
| A.O.V. F-Ratio[b] | | 29.0 | 4.5 | 8.4 | 6.1 | - | 9.3 | 16.2 | 13.7 | 7.5 |

a: Average value of 53 scantlings for each group. cv = coefficient of variation in percentage form.

b: Analysis of variance: F-ratio between the four groups A-D is significant when its value is greater than 2.60 and 3.78 at significance level $\alpha$ of 0.05 and 0.01 respectively.

c: Specific modulus of rupture = MOR $(BD/1000)^{-1.25}$

TABLE 4. Deriving stress grade of bending for the four different groups of shining gum using Pearson's method (7).

| Group | SCSE[a)] | LPL[b)] | BWS[c)] | F-rating[d)] |
|---|---|---|---|---|
| A | 67.8 | 45.3 | 20.4 | F17 |
| B | 71.6 | 46.8 | 21.1 | F17 |
| C | 69.0 | 38.2 | 17.2 | F17 |
| D | 61.3 | 19.5 | 8.8 | F8 |

a): Small clear specimens equivalent = $\bar{x}/(0.96 \times 0.90)$

b): Lower probability limit = SCSE $\times$ (1 - 2.40155 $\times$ CV/100) at $\alpha = 0.01$

c): Basic working stress = LPL $\times$ (9/16 $\times$ 4/5)

d): Corresponding stress grade in accordance with AS 1720-1975(8) Table 2.2.1

Table 4 indicates that there is no ultimate effect on the basic working stresses when the defect intensifies from defect free up to the limits specified in group C. However, the intensity of defect beyond Group C (i.e. more than 20 borer holes in any 100 $cm^2$ and/or black stain distribution density in excess of 2 $cm^2$ per 100 $cm^2$) gave more than 50% reduction in the basic working stress in bending. The relatively high percentage (24%) of the sample with black stain without pinholes (Table 1), as well as the 20% of scantlings of Group D which gave a carroty type fracture, indicate that severe black stain, as occurred in the Group D sample, is an inappropriate defect which is currently allowed by the standard for (9) the higher structural grades of hardwood timber, including shining gum.

TOPIC E13

REFERENCES

1. American Society for Testing Materials (1958). Probability sampling of materials. (ASTM E105: Philadelphia).

2. Standards Association of Australia (1978). Rules for mechanical stress grading of timber. (AS 1749: North Sydney).

3. American Society for Testing Materials (1967). Standard method of static tests of timbers in structural sizes. (ASTM D198: Philadelphia).

4. Mack, J.J. (1979). Australian methods for mechanically testing small clear specimens of timber. CSIRO (Aust.) Div. Build. Res. Tech. Pap. No. 31.

5. Wright, G.W. (1956). The evaluation of visual seasoning defects for quality assessment. British Comm. For. Conf. Timber Seasoning, Communications No. 4. CSIRO Div. For. Prod. Melbourne.

6. United States Department of Agriculture (1974). 'Wood Handbook: Wood as an Engineering Material.' For. Prod. Lab. Agric. Handbook No. 72. (USDA: Washington).

7. Pearson, R.G. (1965). The establishment of working stresses for groups of species. CSIRO (Aust.) Div. For. Prod. Tech. Pap. No. 35.

8. Standards Association of Australia (1975). SAA Timber Engineering code. (AS 1720: North Sydney).

9. Standards Association of Australia (1977). Visually stress graded hardwood for structural purposes. (AS 2082: North Sydney).

# PROOF GRADING - DEVELOPMENTS IN QUEENSLAND

C. MacKenzie[1], G.R. Siemon[2], and W.J. Smith[3]

## ABSTRACT

This paper reports the development of proof-grading of timber scantling in Queensland.

It has been found that mechanical grading allows the upgrading of visually graded timber by one or more stress grades and the recovery of a greater percentage of mill-run scantling.

Proof grading theory was developed through co-operative studies with CSIRO's Division of Building Research. These included research on cypress pine, five plantation softwoods and two rainforest hardwoods. A proof grading machine has been developed and field tested.

Backed by the application of reliability theory and extensive laboratory and field research, proof stress grading is now being used commercially.

Three commercial machines are in use in two States.

The practical and theoretical development of proof grading has enabled Industry in Queensland to apply this method to cypress pine, medium density rainforest hardwoods and some plantation pine softwoods.

## INTRODUCTION

In 1969, S & S Timbers Pty. Ltd., Gympie, Queensland, developed, fabricated and installed a proof testing machine to operate in line with their planer (1). The machine proof tested finger-jointed framing and provided structural scantling with defined bending strength properties.

This original prototype machine is still in commercial use. Its success as a grading method, together with the relative difficulty and usual conservatism of visual grading, provided the impetus for the Queensland Timber Industry and Researchers to fully develop proof grading as a viable, alternative system to either visual or machine stress grading.

---

[1] Timber Research and Development Advisory Council (Central and South Qld.), Brisbane.

[2] Formerly Qld. Dept. of Forestry, Brisbane (presently W.A. Dept. of Forestry, Busselton, W.A.).

[3] Division of Technical Services, Qld. Dept. of Forestry, Brisbane.

In 1976, the Timber Research and Development Advisory Council (TRADAC) and the Queensland Department of Forestry, commenced an evaluation of the mechanical properties of full size cypress pine scantling. These studies confirmed the conservatism of the relevant Australian Standard visual stress grading rules (AS 1648 - 1974). It was shown that, if mechanical grading techniques were applied to cypress pine, a significant upgrading and an increase in recovery of structural timber could be attained.

Industry pursued the objective of developing a proof grading system suitable for application to all species. This was achieved by supporting CSIRO research projects into the theory of proof grading and also by the development by Industry of a proof grading machine suitable for wider commercial use.

This paper presents some early research data for cypress pine, results of the laboratory and field studies for other species and conclusions derived from the developed proof grading theory and the commercial application of proof stress grading, based on these studies.

## EVALUATION OF MECHANICAL PROPERTIES

Between 1976 and 1978 the Queensland Department of Forestry and CSIRO Division of Building Research conducted extensive laboratory testing to evaluate the mechanical properties of full size mill-run timber scantling. These tests gave a comparison of potential reliably stress-rated recovery from three grading systems applied to the same timber.

The cypress pine studies involved two separate samples, taken from the species' geographic distribution in Queensland. The number of pieces of each dimension were in proportion to the total cut. Data were subsequently grouped.

The plantation-grown softwood samples tested in Queensland were slash pine, hoop, Caribbean, loblolly and patula pines. Extensive research done elsewhere on radiata pine will not be discussed herein.

White Eungella satinash was laboratory assessed and, with yellow walnut, mill-evaluated as representatives of medium-density rain-forest hardwoods. Work done by others on southern medium-density openforest hardwoods will not be discussed.

Mechanical stress grading recoveries were predicted from tests of M of E (on flat at worst defect) using the deflection limits for a particular stress grade as defined in the NSW Division of Wood Technology's appropriate "Red" or "Yellow" programmes for the "Computermatic".

Proof stress grades were obtained using a simulated proof grade, based on M of R at worst defect, divided by a working stress ratio of 2.4 ($^{9}/_{16}$ long duration load, $^{4}/_{5}$ safety factor, and allowance for live loading).

Results of these tests are summarised in Table 1 (cypress pine), Table 2 (plantation grown softwood) and Table 3 (white Eungella satinash).

TABLE 1

Comparisons of grading methods - unseasoned cypress pine

| Grading Method | Study No | Stress Grades % Recovery | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | R[c] | F4 | F5 | F7 | F8 | F11 | F14 | F17 |
| Visual (AS 1648-1974) | 1[a] | 21 | 7 | 68 | 4 | - | - | - | - |
| | 2[b] | 19 | 17 | 60 | 4 | - | - | - | - |
| M.S.G. (Simulated) | 1 | 6 | 39 | 53 | - | 2 | - | - | - |
| | 2 | 1 | 11 | 50 | - | 35 | 3 | - | - |
| Proof Graded (Simulated) | 1 | 3 | - | 2 | 4 | 10 | 22 | 28 | 31 |
| | 2 | 1 | - | 1 | 4 | 14 | 22 | 24 | 34 |

Note: (a) Study No. 1 consisted of 300 sticks from seven sawmills.

(b) Study No. 2 consisted of 408 sticks from 17 sawmills.

(c) Below F4 stress grade.

The mean M of E for Study No. 2 was 7 846 MPa (measured long span on edge).

TABLE 2

Comparisons of grading methods - seasoned plantation grown softwood[a]

| Grading Method | Stress grades % Recovery | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | R[b] | F4 | F5 | F7 | F8 | F11 | F14 | F17+ |
| Visual (AS 2099-1977) | 21 | - | 52 | 16 | 9 | 2 | - | - |
| M.S.G. (Simulated) | - | 12 | 53 | - | 27 | 8 | - | - |
| Proof Graded (Simulated) | - | 1 | 6 | 7 | 22 | 27 | 15 | 22 |

Note: (a) The results in Table 2 represent tests carried out on 125 sticks of five different softwood species.

(b) Below F5 stress grade.

The mean M of E for this study was 9 600 MPa (measured long span on edge).

TABLE 3

Comparisons of grading methods -
unseasoned white Eungella satinash[a]

| Grading Method | Stress Grades % Recovery | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | R[b] | F4 | F5 | F7 | F8 | F11 | F14 | F17+ |
| Visual (AS 2082-1977) | 3 | - | - | 21 | 24 | 35 | 17 | - |
| Proof Graded (Simulated) | - | - | - | - | 1 | 1 | 3 | 95 |

Note: (a) The timber sample for this study was 150 sticks obtained from five sawmills.

(b) Below F7 stress grade.

The mean M of E for this study was 11 285 MPa (measured long span on edge).

An evaluation of the tension properties of the mill-run scantling by CSIRO Division of Building Research was included in the laboratory studies for all three species groups.

The laboratory tests indicated the advantages of proof stress grading, particularly over the conservative visual stress grading method. While the data also show an advantage over machine stress grading, the apparent difference is reduced when the need to take stiffness into account in stress rating is considered. Stiffness and tensile strength data from laboratory assessments are applied where necessary to limit proof-grader load settings. As an alternative, the proof grader can be set to identify for regrading pieces with excessive deflection for a particular grade.

MILL STUDIES

Concurrent with the laboratory assessments, mill studies were conducted on unseasoned cypress pine and two unseasoned medium density hardwoods using the TRADAC prototype proof grading machine.

The purpose of these was to:-

(i) assess the damage effects of proof grading.

(ii) assess the effects of grading operator error.

(iii) provide parameters gained from actual proof grading for inclusion in in the theory and mathematical models developed by CSIRO DBR (2) and (3).

The first study assessed the effect of multiple passing, using both edges, on recoveries of F7 stress grade material of cypress pine. This indicated the percentage of "rogue" pieces, which may be weakened by a single or subsequent pass.

Grader operator error was studied by having five experienced graders rank the same sample according to expectations of strength, and comparing their results with actual rankings based on M of R tests.

A further study involved passing the specimens with the machine set at F4 or F5 (worst defect in tension), passing both sides at two stress grades lower, then passing both sides at one stress grade lower (i.e. the intermediate stress grade).

Separate studies were made on two medium density hardwood species from North Queensland rainforests - white Eungella satinash and yellow walnut. Comparisons were made with visual stress grading results.

The results of these studies are given in Tables 4 and 5.

TABLE 4

Mill Study Results - Unseasoned Cypress Pine

| STUDY NO | SAMPLE SIZE | PROOF GRADE SET F7 (NO. OF FAILURES)* | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 'A1' | 'B1' | 'A2' | 'B2' | 'A3' | 'B3' | 'A4' | 'B4' |
| 1 | 519 | 16 | 10 | 1 | 1 | 2 | 1 | 2 | 2 |
| | | VISUAL GRADE % RECOVERY | | | | | | | |
| | | R | | F4 | | F5 | | F7 | |
| | | 10 | | 25 | | 60 | | 5 | |
| 2 | 212 | PROOF GRADE F7 & F11 (NO. OF FAILURES*) | | | | | | | |
| | | 'A1' | | 'B1' | | | | | |
| | | 46 | | 17 | | | | | |
| 3 | 300 | PROOF GRADES (LOAD FACTOR 3.62) (NO. OF FAILURES)* | | | | | | | |
| | | 'F5'$_A$ | | 'F3'$_A$ | | 'F3'$_B$ | | 'F4'$_A$ | 'F4'$_B$ |
| | | 85 | | - | | - | | 3 | 4 |
| | 107 | 'F4'$_A$ | | 'F2'$_A$ | | 'F2'$_B$ | | 'F4'$_A$ | 'F4'$_B$ |
| | | 11 | | - | | 1 | | - | - |

Note: * Load variations:

'A1' = edge 'A' worst defect in tension, pass 1.

'B1' = edge 'B' worst defect in compression pass 1.

'A2' = edge 'A' worst defect in tension pass 2.

'B2' - 'B4' - sequentially as above.

'$F5_A$' = passed through machine at stress grade F5, edge A, worst defect in tension.

'$F3_B$' = passed through machine at stress grade F3, edge B, worst defect in compression

'$F2_B$' - '$F4_B$' - to system above.

TABLE 5

Mill Study Results - Unseasoned Medium Density Hardwoods
(white Eungella satinash, yellow walnut)

| STUDY NO | SAMPLE SIZE | PROOF GRADE (NO. OF FAILURES)* | | |
|---|---|---|---|---|
| | | '$FP_A$' | '$F\ 0.8P_B$' | '$FP_B$' |
| 4(a) | 1087 | 88 | 13 | 50 |
| 5(b) | 250 | 54 | 5 | 16 |
| | | VISUAL GRADES % (AS 2082) | | |
| | | $R^{\emptyset}$ | F7 | F8 | F11 | F14 |
| 4(a) | 1087 | 11 | 3 | 4 | 4 | 78 |
| 5(b) | 250 | 26 | 8 | 12 | 10 | 44 |

Note: * Load variations:

'$FP_A$' = proof grade set at load 'FP' approx. equal to $F17^+$ edge 'A' in tension (edge 'A' randomly selected).

'$FP_B$' = ditto (edge 'B' randomly selected)

'$F0.8P_B$' = proof grade set at load equal to 0.8P, edge 'B' tested in tension.

(a) white Eungella satinash

(b) yellow walnut

$\emptyset$ Below F7 stress grade.

The number of breakages is greatly reduced in commercial operation. Loads applied in these mill studies were set high so as to achieve a high percentage of breakages for the purpose of population definition and "rogue" piece identification in determining operable load settings.

LOAD FACTORS

The data obtained from the laboratory evaluations and the mill studies provided the parameters necessary to determine appropriate load factors using the Reliability Theory (2) and Proof Grading Methodology (3) approaches developed by CSIRO.

Table 6 summarizes the load factors applicable for machine-setting in proof-grading the species considered.

TABLE 6

Load Factors Derived for Proof-Grading
Unseasoned Cypress Pine and Two Medium-Density Hardwoods[ø]

| SPECIES | LENGTH (m) | Load Factor for % Breakage | | | |
|---|---|---|---|---|---|
| | | 1 | 2 | 5 | 10 |
| Cypress Pine | 3.0 | 2.58 | - | 2.92 | 3.41 |
| Medium Density Hardwoods (white Eungella satinash and yellow walnut) | 2.7 | 2.31 | 2.42 | 2.63 | 2.78 |
| | 5.4 | 2.02 | 2.17 | 2.33 | 2.45 |

ø From communications by Leicester (4,5)

Note: The bending stress applied to the timber during proof grading is equivalent to the basic working stress (at a particular stress grade) in bending multiplied by the appropriate load factor.

PROOF GRADING MACHINE

The original prototype proof grading machine developed and commissioned by TRADAC in 1976 proved very reliable when used during the mill studies. The machine is now being fabricated commercially and is capable without modification of testing up to 150 x 50 mm timber, stress grade F17. The current cost of the machine with calibration equipment is less than $10,000.

The machine can be used "in line" with a planer or "hand fed" independently at feed rates to suit.

Three commercial machines have been fabricated. Two are in use in Queensland sawmills; the third, purchased by the WA Forestry Department, will initially be used for mill studies on radiata pine.

COMMERCIAL OPERATIONS

a) MILL A, SOUTH-EAST QUEENSLAND, ON CYPRESS PINE

The machine is used "in line" with a planer and has been operational for over 12 months. The all up installed cost of the machine was approximately $11,000, including a branding wheel and a second pressure gauge.

Currently the machine is only used for stress grading timber for trusses and wall framing.

Monthly throughput exceeds 20 000 lineal metres (80 $m^3$) of 75 x 38 to 125 x 50 mm in stress grades F5 and F7.

Breakages run at less than 1 per cent.

The greatest single advantage is the ability to now obtain high percentages of stress grade F7 and better in cypress pine.

b) MILL B, NORTH QUEENSLAND, ON MEDIUM DENSITY HARDWOODS

The machine, used "in line" with a planer, has been fully operational since March 1981. Installed cost was $10,500.

Currently used only for truss timber, it is intended to stress grade sized wall framing in the near future.

Throughput is approximately 50 $m^3$/month of 100 x 38 to 150 x 38 mm in stress grades F14 and F17.

The greatest single advantage gained here is the ability to produce reliably stress rated F14 and better material from mixed unidentified medium density hardwoods.

FUTURE DEVELOPMENTS

It is anticipated that during 1981/1982 a further mill study assessment will be completed for Queensland Plantation grown softwoods including hoop, slash, Caribbean, loblolly and patula pines.

This assessment will provide the necessary data to enable load factors to be established for these species.

An Australian Standard for proof stress grading is needed and would facilitate the system's wider acceptance and commercial application.

## CONCLUSIONS

A proof stress grading system (theory, practical application and machine) has been developed and is suitable for application to a wide range of timber species.

Application of proof grading can improve the recovery of structural timber by up to two stress grades over those attainable by visual stress grading.

Where proof stress grading is used, mechanical properties other than bending strength must also be assessed and taken into account in allocating stress grades.

## RECOMMENDATIONS

The writers strongly advocate that the Structural Timber Evaluation Committee form a sub-committee, with seconded Industry expertise, to prepare a draft Code of Practice for proof grading and a draft Standard for proof-graded timber.

## ACKNOWLEDGEMENTS

The writers would like to express their thanks to the following for their expertise and collaboration on this research project: Dr R.H. Leicester, CSIRO Division of Building Research, Melbourne and Mr Ian Straker, S & S Timbers, Gympie.

## REFERENCES

1. Straker, I. 1977. A Simple Continuous Testing Machine. Forest Industries Journal Volume 43, No. 2. March 1977.

2. Leicester, R.H. 1979. Proof Grading, a Practical Application of Reliability Theory. Proceedings of 3rd International Conference on the Applications of Statistics and Probability in Soil and Structural Engineering. Sydney, Australia, 1979. pp. 263-277.

3. Leicester, R.H. 1980. Proof Grading Methodology (Third Draft). CSIRO Division of Building Research. Highett, Victoria, December, 1980. Limited distribution.

4. Leicester, R.H. 1980. Proof Grading Study. Interim Report. CSIRO Division of Building Research. Highett, Victoria. June 1980. Limited distribution.

5. Leicester, R.H. 1980. Proof Grading, WESA Trials. CSIRO Division of Building Research. Highett, Victoria. November, 1980. Limited distribution.

# STRESS GRADE CLARIFICATION AND TEST STANDARDIZATION, WITH SPECIAL REFERENCE TO STIFFNESS

S. Panow and W.J. Smith

Division of Technical Services
Queensland Department of Forestry
Brisbane

## ABSTRACT

A need is seen for a clearer definition of the stress grade of individual pieces of timber, in terms of all relevant mechanical properties, but expecially stiffness. Also for the publication of standard procedures to be followed in property testing for and reporting on stress grade evaluation.

## INTRODUCTION

The terms "stress grade", "stress rating" and "F-rating" are now commonly used by timber producers, specifiers, and users, generated by wide application of the SAA Timber Engineering Code (1), the SAA Timber Framing Code (2), the latters' incorporation in Building Codes and By Laws, the wider use of mechanical stress grading systems, and revision of Australian Standards for visually stress-rated structural timber.

Wider use of the terms has led to a more critical appraisal of their definition and the need for any qualification which might be necessary or desirable in reporting results of the increasing volume of quality assurance tests accompanying the wider use of timber stated to have been stress-rated to designated levels by the various grading systems in use.

Some inconsistency between authorities exists in interpreting the results of mechanical property testing for conformity to stress grade rating, particularly in relation to the permissible limits for Modulus of Elasticity. Some variability is also inherent in the evaluation of some properties by different test methods.

The need for a clearer definition of stress grade, as it applies to individual pieces and parcels of timber, and the standardization of test procedures for its evaluation are matters being considered by the national Structural Timber Evaluation Committee, on referral from Dr R.H. Leicester,

CSIRO's Division of Building Research. However, they are briefly discussed herein for wider appreciation of the basis for recent controversial assessments of the structural adequacy of some imported softwoods, and to draw attention to the applicability of such reappraisals to Australian-grown as well as imported timber.

DISCUSSION

1. Stress Grade Definition:- The current definition of the term "stress grade" in the SAA Timber Engineering Code (1) states it "..... indicates primarily the basic working stress in bending for purposes of design and, by inplication, the basic working stresses for other properties normally used in engineering design .....". In turn, "basic working stress" is stated to be "the stress appropriate to an arbitrarily chosen, but constant, basic reference set of conditions ....." and to be "..... derived from the known strength properties of a timber .....".

In neither case is stiffness specifically referred to, although the Code also "requires that deflections shall be so limited that the strength and serviceability of the structure will not be impaired .....". The responsibility for setting deflection limits such that "..... the deflections of a structure shall not impair the strength and serviceability of the structure or any part thereof, nor cause damage to other building components ....." is delegated in the Code to "the Engineer", but suggested limits for some commonly used members are provided in its Appendix C and defined limits have been adopted in developing the grade/span/spacing/size specifications in the widely used Timber Framing Code (3).

The Moduli of Elasticity to be used setting such limits are tabulated for each stress grade in the Code's Table 2.2.1, which originated from the graded stress class system developed by Pearson (4) in establishing working stress limits (including Modulus of Elasticity) for groups of species by graded quality classes.

In developing his tables, Pearson had recognised a need for the interrelatability of Modulus of Rupture (R), Modulus of Elasticity (E) and graded quality, particularly in stiffness-assessed mechanical stress-grading systems. He drew attention to the importance of stiffness as "the design criterion for many applications".

It seems clear that E, as "a property normally used in design" has its working stress limits set by stress grade classification. This could and should be made clearer in definition and tabulation in A.S. 1720.

2. Stress Grade Property Limits:- The values for strength properties, including R, attachable to stress grade classification are lower-limit ones, and pose no problem in the interpretation of test data (4), except in nominating the modification factor to be applied to allow for the effects of duration of load, accidental overload and other incalculables. This is usually 2.22 (2), but not invariably so. The factor to be used and the circumstances under which it can or should be varied should be indicated in stantardized test procedures.

The setting of stiffness limits is the real problem. Pearson's stress-class E values were assessed as averages of species groups and grades, on the bases that there was a lower risk, that limits on average deflections were usually sufficient, and that more stringent restrictions could be imposed on the latter if desired. In the absence of any published guidelines as to how the stress-class E values should be applied in assessing individual pieces or parcels of timber submitted for stress-grade evaluation, there has been some variation in interpretation between testing laboratories, other authorities, and quality controllers in production plants with disputation in some cases.

It has variously been suggested that (a) E should not be considered in allocating a stress-grade (F-rating); (b) that the SAA tabulated E values apply as absolute averages, regardless of often extreme upper and lower limit values for individual pieces in often small samples; (c) that the quality assurance test limits on E in the Australian Standard for the mechanical stress-grading of timber (A.S. 1749) (5) should apply; in this, no specimen can be more than 10% below the lower-limit of E specified for its grade; (d) that 10% or 20% tolerances be permitted on the A.S. 1720 tabulated E value; or (e) that tolerances be permitted as 10%, 20% or even 50% of the pieces being allowed below the tabulated values, without any lower-limit individual value, provided the average for the parcel complied.

Quality assurance procedures in mechanical stress grading (5) require conformity, within a specified tolerance, to ranges of E values representing prediction intervals for points on strength on edge/stiffness on flat regression lines and to lower-limit R values. They assure reliability of strength evaluation within the predetermined confidence limits. Edge-loaded E is not checked in this assurance testing.

The suggestion that a percentage of pieces being stress-graded evaluated be permitted to fall below the average tabulated E with no lower limit on individual pieces' value, is considered undesirable. This would increase the likelihood of deflections occurring to an extent such as to impair the strength and/or serviceability of a structure or at least part of it.

There are structural situations in which the stiffness of individual members is critical, and designers and specifiers need to know the limits on E which apply to the stress-grades being nominated for use. A trend towards longer-span design enhances the need. It should be possible, using established generally good relationships between R and E (4), to set reasonable tolerances on the A.S. 1720 tabulated values of E for stress grades at the individual piece as well as the parcel level.

It is contended that, regardless of whether timber is mechanically or visually graded, any stress rating allocated should require the conformity of each and every piece to designated lower-limit strength values and stiffness values or ranges, within reasonable tolerances.

3. Standardization of Test Procedures:- As indicated earlier, standard procedures are defined for quality assurance testing of the correct operation of stress-grading machines (5). These provide for the evaluation of E on flat over 914.4 mm span under centre-point load and R on edge under four point load at a span:depth ratio of about 11 to 14:1 at the assessed worst defect. However, no standard methods for stress grade mechanical property testing have been published.

Rather than the relatively shear-free centre-point short-span "true" E used in establishing mechanical stress grading control data, a full-span centre-point on edge "gross" E (involving both shear and bending) is often used in design, and it has been found desirable to develop relationships between "true" and "gross" E for conversion purposes. A depreciative effect on "gross" E of decreasing span/depth ratio below 22:1 was demonstrated (6).

Standard test procedures for the evaluation of conformity to stress grade requirements in respect of designated relevant mechanical properties should be published, covering load application, span/depth ratios, defect positioning, modification factors to be applied to test values, and form of reporting. Conversion factors should also be provided to allow inter-relatability of any alternatives provided for in the Standard and of any alternatives likely to be commonly used in grading or stress grade testing in other countries with which we actively trade in structural timber.

The form of reporting should include a statement as to the stress grade classification applicable to each piece tested, as basic information to which a timber testing authority could reasonably be expected to attest. This assessment should not be left to others to interpret from mechanical property data only.

The Sturctural Timber Evaluation Committee would be an appropriate initiating body to make recommendations to the Standards Association of Australia.

REFERENCES

1. Standards Assn. of Australia (1975). SAA Timber Engineering Code, AS 1720-1975. Stds. Assn. of Aust., Sydney. 149 pp.

2. Australian Standard 1684-1979. SAA Timber Framing Code

3. Low-Rise Domestic and Similar Framed Structures Part 1. Design criteria, by N.H. Kloot and Anne Ryan. CSIRO Division of Building Research Special Report, 1974.

4. Pearson, R.G. (1965). The establishment of working stresses for groups of species. D.F.P. Tech. Ppr. No. 35, CSIRO, Melbourne. 40 pp.

5. Standards Assn. of Aust. (1978). Rules for mechanical stress grading of timber, AS 1749-1978. Stds. Assn. of Aust., Sydney. pp. 9-19.

6. Fewell, A.R. (1980). Relations between the moduli of elasticity of structural timber in bending. Bldg. Est. Inf. Ppr. IP28/80. Bldg. Res. Est'ment, Dept. of Env'ment, Watford, England.

# A SIMPLIFIED TIMBER DESIGN CODE

by P U A Grossman
Division of Building Research, CSIRO

ABSTRACT

CSIRO has provided advice to the Fijian Department of Forestry for guidelines on timber design stresses to be used in Fiji. These guidelines are based on the SAA Timber Engineering Code AS 1720-1975, but are very much easier to use. Some simplifications could be achieved because of the limited range of conditions pertaining to Fiji, others by separating design for strength from design for stiffness, by distinguishing between optional and obligatory modification factors and by excluding less common applications.

## 1. INTRODUCTION

Early in 1980 the Fiji Ministry of Forests requested the assistance of the Division of Building Research in drafting parts of proposed guidelines on design stresses for Fijian timbers in local use. While accepting the provisions of AS 1720-1975 (1) as a basis for their specifications, Fijian representatives were perturbed by the complexity of the Australian Code and asked, in particular, whether the rules on modification factors could be simplified.

The role of the Division was purely advisory and the decision to adopt any version was the responsibility of officers of the Ministry of Forests on Fiji and local interested parties. The Division recommended simplifications and commented on their justification, merits and drawbacks. These recommendations were almost totally adopted and, after circulating the proposals widely for comment, the Fiji Department of Forestry issued a booklet (2) providing guidelines for design stresses.

The Fijian Department was advised that a revision of AS 1720 was in preparation. It preferred however, not to delay but to use the 1975 version as a reference. The only changes based on recent proposals were the reduction of

the basic working stress in tension to 0.6 of that in bending, and the reduction of the duration-of-load factor for 5 minutes or less to 1.75.

The departures from AS 1720-1975 fall into three categories. Firstly, some provisions were deleted or abbreviated because of the more limited range of conditions pertaining to Fiji. Secondly, the specifications were rearranged and grouped to help in particular the casual user to recognise readily which of them are relevant to his case. Thirdly, less common applications were excluded and some of the more detailed distinctions waived.

## 2. SIMPLIFICATIONS MADE POSSIBLE BY SPECIFIC FIJIAN CONDITIONS

2.1 The grading rules for Fijian timbers (3) provide for two framing grades, but only No. 1 Framing Grade is recommended for structural use. This corresponds to the Australian Structural Grade No. 3 for smaller sections and to No. 2 for large ones. With only a single visual grade it is possible to associate each strength group directly with a stress grade, for example green material from species of group S4 is subject to stress grade F8.

2.2 All of Fiji is tropical and factor $K_6$ (tropical temperature allowance) of the Australian Code would have to be applied universally. This factor was therefore incorporated into the basic working stresses.

2.3 Equilibrium moisture content on Fiji ranges mostly from 14 to 19 per cent varying between the wet and the dry zones, and between indoor and outdoor situations. While the Australian Code requires the application of modification factor $K_5$ for seasoned timber that averages more than 15 per cent moisture content, the new Fijian specification is based on 19 per cent with provision for an increase in design stress for drier material.

The reduction in basic working stresses to allow for higher equilibrium moisture content and for tropical temperature is approximately equivalent to one step in stress grade; therefore the table of basic working stresses in the Fijian specifications down-grades seasoned timber one stress grade. For example, timber grouped under SD4 and of structural grade 3 in Australia would be given a stress grade F14 and the basic working stresses would have to be reduced in AS 1720-1975 by modification factors $K_5$ and $K_6$ to allow for moisture and temperature conditions. In the Fijian specifications this material is considered to be of stress grade F11 without any requirement for modification factors.

2.4 Because of the high moisture content of seasoned timber, it was thought unwarranted to provide for partially seasoned timber. Such timber is regarded as green and the factor $K_4$ for partly dry timber in AS 1720-1975 is not needed.

2.5 There is no need for size factor $K_{11}$ because the Fiji grading rules are such that large-size members satisfy a higher visual stress grade.

2.6 The Fijian guidelines were intended only for the use of solid members and excluded box and I-sections, plywood and laminated timber. Thus whole sections and also specific provisions in retained sections could be deleted.

## 3. REARRANGEMENT AND REGROUPING

3.1 The guidelines deal separately with modification factors for design when strength is critical and design when stiffness is critical. This avoids the need for repeated parenthetical remarks that certain rules apply to working stresses but not to stiffness and vice versa. It should also make it easier for the user to deal with one property at a time.

3.2 The guidelines make a distinction between optional and obligatory modifications to the working stresses. They also list the conditions under which the tabulated basic working stresses may be used without modifications. Many users only wish to check whether given dimensions are adequate; others are prepared to accept over-conservative dimensions if such acceptance simplifies design. Such users would often only need to check the limitations on the use of the tabulated basic values; if they consider it warranted they may increase the permissible stresses by selected optional modifications.

## 4. EXCLUSIONS AND CONTRACTIONS

4.1 The load-sharing factors for grid systems are listed for two specific ratios of member-spacing to span ($s/L = 0.1, 0.3$). The values are tabulated in a common table with the factors for parallel support ($s/L = 0$). This tabulation avoids the need to determine one factor from a table and then insert it into an equation as required in section 2.4.5.2 of AS 1720-1975.

4.2 The range of the material constant $\rho$ used in evaluating stability factors has been considerably reduced from Table 2.4.8 of AS 1720-1975. The simplified

table ignores Class A straightness and includes only stress grades from F4 to F22 for listing the material constant $\rho$. For each stress grade it gives one value of $\rho$ for green and one for dry material, namely the most conservative value among those relevant to different ratios of temporary to total load. It was considered that the benefit of easy determination of this constant outweighs the possible penalty of an over-conservative design.

4.3 The Fijian guidelines deal with only the most commonly encountered stability considerations. The user is referred to AS 1720 for specialized design.

## 5. CONCLUSIONS

The simplified guidelines cannot be adopted in full in Australia and they cannot replace AS 1720. They contain however features that could be considered by our code-makers. Timber-promotion bodies could also include some of these simplifications in guidelines prepared to provide a first stepping stone for design. Such simplified guidelines can provide figures that are suitable for many situations and are always safe.

## 6. REFERENCES

(1) Standards Association of Australia, AS 1720-1975 - 'Use of Timber in Structures (SAA Timber Engineering Code)' 152 pp.

(2) Fiji, Department of Forestry, 1981 - 'Fiji Timbers and Their Uses, No. 70, Design Stresses for Local Timbers', Suva Govt. printer. 13 pp.

(3) National Grading Rules for Fijian Timbers, 1979. Fiji Government Printing Department, 33 pp.

# INFLUENCE OF ATMOSPHERIC CHANGES ON TOOTH PLATE CONNECTOR JOINTS

E P Lhuede and P U A Grossman
Division of Building Research, CSIRO

## INTRODUCTION

Data relating to the deformation of tooth plate connector joints in timber were presented at the 19th Forest Products Conference (1) and opened up the broader consideration of predicting the long-term structural properties of such joints from the variables affecting both the magnitude and rate of change of the non-linear deformations of the metal-tooth timber connections.

It seems reasonable to assume that time-dependent increases in joint extension are mainly due to deformations of the mechano-sorptive type and it has been established that such deformations are directly related, inter alia, to the magnitude of the change in moisture content (m.c.) of the wood. However, the relationship between changes in moisture content of the wood within a nail plate joint and short and long term rates of change of the atmospheric relative humidity around the plate may require further analysis. In recent designs of plates, the depth of penetration of teeth is of the order of 10 mm and therefore the important m.c. changes are those in the outermost layer of the wood. At the same time the plates themselves may provide some shielding and can be expected to retard the exchange of moisture between the wood surface and surrounding air.

The derivation of working loads for nail plate as well as other connectors as determined by Australian Standards (2) is based on ultimate loads measured in short-term tests and on the assumption that duration of load affects joints in the same manner as clear wood. This assumption is open to challenge. The ultimate aim of the research is to be able to estimate the amount of extension of a nail-plate joint during its service life, given the depth of teeth, the timber species, the load and the meteorological record for the location. The rate of change of the m.c. in the outer layers will indicate to what extent

diurnal and other periodic changes of short period must be considered as significant influences in mechano-sorptive deformation.

Some preliminary measurements have been conducted to determine the rates of change of moisture content in such timber samples, and deformations are being measured under a range of loads and different atmospheric conditions.

## EXPERIMENTAL DETAIL AND RESULTS

### Determination of Moisture Content Changes

(a) Response to step changes in humidity. End-coated samples of *P. radiata* and *E. regnans*, 76 (long) x 90 x 35 mm, were conditioned to a uniform m.c. at 40.5°C dry bulb (DB) and 30.8°C wet bulb (WB) and then subjected to an increased humidity (40.5°C DB; 36.5°C WB). The blocks were weighed at daily intervals and some were sectioned each day to determine the distribution of moisture content.

The results using matched samples did not indicate any reduction in the overall rate of moisture uptake where the surface was covered by a nail-plate of either of two commercial makes. It should not be concluded however, that all parts of the wood under a plate absorb moisture at the same rate as the exposed surface areas. Relatively small regions, under the steel and behind teeth, may have been at a lower m.c. and this was not measurable with the method used. Since these pockets could play a significant part in the deformation of the joint, their existence is being further investigated.

(b) Response to atmospheric variations. Four blocks of *P. radiata* have been exposed to the atmosphere in an enclosed shed since the end of July 1981. Sleeved nails are used to determine moisture contents of the core and the case approximately 3 mm from the surface. The case has been fluctuating over a range of 2 per cent m.c. and the core over a slightly smaller range. Relative humidity is being recorded simultaneously.

### Determination of Extensions

(a) Response to step changes of humidity. An experiment is being commenced at the time of writing, to observe the increases in extension of nail-plate joints caused by successive cycles of humidity. The extreme humidity values

will be maintained long enough to ensure that the case of the joined timber blocks has closely approached e.m.c.

(b) Response to atmospheric variations. Four nail-plate joints of P. radiata have been under constant load in an enclosed shed since late July 1981. One is loaded to 40 per cent of estimated maximum load, the others to 20 per cent. The latter corresponds to a load of 60-70 N per tooth, and has been found to double the extension in one month to about 0.1 mm.

Case and core moisture contents are being measured on some of these samples in the same way as and matched with the blocks referred to previously in (b) above; the data obtained will be used to confirm any hypotheses used to predict mechano-sorptive extension from the observed humidity changes.

## CONCLUSIONS

The work so far indicates that the typical variable-rate increase in deformation reported for such joints over periods of months is possibly made up of a series of short-term changes induced by relatively small (2%) changes in wood m.c.

The retardation of m.c. change in the outer layer of wood by a nail plate may be expected to be of secondary importance, although this requires further investigation. The importance of the mechanical properties of the outermost layer of wood is demonstrated by the noticeable increase in joint extension which occurred in one month during winter when atmospheric conditions are more stable.

## REFERENCES

(1) R.H. Leicester, G.F. Reardon and K.B. Schuster (1979). 'Tooth-plate connector joints subjected to long duration loads'. Proc. 19th For. Prod. Res. Cnf., Topic 2/11.

(2) Standards Association of Australia (1975). AS 1720, SAA Timber Engineering Code.

ACKNOWLEDGEMENT

The authors acknowledge the fruitful discussions with Dr R H Leicester and the proposals made by him.

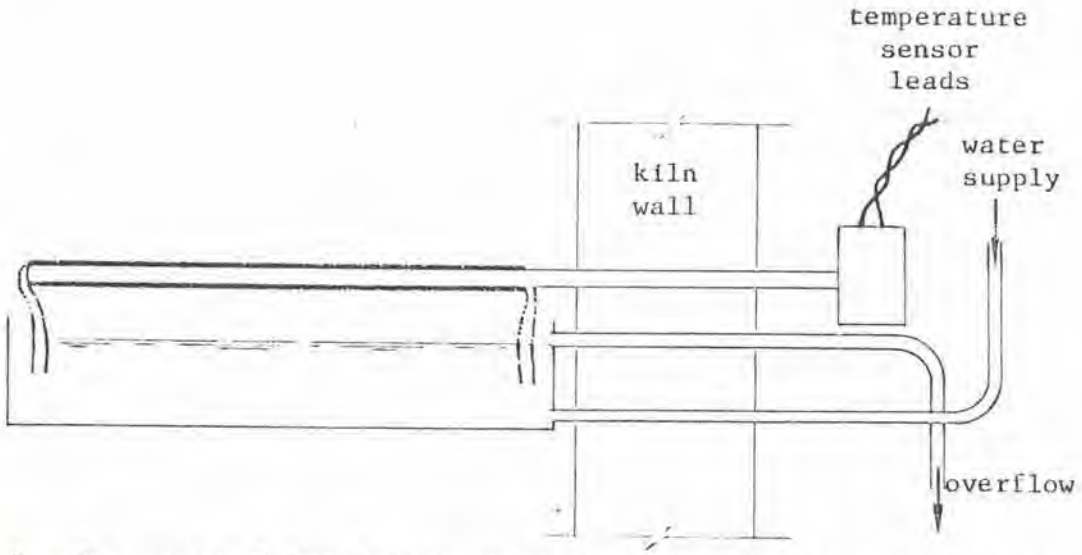



FIG. 1. Conventional Wet Bulb Installation with tubular cotton wick

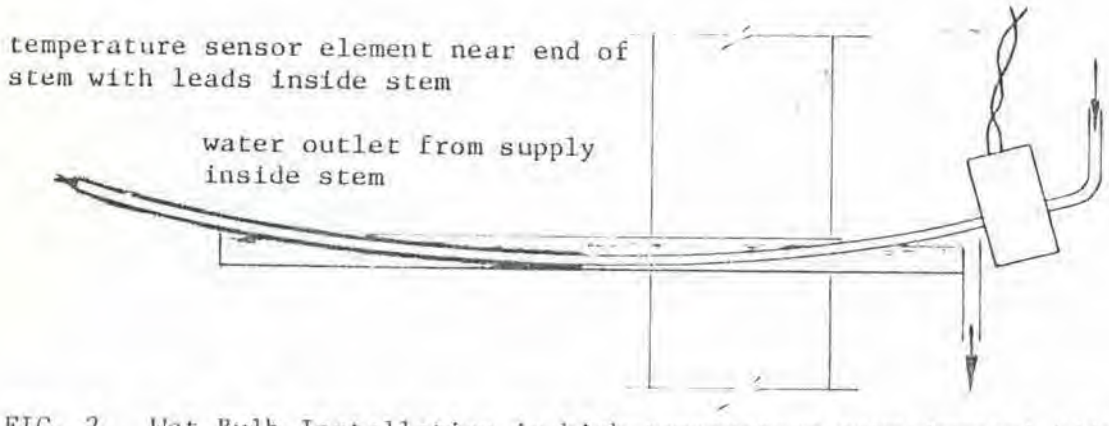



FIG. 2. Wet Bulb Installation in high-temperature experimental kiln

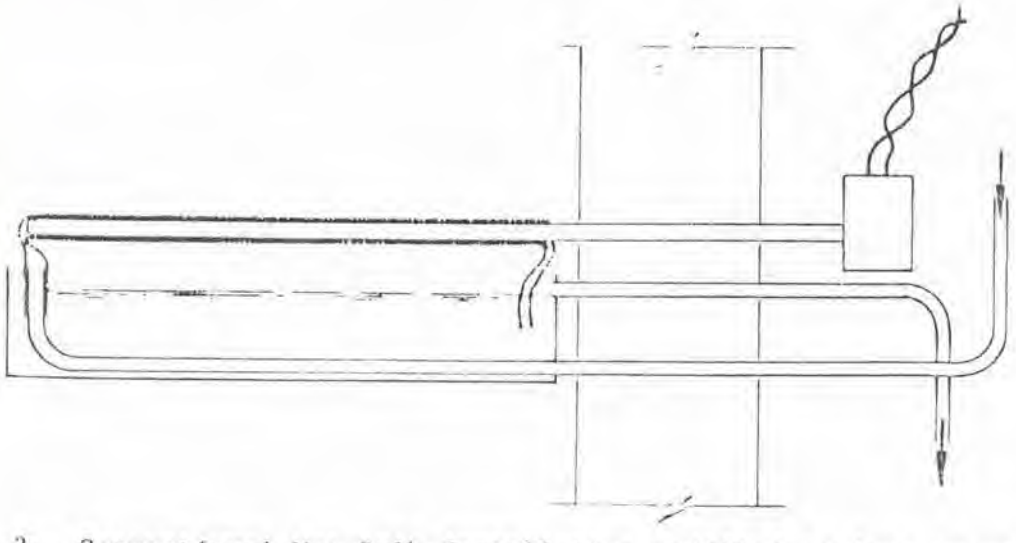


FIG. 3. Conventional Wet Bulb Installation modified to improve water supply to wick

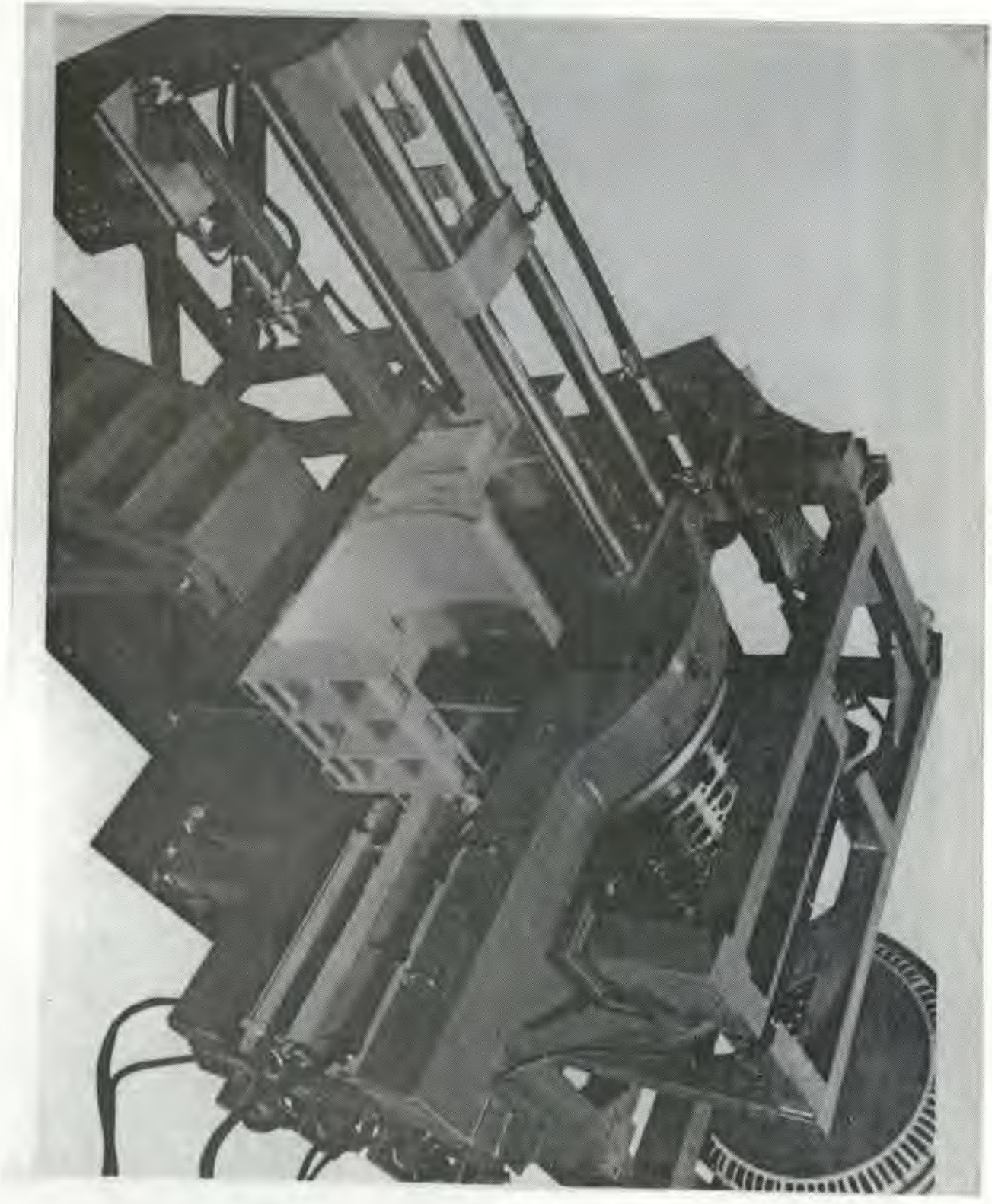


Fig.1.

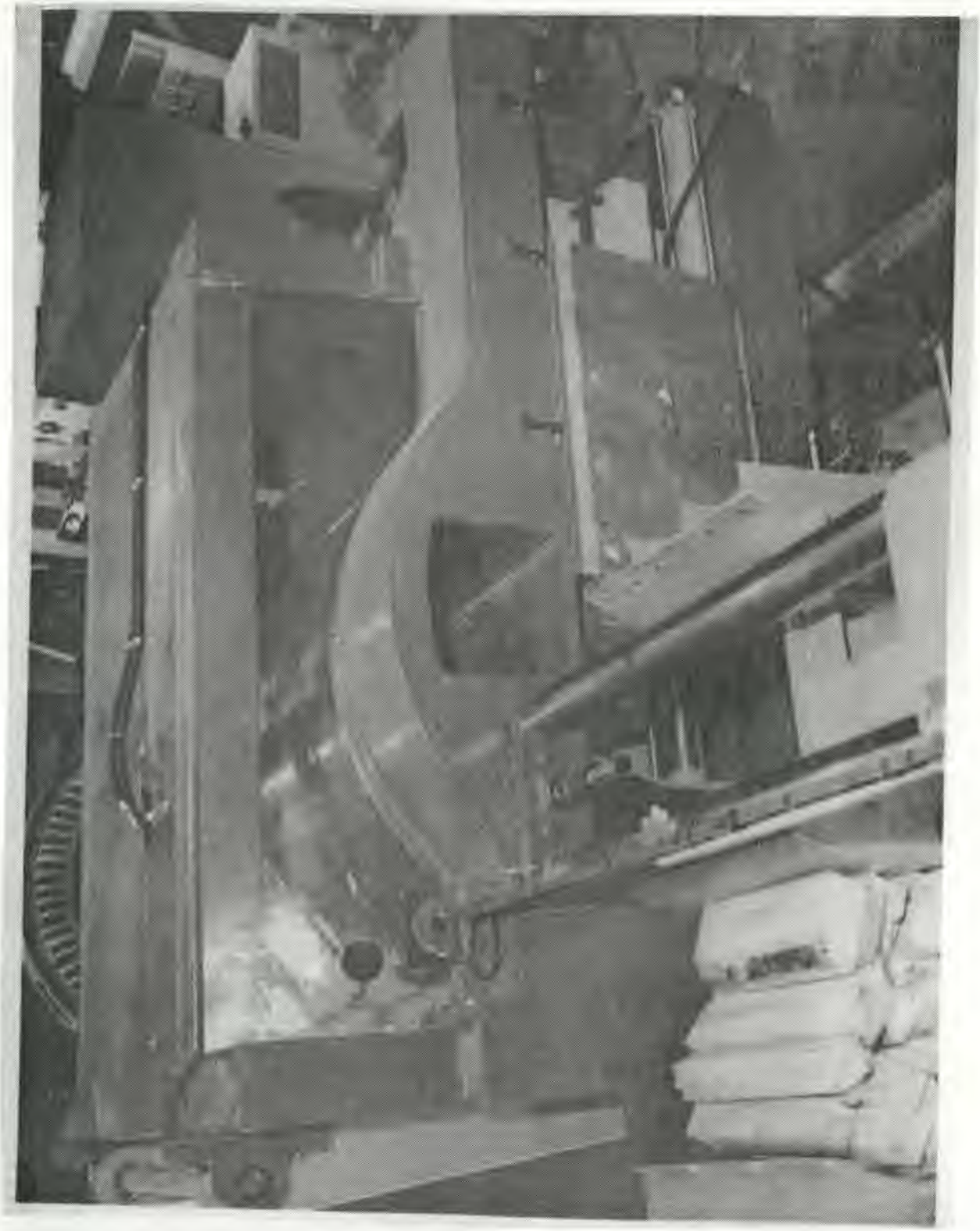


Fig. 2

Glueline temperature as a function of pressing time

FIG. 1. 75 mm

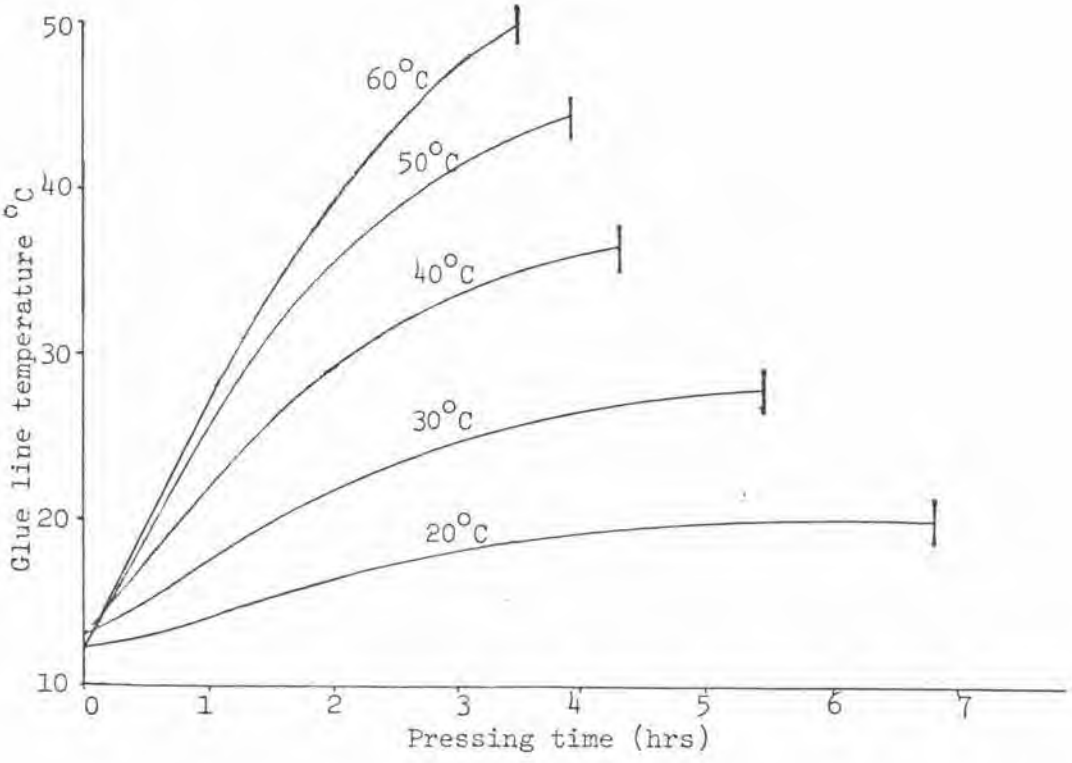



FIG. 2. 100 mm

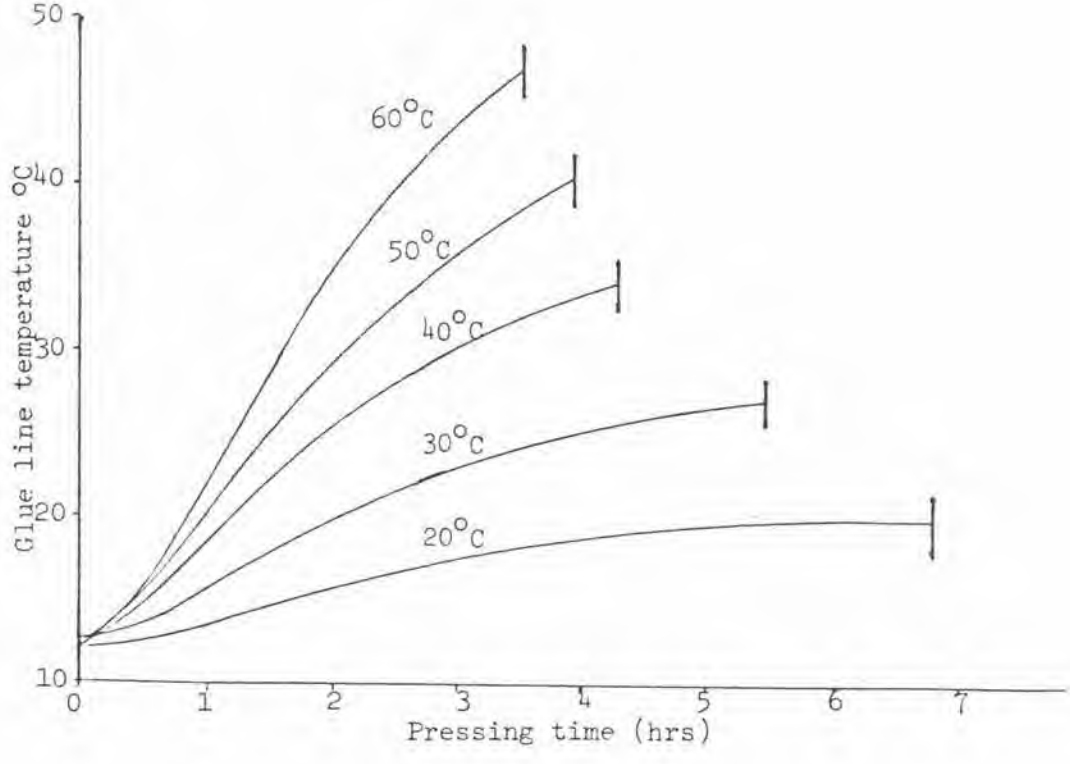


FIG. 3. No post cure (75mm)

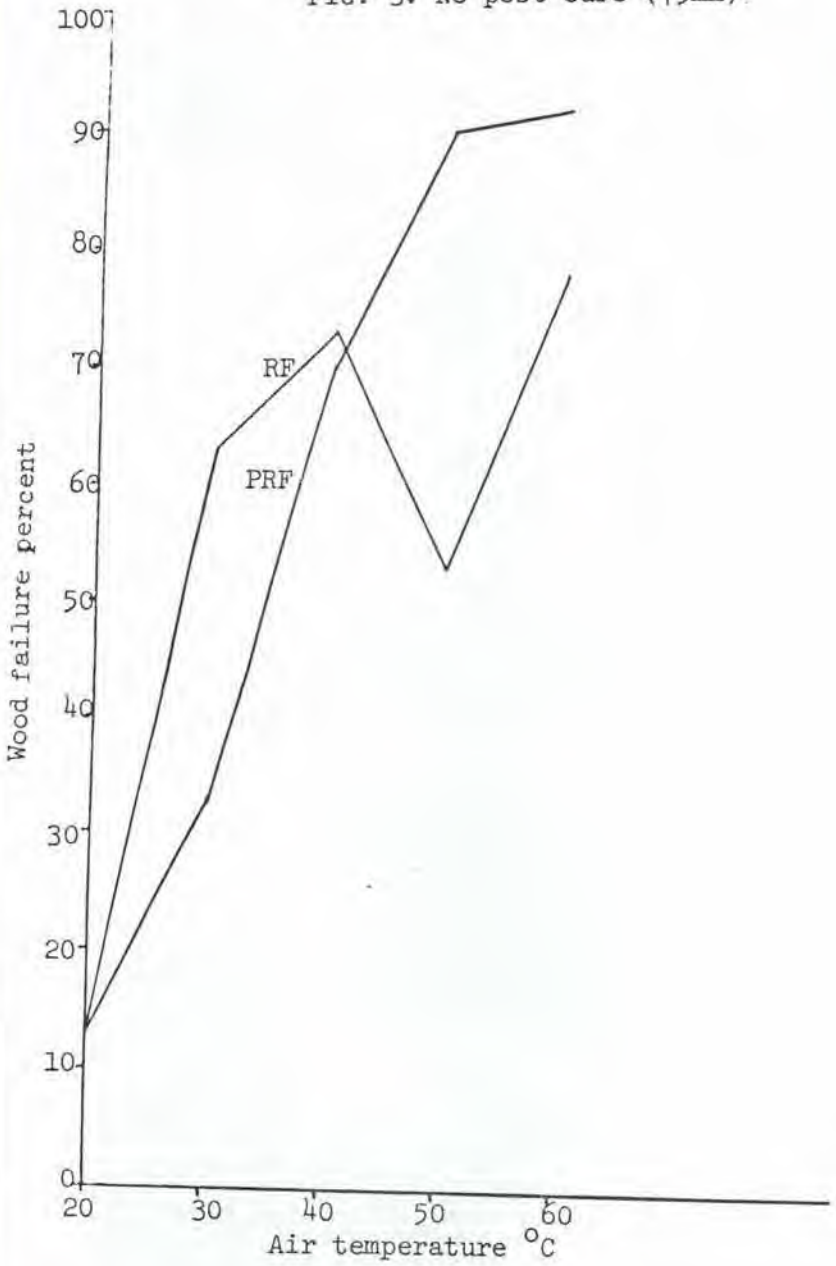
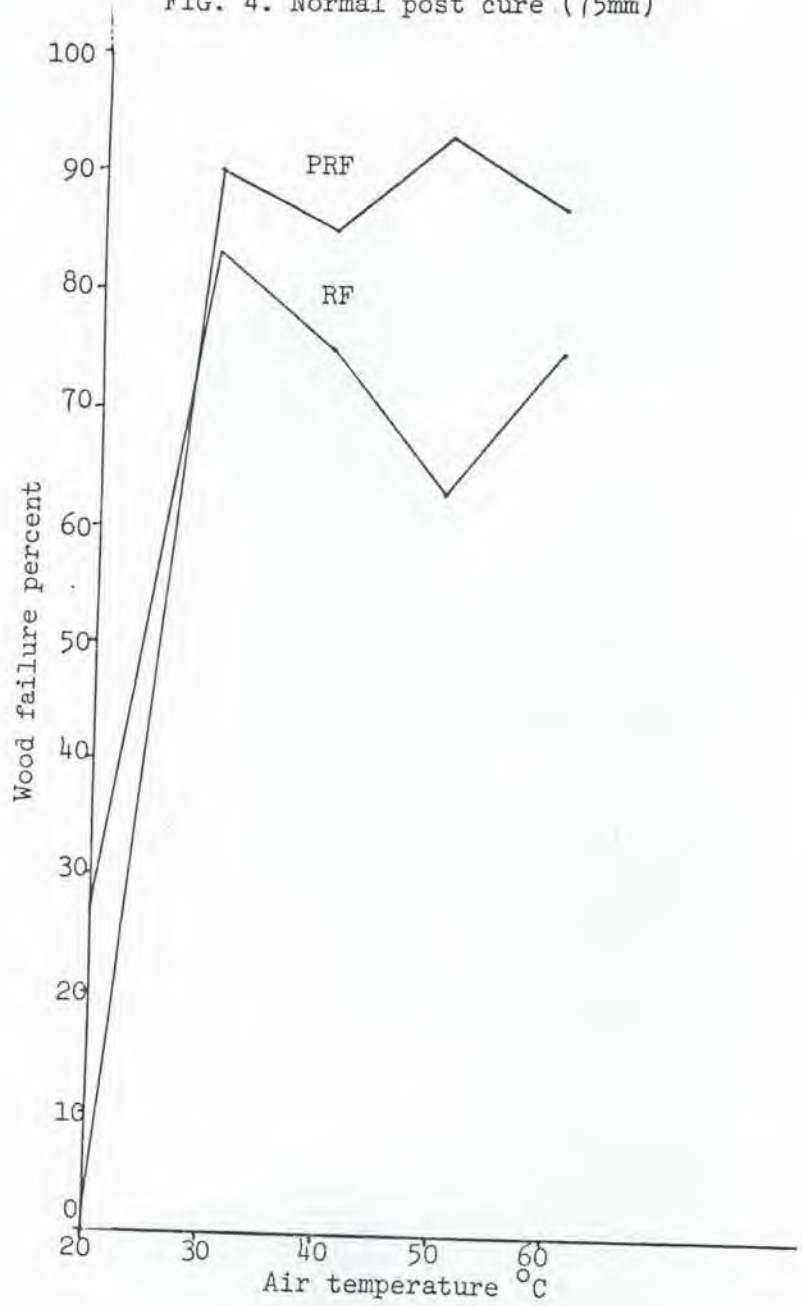



FIG. 4. Normal post cure (75mm)



# 20th FOREST PRODUCTS RESEARCH CONFERENCE

**16.–20. NOVEMBER 1981**

**HELD AT**

# CSIRO

**DIVISION OF CHEMICAL TECHNOLOGY**
**SOUTH MELBOURNE, VICTORIA,**
**Australia**

**VOLUME 2**

**FIBRE, ENERGY AND CHEMICALS FROM WOOD-**
**WOOD PRESERVATION**

8
FOR

E. 14:-

p. 6 - under table, '$FP_A$' - "F17+" to "F17".
p. 7 - Table 6, Heading - add "of" after "Breakage".

E. 15:-

p. 3 - para 3, line 7 - "1%" to "10%".
p. 4 - para 1, line 1 - "stress-graded" to "stress-grade".
p. 5 - para 2, line 1 - "Sturctural" to "Structural".

T. 4:-

p. 4 - FIGURE 1 - "(38)" to "(27)".
p. 7 - para 3, line 3 - "Fogires" to "Figures".
p. 7, para 4, line 2 - "fibre" to "fibres".
p.10, para 1, line 6 - add ",38" after "28".
p.10, para 2, line 4 - add ",38" after "27".
pp. 21 & 22 - check for clarity of printing - spare copies available at desk.
p. 26 - para 3, last line - "thicker" to "thinner".
p. 27 - Ref. 1. - Delete "Appita ..... 128" and substitute "Trans. Formation and Structure of Paper" Symp.: 537-572 - Tech. Sect. Br. Ppr. and Bd. Mfrs. Assn., London.
p.29 - Ref. 27 - page nos. should be "95-110".
p.29 - Ref. 34 - Alter title and source to "The effect of pulping upon the dimensions of wood tracheids. Wood and Fiber 7(3): 226-233".
p.30 - Ref. 39 - Delete "the" before "changes".

==========

(1)

*Corrigenda*

Please note the following corrections to papers W.Q. 9, 10, 11, E. 14, 15 and T. 4:-

W.Q. 9:-

p. 3, para 2, line 7 - "A 12-joule" to "An 18-joule".
p. 3, para 3, line 2 - "an" to "and".
p. 7, Table 6, line 2 - add symbol '+' after Beerburrum.
p. 7, Table 6, footnote '+' - add "(see Table 7)" after "instrument".
p. 7, Table 6, under last line - add "+ - pooled across site qualities".
p. 8, Table 7 - insert extra headings "6-joule Pilodyn" above columns 5 & 6 and "18-joule Pilodyn" above columns 7 & 8.
p. 9, Figure 1 - add "quality" after L. 'Low' site, A. 'Average' site and H. 'High' site.
p.10, Para 1, line 3 - "one" to "an".
p.10, third bottom line, "curve linear" to "curvilinear".
p.11, para 3, line 4 - delete "indicated".
p.12, References, 1/, line 2 - "diun" to "d'un".

W.Q. 10:-

p. 2, para 4, line 4 - "$26^{o}28'$" to "$11^{o}30'$".
p. 3, inset - after Melville Isd. - insert "(Lat. $11^{o}30'$, El. $100^{m}$.)".
p. 6, line 2 - add "and Caribbean Pine on Melville Island" after Queensland.
p. 8, bottom line - add "and Caribbean Pine on Melville Island".
p.10, para 2, 3rd last line - add "within" between "20-tree" and "plot".
p.11, Conclusion 5., line 2 - insert "really" between "only" and "beyond".

W.Q. 11:-

p. 3, last para, 1st line - insert "a" in front of "diametral".
p. 4, para 3, line 1 - "pairs" to "sets".
p. 8, para 1, line 3 - "no" to "not really".
p. 8, References, 4., line 2 - change "Malayan" to "Malaysian".

P.T.O (p.2)

D-06479-I

CSIRO Library Network System
3 9009 00698993 9

VOLUME 2

# FIBRES, ENERGY AND CHEMICALS FROM WOOD

## INVITED PAPERS


| | TOPIC NO. |
|---|---|
| Wood Resources for Fibre, Energy and Chemicals. R.N. Cromer. | T1 |
| Chemical Pulping. P.F. Nelson. | T2 |
| High Yield Pulping. P.J. Nelson. | T3 |
| Fibre Properties Affecting Pulpwood Processing and Paper Properties. W.J. Smith. | T4 |
| Fibre Treatment. A.W. McKenzie. | T5 |
| Refined Wood Fibre-Cement Products. R.S.P. Coutts. | T6a |
| A "Reconsolidated" Structural Wood Substitute. J.D. Coleman. | T6b |
| Applications of Composite Paper-Wrapped Yarns. M.D. Campbell. | T6c |
| Chemicals from Wood. A.A. Sioumis. | T7 |
| Liquid Fuels from Wood. H.G. Higgins. | T8 |
| Wood as a Heating Fuel - Some General Observations. R.M. Liversidge and P.Y.H. Fung. | T9 |
| Forest Residues for Energy and Fibre. C.M. Kerruish, R. Wingate-Hill and W.H.M. Rawlins. | T10 |


## CONTRIBUTED PAPERS


| | |
|---|---|
| Insecticides for the Protection of Wooden Components of Shipping Containers. C.D. Howick. | WP1 |
| Further Information on the Efficacy of Some Synthetic Pyrethroids in Wood Preservation. C.D. Howick and J.W. Creffield. | WP2 |
| Termiticidal Efficacy of Alkyl Ammonium Compounds in Wood. C.D. Howick, J.W. Creffield, H. Greaves and J.A. Butcher. | WP3 |


CSIRO
RECEIVED
9 FEB 1982
LIBRARY
DIVISION OF FOREST RESEARCH

A Rapid Field Assessment of Insecticide-Treated Wood Against Termites. J.R.J. French and P.J. Robinson. WP4

A Field Test of the Natural Durability of the Heartwood of Australian Timbers in Ground Contact. J.D. Thornton, N.E.M. Walters and I.W. Saunders. WP5

Accelerated "Fungal Cellar" Testing of the Natural Durability of the Heartwood of Australian Timber in Ground Contact. J.D. Thornton, G.C. Johnson and I.W. Saunders. WP6

Progress on Investigation of the True Dry Rot Fungus Serpula lacrymans in Relation to the Renovation and Preservation of Buildings. J.D. Thornton. WP7

Aspects to Consider in Evaluating a Non-Destructive Method for Testing Utility Poles. J.D. Thornton and G.C. Johnson. WP8

Penetration of Creosote into Stained Karri (Eucalyptus diversicolor F. Muell.) Heartwood. J.E. Barnacle, G.C. Johnson, M.A. Tighe and A. Antonovsky. WP9

The Performance of One-Piece Pressure Treated Hardwood and Softwood Railway Sleepers in Various Australian States. C.W. Chin and J.E. Barnacle. WP10

Preliminary Investigations into the Treatment of Messmate (Eucalyptus obliqua L'Herit.) by a Modified Form of Double Diffusion. Kofi Ampong and C.W. Chin. WP11

Deleted WP12

Protection of Wood Poles by Groundline Remedial Treatments - Inspection of Pole Test Site at Wedding Bells S.F. R.S. Johnstone. WP13

Glyptotermes in Transmission Poles. R.W. Eldridge and W.D. Gardner. WP14

The Need for Care in the Promotion of Wood for External Use on Buildings. K.R. Bootle. WP15

Deleted WP16

The Application of Timber Pole From House Construction in Queensland. J.L. Grimmett and W.T. Kynaston. WP17

Drywood Termites in Queensland - Eradication, Control and Prevention? R.A. Yule and B.C. Peters. WP18

A Comparison of Preservative Retentions as Determined by Two Different Methods. J. Norton. WP19

Poor Performance of Highly Durable Species in Non-Flooded Areas of Mechanical Draft Water Cooling Towers. B.N. Brown and L. Belland. WP20

Light Organic Solvent Preservatives in Queensland - A Short Position Paper. A. Gardner. WP21

The Distribution of Copper Chrome Arsenic Salts in Slash Pine. J. Norton. WP22

Biocides from Tropical Rainforest Species - Some Results, Practical Problems and Concerns. J.R.J. French. WP23

# WOOD RESOURCES FOR FIBRE, ENERGY AND CHEMICALS

by R.N. Cromer
CSIRO, Division of Forest Research, Traralgon, Vic.

## ABSTRACT

The volume of coniferous timber available on the Australian market will continue to increase over the next 30 years. Adoption by more growers of the heavily thinned high pruned sawlog regimes will increase the production of low density, short fibre core wood. This material could be used as a feedstock for energy or chemical industries but is uneconomic to harvest at present.

The volume of sawlogs from native forests on the other hand will continue to fall. Even aged regeneration resulting from wildfires or clearfelling operations could be thinned to increase the growth and value of the remaining stems. Thinned stems could be utilized for fibre, energy or chemicals if they can be harvested economically.

## INTRODUCTION

The published literature dealing with the potential of agricultural and forestry crops to provide energy increased dramatically following the Middle East oil embargo in 1973. Papers by Siemon (1975), Saddler et al. (1975) and others prompted discussion of the subject in Australia. The most detailed study in this country to date by Stewart et al. (1979), indicated that existing forest residues and new plantation developments covering 1 M ha of land could supply 22 and 53 PJ of methanol respectively. This represented about 11 percent of the liquid fuel used for transport in Australia (1978). The cost of production was expected to be about double the cost for motor spirit. Conversion of natural gas or coal to methanol is likely to be about half the cost of using wood (Wise 1980).

The direct use of wood as a fuel in solid form however is more attractive and can be competitive with oil, particularly if sawmill and forest residues are utilized. The pulp and paper industry in many parts of the world is already well on the way to being self sufficient in energy (Hall 1981).

The studies referred to are probably well known to most people at this conference and I do not intend to labour over the costs and benefits of energy plantations.

It has also been estimated that if existing native forests within 200 km of the major population centres were managed for intensive wood production, they could provide an additional 10 M t (oven dry) of material for energy generation (Harries 1979). This estimate was derived by subtracting the volume of wood committed to other uses from the potential growth of these forests under intensive management.

Management can be "intensified" in many ways however, including genetic manipulation, addition of fertilizers, control of weeds, or more frequent thinning. I intend to examine the forest resources which are likely to become available over the next thirty years, suggest some changes in management which are possible and discuss in qualitative terms the implications this might have for alternative uses of wood.

In general, this implies that the crops I intend to discuss are already growing and the opportunities for substantial genetic improvement are limited. On the other hand, implementation of alternative silvicultural regimes can influence tree size, wood quality and the volume of timber available over a relatively short time interval.

Biomass yields can be substantially increased by harvesting components other than stem-wood but removal of leaves, branches and bark greatly increases the drain of nutrients from a site (Cromer et al. 1980). Only the wood component is considered here but even harvesting this on very short rotations can increase the rate of phosphorus removal (Crane and Raison 1980).

The utilization of forest residues is the subject of another paper at this conference and has not been investigated.

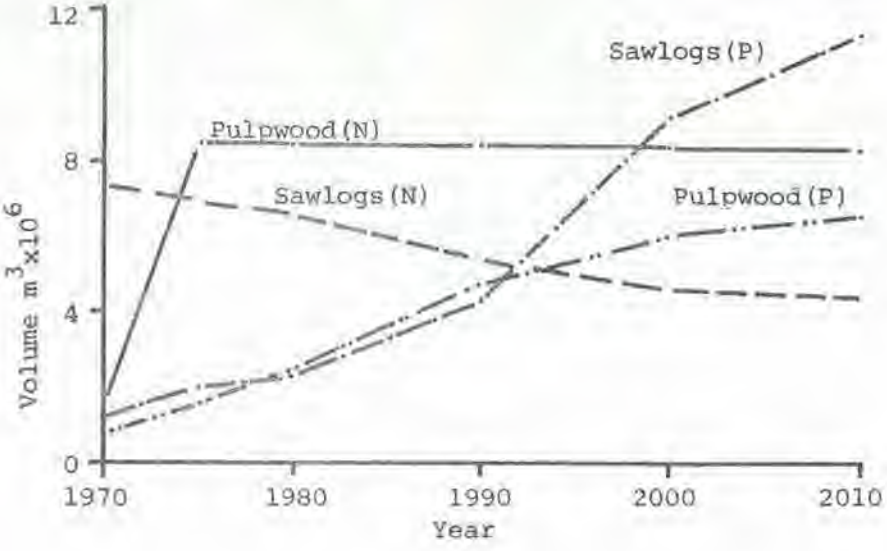
The volume of forest produce which is likely to be available for various end uses in Australia was forecast by Panel 2 of Forwood (1974). Despite the limitations of these estimates they serve as a useful guide to future trends and are presented in Figure 1.

## NATIVE FOREST RESOURCES

There has been a gradual decline in the volume of sawlogs available to industry which will continue into the future (Figure 1). The sudden increase in pulpwood availability during the early seventies was caused by the rapid expansion of the export woodchip market.

Figure 1.

Future availability of forest produce in Australia (after Forwood 1974) N = Native forests, P = Plantations.




The largest and best trees have been selectively logged from native forests in Australia since sawmillers first worked the forests. A silvicultural method called the "Australian Group Selection System", was developed following this selection logging so that existing regeneration was not destroyed. It was primarily useful in fire-resistant species and many fine forests resulted from it (Jacobs 1955). Unfortunately in many areas large unmerchantable trees were also left which suppressed regeneration and reduced productivity.

Selection felling was not suited to the tall, high quality and fire susceptible forests however and these were managed under a clear felling system, often with the retention of seed trees to ensure regeneration.

Under both methods of management, and following the occurrence of wildfires, regeneration was generally prolific resulting in many thousands of seedlings per ha. As a forest matures, competition between trees causes a gradual decline in the number of live stems and the mean diameter of the surviving trees gradually increases (Figure 2). For the unmanaged stand of E.sieberi shown, the number of live stems gradually declined to 1000 $ha^{-1}$ over 60 years, resulting in a mean diameter of 32 cm. A similar stand thinned to 1000 stems $ha^{-1}$ at age 21, reached a mean diameter of 20 cm within 6 years (Figure 3).

Heavier (or earlier) thinning would cause an even greater response in diameter growth.

Figure 2.

Diameter growth and stocking of unthinned E.sieberi (site index 30) in eastern Victoria. (Borough et al. 1978 after Incol 1974.)

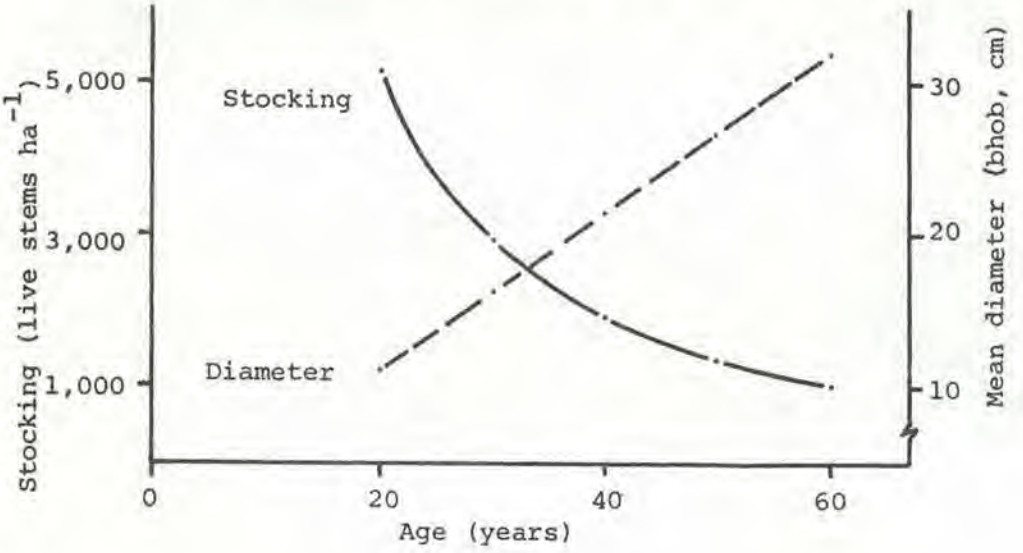
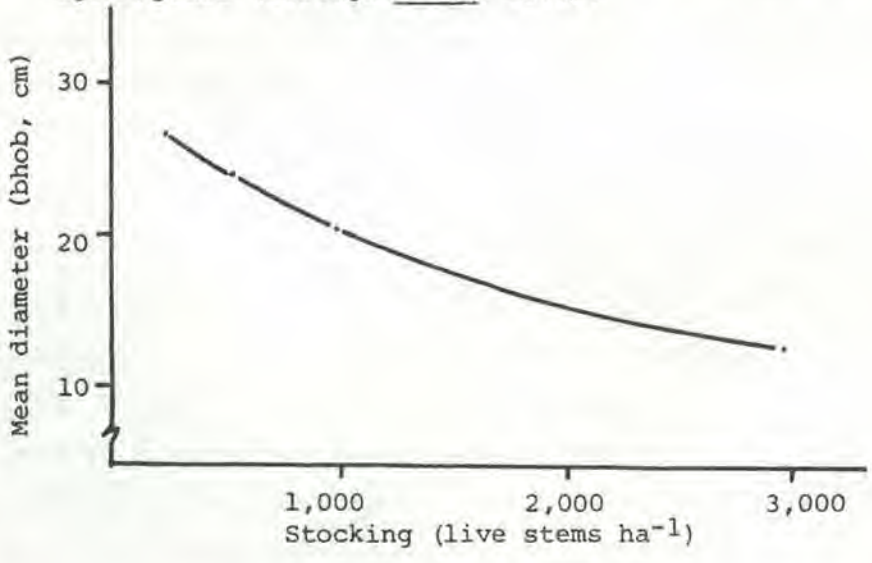



Figure 3.

Diameter of E.sieberi at age 27 following thinning at age 21 years (Borough et al. 1978).



The advent of the export wood chip market created the opportunity to cut existing degraded forests in many areas and establish vigorous even-aged regrowth stands. In addition to these recently regenerated areas, there are large areas of high quality forest resulting from clear felling operations or wildfires such as those which occurred in 1939.

Whilst thinning in many of these forests would be both difficult and expensive, a practical solution would have many benefits. A considerable volume of wood which is now lost through natural mortality could be utilized for fibre, energy or chemicals. The time required for the remaining trees to reach mill log size would also be greatly reduced.

## PLANTATION RESOURCES

### CONIFERS

The availability of timber from coniferous plantations will continue to increase, particularly in the larger sizes after 1990 (Figure 1). The availability of trees of millable size from plantations is expected to exceed the volume available from native forests soon after 1990.

The silvicultural regime adopted by plantation owners has a significant impact on the size of the trees harvested, the volumes produced and the economic viability of the enterprise. In New Zealand, the lack of a market for small trees and the premium royalties paid for clear timber in large diameter trees has led to the adoption of short rotation sawlog regimes which include heavy and early non commercial thinnings combined with high pruning. The most recent modification of this regime recommends that stocking be reduced to 200 final crop stems $ha^{-1}$ at a mean height of 10.7 m.

Markets for thinnings are available only for those forests committed to a pulpmill (or other residue-using plant) prepared to pay the additional harvesting costs (Sutton 1981).

Similar short rotation sawlog regimes have now been adopted in Western Australia where a final crop stocking of only 125 stems $ha^{-1}$ is envisaged. It has been found that wide spacings insure plantations against drought on all except very shallow soils and permit continued growth of crop trees during drought periods (McKinnell 1981).

More conventional spacing and thinning regimes continue to be applied by most other plantation growers in Australia. There is an increasing area being planted by private individuals under Farm Forestry agreements with the States (e.g. Forests Commission Victoria 1980) and no doubt some of this will

be managed under wide spaced, high pruned agro-forestry regimes (Anon. 1978).

Whatever the silvicultural regime adopted however, the application of more intensive methods to ameliorate adverse site factors is becoming more widespread. In South Australia, increased expenditure on intensive silvicultural treatments including fertilization, weed control and tree breeding are expected to increase average site quality from the present IV plus to the minus side of III over the next 40 years (South 1981).

EUCALYPTS

Eucalypt plantations cover an area of about 50,000 ha in Australia and will therefore contribute little to the overall availability of wood in the near future. The area being planted each year is increasing however with about one third of new plantings being established by private industry. The intensive silvicultural regimes being adopted in coniferous plantations can also be applied to eucalypts to increase productivity. In the absence of thinning, such intensive regimes are economically viable for private industry but not for State Forest Services (Cromer 1981).

In New Zealand however a heavy early thinning to 100 stems $ha^{-1}$ has been suggested which would produce large sawlogs (70 cm d.b.h.) in 35 to 40 years (Revell 1981). A thinning at age 12 to 14 would produce a large volume of wood (e.g. 250 $m^3$ $ha^{-1}$ in 14 year old E.saligna thinned from 1250 to 100 stems $ha^{-1}$). The reduction in rotation length combined with higher prices for the sawlogs could make such a regime economically viable for State Forest Services.

## WOOD PROPERTIES

CONIFERS

The properties of coniferous wood vary with age, height up the stem, silvicultural treatment and the edaphic-climatic conditions under which it is grown.

Overstocked stands of P.radiata in the Mediterranean climatic zone of Western Australia typically have narrow latewood bands and consequently wood density is not high. Thinning extends the length of the growing season during the period of late wood formation and preliminary data indicate that wide spacing actually increases wood density (McKinnell 1981). Similar observations have been made following irrigation of P.radiata in South Australia and the A.C.T. (Nicholls 1971, Nicholls and Waring 1977). Studies in other areas have generally found some reduction in basic density as a result of thinning

(Nelson et al. 1980, Cown 1974A).

The major effect of thinning on basic density however is the reduction in time for trees to reach a specific merchantable size. Compared to older unthinned stands of the same mean diameter, 25 year old thinned trees at Kaingaroa had 8 to 10% lower density and 10% shorter tracheids (Cown 1974A).

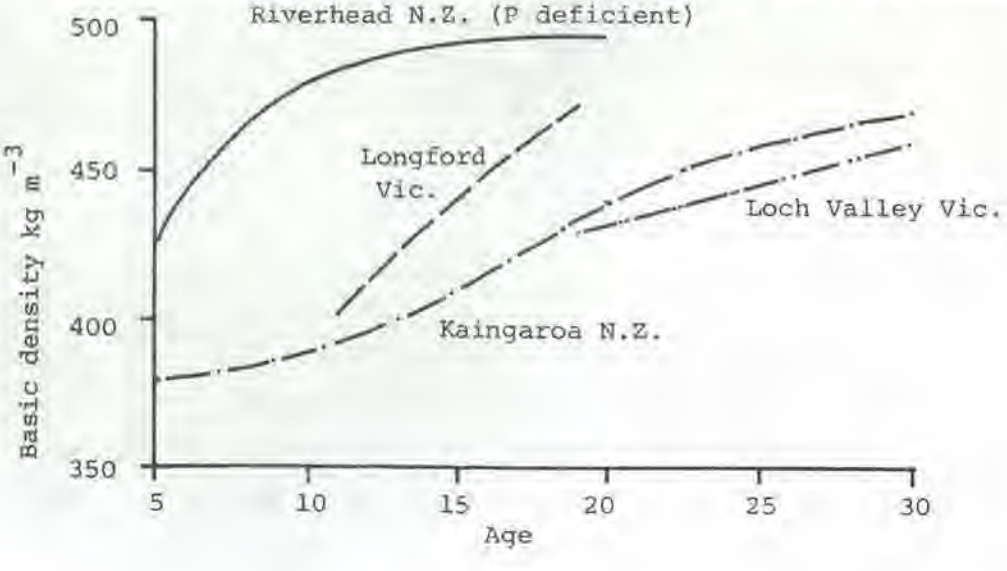
Under the sawlog regimes which incorporate very heavy early thinning, the thinned stems are normally considered to be unmerchantable and expensive to extract. These young, fast grown trees would contain corewood of low density with short fibres but may be useful for energy or chemical production.

Even where more conventional spacing and thinning regimes are employed, fertilizers and herbicides are used to increase growth. A substantial reduction in basic density was found in wood from 4 year old fertilized P.radiata, but smaller and inconsistent changes in older trees (Nelson et al. 1980). Cown (1974B) suggested that fertilizer applied to trees on deficient sites reduced wood density to the level which would be expected on non-deficient sites.

The effects of age and environment have substantially greater impacts on wood density than silvicultural treatments as shown in Figure 4. Mean basic density at breast height in 15 year old P.radiata varies from 410 kg $m^{-3}$ at some Kaingaroa sites to 490 kg $m^{-3}$ on phosphorus deficient sites at Riverhead. A reduction in average basic density in the order of 75 kg $m^{-3}$ is recognised from Auckland Conservancy (455 kg $m^{-3}$) to Canterbury Conservancy (380 kg $m^{-3}$) in New Zealand (Harris 1981). It is probable that a higher proportion of dense late wood fibres are laid down during the longer growing season of Auckland.

Figure 4.

The effect of site and age on the basic density of P.radiata wood. Data from Cown (1974B) and Nelson et al. (1980) for breast high samples.



EUCALYPTS

Wood quality in eucalypts has been examined in detail by Hillis (1978) who noted that considerable variations in density occur between and within eucalypt species and within trees. Basic density generally increases from pith to bark but there is sometimes a decrease in the first few centimetres of growth. Zobel (1981) noted that eucalypts lack juvenile wood with adverse properties and for many purposes the younger wood is often superior because it has lower phenolic deposits than are found in old wood.

Fertilization has been found to reduce basic density in eucalypts whereas the effects of thinning are variable (Hillis 1978, Cromer and Henderson 1981).

No correlation was found between diameter increment and stress level in E.regnans and there is no quantitative evidence that rapid growth results in higher growth stress (Hillis 1978). The likelihood that growth stresses are similar for large and small trees so their effect is reduced in large trees, is critical to the heavy thinning, sawlog regime proposed for eucalypts in New Zealand (Revell 1981).

## DISCUSSION

There will clearly be an increasing volume of coniferous timber available on the Australian market. The introduction of intensive silvicultural regimes means that on average, growth rates will be more rapid than in the past and rotation lengths will be shorter. If the New Zealand experience can be used as a guide, the market for young, small diameter pulpwood will be less attractive than that for large diameter, high quality timber. It is possible that other States may follow Western Australia in the move towards heavy early thinning for high value timber production. This would create a large resource of small diameter, very young trees containing mainly core wood with low density and short fibres. This material would be unattractive to the pulp and paper industry but could be utilized for energy and chemicals. Pulp and paper manufacturers are likely to rely on more traditional spacing and thinning regimes in order to maintain pulp quality.

The volume of eucalypt sawlogs in sizes which the industry has traditionally utilized will continue to fall. Large areas of regrowth forest now exist and will be regenerated in the future. The majority of these forests under public control receive little silvicultural treatment and carry high stockings. Competition between trees results in heavy mortality and a large loss in the volume of timber harvested. Long rotations are required to produce stems of merchantable size where stands are not thinned. An early and reasonably heavy

thinning in these stands could produce large volumes of timber and increase the value of the remaining trees. The wood of the thinned trees could provide a valuable resource for fibre, energy or chemical feedstocks.

Currently it is not possible to utilize these resources because the cost of harvesting exceeds the value of the wood produced. Thinning in high quality eucalypt forests which exceed 50 m also causes excessive damage to the remaining stems. Large volumes of potentially useful material could become available if these practical and economic problems can be solved.

The old growth eucalypt wood currently being exported in the form of chips could also be utilized in Australia if local fibre, energy or chemical industries could compete economically for this resource.

## REFERENCES

Anon. 1978. Agro-forestry - a new kind of farming? Rural Res. 99, 4-9.

Borough, C.J., Incoll, W.D., May, J.R. and Bird, T. 1978. Yield Statistics. Chapt. 10 in "Eucalypts for wood production". W.E. Hillis and A.G. Brown eds. CSIRO, Aust.

Cown, D.J. 1974A. Comparison of the effects of two thinning regimes on some wood properties of radiata pine. N.Z. J. For. Sci. 4, 540-51.

Cown, D.J. 1974B. Wood density of radiata pine: its variation and manipulation. N.Z. Jour. For. 19, 84-92.

Crane, W.J.B. and Raison, R.J. 1980. Removal of phosphorus in logs when harvesting E.delegatensis and P.radiata on short and long rotations. Aust. For. 43, 253-60.

Cromer, R.N., Williams, E. and Tompkins, D. 1980. Biomass and nutrient uptake in fertilized E.globulus. Paper presented to IUFRO Symposium and Workshop on Genetic improvement and productivity of fast growing trees. São Pedro, São Paulo, Brazil. August 1980.

Cromer, R.N. and Henderson, V.T. 1981. Alternative silvicultural practices for eucalypt plantations in Australia. Paper presented to a workshop on "Wood: future growth and conversion". A.N.U. Canberra, 5-8 May.

Forests Commission Victoria. Annual Report 1979-80. Govt. Printer Melb. 67p.

Forwood. 1974. Report of Panel 2, Forest Resources. Authorised by the Aust. For. Council. Aust. Govt. Pub. Serv. Canberra. 56p.

Hall, M.J. 1981. Possibilities of fuel wood production from pine - especially where a pulpwood market is not available. Paper presented to "Fuel wood cropping investment seminar". Internation Tree Crop Institute. Melb. March 1981.

Harries, E.D. 1979. Wood for energy generation. An estimate of availability from Australian forests. Paper 4B/1. 19th Forest Products Res. Conf. CSIRO. Div. Build. Res. 12-16 Nov. 1979.

Harris, J.M. 1981. Future technologies - some basic viewpoints. Paper presented to a Workshop on "Wood: future growth and conversion". A.N.U. Canberra, 5-8 May.

Hillis, W.E. 1978. Wood quality and utilization. Chapt. 12 in "Eucatlypts for wood production". W.E. Hillis and A.G. Brown eds. CSIRO Aust.

Jacobs, M.R. 1955. Growth habits of the eucalypts. For. & Timb. Bureau. Canberra 262p.

McKinnell, F.H. 1981. Wide spacing silviculture in Western Australianpine plantations. Paper presented to a Workshop on "Wood: future growth and conversion". A.N.U. Canberra 5-8 May.

Nelson, P.F., Hall, M.J., Hansen, N.W., Henderson, V.T. and Turvey, N. 1980. The effect of silvicultural practices on kraft pulping properties of P.radiata. Appita 33, 368-78.

Nicholls, J.W.P. 1971. The effect of environmental factors on wood characteristics. Silv. Genet. 20, 26-33.

Nicholls, J.W.P. and Waring, H.D. 1977. The effect of environmental factors on wood characteristics IV. Irrigation and partial droughting of Pinus radiata. Silvae Genetica 26, 2-3.

Revell, D.H. 1981. Silviculture of eucalypts; New Zealand experience. Paper presented to a Workshop on "Wood: future growth and conversion". A.N.U. Canberra, 5-8 May.

Saddler, H.D.W., McCann, D.J. and Pitman, M.G. 1975. An assessment of crop production for energy in Australia. Aust. For. 31, 5-15.

Siemon, J.R. 1975. The production of solar ethanol from Australian Forests. CSIRO Solar Energy Studies report No. 75/5.

South, P.M. 1981. Silvicultural practices intensively grown. Paper presented to a Workshop on "Wood: future growth and conversion". A.N.U. Canberra, 5-8 May.

Stewart, G.A., Gartside, G., Gifford, R.M., Nix, H.A., Rawlins, W.H.M. and Siemon, J.R. 1979. The potential for liquid fuels from Agriculture and Forestry in Australia. CSIRO, Aust. Govt. Printer 1979, 147p.

Sutton, W.R.J. 1981. New Zealand - an overview of radiata pine silviculture. Paper presented to a Workshop on "Wood: Future growth and conversion". A.N.U. Canberra, 5-8 May.

Wise, P.K. 1980. Forests for methanol production. Aust. For. 43, 44-51.

Zobel, B. 1981. Wood quality from fast grown plantations. Tappi 64, 71-74.

20TH FOREST PRODUCTS RESEARCH CONFERENCE

# CHEMICAL PULPING

P. F. Nelson
Australian Paper Manufacturers Limited

Chemical Pulping comprises those processes in which wood is substantially delignified in the course of liberating its constituent fibres. It is readily distinguished from mechanical pulping, in which the wood lignin is left essentially intact during fibre separation, but less readily from the low yield end of the spectrum of so-called semichemical processes which occupy the large middle ground between the other two categories. Thus, in most chemical pulping processes the yield of fibre from wood is approximately 50%, usually somewhat lower, even before bleaching, whereas in mechanical processes the yield is around 95%. At what stage a high-yield chemical pulp should be called semichemical is a matter for more or less arbitrary decision.

What are the factors which determine the type of process used for chemical pulping? A major aim of the latter has been to obtain the maximum yield of carbohydrate material consistent with the properties desired in the product for which the pulp is to be used. This aim reflects the fact that the cost of wood is usually the major factor in the cost of pulp, constituting about 50% in Sweden today. Its attainment requires that the delignification method employed be selective i.e. that the chemicals used attack lignin readily and carbohydrate as little as possible.

The cost of the pulping chemicals themselves is usually minimised by employing a recovery system in which they, together with the dissolved wood substance, are concentrated and burned in a suitable furnace. The chemicals do not usually emerge from such a process in their original form and considerable further processing may be necessary to achieve this. The "chemical recovery system" may therefore be quite complex and expensive and will usually constitute between 25 and 45% of the cost of a new mill, depending partly on whether it is to produce unbleached or bleached pulp.

The purpose of the recovery system, however, is not only the recovery of chemicals. The dissolved wood substance is a valuable fuel, the importance of which has increased with the price of alternative fuels. A modern kraft pulp mill is close to being self-sufficient in energy and an increase in pulp yield, by reducing the amount of dissolved wood substance, may require the use of oil or some other fuel in order to raise the necessary energy. The resulting fuel cost must be offset against the saving in wood cost due to the higher pulp yield.

Chemical pulping processes have been dominated by the use of sulphur compounds, mainly sulfide and sulfite. The reason for this has become clear due to the work done over the last couple of decades, especially in Sweden, on the chemical mechanism of delignification. It may be summed up in the term "nucleophilicity", a property of certain negative ions and neutral molecules which makes them agressive toward some of the types of structural units existing in lignin. Sulfide (or more accurately hydrosulfide in the case of kraft pulping) is a rather powerful nucleophile and well suited to this purpose. Sulfide and hydrosulfide ions are only able to exist in alkaline solution and the dominant kraft process is, of course, an alkaline one.

Sulfite and bisulfite ions are also strong nucleophiles, stable in alkaline and acid solution respectively so that a wider pH range can be covered in sulfite than in kraft pulping*. However sulfite chemical pulping has been losing ground steadily to kraft for many years and is now a relatively minor process. The reason for this is essentially environmental. Traditionally, sulfite mills have been based on the use of calcium bisulfite, a rather cheap chemical, and the spent liquors were disposed of to the nearest river or lake, sometimes after fermentation to reduce the carbohydrate content (and hence BOD) and produce alcohol. This kind of disposal has become less acceptable in recent times and mills have moved away from calcium to other bases such

* The term "kraft" pulping is used here as synomymous with "sulfate" pulping, i.e. to cover alkaline sulfide systems. In Scandanavia the term "kraft" is sometimes restricted to strong softwood sulfate pulps.

as sodium or magnesium, for which recovery systems have been developed. Magnesium can only be used in acid conditions and this limits the quality of the pulp obtained, principally due to the fact that wood polysaccharides (carbohydrate) are generally more severely degraded by acid than alkali. Sodium can be used in both acid and alkaline solution but recovery systems for sodium sulfite or bisulfite tend to be complex (and therefore expensive) and some are beset by technical problems not yet fully solved. However, as we shall see later, there are some signs of a renewed interest in sulfite pulping thanks to the development of new delignification additives.

The pre-eminence of the kraft process depends upon four main factors:

a) It produces pulp of generally higher strength than other processes.

b) It is very tolerant of differences in raw materials, being suitable for annual plants and residues of various kinds in addition to wood chips.

c) The quality of the pulp produced is, within reasonable limits, not very sensitive to the pulping conditions, making quality control relatively easy.

d) A chemical recovery system is available based on relatively simple unit processes.

In view of these virtues it might well be questioned why one would want to develop an alternative to kraft. There are two reasons for such an endeavour. The first is the very high capital cost of kraft mills and the second is the formation in kraft cooking of sulfur compounds with powerful and offensive odours. The environmental effect of the second factor can be overcome only by aggravating the first, since the necessary provision for scrubbing, collection, oxidation, combustion, etc. can add ca 15% to the capital cost of a new kraft mill.

As already noted, the biggest single factor in the cost of a new mill is the recovery system. The need to recover the sulfur in a reduced form, i.e. as hydrosulfide ion, means that reducing conditions must be maintained in parts of the recovery furnace and this leads to emission of some "TRS" (total reduced sulfur), mainly hydrogen

sulfide. While today's low-odour recovery boilers allow this to be kept to a few ppm, this is only achieved at additional cost.

The table below gives an approximate breakdown of the cost of a new unbleached kraft mill among its various components. In this case the pulp is used on site in an integrated mill.

Capital Cost of a 200 tonne/day unbleached kraft mill

| Department | % of Total Capital Cost |
|---|---|
| Woodyard, barking & chipping | 8 |
| Digesters, washing & screening | 23 |
| Evaporation, recovery & causticizing | 35 |
| Power generation, bark boiler | 13 |
| Water & effluent treatment | 8 |
| Buildings, etc. | 13 |

The burden of the high cost of kraft mills bears particularly heavily on small scale mills since the normal scale factors apply, i.e.:

$$\frac{Ia}{Ib} = \left\{\frac{Ca}{Cb}\right\}^{0.6-0.7}$$

where Ia is the investment required for a mill of capacity Ca
and Ib is the investment required for a mill of capacity Cb.

The effect of such a scale factor is that a fivefold increase in capacity involves only 2.5 fold increase in capital cost. This gives a clear advantage to large mills.

Elimination of sulfur from the kraft process, i.e. cooking with sodium hydroxide alone ("soda cooking") has been carried out

successfully with hardwoods though at the penalty of some loss of pulp strength. For some applications this is not important. However, for softwoods soda cooking is normally quite unsatisfactory since the relatively slow delignification process is accompanied by severe attack of the alkali on carbohydrates. Various attempts have been made to overcome this, the most promising up to the mid-seventies being the soda- oxygen process. This made use of the fact that lignin can be effectively degraded by oxygen under pressure in an alkaline medium. However, this system suffered from several drawbacks, including the difficulty of obtaining efficient mass transport of oxygen into the chips and the fact that polysaccharides are also attacked by oxygen in alkali. The latter was partly overcome by the use of "protectors" for the cellulose, usually magnesium salts, but the former required sub-division of the chips to increase their surface area, a result most effectively achieved by first cooking to a higher than normal yield with sodium hydroxide alone, defibering in a disc refiner and then treating the resulting pulp with alkali and oxygen in a further stage. The process was more complicated than kraft and was therefore not cheaper; it gave tearing strength substantially inferior to that of kraft pulps. As far as the writer is aware it is not practised, though one U.S. company carried out extensive large scale tests.

In the mid-seventies, a radically new alkaline pulping method was discovered quite independently in Japan, Canada and Australia. This involved the catalysis of soda cooking by a dyestuffs intermediate anthraquinone (AQ). Additions of only 0.01-0.2% on wood (oven dry basis) were required to bring the rate of soda cooking up to kraft levels. This contrasts with the several percent of sulfur used in the kraft process. In the intervening years there has been a veritable explosion of investigations on the process. To our knowledge, the first explanation of the mechanism of action of AQ was the redox hypothesis put forward from our own laboratories in our original patent application and its main features have since been confirmed in various countries.

Soda-AQ pulping is of very great theoretical interest because it demonstrates that certain additives are far more effective than sodium sulphide in bringing about delignification. On a molar basis anthraquinone is about two orders of magnitude more effective. Its use

enables elimination of sulfur from the cooking chemicals and thereby reduces, or even eliminates, the formation of odourous sulfur compounds. Unfortunately, sulfur is ubiquitous and enters the cooking cycle in wood and also oil where the latter is needed as an auxiliary fuel. Such adventitious sulfur will build up in a well-closed system such as is demanded by current environmental limitations. If the furnace can be run under completely oxidising conditions, the sulfur will be present as sulfate and will not cause odour.

Despite these advantages, soda-AQ pulping has so far been adopted for continuous operation by very few companies, though, fittingly, one of these is Australian. The reason for this slow adoption of the new method is two-fold. In the first place, soda-AQ pulping does not give a significant saving in capital cost, as any reduced expenditure on air pollution control is offset by the need for additional causticizing capacity. The latter follows from the fact that the sulfide which makes up 20-40% of the alkali in the kraft process does not require causticizing with lime, whereas in the soda process the whole of the alkali must be causticized. In the second place, the strengths of soda-AQ pulps are not quite up to kraft standard. This may not be crucial where the pulp is being used internally in, say, an integrated mill, but could be a disadvantage for market pulp. The main concern is the tearing strength with softwood pulps and while in our own work we have been able to reduce the deficit to somewhere between 0 and 10%, some overseas workers report deficits of 10-15%. This is a handicap in a competitive market. However, we are confident that with further research means will be found of overcoming this.

In Australia the available softwoods are P.radiata in NSW, Vic., SA and Tas. and P.elliottii in Queensland. The P.radiata currently in use for kraft pulping is fairly young and therefore somewhat lacking in tearing strength potential; its value is therefore rather sensitive to any factor which lowers tear further. P.elliottii soda-AQ pulps appear to suffer a greater strength deficit than P.radiata in comparison with kraft, perhaps due to difficulties in obtaining penetration of the additive into the thicker P.elliottii summerwood fibres. This wood is particularly well suited to kraft pulping as is recognized in the southern United States. Although it can be used for mechanical pulping, it is not a favoured species for this purpose, its thick-walled summerwood fibres, the feature which provides its high tear, being a dis-

advantage in mechanical pulping as they require an even higher refining energy consumption than loblolly pine. Moreover, the relatively high resin content of P.elliottii, a potential advantage in kraft or soda-AQ pulping as a source of tall oil, can cause considerable problems in mechanical pulping in the way of pitch accumulation, a feature for which "southern pines" are well known.

Simplification of the recovery system would be a major step forward in cheapening chemical pulping processes. The possibilities for doing this are greater for the soda-AQ than the kraft process because oxidising systems can be used in the former case, there being no sulfur which has to be retained in the reduced form. We are attempting to solve this problem in our work on the DARS process using a fluidized bed. This system eliminates the need for a separate causticizing step and we expect the capital cost to be significantly less than that of a kraft recovery.

The use of AQ is not limited to soda pulping. In a sense the AQ performs the same sort of function as the sulfur in kraft cooking and can be partially substituted for the latter, thereby reducing the formation of sulfur compounds in cooking. If the sulfur level is maintained at the normal value, say 25%, addition of AQ can give an increase in pulp yield or alternatively allow a reduction in lignin content for the same yield. Due to the high price of AQ, the value of the yield increase is in most cases offset by the cost of the additive but the method can be valuable where there is a bottleneck in the mill preventing increased output by other means. The option of using AQ to obtain a lower pulp lignin content could be useful in bleaching, since it means that there is less lignin to be removed and the amounts of bleaching chemicals used and effluent produced are thereby reduced.

Perhaps the most surprising discovery in the AQ story was that made in our own laboratories in relation to neutral sufite semi-chemical (NSSC) pulping. In this process the wood is cooked with a mixture of sodium sulfite and sodium carbonate or bicarbonate. Hitherto this process has mostly been used with hardwood as softwoods require long cooking times even for high yields and the stronger pulps potentially available by reducing the yield have been inaccessible.

NSSC pulping is often conducted at pH values from 7 to 9. In the soda system, e.g. sodium carbonate - caustic soda mixtures, AQ is quite ineffective at pH values up to ca 12 and it was expected to be similarly ineffective in NSSC. However, in NSSC pulping of P.radiata, small additions of AQ increase the pulping rate by two or three times and its use had added a new dimension to sulfite pulping. The process is already in use in Australia. NSSC softwood pulps can now be prepared for bleaching at yields considerably above kraft yields and with similar properties except for a somewhat lower tearing strength.

There is no doubt that the discovery of AQ and related additives is the most significant development in chemical pulping technology for many years. The wider use of such additives would be greatly facilitated by development of improved recovery systems and this must be seen as one of the most important tasks of current pulping research and development.

# HIGH YIELD PULPING

P.J. Nelson

Division of Chemical Technology, CSIRO,
P.O. Box 310, South Melbourne, Victoria.

## ABSTRACT

This paper reviews processes available for the manufacture of high yield pulps. Only processes which require a considerable amount of mechanical energy for separation of the wood fibres are considered. Some of the current theories on refining of wood chips are outlined and the latest developments for reducing the amount of energy required for the manufacture of mechanical pulps are discussed. Research work carried out at the Division of Chemical Technology, CSIRO, with the aim of developing methods for the manufacture of high yield pulps with good papermaking properties from Australian wood species is summarized.

## INTRODUCTION

Chemical pulps are produced from wood by the removal of most of the lignin with chemicals, thereby allowing the delignified wood to disintegrate into its component fibres without the need for mechanical action. Wood can also be separated into fibres by purely mechanical means. In a mechanical pulping process it is converted into papermaking pulp in about 95 per cent yield compared with about a 50 per cent yield in a chemical pulping process such as the kraft process. This large difference in pulp yield represents a huge saving in raw material, and has been the stimulus for much of the commercial development in high yield pulping over the past decade. An additional advantage of high yield pulping is that the capital cost of mechanical pulping facilities is about one-tenth that of a chemical pulp mill such as a kraft mill compared on the basis of the minimum economically viable size (1). The replacement of chemical pulps by high yield pulps raises the question of the comparative qualities of the two types of pulps. High yield pulps have inferior strength properties compared with chemical pulps. Another disadvantage is that they require a large amount of electrical energy in their manufacture. These shortcomings have attracted a great deal of research effort and a number of workers have studied the use of chemicals at particular stages of the manufacture of

of mechanical pulp in an effort to reduce the energy requirements and increase the pulp quality.

The term "high yield" pulp requires definition as it has been used to describe a wide variety of pulps. In this paper only pulps which require a substantial amount of mechanical energy in their production will be included in this category.

A general division between the various types of high yield pulps is as follows:-

| | |
|---|---|
| Mechanical pulps | 94 - 97 per cent yield |
| Chemimechanical pulps | 80 - 95 per cent yield |
| Semichemical pulps | 65 - 80 per cent yield |

This differentiation is based on whether or not chemicals are used and on the extent of lignin removal during the chemical treatment. Atack et al (2) regard chemimechanical pulps as pulps which bridge the gap between those with "chemical character" and those with "mechanical character". A pulp with mechanical character is defined as one which shows an increase in light scattering coefficient as its breaking length is increased by beating or refining. These authors have introduced a sub-class named ultra-high yield pulps for chemimechanical pulps which exhibit mechanical pulp properties according to this definition.

In the following discussion the various high yield pulps will be considered in the three classes listed above.

## MECHANICAL PULPS

### STONE GROUNDWOOD (SGW)

The oldest method of converting wood into mechanical pulp is the stone groundwood process in which logs of wood are pressed against the surface of a large rotating grindstone. The stone is sprayed with water to remove the pulp formed and to cool the surface. The logs of wood are held so that the fibres in the wood are aligned at right angles to the direction of movement of the stone and parallel to the axis of the stone. The quality of the pulp produced in this process is not high because the individual fibres undergo considerable damage during defibration of the wood. In general, softwoods are much more suitable than hardwoods as a raw material for this process. The principal exceptions to this generalization are a small number of low density species, for example, aspen, and wood from very old ash eucalypts. High density hardwoods produce pulps with strength properties less than 25 per cent of those of spruce SGW.

A recent development in the manufacture of stone groundwood has been the use of pressurized grinders (3). The wood grinding zone is totally enclosed and a

gauge pressure of about two atmospheres is maintained using compressed air. The pulp produced has the same light scattering coefficient as stone groundwood, a property which is important when the pulp is used for the manufacture of newsprint. The Tampella Company which is developing this process claim, on the basis of pilot plant data for various wood species, that there is a 20-60 per cent improvement in strength characteristics over groundwood without any increase in specific power consumption. However, the claim remains to be verified using mill scale equipment over an extended period.

One of the disadvantages of the stone groundwood process is that the wood has to be in the form of logs. This requirement limits the range of raw material suitable for this process, as sawmill residues etc. in the form of wood chips cannot be handled by equipment now available. A recent report (4) describes equipment developed by the Oji Paper Company in Japan for the manufacture of SGW from wood chips. The strength properties of the pulp are lower than conventional groundwood pulp and the amount of fine material is higher. The energy required to produce the pulp appears to be slightly higher than for SGW made from logs. When the pulp was used for the manufacture of newsprint the paper had superior printing properties.

REFINER MECHANICAL PULP (RMP)

A more recent technological development for mechanical pulp manufacture has been the use of disc refiners for the conversion of wood chips into their constituent fibres. The wood chips are passed between narrowly separated rotating discs which have surfaces consisting of bars and grooves. The diameters of the discs are as great as 137 cm in some of the large commercial refiners. In most commercial installations the refining is carried out in two stages as it is difficult to manufacture a pulp with good papermaking properties in a one-stage refining process unless the disc diameter is very large. Refiner mechanical pulping has two main advantages over stone groundwood pulping. Firstly, the pulp produced is stronger, and secondly, wood chips are used instead of logs, which means a much wider range of raw material can be utilized. The principal disadvantages are that the energy requirements of the process are higher and opacity is lower than for SGW.

THERMOMECHANICAL PULP (TMP)

A logical extension of refiner mechanical pulping was to pressurize the refiner with steam and carry out the defibration procedure at a temperature higher than 100°C. The process is known as the thermomechanical process and produces pulp which is stronger than RMP manufactured in an unpressurized refiner. At the higher temperatures the wood is softened and this results in

the TMP containing a greater proportion of undamaged fibres. The temperature of defibration strongly influences the properties of the pulp. At temperatures in excess of about 150°C the lignin in the wood becomes so soft that fibre separation occurs in the middle lamella region of the wood resulting in fibres coated with lignin and not well suited for papermaking. In most thermomechanical pulping operations the wood chips are heated to about 120°C prior to defibration. At this temperature the wood is sufficiently soft so that fibre damage is minimized while fibre separation takes place between the S1 and S2 regions of the fibre wall giving cellulose-rich surfaces suitable for good interfibre bonding. The higher strength properties of TMP compared to SGW and RMP are obtained with a higher consumption of electrical energy. However, a large proportion of the electrical energy is converted to steam which can be recovered at a pressure suitable for use in the drying section of a paper machine. It has been claimed that this recovered heat reduces the net energy requirement for TMP to about the same as that for SGW (5). The pulp yield and brightness of TMP are slightly lower than for RMP.

A recent development in refiner design has been the use of refiner plates with additional segments attached so that they are at an angle to the main portion of the plate (6). This development has arisen from the trend in recent years towards refiners with larger diameter plates to achieve higher production capacity. This has led to very high peripheral velocities and correspondingly increased centrifugal force which has created problems in the construction of discs with sufficient strength. In the new type of plates the outer refining zone is oriented at an angle of 105°C to the flat zone to form a conical refining surface in relation to the rotational axis. An increase in total refining surface area is achieved for only a marginal increase in the overall disc diameter. Mill trials with commercial refiners have shown that this concept is a practical one (7). However, hopes that dissipation of some of the kinetic energy of the pulp in the conical refining zone would lead to an overall reduction in energy consumption have not been realized.

ENERGY CONSUMPTION DURING MECHANICAL PULPING

The principal problem facing thermomechanical pulping is the high energy consumption. This was highlighted by Jaakko Pöyry (8) in his keynote address entitled "Are Energy Costs the Achilles' Heel of Mechanical Pulp?" given at the International Mechanical Pulping Conference at Helsinki in 1977. If energy costs continue to rise the point may be reached where it is cheaper to use SGW, which requires less energy than TMP, for a product such as newsprint by upgrading its properties by the addition of kraft pulp. A kraft mill has a very low external energy requirement because about half of the wood substance entering the mill is burned during the chemical recovery process and the heat produced is used to generate steam. Attempts to lower the energy requirements of the thermomechanical process have focussed on two areas, recovery of the steam generated and the use of chemicals. The use of chemicals in mechanical pulping will be discussed in the last part of this paper.

The difference in energy requirements between grinding and disc refining of wood has been analysed by Gavelin (9). The specific energy consumptions for a large number of stone groundwood and thermomechanical pulp mills using spruce wood are depicted in Figure 1. The values for the energy requirements fall within two separate bands - the higher band being for thermomechanical

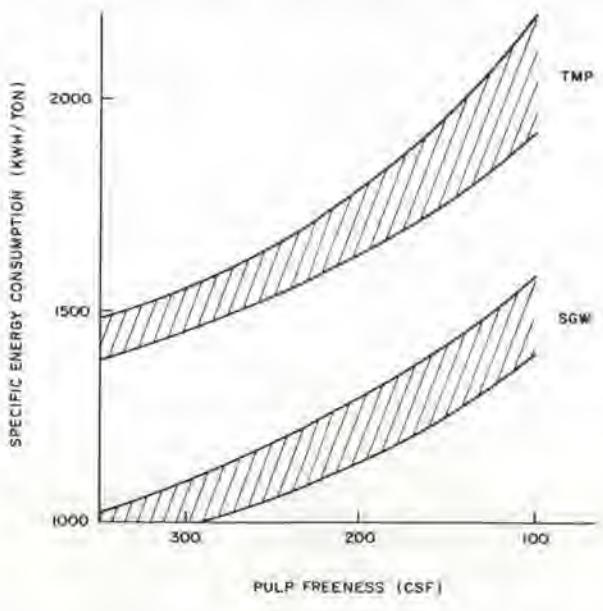



Figure 1. Specific energy requirements for the manufacture of spruce stone groundwood and thermomechanical pulps at different freeness levels (9).

processes. Gavelin advanced the hypothesis that the difference in specific energy consumption between TMP and SGW is due to the random orientation of

the fibres between the discs of a refiner, as compared to the crosswise orientation of the fibres with respect to the movement of the stone surface during grinding. The latter orientation would result in a more efficient utilization of the applied energy.

Atack (10,11) studied the orientation of fibres in a disc refiner using a photographic technique and found that the wood chips were reduced to match stick sized fragments in the breaking zone of the refiner plates and that these fragments rapidly aligned themselves in a tangential direction to the bars in the outer part of the refiner plate. On the basis of this evidence he proposed that chip refining is an almost idealized form of longitudinal grinding. Data for specific energy - pulp quality relationships obtained in a study of longitudinal grinding by de Montmorency (12) showed that the energy consumption was appreciably higher than in conventional transverse grinding and was similar to that required for chip refining. The current thinking on the question of the specific energy requirements in mechanical pulping is that the stone groundwood process and the refiner mechanical process involve fundamentally different mechanisms and therefore it is unlikely that the energy consumption in disc refining will be reduced to the level of the stone groundwood process.

## CHEMIMECHANICAL PULPS

The use of chemicals during the manufacture of mechanical pulps has been investigated as a means of improving the pulp quality and reducing the energy requirements. Chemicals can be applied at three different stages in the process: as a pre-treatment of the wood, a post-treatment of the pulp or as an interstage treatment between a first and second refining stage. When defibration of treated wood is carried out at a temperature of 100°C or lower the pulp is known as chemimechanical pulp (CMP), and if the temperature is above 100°C it is known as chemithermomechanical pulp (CTMP). Pulp prepared using an interstage treatment is often referred to as TCMP.

Mutton et al (13) used sodium sulphite at various stages in the preparation of CMP from a mixture of softwood species. The data, summarized in Table I, illustrate some of the principles involved in the use of chemicals for the manufacture of chemimechanical pulps. A RMP from the same wood sample is included for comparison.

TABLE 1

Properties of Pulps Prepared by Sulphonation at Various Stages in Their Manufacture (13)

| | | Sulphonation Procedure | | |
|---|---|---|---|---|
| | RMP | Pre- | Interstage | Post- |
| Freeness, Csf (ml) | 104 | 380 | 124 | 110 |
| Apparent density ($kg/m^3$) | 333 | 400 | 435 | 500 |
| Breaking length (km) | 3.0 | 4.8 | 5.3 | 5.0 |
| Tear Index $mN.m^2/g$ | 6.0 | 9.6 | 6.8 | 6.0 |

Sulphonation softened the wood chips so that fibre damage during defibration was minimized. The resulting CMP had a higher freeness value and tear index than a corresponding RMP because there was a larger proportion of undamaged fibres and less fine material in the pulp. Interstage sulphonation gave a pulp with strength properties superior to those of a post-sulphonated pulp because the treatment made the fibres more flexible and this decreased the amount of fibre damage during the second refining stage. Post-sulphonation was an effective means of increasing the bonding properties of RMP but did not increase the tearing strength which is dependent on the proportion of undamaged fibres in the pulp. Treatment of the chips prior to defibration is essential if pulp with a high tearing strength is required.

Pre-treatment of hardwoods with chemicals results in a much better pulp than from untreated wood. In fact, it is not possible to prepare high yield pulp of acceptable quality from most hardwoods without chemical pre-treatment of the wood. In contrast to the response of hardwoods to chemical pre-treatment, the relative increase in pulp quality on chemical treatment of softwoods is much smaller, mainly because of the good papermaking properties of pulp from untreated wood.

Chemicals can be used in the manufacture of SGW but this involves the treatment of logs. The uniform penetration of chemicals into logs requires the application of pressure for an appreciable time and is probably why the practice is not widespread and is confined mainly to mills using hardwoods. At the pulp mill of Australian Newsprint Mills Ltd., in Tasmania, logs from young eucalypts are treated with sodium hydroxide and then subjected to stone grinding.

Disc refining of wood chips is well suited to the use of chemicals as chips are more easily treated with chemicals than logs. The most commonly used chemicals for the production of CMP and CTMP from softwoods are sodium sulphite and bisulphite. Hardwoods show a much greater response than softwoods to alkaline reagents such as sodium hydroxide and alkaline sodium sulphite. For this reason these chemicals are usually favoured for production of CMP and CTMP from hardwoods. Sulphonation of softwoods has been studied in a number of laboratories (2, 14-19) and the beneficial effects of this treatment have been related to modification of the lignin. Sulphonation of the lignin softens the wood so that defibration takes place with less fibre damage. In addition, the fibres are more conformable so that the bonding properties of the pulp are superior to those of a pulp from untreated wood.

The second important effect of the use of chemicals in refining of wood is that a reduction in energy can be achieved. Various commercial processes using sulphite pre-treatments are discussed by Collicut et al (20) and data presented in their review show that the energy consumption is lowered as the pulp yield is reduced. Danielsson et al (6) reported that injection of chemicals such as sodium sulphite into the refining zone of the primary refiner reduced the energy consumption at a given pulp strength level. A similar reduction of energy was observed when alkaline hydrogen peroxide was introduced into the refiner zone in so-called "refiner bleaching" (21).

The work on high yield pulping carried out at the Division of Chemical Technology, CSIRO, over the past five years has concentrated on developing methods of preparing CMP and CTMP from commercially important Australian wood species. Some of the pioneering work in chemical pre-treatment of wood chips prior to thermomechanical pulping was done in the initial phase of this investigation and the terminology "CTMP" was invented to describe the resulting pulps. The use of alkaline sodium sulphite has been extensively studied for the pre-treatment of eucalypts and pines (19,22,23). High quality CTMP from *E. regnans* wood was prepared by pre-treatment with this reagent followed by defibration at 100°C. Chemically treated *P. radiata* wood had an optimum defibration temperature of 100-108°C compared to 125-130°C for untreated wood.

More recent research has examined the use of alkaline hydrogen peroxide in the preparation of CTMP from eucalypts and *P. radiata* (24). When a mild oxygen-alkali treatment was carried out prior to the peroxide treatment

the peroxide consumption was reduced and the quality of the pulp raised (25). The program of work has included investigations of the fundamental principles involved in chemical pre-treatments and defibration of wood. The dynamic mechanical properties of treated and untreated wood were studied by means of a torsional pendulum (24,25) and the glass transitions of various lignins determined by differential thermal analysis (26).

SEMICHEMICAL PULPS

Semichemical pulps are produced when wood chips are subjected to more drastic chemical treatment than in the manufacture of chemimechanical pulps. The pulp yield is lower and the amount of energy required for fibre separation is considerably reduced. The principal semichemical process is the neutral sulphite semichemical (NSSC) process in which wood chips are heated at elevated temperatures in a neutral or slightly alkaline sodium sulphite solution and then mechanically defibrated. At least half of the lignin and a major part of the hemicellulose originally present in the wood is retained in the pulp. The process is best suited for hardwoods as softwoods require a large amount of chemicals and are less reactive to the pulping liquor. Paper made from NSSC pulp is stiff and this property is the reason why large quantities of the pulp are used in the manufacture of corrugating medium.

The recent discovery (27) that anthraquinone accelerates delignification in the NSSC process has introduced the possibility of using the process for the pulping of softwoods. The effect on the pulping rate is greater for softwoods than for hardwoods.

High yield kraft pulps from coniferous woods are used for products such as linerboard and corrugating medium. The yield of the pulps are in the range 65-80 per cent. The quantities of the chemicals used in the chemical treatment are about half those used for manufacture of a chemical pulp with a low lignin content. The pulps are dark-coloured but this is not a serious disadvantage for these products.

Chemical treatments such as acid sulphite and bisulphite cooks are well suited for pulps required for use in furnishes for printing papers. The advantage of these treatments is that the brightness of the pulps is high.

REFERENCES


1. Leopold, B., 1979, "The Pulping Process - Opportunity or Headache?" Paper presented at the Paper Science and Technology - The Cutting Edge Conference at the Institute of Paper Chemistry, Appleton, Wisconsin, May, 1979. Proceedings 133-142.

2. Atack, D., Heitner, C. and Stationwala, M.I., 1978, "Ultra High Yield Pulping of Eastern Black Spruce" Svensk Papperstidning 81 (5) 164-176.

3. Aario, M., Haikkala, P. and Lindahl, A. 1980 "Pressure Grinding is Proceeding" Tappi 63 (2) 139-142.

4. Kaneko, K., 1981, Stone Groundwood Pulp from Chips (FGP) with Three 50-tpd Grinders by Oji Paper" Japan Pulp and Paper 19 (1) 49-55.

5. Leask, R., 1981 "CTMP and Heat Recovery Main Areas of TMP Interest According to 1980 Survey" Pulp Paper Can. 82 (3) 13.

6. Danielsson, O., Hartler, N. and Ryrberg, G., 1981, "Energy Reductions in Thermomechanical Pulping" Appita 34 (4) 306-308.

7. Tistad, G., Asklund, S., and Görfelt, P., 1981, "TMP for Newsprint Produced by Single Stage Refining with and without Conical Periphery Segments. Operating Experience from Hallsta Papermill". Paper presented at the International Mechanical Pulping Conference, Oslo, June 1981.

8. Pöyry, J., 1977 "Are Energy Costs the Achilles' Heel of Mechanical Pulp?" Paperi ja Puu 59 (10) 604-608.

9. Gavelin, G., 1978, "The Energy Consumption in TMP Pulping" Svensk Papperstidning 81 (9) 283-384.

10. Atack, D., 1980, "Towards a Theory of Refiner Mechanical Pulping" Appita 34 (3) 223-227.

11. Atack, D., 1981, "Fundamental Differences in Energy Requirement Between the Mechanical Pulping Processes", Paper presented at the International Mechanical Pulping Conference, Oslo, June, 1981.

12. de Montmorency, W.H., 1948, "The Longitudinal Grinding of Wood - Further Work" Pulp and Paper Mag. Can. 49 (3) 115-123.

13. Mutton, D.B., Tombler, G., Gardner, P.E. and Ford, M.J., 1981, "The Sulphonated Chemimechanical Pulping Process". Paper presented at the International Mechanical Pulping Conference, Oslo, June, 1981.

14. Atack, D., Heitner, C. and Karnis, A., 1980, "Ultra High Yield Pulping of Eastern Black Spruce Part II", Svensk Papperstidning 83 (5) 133-141.

15. Atack, D. and Heitner, C., 1979, "Dynamic Mechanical Properties of Sulphonated Eastern Black Spruce" Transactions of the CPPA Technical Section 5 (4) TR 99-108.

16. Vikström, B. and Nelson, P., 1980 "Mechanical Properties of Chemically Treated Wood and Chemimechanical Pulps" Tappi 63 (3) 87-91.

17. Vikström, B. and Hammar, L., 1979, "Defibration in Chemimechanical Pulping. Viscoelastic Properties of Kraft, Sulphide/Sulphite and Bisulphite Cooked Spruce Wood". Svensk Papperstidning 82 (6) 171-177.

18. Giertz, H.W., 1977, "Basic Wood Raw Material Properties and Their Significance in Mechanical Pulping". Paper presented at the International Mechanical Pulping Conference, Helsinki, June, 1977.

19. Higgins, H.G., Irvine, G.M., Puri, V. and Wardrop, A.B. 1978, "Conditions for Obtaining Optimum Properties of Radiata and Slash Pine Thermomechanical and Chemithermomechanical Pulps" Appita 32 (1) 23-33.

20. Collicut, S.A., Frazier, W.C., Holmes, G.W., Joyce, P., Mackie, D.M. and Torza, S., 1981, "Developments in Refiner Mechanical Pulping" Tappi 64 (6) 57-61.

21. Ryrberg, G., 1978, "Good Results Obtained by Bleaching Directly in TMP Pressurized Refiner" Pulp and Paper (8) 115-117.

22. Higgins, H.G., Garland, C.P. and Puri, V., 1977, "Thermomechanical and Chemithermomechanical Pulps from Eucalypts and Other Hardwoods" Appita 30 (5) 415-423.

23. Higgins, H.G., Puri, V. and Garland, C., 1978, "The Effect of Chemical Pretreatments in Chip Refining" Appita 32 (3) 187-200.

24. Puri, V.P., Nelson, P.J. and Higgins, H.G., 1981, "Oxidative Pretreatments in the Preparation of Eucalypt and Pine CTMP" Transactions of the CPPA Technical Section 7 (1) TR14-21.

25. Nelson, P.J., Irvine, G.M., Puri, V.P. and Higgins, H.G., 1981, "The Effect of Chemical Modification on the Structure and Thermomechanical Behaviour of Wood". Paper presented at Ekman Days International Symposium on Wood and Pulping Chemistry, Stockholm, June, 1981.

26. Irvine, G., 1980, "The Glass Transition of Lignin and its Relevance to Thermomechanical Pulping" CSIRO Division of Chemical Technology Research Review.

27. Farrington, A., Raverty, W., Vanderhoek, N., Cameron, D.W. and Samuel, E.L., 1981, "The Effect of Addition of Quinonoid and Hydroquinonoid Derivatives in NSSC Pulping". Paper presented at Appita Conference, Rotorua, N.Z., April, 1981.

# FIBRE PROPERTIES AFFECTING PULPWOOD PROCESSING AND PAPER PROPERTIES

W.J. Smith

Division of Technical Services
Queensland Department of Forestry
Brisbane

## ABSTRACT

An assessment is made of the influence of seven fibre properties considered to affect pulp and paper properties and of their related anatomical, chemical, physical and mechanical characteristics. No one fibre property operates exclusively and their effects vary with the defibration process and level of refining.

Fibre density and separability have most influence on yield. Flexibility is the main determinant of bond-related properties such as burst, tensile strength and early tear development, with cell wall thickness and wall thickness/diameter ratios negatively correlated. Fibre structure influences flexibility and bonding through effects on fibre wall delamination and fibrillation, both in defibration and refining. The flexibility of thick-walled fibres can be improved by beating, but only to equivalent bond capacity with thinner-walled fibres. In softwoods, fibre length has a positive effect on burst, tensile strength, stretch and tear only in its contribution to inter-fibre bonding, as a supplement to the primary influence of flexibility. However, length assumes more importance in the hardwoods. Fibre strength, as expressed in cross-sectional dimensions, operates largely conversely to flexibility, but cell wall thickness has a primary positive effect on maximum tear. Larger (flatter) fibrillar angle contributes to burst and tear development by facilitating extensibility. Smaller (steeper) angles are associated with improved refiner groundwood paper properties and apparently with higher tensile strength in chemical pulp. Fibre density and fibre coarseness are integrators of other properties, with the latter considered to be less effective as such.

Wall thickness and fibre structure (especially fibrillar angle) have a primary influence on most important paper properties in both softwoods and hardwoods. Fibre length is an added factor in hardwoods but considered much less so in softwoods than earlier research suggested. The effects of juvenile corewood, rootwood and bark fibres are briefly considered.

INTRODUCTION

The complex inter-relationships between fibre and other wood properties, processing variables, and paper properties have been comprehensively and critically appraised in numerous papers (e.g. 1, 2, 3, 4, 5, 6, 7, 8, 9, 10) and several text-books (e.g. 11, 12). These have covered both softwoods and hardwoods in some cases (1, 2, 5, 11, 12), focussed on one of these two fibre sources in others (3, 7, 8, 9) and, in some analyses, concentrated on individual species (4, 6, 10).

This paper does not presume to undertake a complete review of the voluminous and often apparently conflicting literature, but is, rather, a selective reassessment of, and commentary on, those fibre properties of major significance in relation to pulpwood processing and paper properties.

There is general agreement with Dinwoodie (2) that three fibre properties exert a major influence, viz. fibre density, fibre length, and fibre strength. Together with a fourth property, fibre flexibility, which Dinwoodie classified under density, these are all considered relatable to pulp and product properties and performance, to variable degrees depending on the process and the product. Fibre density is a component of wood basic density more closely relatable to the latter in softwoods than hardwoods, because of the interacting effect on density in hardwoods of the often higher parenchymatous tissue component and the variable but often very large vascular component. Fibre strength, density and flexibility effects are generally established through more easily measured indices available as parameters of fibre geometry and architecture.

Flexibility and density indices are usually the fibre cross-sectional dimensions - cell diameter (FD), lumen diameter (ld), wall thickness (WT), or constructs of same, such as the so-called Runkel ratio ($\frac{2WT}{ld}$, where WT is the radial wall thickness); the Mühlsteph ratio (cell wall cross-sectional area/fibre cross-sectional area); and the coefficient of flexibility (lumen diameter (ld)/fibre diameter (FD)).

However, an index of longitudinal flexibility used is the 'felting coefficient' (length/diameter) and Horn's (8) recently developed index of pulp fibre flexibility, the ratio of length to wall thickness (FL/WT).

Indices including a wall thickness component are, together with cell wall organization, relatable to fibre strength.

A fifth property often referred to in the literature, fibre coarseness, integrates the other four in its expression of mass per unit length of fibre (12).

To these five inherent physical and mechanical properties, two others should be added. Fibre structure, like the others, is an individual fibre property, embodying consideration of the component elements, as well as their architectural construction.

Fibre separability is a property of primary importance in processing for reconstitution to different formations the bonded systematic assemblies of fibres and other wood elements which constitute solid wood. It involves inter-fibre and inter-element components and connections.

The effect of these seven fibre properties on reconstituted product processing and product properties will be considered separately and in interaction.

## FIBRE STRUCTURE

A wood fibre[1] has been described (13) as 'a filament-wound, closed-end spindle of reinforcing filaments (microfibrils) in a cementing matrix of amorphous and/or paracrystalline polymers'.

The filaments of the framework are aggregations of long-chain cellulose molecules. These macro-molecules, about 25 000 to 50 000Å long, are formed into ribbon-like ultra-structures known as microfibrils, about 100Å x 35Å in cross-section, with alternating parallel oriented highly crystalline regions about 600 x 100 x 35Å and shortly disoriented regions. Inter-microfibrillar amorphous regions in the cell wall have been attributed to the disoriented regions forming a network connecting adjacent microfibrils (14).

Cellulose forms the structural framework of a woody cell wall in which the matrix constituents are hexosans, pentosans, polyuronic acids and protein, and the main encrusting substance is lignin (15).

Several concepts of the architecture of a typical fibre have been developed (see 13), but with relatively minor differences, and that of Wardrop and Bland (16), with further detailing by Wardrop and Harada (17), is representative. Their concept is shown in Figures 1 and 2.

As shown, there is an inter-fibre bonding lamella, an outer primary wall (P); an inner secondary wall made up of three layers – a thin outer one (S1), a relatively thick middle one (S2), and a thin inner one (S3); all surrounding a central lumen. The layers themselves are lamellated.

---

1 In this paper, the term 'fibre' refers to both angiosperm fibres and gymnosperm tracheids.

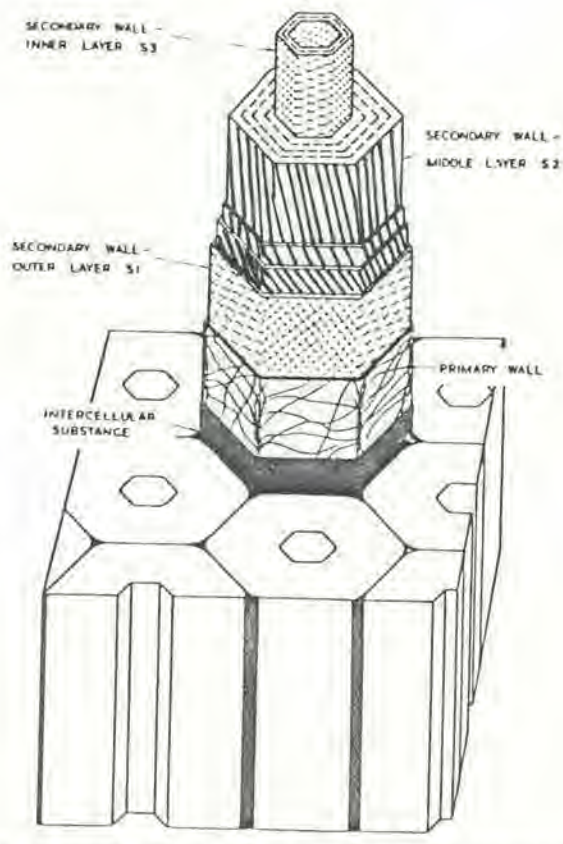



FIGURE 1. Diagrammatic representation of the structural organization of a typical wood fibre (From Davies (38))

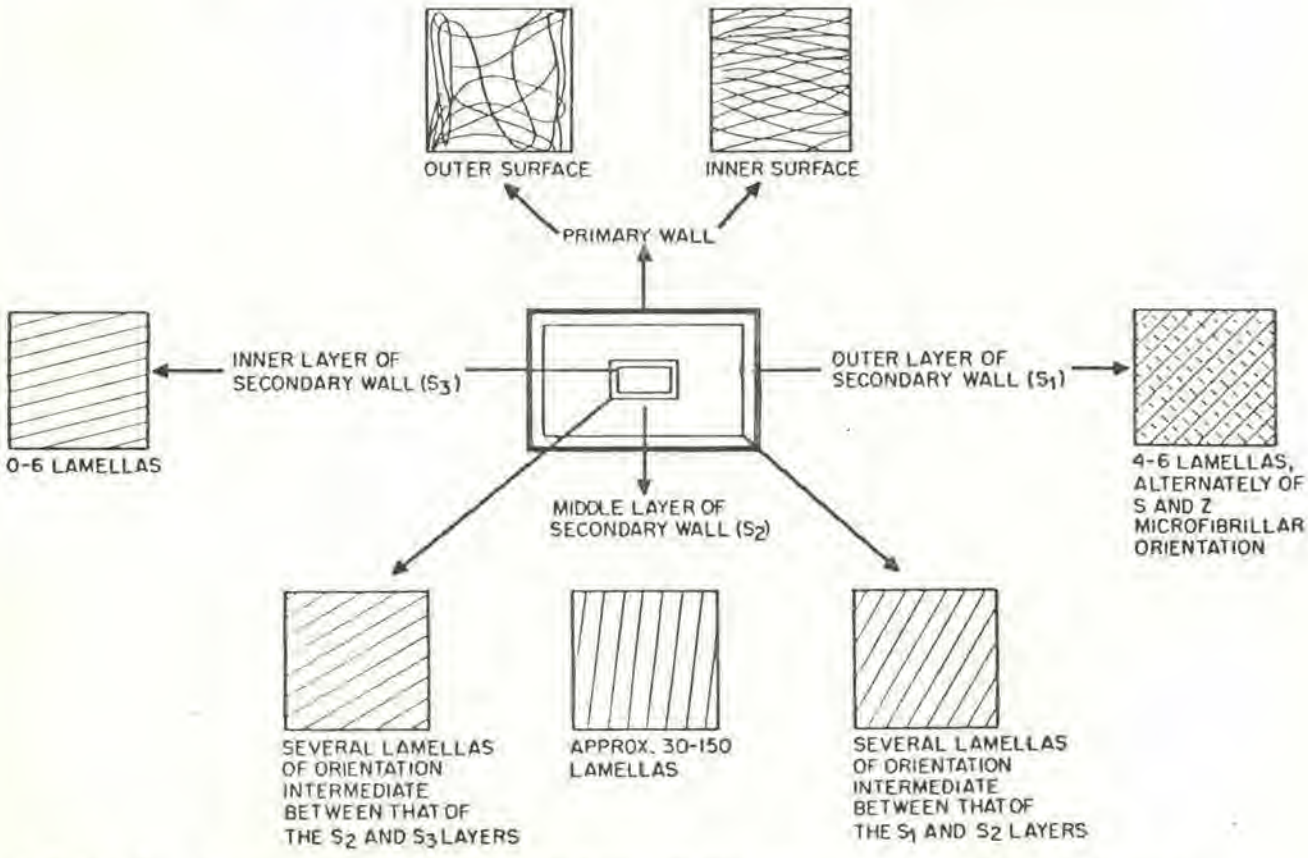



FIGURE 2. Diagrammatic representation of the arrangement of wall layers, lamellae and cellulosic microfibrils in a typical fibre (from Wardrop and Harada (17))

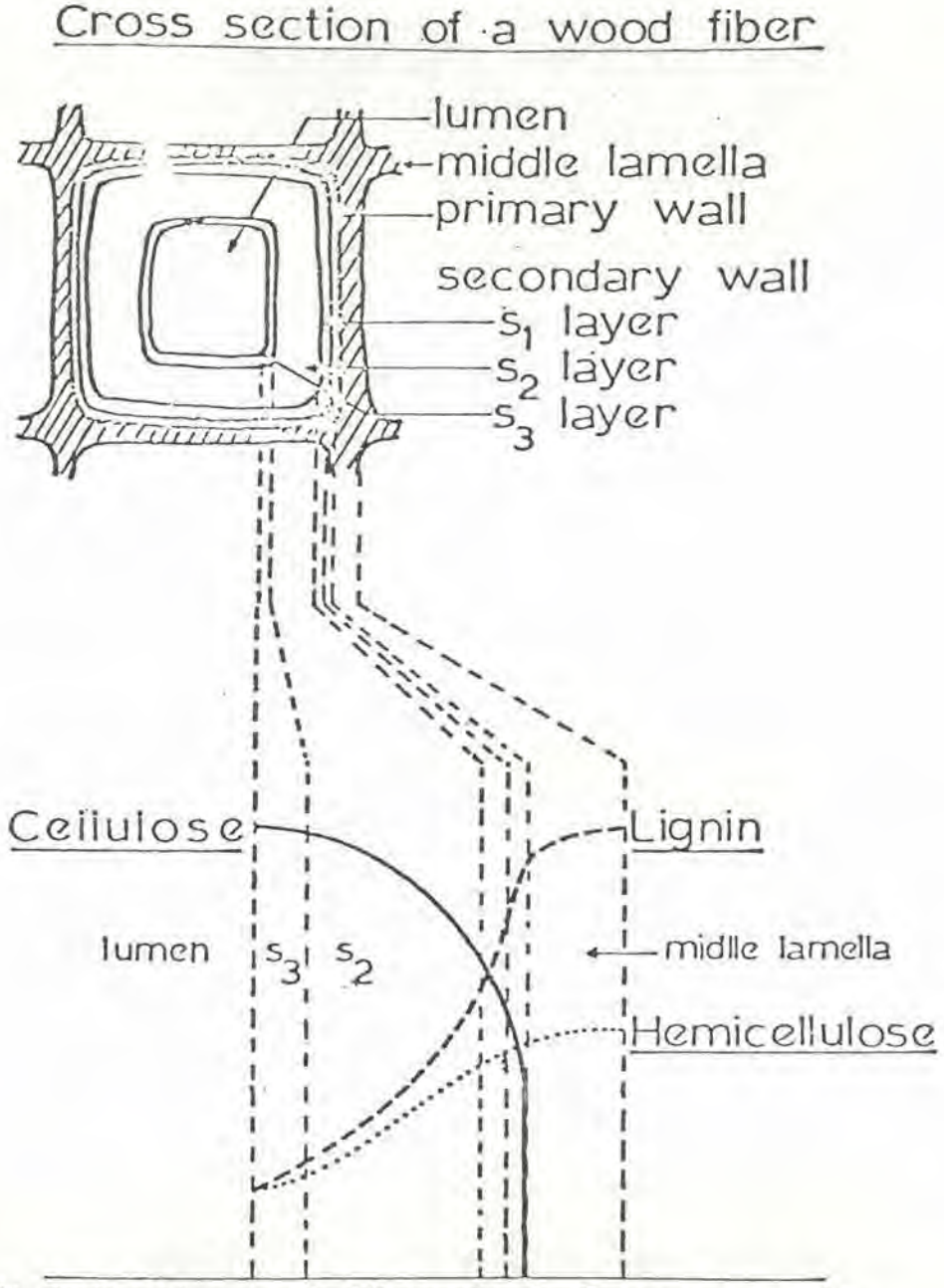



FIG. 3 Distribution of Chemical Components Across the Cell Wall (From Balodis (18))

Distribution of the framework, matrix and encrusting components in the cell wall is most important in relation to fibre separability. Literature reviewed by Wardrop (5) shows cellulose percentage increases from the peripheral primary wall inwards to the middle layer of the secondary wall and, in some cases at least, to a maximum in the S3 layer adjacent to the fibre's lumen; also that lignin and the matrix polysaccharides are most highly concentrated in the inter-fibre middle lamella and primary wall and decrease internally through the secondary wall, as shown in Fig. 3, taken from Balodis (18).

Quantitatively, work reviewed by Wardrop (5) reveals about 70% of the lignin in wood is located outside the S2 layer, compared with about 16% near the lumen. However, this higher proportion does not necessarily mean higher amounts than in the other S layers because of the volume effect.. Hardwoods generally have lower lignin concentrations than softwoods, and at least one study has shown this relatable, at least in part, to lower secondary wall concentrations (see 5).

The high-lignin-content compound middle lamella (including primary walls of two adjacent fibres in this case) has a lower component packing density and is more porous (by 10 to 20%) than the secondary wall (19, 20, 21). Together with the decreasing lignin and hemicellulose gradients internally across the fibre wall, these are considered to reflect an internally increasing gradient in packing density, at least to the S2/S3 boundary. This trend is particularly relevant to fibre separability and flexibility. Removal or flow of lignin and matrix components enables intra- and inter-lamella and wall layer skrinkage and swelling of the cellulose framework, with consequent differential contraction and expansion, fibrillation, flexure, kinking, delamination, and effects on strength.

In physical organization, the microfibrils are differently oriented in relation to the fibre's long axis in the four layers. In the relatively thin (about 0.1 μm) primary wall, they are randomly arranged, but more nearly transverse (at about an $85^{\circ}$ angle) with longitudinal ribs of microfibrils at the corners (22) (see Figures 1, 2).

The secondary wall's S1 layer has a crossed helical structure, at a relatively flat angle in alternating S and Z spirals. It is usually about 0.1 to 0.2 μm thick in normal wood and, although often vastly thicker in reaction wood, is invariably thinner than the S2 layer.

The middle S2 layer, also lamellated, has a single direction of microfibrillar helical orientation, usually much steeper than the S1 and S3. Generally considered to be at a $10^{\circ}$ to $30^{\circ}$ angle to the long axis, it can range from less than $5^{\circ}$ to more than $70^{\circ}$ (23). Although extremely variable in thickness, it almost invariably constitutes by far the greatest porportion of cell wall thickness, with exceptions in angiosperm tension wood fibres. By virtue of its volume and mass, the S2 layer is a major determinant of fibre and wood properties.

The inner S3 layer has a microfibrillar spiral angle flatter than the S2 and similar to that of the P/S1 lamellar interface. If, as some propose, there is some tendency to crossed lamellar structure, it is less so than in the S1. S3 layer thickness is generally less than S1 in normal wood, but vastly thicker in compression wood.

Most importantly, there is a well established major change in cell wall composition and physical organization in the cell wall between the S1 and S2 layers (22) (see Fogires 1, 2).

Because of their closed-end construction, inter-fibre passage of liquids is via a system of lateral pitting, connecting fibre to fibres, rays and, in the case of hardwoods, vessels and vertical parenchyma. Typical pit structures are illustrated by Wardrop (22). There is an essential difference here between softwoods and hardwoods. The former have a highly efficient interfibre connective system via numerous bordered pit pairs in adjacent fibre walls, with passage through the apertures controlled by a diaphragm-like 'torus' supported on a microfibrillar web ('margo'), with a secondary but significant contribution (usually less than one-third) via the half-bordered or simple ray-fibre pitting. On the other hand, the effectiveness of the usually much smaller, hardwood inter-element simple pit system in permeability and diffusion is generally low, despite a greater contribution by the ray cells of hardwoods than in softwoods (15). Transmission from the relatively large-diameter conductive vessels to the lumina of the surrounding fibres is relatively difficult to achieve.

Microfibrillar orientation deviates around the pits, making these sites potentially weak other than in softwood fibre to fibre bordered pit pairs, in which case Mark (13) considers the microfibrillar borders as strengthening in effect. Pits are usually more numerous on radial than tangential walls.

Modifications to the composition, texture and organization of the typical fibre's structure accompany the formation of reaction wood developed in leaning or bent stems. The compression wood of conifers generally has lower cellulose percentage and abnormally high lignin content, the fibres are shorter, more rounded, with intercellular spaces, radial helical striations in the cell wall, much thicker S1 and S2 layers, no S3 layer and a flatter S2 microfibrillar angle (24).

The tension wood of angiosperms typically has abnormally low lignin concentrations, higher cellulose content, a so-called inner 'gelatinous' (G) layer around the fibre lumen, of highly crystalline cellulose relatively steeply spiralled in a virtually unlignified stratum and with weak lateral inter-microfibrillar bonding (25). The S1 layer may be thinner; S3 or both S2 and S3 may be missing. Cell wall deformations (so-called 'compression failures' and 'slip-planes'), are common.

FIBRE SEPARABILITY

Fibre separability depends on the nature and extent of processing, as well as inherent fibre properties. The effects on fibre separability and fibre and product properties of primary mechanical processing (e.g. by grinding); chemical pre-softening prior to grinding; chemical processing with or without subsequent mechanical refining; and heat treatment with or without chemical assistance and/or subsequent mechanical refining have all been investigated, with establishment of often different structural, chemical and physical fibre properties as being of major significance.

Fibre separation without loss of mass would seem an idealistic objective, and the high yields from mechanical and thermo-mechanical processing infer apparent achievement. However, the degree of separation to individual fibres and the capacity for the separated fibrous component to be reformed and rebonded into usable products with acceptable mechanical and physical properties are modifiers which must qualify any judgements based on yield.

High yield pulps contain almost all of the lignin, which is usually a deterrent to satisfactory formation and bonding, in that it reduces flexibility and inhibits the development of fibre characteristics which facilitate chemical and physical reconnection. Also, in groundwood, the fibres are not separate entities but, rather, fibre bundles and fragments. Complete separation has not been achieved and the degree to which it has been induced is at the expense of damage to two other properties, fibre length and strength.

In thermo-mechanical pulp (TMP) processing, more whole fibres are obtained, but the lignin remains to inhibit the development of characteristics which assist fibre bonding. At high temperatures above about 150°C, which reduce the energy requirement for TMP defibration, the lignin is plasticised and encases the separated fibres in a smooth sheath which resists further refining, with adverse effects on product properties. This has imposed a lower operational temperature range of from 110° to 140°, boosting defibration energy needs, but treatments such as with ozone have been found to modify this lignin sheath so as to allow the fibre wall to respond more effectively to refining (26).

Chemical separation processes have been reviewed by Wardrop (5). In chip digestion, initial entry is through the open ends of cut and broken fibres and, in the case of hardwoods, the vessels, on chip ends and surfaces, thence into adjacent fibres and other elements via the pits.

Passage through the pits serves to introduce the pulping medium into the porous, low-packing-density, highly lignified middle lamella as an assumed preferential longitudinal diffusion pathway. Penetration is further facilitated by progressive delignification and the solution of matrix polysaccharides along the decreasing lignin/increasing packing density gradients through the P, S1 and into the S2 layers. This variation in packing density of the cell wall does not seem to affect penetrability with, at least, alkaline pulping media, as simultaneous diffusion takes place from the lumen outwards at an apparently similar rate.

The main body of evidence suggests that, with alkaline media, the delignification process starts on the secondary wall before the middle lamella, with the reverse the case for acid media. This apparent potential for more effective compromise between yield and defibration with acid than alkaline media is exemplified in sulphite/sulphate pulp yield comparisons and even more so with the higher-yielding neutral sulphite semichemical (NSSC) process, in which the pulping medium also defibrates by initial preferential delignification of the middle lamella (27).

Even with chemical pulping, the degree of delignification and separation depend on chip penetration, and incomplete separation ex digester is common, so that the response of fibres to subsequent refining must be considered in relation to fibre separability; even more so with primary mechanical processing, especially since the separation process has to be extended to the intra-fibre level for most effective reformation.

Fibrillation involves the partial or complete separation of bundles or sheets of fibrils as fibre laminae are chemically, physically or mechanically loosened and eventually separated from the fibre's secondary wall surface. It is generally conceded as playing an important role in the development of paper properties, regardless of some disagreement as to whether the mode of its operation is physical, chemical or both (e.g. 6, 12, 27, 28).

Changes in fibre dimension longitudinally or laterally, by expansion or contraction, can and do cause fibre wall layer rupture and delamination, if not separation and fibrillation even in unbeaten fibres particularly at the S1/S2 boundary (27), due to differential effects on the anisotropic fibre structure of swelling in pulping liquors and contraction in drying.

Fibre separation thus takes place at the middle lamella in chemical and semi-chemical pulps with the cell wall layers relatively intact before mechanical treatment (5), apart from laminar loosening, wall delignification and related softening and variable swelling while still wet.

In mechanical pulps, fibre separation is accomplished largely by mechanical fracture at or about the S1/S2 boundary, but with an appreciable temperature contribution to middle-lamella separation in TMP pulping.

In subsequent mechanical refining (beating), the outer P and S1 layers, already often loosened, are shed in layers, partial strips or smaller particles very readily early in the beating cycle, facilitated by fibre wall swelling pressure in some cases, as well as the mechanical action. This exposes larger areas of cellulosic material as potential bonding sites during sheet formation (27) and opens up the S2 surface for further fibrillation. The progressive development of this process from barely beaten fibres through to pulps beaten to and beyond the normal commercial range of freeness has been quantitatively established for softwood kraft pulps using a so-called 'cell wall layer separation index' developed by the writer and used in studies reported by Barefoot *et al.* (6).

The marked differences in microfibrillar orientation between the various wall layers and the higher lignin concentrations in the outer wall layers (P and S1) are responsible for preferential delamination at the S1/S2 boundary. Swelling in pulping liquors could be expected to be greater in the more closely packed hydrophilic cellulose framework of the thick S2 layer than in the more loosely packed, thin S1, putting longitudinal and lateral tensile stress on the S1. The longitudinal component would be greater for increasing (flatter) microfibrillar angle and the lateral component greater for decreasing (steeper) spiral angle. The two components would contra-act most with increasing difference in angle between the S1 and S2 layers. The generally large S1/S2 differential predisposes failure at this boundary.

It has been suggested that, in fibre expansion or contraction, the crossed-lattice alternate lamellar S and Z microfibrillar orientation in the S1 layer would cause a tendency to longitudinal contraction of the S1 layer as a fibre swelled laterally, and expansion as it lengthened or shrank laterally (29), thus intensifying the shear stress already generated at an S1/S2 interface by differential direction and rate of movement in the two layers.

Support for these concepts is found in the manner of some separations of the S1 layer in even very lightly beaten chemical pulps; a 'rucked sleeve' effect is frequently observed (e.g. 12, 18), presumably due to contraction of the loosened S1 layer along the fibre on release from tension by mechanical rupture. Also in the observation of a slight increase in average whole fibre length after very light beating of kraft pulps, presumably due to release from tensile constraint on rupture of the S1 layer (6).

Analyses of cell wall mechanics (e.g. 5) show that, if the S1, S2 and S3 are considered as a series of springs with typically different filament winding angles, the different rates of lateral expansion and contraction of each if the fibre system was placed in longitudinal tension or compression or in torsion would be such as to cause separation at the S1/S2 boundary and only later failure in the S2. Although the S3 angle approaches that of the S1, its sense is the same as the S2 and so less contraposed in reaction than the S1 (13).

Wardrop (5) suggests that similar considerations apply to purely mechanical pulps as well as treated fibres. Forgacs (30) has related coherence and strength development in groundwood paper largely to ribbon-like fibrillar particles separated by unravelling of the S2 layer. McMillan (31) indicates these result from torque generated failures in diagonal tension for shorter, flat-spiralled fibre structures and in shear parallel to fibrillar angle and more nearly to the fibre axis for longer, steeper-spiralled structures.

FIBRE LENGTH

Softwood fibres usually range from about 2 mm to 5 mm and more in length and 20 to 40 μm or more in diameter. Hardwood ranges are from less than 1 mm to a little over 2 mm in length and around 10 to 25 μm in diameter.

Longer fibres have traditionally been associated with superior paper properties, often erroneously (11). More recent analyses of its effect have shown that the frequent interrelationship of length with other fibre properties has led to misinterpretation of its influence on some paper properties.

It is now a widely-held view that fibre length is positively correlated with tear, but not really significant or of less importance for burst, breaking length and tensile strength (1, 2, 4, 11), but this is till not universally supported. Horn reports fibre length *per se* to have no significant effect on the tear strength of paper from softwood kraft pulp (8), but to have a primary influence on tear in hardwood kraft pulp handsheets (9). Barefoot *et al.* (6) noted a positive influence of fibre length but one which, in multiple regression analysis, rarely added to the overshadowing effect of wall thickness.

It has been suggested that fibre length contributes to burst (5, 8), breaking length (5) and tensile strength (8) only insofar as a minimum length is required for bonding, inferentially supported by the influence of the length/diameter ratio effect reported by Wangaard *et al.* (4) for softwoods and the length/wall thickness ratio effect observed in unbeaten hardwood pulps by Horn, who also found fibre length correlated with stretch in unbeaten, but not in beaten, hardwood pulps (9).

Some of this apparent confusion is due (i) to the effects of different levels of fibre processing in modifying the properties of the same type of fibre, and (ii) the different effects of similar processing on different types of fibre.

For example, in one study (6), successively higher levels of refining a softwood kraft pulp progressively reduced the average length of the fibrous component as the percentage of broken fibres increased; the degree of cell wall layer separation increased; 'fibre' width initially increased, then decreased; and average 'fibre' length/width ratio and average 'fibre' area decreased (Figure 4). Concurrently, burst (and tensile) strength and apparent density increased; freeness decreased; and tear initially increased and then decreased (Figure 5, from 6).

Since 'fibre' length decreased even while tear initially increased, they seem unlikely associates. A strong positive relationship between tear and length came into operation only after maximum tear had been generated in refining and both tear and length declined together. This relationship was most likely more apparent than real. The concurrent development of inter-fibre connection (inherent in increased burst) while maximum tear was still increasing and 'fibre' length decreasing suggests a more likely effect of intra-fibre separability (increasing) making more bonding sites available and simultaneously inducing flexibility ('fibre' width increase). The fact that, in this same study, longer fibred trees had higher-level but identical tear trend patterns with beating could possibly be regarded as supporting the suggested influence of length on bond-strength, except that these lengths should not have been limiting.

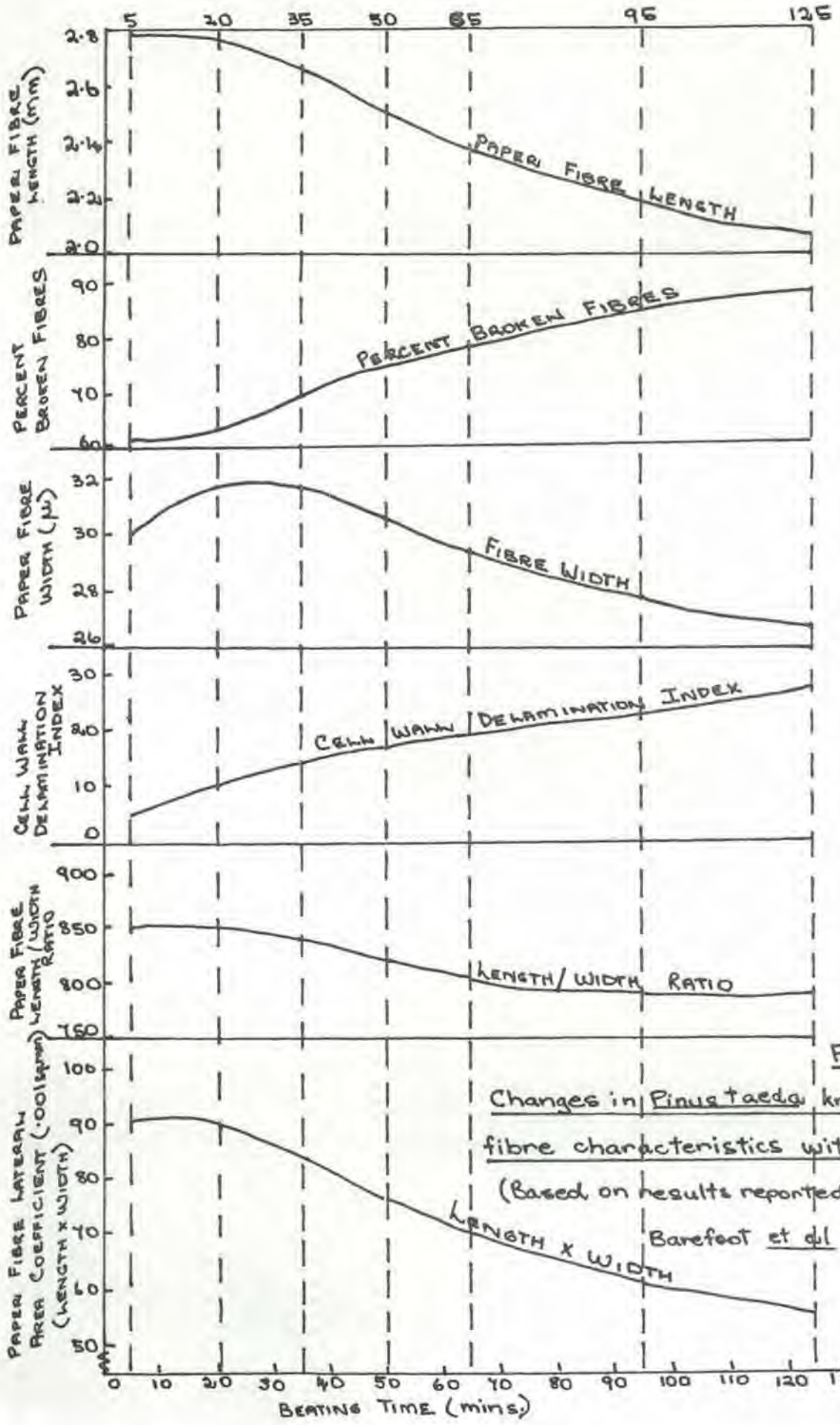



FIG. 4 - Changes in Pinus taeda kraft paper fibre characteristics with beating. (Based on results reported in Barefoot et al (6).)

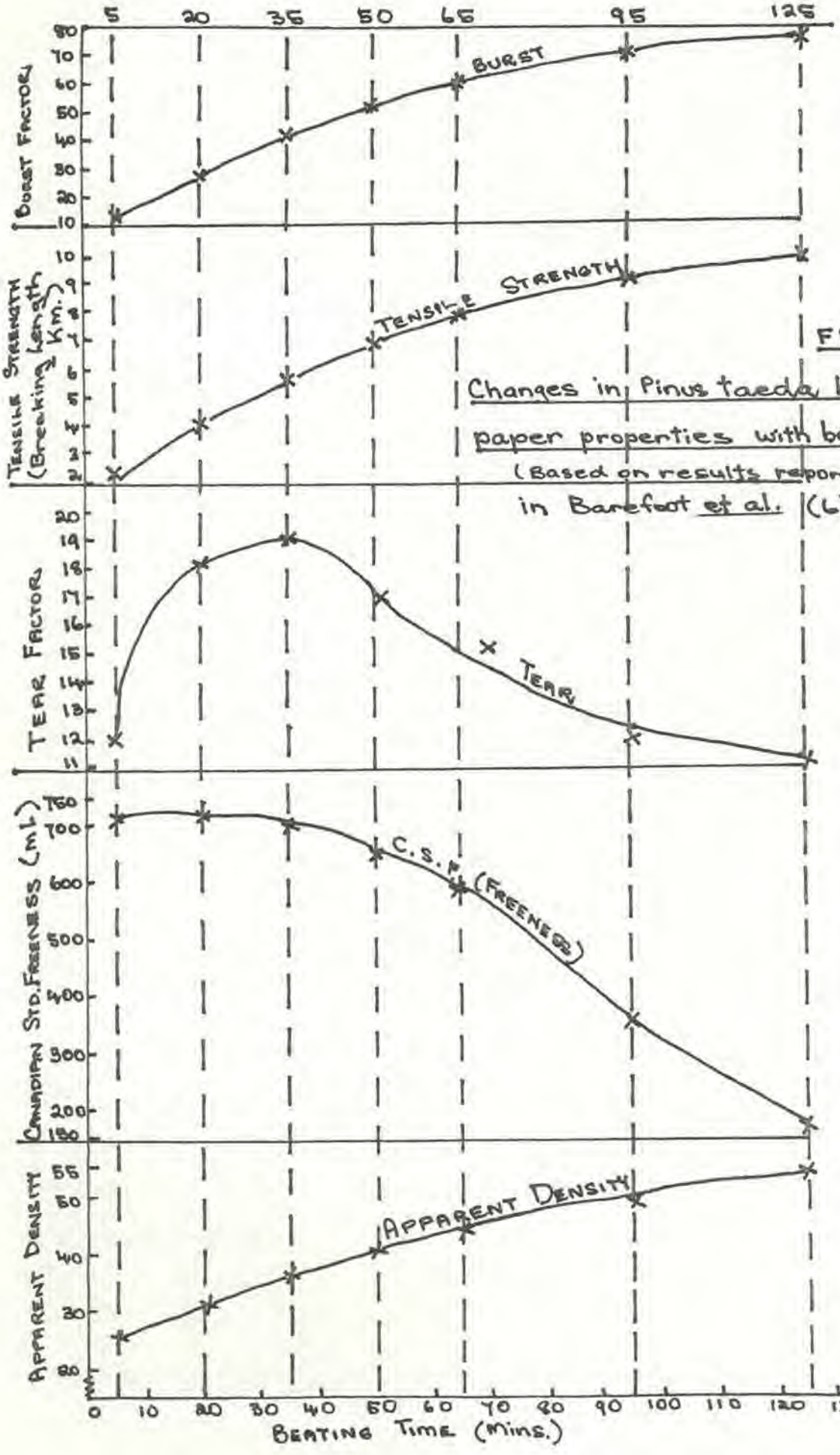



FIG. 5 - Changes in Pinus taeda kraft paper properties with beating. (Based on results reported in Barefoot et al. (6))

The primary influence of hardwood fibre length on tear in Horn's work (9) is more supportive of a likely effect on development of maximum tear through greater capacity for inter-fibre connection in longer fibres in this range of shorter fibres.

Processing reduces original wood fibre length quite rapidly. Long softwood fibres have been reduced by fracture in the separation process to around 60 per cent to 70 per cent of their original length after chipping and only five minutes refining in a laboratory Valley beater (6). After beating to the lower limit of the normal commercial freeness range for a softwood kraft pulp, the average length of the fibrous component was further reduced to about 40 per cent of the original length.

Longer fibres would be expected to be and are more readily damaged in processing. Thinner-walled fibres might be expected to resist fracture better than thicker-walled ones because of greater flexibility but, in at least one study (6), the reverse was the case, with the lower strength of thin walls being associated with a higher percentage of broken fibres. Despite a greater tendency to break, wood with initially longer fibres produced paper with longer average 'fibres' even into well-beaten stages of processing, although their initial advantage was progressively reduced.

In this study, there were indications that there was no advantage in having wood with fibres longer than about 4.25 mm in a well-beaten softwood kraft pulp. This is in general agreement with Dadswell and Watson's assessment of 4 to 5 mm (1) as an upper limit of useful length.

FIBRE FLEXIBILITY

Fibre flexibility, strength, density and coarseness are all strongly influenced by fibre cross-sectional dimensions and, hence in general, by wood basic density. Flexibility and strength have cell wall organization as additional determinants.

Lateral and longitudinal fibre flexibility are both significant components of this property, with the former more wood density related.

The resistance of paper to tensile fracture is related to the frictional resistance of fibres to being pulled out when stressed. This is relatable to sheet density and, hence, fibre compressibility and an increase in the area available for bonding (12) through improved conformability.

The ratio of wall thickness to diameter (WT/FD, WT/ld or 2WT/ld, e.g.) is a primary factor determining whether fibres remain more or less rounded or collapse to become more ribbon-like in drying and pressing (5). Possible extremes, with obvious effects on paper properties, are illustrated in Figure 6, from Higgins and Balodis (32).

The effect of fibre cross-sectional dimensions (and density) on the lateral flexibility (capacity for change in shape) of fibres, on paper density, bonded area, and bond-related paper strength properties is illustrated in Figure 7, from Higgins *et al.* (33).

Burst, breaking length, tensile strength and tear have all been correlated with flexibility indices, with thinner walled, lower Runkel ratio fibres from usually lower-density wood generally stated to give higher burst, breaking-length and tensile strength but lower tear than thicker-walled, higher Runkel ratio fibres from higher density wood (1, 2, 4, 6, 8, 11, 12). An exceptional result was Horn's (9) finding that fibre length and fibril angle were the determinants of tear in hardwoods, but not softwoods.

These generalised observations have to be qualified by consideration of the effect of refining on flexibility. As discussed earlier, fibre structure affects intra-fibre as well as inter-fibre separability. This has a very marked effect on flexibility.

The degree to which stiffening lignin is removed from the fibre surface and inter-fibrillar spaces has a very marked effect, giving differences in collapsibility between pulps by different processes, with high-yield groundwood and TMP pulp fibres being less conformable than low-yield chemical pulp fibres from the same basic wood stock.

Flexibility is also obviously increased by the wall layer separation, delamination and fibrillation induced to an increasing degree with higher levels of refining (6, 10, 11, 12, 27, 28). Thus, thicker-walled, higher Runkel ratio fibres can have bonding properties, reflected in burst and tensile strength, developed by refining to a level comparable with but apparently not better than those for thinner walled fibres. This has been established in mature vs juvenile wood softwood kraft pulp comparisons (6). The thicker-walled fibres can, however, retain higher tear resistance while the bond strength is being improved.

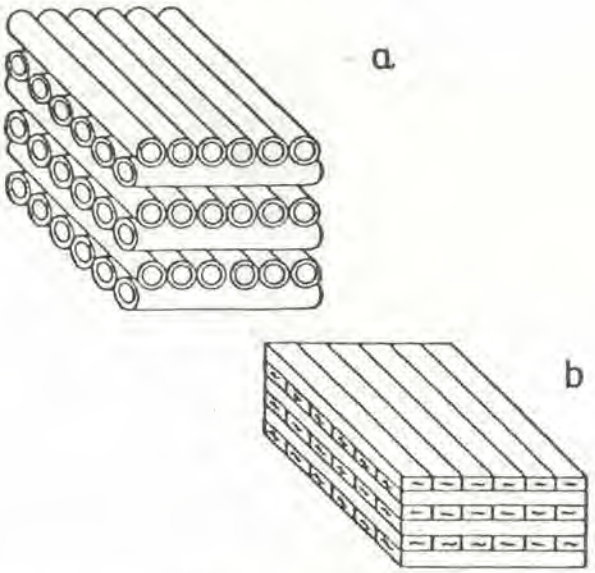



FIGURE 6. Illustration of the effect of fibre collapse on conformability, bonded area, and sheet density (after Higgins and Balodis (32))

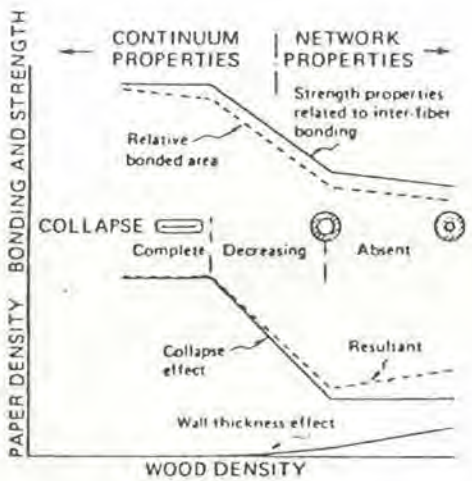



FIGURE 7. Effect of fibre cross-sectional dimensions (and density) on lateral flexibility, conformability, paper density and bond strength development (From Higgins *et al.* (33))

It is not uncommon for softwoods and hardwoods to be broadly classified as thin- and thick-walled, respectively, as well as long and short fibred. While the latter is mostly true, the former is often not. The double-wall-thickness of even the densest Eucalypts is about 12 μm (7). This is quite common even in *Pinus taeda* L. corewood, and up to 19 μm in outerwood (6). It can vary over a range of at least 6.4 to 15.3 μm in USA hardwoods (9, 33).

It is more generally but not invariably correct that the thickness/lumen ratio is lower in softwoods than hardwoods, with notable exceptional contrasts between low-density hardwoods and high-latewood content, high-density material from, e.g. *P. elliottii* Engelm. and *P. taeda*.

Longitudinal flexibility contributes to strength in the fibrous web by facilitating inter-weaving of fibres and maximising the contribution of an individual fibre to inter-fibre connection and consequent stress distribution. It interacts with lateral flexibility for optimum effect, and, thus, the value of the so-called felting coefficient (length/diameter) as an expression of this property is sensibly improved on by Horn's (8) fibre flexibility index (length/wall thickness), doubtless due to the relatively greater effect of wall thickness than diameter on conformability and bond strength development. Horn's study (8) made a very useful contribution to the analysis of factors influencing tensile and burst strength, in showing that, while wall thickness exerted the primary influence, a minimum fibre length was required for bonding and stress distribution, and that there was a significant combined effect of both.

Longitudinal flexibility parameters have been shown (6) to be modified by refining, with average 'fibre length' decreasing and 'fibre width' increasing then decreasing (see Figure 4).

Inter-lamellar flexing and fibrillation can be reasonably envisaged as facilitating the flexure of walls. It has also been observed that wall thickness, as well as width, also decreases appreciably due to repacking of the cellulose on drying after pulping (34). Presumably, these must be compensatory movements, with progressively smaller fibrous components inter-bonding, or else some other factors come into operation to account for the continuing development of bond-related paper properties with beating.

FIBRE STRENGTH

It now seems well demonstrated that, once sufficient inter-fibre bonding has been achieved to cause the strength of the fibre itself to interact, the latter becomes most important as a determinant of burst, tensile strength, stretch and tear, expressed in one or more of its factors (2, 4, 6, 8, 9).

This seems to apply to both softwoods and hardwoods (8, 9). Factors involved include cell wall thickness, thickness/diameter ratios, microfibrillar angle and degree of crystallinity of the cellulose.

Since flexibility and strength are inter-related, the higher potential of thinner-walled, and hence weaker, fibres for the development of bond-related burst, tensile strength and early tear has already been indicated.

In addition, Dinwoodie indicates a positive influence of degree of polymerization of the cellulose on breaking length and burst, adversely affected by progressive levels of refining; also that higher residual lignin also adversely affects fibre strength (2). Although in hardwoods, fibre length and longitudinal flexibility appeared to predominantly influence all paper properties in one study (9), the strength affecting structural feature, microfibrillar angle had a strong influence on stretch, tear and tensile strength.

This structural feature was one of the most important fibre characteristics influencing paper properties from both unbeaten and beaten *Tsuga heterophylla* (Ref.)Sarg. kraft pulps (35) and had the greatest influence on stretch in a study involving twelve softwoods (8).

Fibril angle was negatively correlated with tensile strength and positively correlated with stretch in both softwoods and hardwoods, and was positively related to tear in the hardwoods. That is, steeper helix fibres were associated with higher tensile strength and flatter helices with higher stretch and tear.

In these studies, the effect of fibrillar angle generally remained prominent, but decreased somewhat in importance on beating, and an index including an expression of the effect of cross-sectional dimensions, including wall thickness, often came into operation.

Fibres with steeply spiralled wall structure resist fracture under tensile stress much better than flatter helices; so do thick-walled fibres (13). However, Mark's mechanical analyses (13) also showed flatter-spiralled helices will stretch and extend more before failure in longitudinal tension than more steeply oriented structures.

The foregoing evidence is interpreted as indicating that, when sufficient inter-fibre connections are achieved to place a stress in tension on the fibres, fibre extensibility (greatest in flatter angled fibre wall structures) comes into operation; giving the positive effect observed on stretch and tear until stronger bond development in processing brings the wall section component of fibre strength into operation under tear stress, with thicker walled fibres resisting ultimate failure better than thinner ones.

The association of higher tensile strength with steeper-spiralled wall structures is not as readily explicable, even though such fibres would be individually stronger in tension, unless it be an association through mutual correlation with longer fibres which, in general, would be the case. An extensibility component would be expected in tensile strength development, but may be overshadowed in analysis by fibre properties facilitating lateral and longitudinal flexibility and bonding.

FIBRE DENSITY

Fibre density, or mass per unit volume, was considered by Dinwoodie (2) to be the most important property influencing pulp and paper properties, with considerable justification since, as considered by him, it encompassed the flexibility and strength parameters already discussed in this paper. It also involves structural aspects including modifications as in reaction wood, the relative proportions of component elements and packing density of the wall layers.

As indicated earlier, the relationship between fibre and wood density is closer in softwoods than hardwoods, because of the latter's more heterogeneous wood structure, detailed comparatively in many texts (e.g. 12). Examples of some relative differences between wood basic density and fibre density for a wide range of Eucalypts are given in Higgins *et al.* (7), in which the latter is more closely represented by their vessel-free wood density data. In this case, as in most others, there was a close relationship between wood and fibre density, but invariable conformity to this should not be assumed. Association of density with a fibre shape factor and the Runkel ratio was also shown, and these related in turn to paper surface characteristics as well as conformity.

High-density, thick-walled, high Runkel ratio fibres do not collapse readily, and give bulky, open sheets with rather rough surfaces (1), unless well-refined.

Higher-density fibres have a disadvantageous effect on surface roughness but this is improved by refining, with the added advantage that, in simultaneous strength improvement, paper opacity and brightness is not reduced, at least in hardwoods (7).

Fibre density is obviously yield-related, with a strong process interaction depending on the proportions of lignin, cellulose and hemi-celluloses. However, reaction wood fibres are usually of higher density because of increased wall thickness rather than changes in constituent relativity.

FIBRE COARSENESS

Coarseness, expressed as mass per unit length, is considered by Clark (12) to have been greatly underestimated in importance. He considered an apparent concentration on the advantages of higher density and longer fibres had overlooked that longer softwood fibres tend to be denser and, hence, coarser, stronger, less flexible, and less well adapted for the development of bond-related burst, stretch, tensile strength and early tear without being well refined, even if advantageous for higher maximum tear and higher yields.

Coarser fibres affect paper surface roughness, but can be an advantage in, e.g., wax-impregnated containers.

This property seems to be merely an attempt to express the integrated effects of length, strength, flexibility and density, and, since these interact in paper property determination in different ways to varying degrees under different processing conditions, its use as an indicator of pulp quality for various products should be tempered by consideration of its component factors and the process. For example, a study by McMillin (31) showed that burst, breaking length and tear could be improved in well-refined *P. taeda* refiner groundwood by using fibres which would have to be defined as coarse, but with a structure-related facility for separation into ribbon-like fragments.

REACTION-WOOD FIBRES

Reaction-wood contains high-density fibres, coarse because of their high mass to length ratio. They are high in cellulose yield potential, being both thicker-walled and with a higher cellulose/lignin ratio in tension-wood; and thicker-walled in the softwoods to overcompensate in amount for their lower cellulose percentage.

Compression-wood fibres are shorter. In processing, they are less readily separable because of higher lignin content and a lesser differential in S1/S2 wall layer fibrillar orientation. The radial striations probably facilitate fracture rather than spiral ribboning in refiner groundwood production, because of the flatter fibrillar angle.

The round, thick-walled fibres are less flexible and conformable than those of normal wood and, therefore, less suited to bond development. This negates any apparent advantage of the flat spiral in stretch and tear and of the thicker wall in tear, because their operation depends first on adequate bond strength development.

Tension-wood fibres should be more readily separable than normal hardwood fibres, because of lower lignin content, a thinner S1, and a maintained fibrillar angle differential between this and the adjacent inner layer (whether S2 or the steeper G layer), but still suffer the serious disadvantages of low flexibility which inhibits bond development.

Reaction wood is believed to occur to some extent in all trees, although the more bent stem lengths and those with excentric pith would generally have a higher incidence. It would seem the only advantages in segregating these for separate processing, if such was in fact economically feasible, would accrue from (i) adjustments to primary defibration and refining treatments to minimise under or over treatment, (ii) the capacity for generation of higher flexibility and better conformability in relative isolation compared with the usual random mixture of normal and reaction wood; and (iii) the ability to better control the effects of stock with higher reaction wood content on pulp and paper properties by controlled blending.

ROOT AND BARK FIBRES

The trimmed taproot of 22 yrs old *Pinus elliottii* trees has been estimated to have a green wood weight approaching 20% of that of the merchantable stem (41), with fibres which are considerably longer and larger in diameter (by one-third) and thinner-walled than stemwood fibres (42). Although slightly lower in yield potential due to higher lignin and lower cellulose content, softwood rootwood fibres have the morphological attributes for high burst, tensile strength and stretch if they could be economically extracted and processed.

Bark constitutes up to 20% of the merchantable stem volume and its removal for pulping is a significant component of processing costs. Comparatively recent interest in whole-tree pulping, including that of coppiced hardwoods, has led to some investigation of the effect of the bark's components on pulp yields and properties. Phloem fibres, sclereids, sieve cells and sieve-tube elements have been considered of interest to processors (43).

Bark is lower in density than wood, and lower-yielding when pulped, with solids yields of 26 per cent and 33.4 per cent, respectively, reported for USA softwoods and hardwoods (43).

Softwoods have been assessed in one study as having almost no usable fibrous component (43), and that of hardwoods variously as sometimes useful (45), at least not seriously detrimental in controlled proportion admixtures with wood (44), or with a generally depreciative effect (33).

Sieve-tubes and other thin-walled cells could have a contribution to make to bonding and, in young coppiced *Eucalyptus viminalis*, the bark fibrous components were longer than the wood fibres (45).

The bark and wood fibres of kenaf (*Hibiscus cannabinus*) have been intensively studied (e.g. 46). They resemble those of a softwood and hardwood, respectively, with corresponding pulp properties. The bark is being used to commercial advantage in this case.

There is an evident need for more definite information on tree bark fibre characteristics and their effect on paper properties.

NON-FIBROUS ELEMENTS

Non-fibrous elements such as parenchyma and vessels have an effect on paper properties which interact with the fibres in some cases.

The thin-walled parenchyma cells are considered to have little effect on strength properties, but act as a filler to affect drainage in sheet formation (40) and possibly surface properties.

The vessel elements of hardwoods can have an adverse effect on printability, through a tendency for elements of these relatively very large-diameter cells to be 'picked out' from the paper surface in printing. The tendency increases with vessel size and vessel/fibre ratio. It is also affected by the inter-conformability of associated fibres and vessel-picking is, thus, reduced by refining (47)

FIBRE PROPERTIES IN RELATION TO THE RESOURCE

Juvenile wood constitutes an appreciable proportion of that part of the available resource allocated for processing as pulpwood. Its effect on pulp and paper properties has been widely discussed in the literature and the analyses are quite encouraging (e.g. 6, 10, 33, 39, 40).

This central core of wood formed in the earlier stages of a tree's diametrical growth at all heights (and it is important to recognise its existence at all levels in even the oldest tree) has anatomical and physical characteristics which differ from that of the outer wood.

In age-related variation from pith to bark, fibre length and basic density (and, hence, fibre density and cell wall component) increase and microfibrillar angle decreases in softwoods and, usually, in hardwoods. Percentage latewood also increases in species with marked seasonal growth periodicity. There are exceptions, as, e.g., in the absence of a marked density trend in *Araucaria cunninghamii* Ait. ex D. Don and in some hardwoods.

Some of these trends are illustrated in Figure 8 from Hillis (36).

This corewood also contains more lignin and less cellulose than outerwood in softwoods, with the reverse the case in hardwoods (36, 37), so that chemical pulp yields tend to be lower in young softwoods and higher in young hardwoods than in mature stems.

Juvenile corewood fibres thus, in general, tend to be of lower density, less coarse, weaker, more laterally flexible, shorter, and flatter spiralled in wall structure, with good bonding and extensibility but relatively low ultimate tear strength potential. For chemical pulping, they could be expected, on these properties, to compare favourably with outer-wood in terms of burst, tensile strength and stretch but not tear. This was established for a softwood in at least one study (6) and, for burst at least, for a range of USA hardwoods (33). In the former case, it was found outerwood bond strength comparable with that of lower-density corewood fibres could only be developed with considerable refining. However, the economic factor, yield, is a most important one, as also is the need for higher tear in many products.

Also, as indicated in the previous section, other processes have other effects, and well refined outerwood-type fibres have been shown to be advantageous in improving important refiner groundwood paper properties (31).

The available evidence indicates that younger regrowth softwood and hardwood resource components need not cause concern to pulp processors, provided the potential of their fibre properties is optimised in processing for specific products and their limitations recognised. The juvenile corewood is usually considered as being contained within the first ten-year increment from pith, so that there will be a large volume of complementary outerwood in the pulpwood fraction of the resource. Supplementation is also available from outer slab-wood milling residues. Hardwood regrowth material should be largely self-sufficient in properties for its normal applications.

Any deficiencies seen in the yield potential of softwoods from shorter pulpwood rotations could, if deemed serious enough, be compensated for by using higher-yielding processing techniques, with any blending necessary for specific paper property improvement.

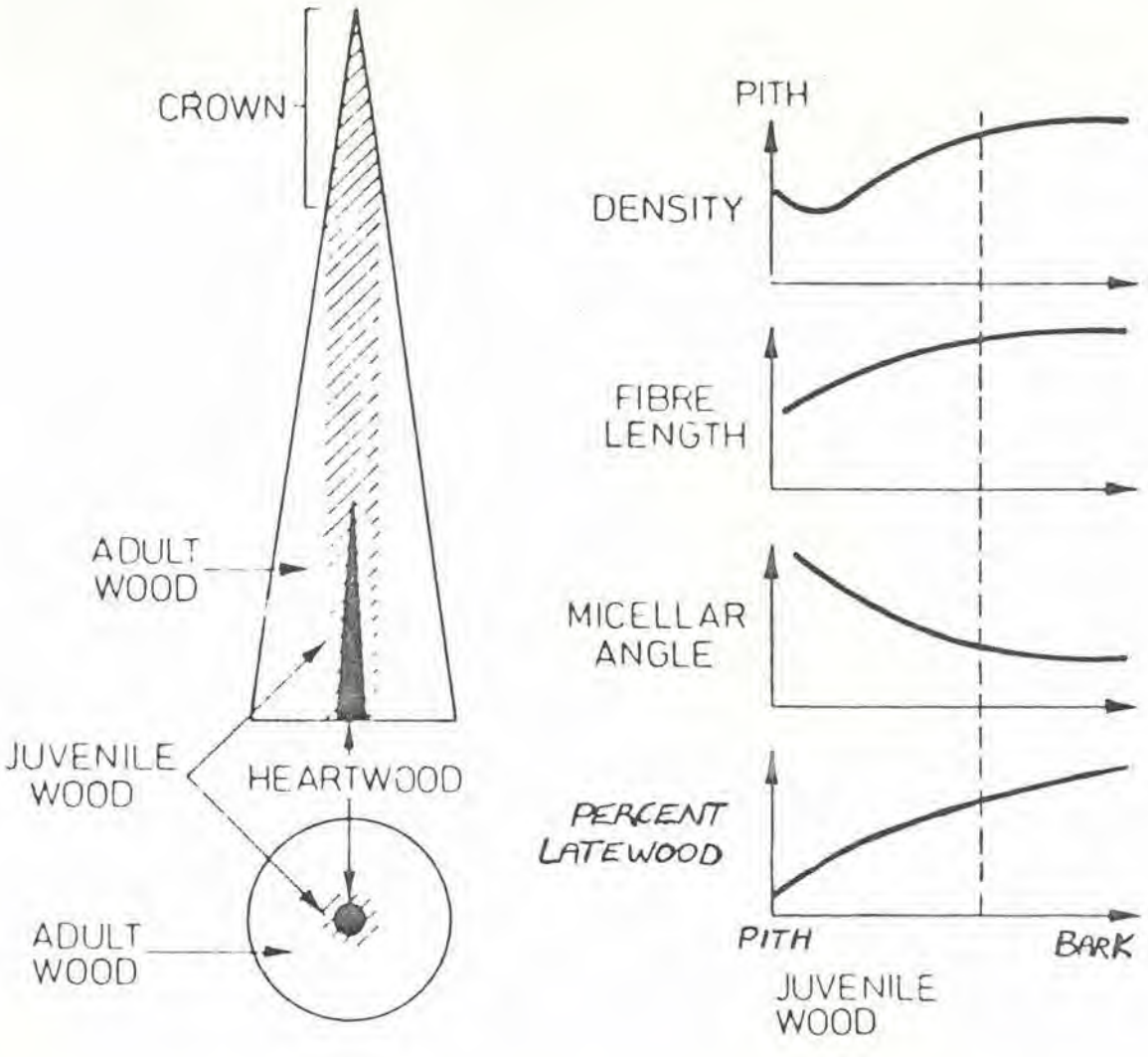



FIGURE 8. Juvenile corewood in a tree and its effect on age-associated variation in some fibre and wood properties from pith to bark (Adapted from Hillis (36)).

## CONCLUSIONS

In assessing the fibre properties of major importance as determinants of pulp and paper properties, it is concluded that no one fibre property operates exclusively. Also that the influence of inherent fibre properties and their related physical and chemical factors are very strongly interactant with the type of initial defibration process employed and level of subsequent refining.

Of the seven fibre properties considered, fibre density, separability and structure have most influence on pulp yield. Density provides an initial base potential on which defibration processes variably interact with the chemical component elements of fibre structure to determine yield levels, with the latter determined mostly by the extent to which processes separate fibres without removing matrix components.

Fibre flexibility is the principal determinant of bond-strength related paper properties such as burst and tensile strength, and of early tear development, which is also associated with bond strength development. Cell wall thickness and wall thickness/diameter ratio components are negatively correlated with these paper properties. Fibre structure strongly influences inherent flexibility and bonding in facilitating delamination and fibrillation in both initial defibration and later refining. Inherently less flexible fibres can be made flexible and their bonding capacity improved by beating, but not to an extent greater than thicker-walled, originally more flexible fibres.

Fibre length appears to positively influence burst, tensile strength, stretch and tear in softwoods only in its early-stage contribution to the development of interfibre bonding to a level allowing other fibre properties to operate. In hardwoods, it seems the shorter fibres available may become more limiting in their capacity to develop interfibre bonding and, hence, fibre length tends to assume more importance than in the softwoods.

Fibre strength is, to a considerable extent, the converse of flexibility, and affects paper properties accordingly. However, it is the prime determinant of maximum tear, through the positive effect of cell wall thickness in providing higher tear after initial development of adequate interfibre connection. There is an apparent but inadequately explained effect of structural organization on tensile strength, with steeper-spiralled, higher tensile strength fibres relatable to this paper property.

Extensibility is also affected by the fibre structural feature microfibrillar angle, with flatter angles increasing stretch and contributing to burst and tear development.

Steeper-wound fibres contribute to improvement of most refiner groundwood properties in their mode of reaction to processing. This response to processing of latewood-type fibres is markedly different from that in chemical processing.

An overall assessment shows wall thickness and fibre structure (particularly fibrillar angle) to be emerging as major determinants of paper properties. They are supplanting fibre length, once considered to be a most influential factor, in softwood pulping potential assessment. However, fibre length continues to be one of the important indicators of hardwood paper properties.

Fibre density and fibre coarseness are relatable to paper properties through component factors of some of the other properties. Fibre density is an effective integrator of lateral flexibility and sectional strength and has the very practical added value of being generally well correlated with the more easily determined property, wood density. Fibre coarseness is considered to be a less effective integrator of the same factors, in that it allows equation of cross-sections with markedly different lateral flexibility (e.g. larger-diameter, thinner walled fibres and smaller-diameter, thicker walled fibres could be assessed as of the same coarseness on a mass/fibre length basis).

The appreciable proportion of juvenile corewood in the available pulpwood resource, while of lower yield potential in softwoods (but not hardwoods), offers advantages in having fibre properties associated with the attainment of good burst, tensile strength, stretch and adequate tear, with minimal refining. The thicker-walled, less flexible fibres from milling residues and other outerwood sources have a higher tear potential. They require but respond well to beating for bond development to and beyond maximum tear, and can be used to maximum advantage by determination of optimum refining levels for bond, tear and surface property requirements for specific products.

Rootwood is a potential source of fibres with good bond-strength related properties.

More detailed information is needed on both softwood and hardwood bark fibre properties and their effects on pulp and paper properties.

REFERENCES

1. Dadswell, H.E. and Watson, A.J. (1962). Influence of the morphology of wood pulp fibres on paper properties. APPITA 15(6): 116-128.

2. Dinwoodie, J.M. (1965). The relationship between fibre morphology and paper properties: a review of the literature. Tappi 48(8): 440-447.

3. Dinwoodie, J.M. (1966). The influence of anatomical and chemical characteristics of softwood fibres on the properties of sulfate pulp. Tappi 49(2): 57-67.

4. Wangaard, F.F.; Kellogg, R.M.; and Brinkley, A.W. Jr. (1966). Variation in wood and fibre characteristics and pulp-sheet properties of Slash Pine. Tappi 49(6): 263-277.

5. Wardrop, A.B. (1969). Fiber morphology and papermaking. Tappi 52(3): 396-408.

6. Barefoot, A.C.; Smith, W.J.; Parham, R.A.; Hitchings, R.G.; and Wilson, E. (1971). Preliminary investigations on the effect of loblolly pine cell morphology on paper fibres prepared in a laboratory Valley beater. Tech. Rept. No. 47, N. C'lina State Univ. Sch. For. Resources, Raleigh, N.C., USA.

7. Higgins, H.G.; de Yong, J.; Balodis, V.; Phillips, F.H.; and Colley, J. (1973). The density and structure of hardwoods in relation to paper surface characteristics and other properties. Tappi 56(8): 127-131.

8. Horn, R.A. (1974). Morphology of wood pulp fiber from softwoods and influence on paper strength. Res. Ppr. FPL242, USDA For. Serv. For. Prods. Lab., Madison, Wis., USA: pp. 11.

9. Horn, R.A. (1978). Morphology of pulp fiber from hardwoods and influence on paper strength. Res. Ppr. FPL312, USDA For. Serv. For. Prods. Lab., Madison, Wis., USA: pp. 8.

10. Kibblewhite, R.P. (1981). The qualities of radiata pine papermaking fibres. pp. 16 + 17 Fig. In Procs., 1981 Conf., Aust. and N.Z. Pulp and Ppr. Ind. Tech. Assn., Rotorua, N.Z. Appita, Melb., Aust.

11. Casey, J.P. (Ed.) (1980). 'Pulp and Paper Chemistry and Chemical Technology, 3rd Ed., Vol. 1 (John Wiley and Sons: N. York, USA). pp. 920.

12. Clark, J. d'A. (1978). 'Pulp Technology and Treatment for Paper' (Miller Freeman Publicns: San Francisco). pp. 751.

13. Mark, R.E. (1967). 'Cell Wall Mechanics of Tracheids' (Yale Univ. Press: New Haven, USA). pp. 310.

14. Frey-Wyssling, A. (1957). 'Macromolecules in cell structure' (Harvard Univ. Press: Cambridge).

15. Stamm, A.J. (1964). 'Wood and Cellulose Science' (Ronald Press Co.: N. York). 549 pp.

16. Wardrop, A.B. and Bland, D.E. (1959). The process of lignification in woody plants. pp. 76-81 In Procs., 4th Int. Congr. of Biochem. (Pergamon Press: N. York). XI + 285 pp.

17. Wardrop, A.B. and Harada, H. (1965). The formation and structure of the cell wall in fibres and tracheids. J. exp. Bot. 16(47): 356-371 + 7 plates.

18. Balodis, V. (1977 unpublished). Wood properties of importance for pulp and paper industry. Lecture to 1977 Pulp and Paper Seminar, Sarawak. CSIRO Div. Chem. Tech., Melbourne: pp. 12.

19. Lange, P. (1954). The distribution of lignin with cell wall of normal and reaction wood from Spruce and a few hardwoods. Svensk Papp Tidn. 57(15): 525-535.

20. Asunmaa, B. and Steenderg, B. (1957). Relative scattering densities in Pine heartwood, Pine sapwood and Spruce. Svensk Papp Tidn. 60(20): 751-761.

21. Wardrop, A.B. and Davies, G.W. (1961). Morphological factors relating to the penetration of liquids into wood. Holzforschung 15(5): 129-141.

22. Wardrop, A.B. (1963). Morphological factors involved in the pulping and beating of wood fibres. Svensk Papp Tidn. 66(7): 231-247.

23. Preston, R.D. (1952). 'The molecular architecture of plant cell walls' (Chapman and Hall: London).

24. Wardrop, A.B. and Dadswell, H.E. (1950). The nature of reaction wood. II The cell wall organization of compression wood tracheids. Aust. J. sci. Res. 3B(1): 1-13.

25. Cote, W.A. and Day, A.C. (1965). In "Cellular ultrastructure of woody plants": 391. (Syracuse Univ. Press: N. York).

26. Allison, R.W. (1980). APPITA 34(3): 197.

27. Davies, G.W. (1966). Optical and electron Microscopy of NSSC pulps. APPITA 19(4): 94-110.

28. Emerton, H.W. (1965). pp. 10-41 In "Staff preparation for paper and board making (F. Bolam, Ed.), Tech. Sectn, Bri. Ppr. and Bd. Mfrs. Assn., London. Vol. 1.

29. Cockrell, R.A. (1947). Explanation of longitudinal shrinkage of wood based on interconnected chain-molecule concept of cell-wall structures. Trans. Amer. Soc. Mech. Engrs. 69(8): 931-935.

30. Forgacs, O.L. (1963). Pulp Paper Mag. Can. 64, No. C, T89-T118.

31. McMillin, C.W. (1969). Aspects of fiber morphology affecting properties of handsheets made from Loblolly Pine refiner groundwood. Wood Sc. and Technol. 3(2): 139-149.

32. Higgins, H.G. and Balodis, V. (1965). In "Fracture", Procs. 1st Tewksbury Symp. of Univ. of Melb.-Butterworths, Melb.

33. Jett, J.B. and Zobel, B.J. (1975). Wood and pulping properties of young hardwoods. Tappi 58(1): 92-96.

34. Scallan, A.M. and Green, H.V. (1975). A technique for determining the transverse dimensions of the fibres in wood. Wood and Fiber 5(4): 323-333.

35. Kellogg, R.M.; Thykeson, E.; and Warren, W.G. (1975). The influence of wood and fiber properties on kraft converting-paper quality. Tappi 58(12): 113-116.

36. Hillis, W.E. (1980). APPITA 33(5): 339-344.

37. Dadswell, H.E.; Watson, A.J.; and Nicholls, J.W.P. (1959). What are the wood properties required by the paper industry in the trees of the future? Tappi 42(7): 521-526.

38. Davies, G.W. (1966). Optical and electron microscopy of papers made from chemical pulps. APPITA 20(1): 21-32.

39. Zobel, B.J. (1976). Wood properties as affected by the changes in the wood supply of southern pines. Tappi 59(4): 126-128.

40. Hillis, W.E. (1972). Properties of eucalypt woods of importance to the pulp and paper industry. APPITA 26(2): 113-122.

41. Koch, P. (1974). Harvesting Southern Pine with taproots can extend pulpwood resource significantly. J. For. 72(5): 266-268.

42. Manwiller, F.G. (1972). Wood Science 5: 122-124.

43. Harder, Marianne L.; Einspahr, D.W.; and Parham, R.A. (1978). Tappi 61(11): 121-2.

44. Einspahr, D.W. and Harder, M.L. (1980). Tappi 63(9): 121-124.

45. Nicholls, J.W.P. and Phillips, F.H. (1970). Preliminary study of coppice-grown *Eucalyptus viminalis* as a source of chip material. Div. For. Prods. Tech. Ppr. No. 58, CSIRO, Melbourne: pp. 28.

46. Watson, A.J.; Davies, G.W.; and Gartside, G. (1976). Pulping and papermaking properties of Kenaf. APPITA 30(2): 129-134.

47. Colley, J. (1975). Factors affecting the vessel picking tendency of hardwood pulps. APPITA 28(6): 392-398.

# FIBRE TREATMENT

A.W. McKenzie

Division of Chemical Technology, CSIRO
P.O. Box 310, South Melbourne, Victoria,
Australia, 3205.

## ABSTRACT

The evidence for the "refining of flocs" hypothesis is summarized. It is concluded that a number of factors associated with the fibre entrapment process in a barred beater or refiner are affected by the degree of flocculation of the pulp suspension. These include the entrapment process itself, the extent of bar coverage, the pressure exerted on the trapped fibres and the optimum specific edge load for minimum energy consumption.

## INTRODUCTION

Papermaking fibres as produced by any of the normal pulping processes are not immediately useable for paper manufacture. In order to develop the balance of properties required for a particular type of paper, the virgin pulp fibres are subjected to a mechanical treatment. This process is known as beating or refining. These two terms are often considered to be synonymous although strictly, beating is a batch process, while refining is a continuous operation. Refining, in this context, should not be confused with the so-called chip refining processes in which wood chips are mechanically reduced to pulp. The latter should more accurately be described as defibration or fiberization.

The beating operation is highly energy intensive, typically requiring an energy input of 500-1500 MJ per tonne of pulp. It is also generally believed to be wasteful of energy because of the inefficiency of the energy transfer process. However, an accurate estimate of efficiency is not yet possible. There is no reliable information available on the relationship between the total energy input, the energy absorbed by the fibre and the energy absorbed which is transformed into useful beating effects.

Of the many types of treatment given to papermaking stock and the subsequent paper web during the process of converting wood fibres into the finished paper web, beating is probably the most universal, the most necessary and the least understood. At a recent international symposium it was stated that there is "no generally accepted theory of refining that would tell the papermaker what is the exact effect of the various controlling variables on the structural changes obtained. It was also said that "with a good theory of refining one could increase the efficiency of refining considerably and obtain combinations of refined fibre properties which are impossible with today's refining techniques" (1).

In recent years, a body of evidence has been accumulating which suggests that pulp is present in the beater in the form of fibre aggregates or flocs rather than as individual fibres. The purpose of this paper is to examine the evidence supporting this hypothesis and to consider some of its implications.

## BACKGROUND

The first evidence suggesting that flocculation is a significant variable in the beating process came from measurements of the gap between roll and bedplate in a Valley beater. At a "Symposium on Beating" in 1951, Steenberg (2) reported a significant reduction in this gap on adding what he called slime producing substances. These included carboxymethylcellulose and other polysaccharides, alkalis, fatty oils and bentonite. In subsequent discussion, Underhay (3) suggested that the observation might be a result of the substances used keeping the fibres more uniformly dispersed. Watson and Phillips (4) observed a similar phenomenon in the PFI mill and also found that the presence of alum increased the gap between roll and housing. They attributed both effects to changes in the degree of flocculation of the pulp.

Further indirect evidence of the presence of flocs was provided by Steenberg (5,6). He found that pulp suspensions would not flow between a rotating disc and a stationary disc if both surfaces were smooth, but that an even flow could be maintained if radial grooves or interconnecting holes were machined into the disc surfaces.

The first direct observation of flocs in the refining zone appears to have been made by Page *et al* (7). They observed groups of fibres between the bars of an Aylesford beater, but only rarely lying over the bar edge as would have been expected on the basis of the "fibrage" theory currently accepted at the time. Banks (8) and Fox *et al* (9) have since shown that a similar situation applies in a disc refiner. In recent work in a PFI mill (10), we have found that the size and strength of the flocs varies with fibre properties. Larger, stronger flocs are produced from longer, more flexible, more fibrillated fibres.

Floc size is reduced by beating; presumably the reduction in fibre length has a greater effect than the increase in fibrillation and flexibility.

Assuming that the fibrous unit being treated in a beater or refiner is indeed a floc, rather than a single fibre, the following sequence of events has been suggested as a possible description of the beating process (8,10).

(i) A floc is trapped between the approaching edges of opposing bars and consolidated.

(ii) The consolidated floc, at a reduced moisture content, is drawn between the bars somewhat in the manner of a thread being drawn between the blades of a blunt pair of scissors.

(iii) Plastic deformation of the fibres in the floc occurs as a result of (a) distortion of the floc, (b) shear and compression forces acting on the floc and its component fibres and (c) the forces generated as flocs are pulled apart, the fibres being pulled rapidly through a tortuous path within the fibre network.

(iv) The release in pressure allows water to be absorbed into those parts of the cell wall where plastic deformation has disrupted the intra-fibre hydrogen bonding.

(v) The treated fibres are released to the bulk of the pulp in the beater/refiner where they can form new flocs ready to repeat the process.

(vi) At the same time, any relative movement between individual fibres or between fibres and bar surfaces will abrade the fibres, producing fibrillation and fines.

## DISCUSSION

In examining the implications of floc treatment as the fundamental operation in refining, we face a number of problems. These arise firstly because of the difficulty in varying flocculation characteristics, without changing other pulp properties, and secondly because laboratory beaters such as the PFI and Lampen mills do not use the principle of opposing bars and hence do not have a fibre entrapment mechanism which would be affected by changes in flocculation in the same way as commercial units. However, a number of significant observations have been made using small conical or disc refiners.

Goncharov (11) has measured the compressive force acting across the width of a refiner bar and found that the stresses obtained were 13 times greater than that calculated from the axial thrust. However, these stresses only occurred over the front 2.5 to 3 mm of the leading edge of the bars. Although Goncharov postulated that this was the result of fibrage being compressed in

the nip between the approaching bars, it was observed at clearances of 0.3 mm or more, which is equivalent to ten fibre diameters. Thus the observation seems to be more consistent with the trapping of flocs, rather than the compression of a layer of individual fibres stapled over the bar edges.

Ebeling (1) has estimated from single frames taken from high speed movies that only about 10 per cent of the total bar crossing area is covered by flocs. From this, he calculated that each floc was subjected to a pressure pulse of over 10 MPa for 0.2 to 0.5 milliseconds. This is of the same order as the 3.5 MPa calculated by Goncharov. Even in the PFI mill, a long-fibred pulp only covers 30-50 per cent of the bar surface as estimated from photographs obtained as described in Reference 10. If the pressure was uniform across a PFI bar, this would mean a pressure of 1.3 to 2.2 MPa but because of the geometry of the PFI mill, maximum pressure is undoubtedly higher than this. Thus the degree of flocculation, by affecting the efficiency of fibre entrapment and the amount of bar coverage, will have a direct effect on the pressure exerted on the fibres, and the pressures so exerted are very large. It has been postulated that compression-induced movement of water inside the cell wall is a primary factor in increasing fibre conformability (1). However, Murphy (12), by matching the roll and housing speeds in a PFI mill, produced a situation in which compression was present but shear absent. Under these conditions beating rate was very low. At the same time, the gap between roll and housing (and presumably the quantity of fibre in the gap) increased. Clearly, a shear component is necessary to produce effective beating. The linear relationship between beating rate and the relative speed of roll and housing reported by Murphy, taken in conjunction with the markedly curvilinear relationship between relative speed and beating gap, suggests that there is a real need for a shearing force to act on the cell wall. However, the possibility that the shearing force merely reduces the amount of fibre between the working surfaces, thus increasing the pressure on the remaining fibres, cannot be entirely discounted.

Differences in the response of pine (long fibred) and birch (short fibred) kraft pulps to an increase in specific edge load in an Escher-Wyss conical refiner have also been attributed to differences in floc size. Levlin (13) has found that an increase in specific edge load of a refiner from 1.0 Ws/m to 4.0 Ws/m with pure specific refining energy constant, has opposite effects on the development of freeness and tensile index of the two types of pulp. Increasing the specific edge load gives higher tensile index and Schopper-Riegler freeness (lower Csf) with the pine pulp but lower tensile index and S-R freeness with the birch pulp. This observation would be interpreted conventionally as meaning that hardwood pulp refining should be applied in the form of many gentle impacts while softwood responds better to a few hard

impacts, energy input being constant. The alternative explanation advanced by Levlin is that bar clearance is reduced as specific refining energy is increased and an optimum clearance exists for any pulp below which the efficiency of fibre entrapment is reduced and thus less fibre is being treated. This results in a reduction in refiner efficiency. Above this optimum clearance, the efficiency of energy transfer to the pulp will be lessened. Such a situation is shown in Figure 1 (14). The optimum bar clearance is postulated

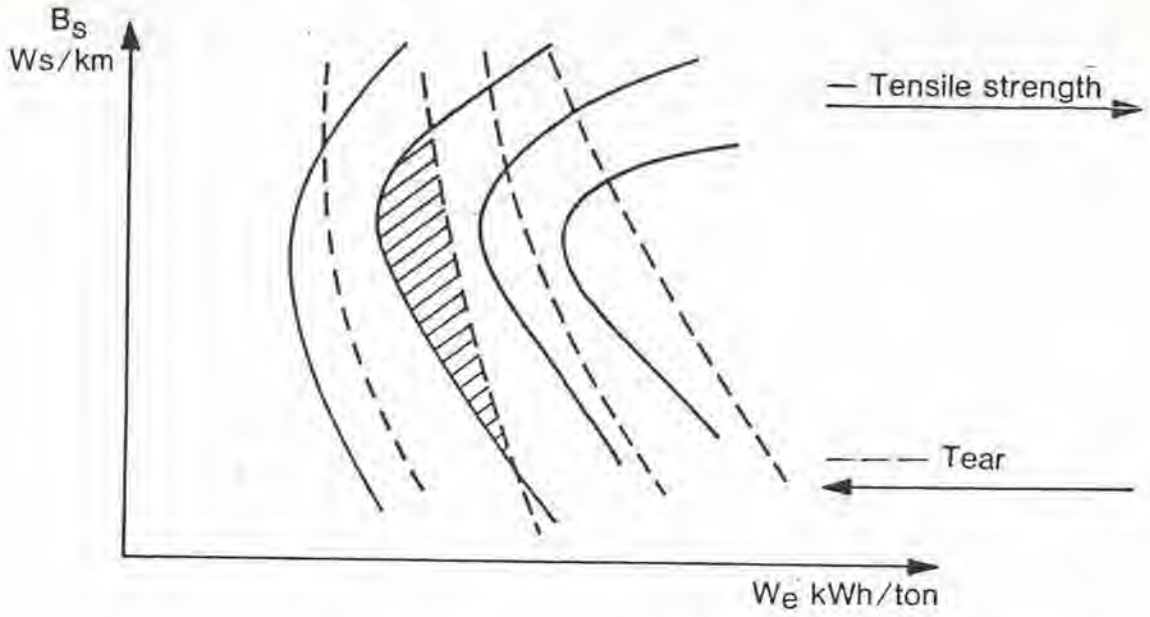



FIG. 1. Optimization of specific edge load for minimum energy consumption.

$B_s$ = Specific edge load

$W_e$ = Specific refining energy

as being related to floc size and strength. The actual clearance at any specific edge load will also vary with floc properties so it is not surprising that the optimum specific edge load is different for hardwoods and softwoods.

In order to determine whether floc properties have a significant influence on the response of the pulp to a compressive shear once it is trapped between the working surfaces, the effect of flocculants and deflocculants on beating rate have been investigated in this laboratory. It has been shown (4) that alum increases the gap between the working surfaces of a PFI mill while guar gum decreases it. Alum (0.5g) and guar gum (0.1)g were therefore added to standard

pulp charges as possible flocculant and deflocculant respectively. Pulp samples were commercial pine kraft and eucalypt kraft. Unfortunately, most additives which affect flocculation characteristics also have other effects on fibre and paper properties. Alum and guar gum are no exception and, in assessing the effect of changes in floc structure on beating rate, one must make due allowance for these side effects. Both long- and short-fibred pulps show a slight increase in beating effect in the early stages of beating in the presence of guar gum and a significant decrease at all stages in the presence of alum. This is as would be expected from the presence of a plant gum and a trivalent electrolyte respectively. Previous work using the Lampen mill (15) has shown that beating rate is in itself apparently reduced by aluminium salts. However, it is probable that this reduction is caused by a decrease in fibre swelling rather than by flocculation. Overall there is no evidence in the results obtained to suggest that the changes in flocculation induced by alum or guar gum are sufficient to affect the response of the fibres between the working surfaces to compressive shear forces.

## CONCLUSIONS

Fibres in a refiner or beater are usually present as flocs rather than as individual fibres. Floc size and strength are controlled by fibre properties. The process of fibre entrapment, the extent of bar coverage, the pressure exerted on the fibres and the optimum specific edge load required to produce any beating effect at minimum energy input are all affected by floc properties in beaters and refiners with a bar-to-bar type of action. Evidence at present available does not indicate any effect of flocculation on the type of action occurring once fibre entrapment is achieved.

## REFERENCES


1. Ebeling, K. "A Critical Review of Current Theories for the Refining of Chemical Pulps". International Symposium on Fundamental Concepts of Refining, Madison, WI, USA (1980).

2. Steenberg, B. Proc. Tech. Sect BPBMA 32 (2) 388 (1951).

3. Underhay, G.F. Proc. Tech. Sect BPBMA 32 (4) 402 (1951).

4. Watson, A.J. and Phillips, F.H. Appita 18 (3) 84 (1964).

5. Steenberg, B., "Fundamentals of Papermaking Fibres" ed. F. Bolam, BPBMA, London, 1961, p. 339.

6. Steenberg, B. and Johanson, B. Svensk Papperstidn. 61 (18B) 696 (1958).

7. Page, D.H., Kosky, J. and Booth, D. BPBIRA Bulletin "What We Are Doing" 28 15 (1962).

8. Banks, W.A. Paper Technol. 8 (4) 363 (1967).

9. Fox, T.S., Brodkey, R.S. and Nissan, A.H. Tappi 62 (3) 55 (1979).

10. McKenzie, A.W. and Prosser, N.A. Appita 34 (4) 293 (1981).

11. Goncharov, V.N. Burmazh. Prom. (5) 12 (1971).

12. Murphy, D.C. Appita 16 (1) (1962).

13. Levlin, J-E. "Some Differences in the Beating Behaviour of Softwood and Hardwood Pulps", International Symposium on Fundamental Concepts of Refining, Madison, Wl, USA 1980.

14. Anon. Jylha News, llE, Jylhävaara, Finland.

15. Cohen, W.E., Farrant, G., and Watson, A.J. Appita Proc. 3 1 (1949).

# REFINED WOOD FIBRE-CEMENT PRODUCTS

R.S.P. Coutts

Division of Chemical Technology, CSIRO, Box 310, South Melbourne 3205

## ABSTRACT

Laboratory and pilot plant evaluations have shown that the production of an asbestos-free fibre reinforced cement sheet can be achieved with modified wood fibres as the sole source of reinforcement.

Products with a modulus of rupture of greater than 20MPa and toughness comparable to commercially available asbestos cement sheeting indicated that commercial manufacture was realizable - a product is now available under the trade name "Hardiflex II".

## INTRODUCTION

At the 19th Forest Products Research Conference work on the chemical modification of the surface of wood fibres was reported (1). The treatment of such fibres before incorporation into a cement matrix was believed to result in a modified interfacial region between the wood fibre and the cement matrix and hence changed the mechanical performance of the resulting composite.

More recently mechanical modification of the surface of wood fibres has been studied in relation to its effect on the properties of cement and mortar composites (2). In particular, a joint project with James Hardie and Company Pty Limited was initiated to look at wood fibre reinforced cement as a replacement for asbestos reinforced cement products.

Although effective as a reinforcement in a cement matrix (3), kraft pulp fibre performed poorly in asbestos-free formulations prepared on a Hatschek machine due to the inability of the fibres to form webs capable of retaining cement and silica particles (4). A Hatschek machine is a continuous industrial plant, very similar to a paper machine. A slurry of fibres and matrix (10% solids) is picked up on screen cylinders, plied onto a felt screen, vacuum dewatered and then formed into a sheet. The open nature of the fibre webs permitted rapid drainage and, in the case of low consistency slurries, loss of the particulate matrix with a resulting loss of product strength. The loss of solids can be minimised by reducing the drainage rate of the slurry. This can

be approached from two different directions. Firstly, reduction of water in the slurry improves product strength but is impracticable on the Hatshek machine (3). Secondly, reduction of the natural drainage rate of the pulp fibres can be achieved by beating.

No literature was available concerning the effect of beating natural fibres to improve their reinforcing properties in autoclaved cement composites. This paper summarizes the results of laboratory and pilot plant evaluations of beaten kraft pulps in asbestos-free fibre-cement sheets.

## RESULTS AND DISCUSSION

Initially, samples were prepared in the laboratory by dewatering a slurry in a pressure mould. The data obtained for specimens containing pulp prepared in a Sprout Waldron disc refiner suggested that the modulus of rupture (MOR) passed through an optimum as the degree of refining increased. At the same time the impact toughness decreased and the density increased slightly.

To confirm the preliminary observations on the Sprout Waldron refined fibre composites, a more intensive investigation was undertaken in the laboratory using pulps refined by other techniques, e.g. Valley Beater and PFI Mill. Earlier work had shown that the MOR versus fibre content curve showed a maximum (3). In this study it was observed (see Fig. 1) that approximately 8-10% fibre by weight produced the maximum value of MOR.

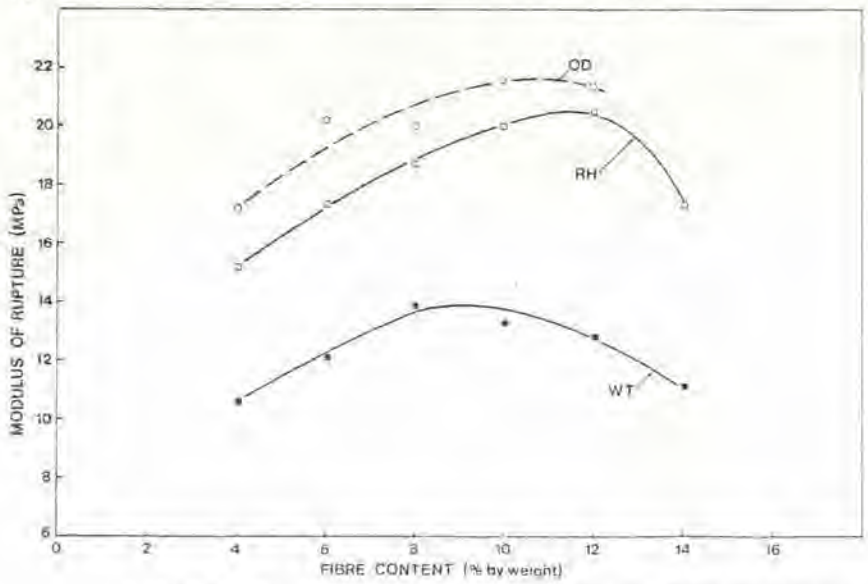



FIG.1 FLEXURAL STRENGTH vs FIBRE CONTENT (AT DIFFERENT MOISTURE CONTENTS)

## EFFECT OF MOISTURE

Testing techniques for wood pulp fibre cement composites have not yet been standardized. Inconsistencies were often detected with test samples dried above 100°C. More reproducible results were obtained when test samples were placed in a controlled atmosphere with a relative humidity of 50 ± 5% RH

and a temperature of 22 ± 2° (see Fig. 1).

Having recognized that the strength properties of a cellulose fibre reinforced cement-silica composites diminish when the sample is wetted we have more recently adopted a "wet" test (48h soaking prior to test) as part of our standard testing program.

Although the oven dried and controlled atmosphere results are generally of the same magnitude, samples tested wet are between 30-40% lower than the samples tested in a controlled atmosphere (Fig. 1).

The effect of moisture on MOR is in contrast to the effect of moisture on toughness. Figure 2 shows the fracture toughness of samples at various compositions when tested at different moisture contents.

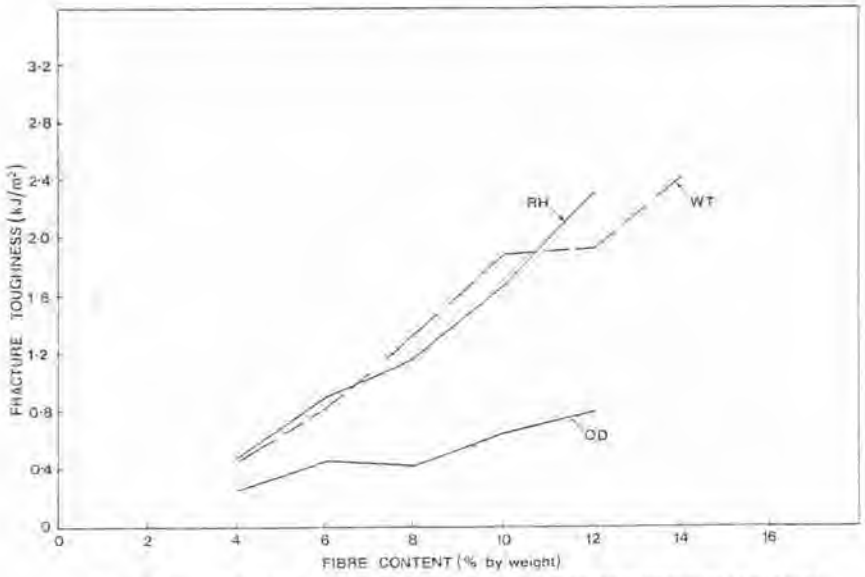



FIG.2 FRACTURE TOUGHNESS vs FIBRE CONTENT (AT DIFFERENT MOISTURE CONTENTS)

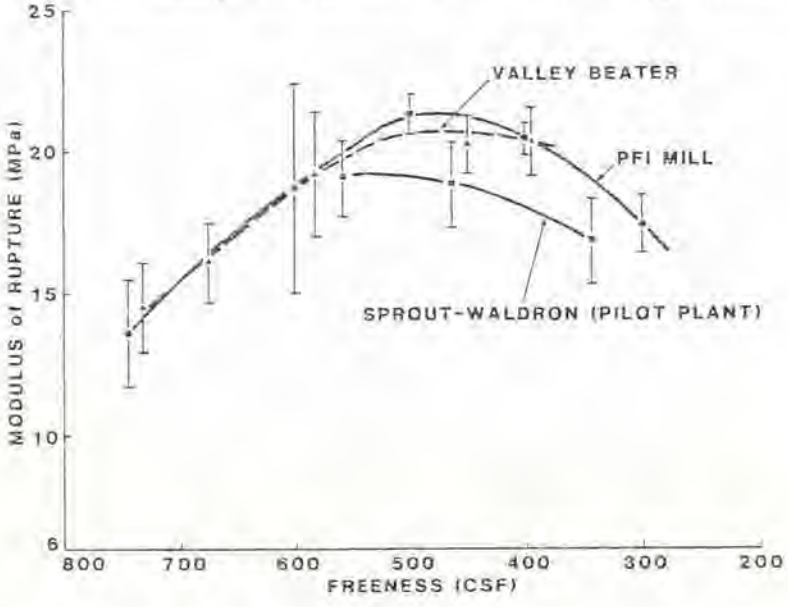
Samples tested wet maintain high toughness, whereas oven dried samples show drastically reduced toughness. The toughness or shatter resistance, under ambient conditions, of cement composites reinforced with wood fibre could be attributed to the large amount of energy absorbed in debonding, stretching, and pulling out the fibres after the matrix has cracked.

Fortuitously the samples conditioned at rh of 50 ± 5 per cent and 22 ± 2° (approximately ambient conditions) are seen to display both strength and toughness.

## EFFECT OF REFINING

The values of MOR at various levels of refining for a composite containing 8% fibre by weight is shown in Figure 3. The points on the graph designated

"Sprout (Pilot Plant)" relate to a machine run which contained 8% fibre by weight. We see a trend for the MOR to optimize as the degree of beating of the pulp is increased. At an 8% loading the optimum freeness is approximately 500 CSF.




As was seen in Figure 2 the toughness of a composite increases with increasing fibre content. In general terms, the toughness of a sample of constant fibre composition tends to decrease as the fibres is refined.

Decrease in toughness with refining can be associated with the reduction in length of the fibres during refining which reduces the capacity of the fibre to resist fibre pullout with its associated frictional energy.

## PILOT PLANT TRIALS

Needless to say, as with any attempt to move from laboratory to pilot plant scale, difficulties with adjustment of machinery was experienced. It is not our intention to discuss them in this paper. We will consider only the evaluation of the products produced on the pilot machines.

The Sprout Waldron disc refiner was capable of producing sufficient pulp for initial pilot plant trials. Thus sheets containing 8% by weight refined pulp in a 1:1 cement-silica matrix were produced on a pilot plant scale Hatschek machine. In keeping with the laboratory work it was found that when the pulp had a freeness of 560 CSF the MOR value of a sample tested oven dry was 19.1 $\pm$ 1.4 MPa; when the freeness was 467 CSF, MOR was 18.8 $\pm$ 1.5 MPa and when the freeness was 343 CSF, MOR was 16.8 $\pm$ 1.5. Unlike the laboratory samples which have the fibres virtually random in a two dimensional plane, machine samples have preferred alignment of the fibres in the direction of the machine. Hence the values referred to in the pilot plant trials are average of

values of the machine direction and cross machine direction.

It should be noted that the same pulp when slushed, but not refined, produced sheets (under similar machine conditions) with a MOR value less than 10 MPa.

James Hardie and Company Pty Limited have produced over 50,000 sheets of the new board on pilot-scale equipment. Samples with flexural strengths of greater than 23 MPa and impact toughness values comparable to standard Hardiflex board (an asbestos fibre reinforced cement sheeting product) have been produced.

The asbestos-free board will be generally available under the trade name "Hardiflex II" when the company has completed conversion of seven of its board-mading plants at a cost of some $8 million.

## CONCLUSIONS

1. The flexural strength and toughness of a wood fibre reinforced cement composite varies with the mass fraction of fibre and its degree of refining.
2. The mechanical performance of a wood fibre reinforced cement composite is dependent on moisture content.
3. Refining cellulose fibres enables them to form a web more able to retain the particulate matrix and yet still maintain sufficient drainage rate to be successfully processed on a modified Hatschek machine.
4. Asbestos can be replaced totally by modified wood fibres for the commercial production of fibre reinforced cement sheeting.

## REFERENCES

1. Coutts, R.S.P. (1979). "Wood fibre-cement composites", 19th Forest Products Research Conference, Topic 4B/7, 1-5.
2. Coutts, R.S.P. and Ridikas, V. "Refined wood fibre-cement products" Appita (in preparation).
3. Campbell, M.D. and Coutts, R.S.P. (1980). "Wood fibre reinforced cement composites", J. Mater. Sci. 15, 1962-1970.
4. Ridikas, V. (1978). Unpublished results.

# A "RECONSOLIDATED" STRUCTURAL WOOD SUBSTITUTE

J.D. Coleman
Division of Chemical Technology, CSIRO,
P.O. Box 310, South Melbourne, Victoria 3205.

## ABSTRACT

The main requirement for structural load bearing is high strength and stiffness associated with minimum weight and low creep value. In addition the material must be durable, machinable and able to be fastened. To achieve the necessary directional properties in a reconstituted wood product the various elements must be aligned and considerable research has been undertaken into this problem. Structural class panels as distinct from sections have been manufactured commercially.

The reconsolidation process is intended to produce heavy sections. Wood stems are rended to a point where the resulting mass can be moulded and retaining throughout much of the orientation of the parent wood. The stem is cut to length and worked down into a long, loosely connected and flexible web of strands and splinters. These are dried, coated with adhesive combined with other webs to meet size requirements and then pressed.

Typical composite failures have been observed in laboratory bending tests and strength recovery in the order of seventy percent of "clear" quality parent timber is obtainable. Otherwise the composite properties reflect that of the parent wood.

The prospects for commercial development are being examined with Repco Limited and test beams of structural dimensions have been produced.

## STRUCTURAL SUBSTITUTES - STATE OF THE ART

The main requirements for a structural load bearing are high strength and stiffness associated with minimum weight and low creep. In addition the material must be durable, machinable and able to be fastened. The first essential is that a high degree of alignment is developed, particularly in the surface layers. This is achieved either by assembly of preformed components or controlled deposition of particulate elements. While the deposition of particles is favoured for lighter panels, most attempts to

generate structural sections at present fall into the "re-assembled" category.

The laminated beam is the only product in general commercial use. Plystran is being manufactured on a limited scale but the intention finally to produce heavy sections for sawing has not come to fruition. Press Lam and Micro Lam are still under development. Difficulties have been encountered with drying and high resin consumption with these products and the economics are dependent on the price and availability of peeler logs. Commercial trials have been undertaken with Comply but it is heavy, reactive and loses strength when the veneered surface is checked.

In other developments the Sector Board concept was announced recently by Weyerhauser. The intention is to saw smaller diameter logs lengthwise along radii into long "sectors" for repositioning and gluing to form a flat billet. Attempts have also been made, the most recent of Norwegian origin, to produce framing from hardboard strips set in an "I" configuration (1). At least one attempt (2) has been made to introduce reinforcing strands into reconstituted sections.

Considerable effort has been directed toward using mechanical or electrostatic techniques to align individual particles. Selection of the process is governed by the size of the particle. However, there seems to be no satisfactory compromise where structural properties are required. If the wood is reduced to a fibre bundle able to respond to electrostatic forces the product will be more akin to pressboard than wood. Conversely, mechanical systems seem unable to cope with the longer strands needed to impart desired wood-like characteristics. In addition the present means of producing the strands are perhaps less than ideal for preserving these characteristics.

## RECONSOLIDATED WOOD PROCESS

In some degree each of these developments involves the steps of breaking down or disintegration of the raw wood and subsequent realignment and attachment. It may be that this common sequence is in itself the factor inhibiting commercial success with structural sections. Thus it could be useful to think instead of a process in which the raw wood is reduced only to a condition from which it can be "reconsolidated" to form a product and throughout which, as far as possible, the elements are maintained interconnected and in their initial relationships. The structural character of the parent species would then be inherited by the product while the

problem of re-aligning smaller elements is avoided altogether (4).

The "reconsolidation" process involves no more than rending woody stems to a point where the resulting mass of still interconnected strands can be conveniently dried and a resin applied before pressing and reshaping to final form. Heavy sections can be built up by combining several of these strand bundles, which are easily manipulated by virtue of their relatively massive size.

FORESTRY AND RAW MATERIAL

The process is facilitated by using long slender stems, preferably equal in length to the final product, to produce zero "grain" angle. A grain angle as low as 5° can reduce strength by up to ten percent in sawn timber (5) although this may not apply to reconsolidated products. Stems from 80-160 mm in diameter are well suited to the process and it is envisaged that they will be harvested mechanically from coppiced or dedicated forest on a short rotation basis, perhaps a 4-8 year cycle depending on the species and growing regime. High stem density could ensure that total biomass is maintained at an acceptable level and suppress the development of knots and excessive taper. Young stems would be free from heartwood. These factors may help compensate for the juvenile character of the wood and the initial disadvantage in strength compared with mature parent material. In some species the bark may be difficult to remove. In others it falls away during the reduction stage.

Systematic and sustained wood production is very desirable as a basis for commercial operation, to simplify processing and allow uniformity in the product. The projected growth cycle allows this as well as offering a return on investment within a realistic time scale. There is an option to establish plantations where it is most convenient in relation to markets and other operating requirements. It may be possible to utilize thinnings from established sites or alter the regime of stands intended finally for logging to provide an early crop for reconsolidation.

An overriding requirement is that the stem is fissile and will rend to form the necessary web mass. The principal commercial species have been evaluated for this property and are generally satisfactory. Most eucalypts will respond, particularly *E. viminalis* although at the other extreme *E. globulus* may be too soft. Some poplar clones gives excellent results as the growth rings separate easily. Interestingly, *A. dealbata* and *E. camaldelenis* can be processed. However, on balance

*P. radiata* was selected for testing and developing the pilot machine. It is a ubiquitous species, grows fairly rapidly and splinters readily, although the spiral grain presents some difficulty especially in younger stems. In the longer term,selective breeding of desirable characteristics may be possible.

PROCESSING & EQUIPMENT

Materials handling and drying systems will need to be adapted to handling the web bundles on a commercial scale but with the exception of the reduction mill no new technology is required.

The drying of wood is well understood. If the "scrim", as the rended wood is referred to, is properly ventilated, moisture loss is rapid and drying time is measured in minutes at temperatures below one hundred degrees.

Rending the stems can be approached in several ways but rolling is presently favoured as being the simplest and most practical means. Satisfactory results can be obtained by multiple passes through a single stage. However, a synergism exists between multiple stages and a line is presently under development to produce the web continuously in one pass. This is seen as being essential to commercial production. Power consumption is minimal as the separation propagates along the grain and there is no cutting action as such.

Most liquid resin combinations can be used as adhesives. Consumption can be varied by adjusting viscosity and doctoring rates and cost can be controlled by blending. Typically the product contains 5-12% resin which compares favourably with particleboard. Of particular interest is the prospect of applying polyisocyanate resin in emulsion form. Given the order of difference in specific surface area of scrim compared to flakes this resin might be employed at economic cost particularly where durability is a prime requirement and if sufficient crosslinking is developed to ensure an acceptable creep rate (6). Dry powder resin has been used but is not as convenient as liquid. Good dispersion can be obtained with a fine powder but the scrim may be damaged and the product tends to be more reactive to water.

Conditions for pressing and curing the scrim do not vary greatly from those already in use for particleboard. Cycle time may be longer as the compressed scrim is in the nature of a packing and may impede the flow of steam which heats the centre of particleboard and compensates for the poor

thermal conductivity of wood (7). Tests with high frequency heating have shown considerable promise. The cycle time will be much shorter if this technique can be adapted on a commercial scale and the quality of the product itself may be improved by more uniform heating. Given the incentive, it should be possible also to press continuously any required length, although this could introduce a grain angle depending on the length of the scrim bundles and the option selected for loading the mould.

PROPERTIES & CHARACTERISTICS OF SCRIMBER*

Splitting and reduction in size of the strands is progressive during the "scrimming" process. Ultimately the individual elements begin to lose their wood-like character and the natural interconnecting material is progressively severed. Provided reconsolidation is effected before this is well advanced the properties of the parent wood are reflected in the product.

The "grain" is essentially straight and parallel although some overlapping of the strands occur, or can be introduced, which reduces the tendency to split lengthwise. Imperfections which otherwise prevent the attainment of specific strength values in commercial timbers are modified and randomized during processing and it is usual to recover some seventy percent of the strength in bending of clear quality mature parent timber, i.e. a quality approaching select engineering grade timber might be manufactured from immature stems. The material has excellent stiffness and good compression properties. Failure occurs by tensile fracture of the wood strands and no delamination in shear has been observed. The strength of the wood is the limiting factor. If allowance is made for the fact that juvenile wood ranges between 50-70% of the strength of mature stock and correcting for some densification it seems that the process randomizes imperfections sufficiently to allow near perfect strength recovery.

Surface finish and density are determined by strand size and forming pressure. To obtain a close knit surface from *P. radiata*, for example, the density is controlled in the range 600-650 kg/m$^3$, similar to particleboard. The relationship between density and strength is close to linear. Open lattice structures possessing good stiffness have been made with densities down to 400 kg/m$^3$.

---

*Trade Mark Repco Ltd.

With proper resin formulation, end grain samples will withstand immersion for 24 hours and more,even if boiled, but swelling does occur, as with any cellulosic material and is typically in the range 10-20 percent. The reaction to water is a reflection of the manner in which the scrim is compacted and pressed and the stability is expected to improve as the processing is refined.

The material can be sawn,planed and sanded. While some fissures have been observed in the surface of the strand elements there does not seem to be any significant damage or permanent compression of the cell structure. The ability to retain fastenings can be affected by these changes but has been rated as satisfactory, if not as good as the parent wood.

Fillers, colours and active chemicals might be incorporated during manufacture. The rather bland appearance of *P. radiata* for example can be given a more interesting texture by this means.

Comparison of test results may not give full insight into the potential for the material or its limitations. It should be noted that the scrim can be moulded in two directions, or even pierced during the pressing operation. Samples have been prepared in which a three dimensional "lacework" was generated about the neutral axis of a rectangular section to form the equivalent of an "I" beam. The density calculated on the crude dimensions of such a section is lowered and it is possible, in theory, to generate a greater volume of SCRIMBER than existed in the original stems. Rebating the semi-finished beam generates a similar product. The shavings can be used as a fuel.

Sinuous elements can be made,perhaps for assembly into lightwieght trusses. It is also possible to laminate, or produce 'in situ', veneered Scrimber sections.

ECONOMICS AND FUTURE DEVELOPMENT

The prospect of obtaining deep structural sections from young forest is attractive. The process is presently the subject of an option to Repco Ltd. Much of the work has been on a collaborative basis with this company. At this stage, cost estimates suggest that further development is justified and the intention is to look at products with high unit value, worthwhile market volumes and unspecified performance requirements. Skirting board falls into this category. Concurrently, products with larger markets but more demanding specifications are being explored and include flooring and structural applications.

REFERENCES

1. Schultz, L.G. Current & Future Developments in Panel Products in Australia. Inst. Wood Sci. Conf. Aust. Branch (1975).

2. Saucier, J.R. and Holman, J.A. F. Prod. J. 25 (9):69 (1975).

3. Koenigshof, G.A. F. Prod. J. 29 (11):37 (1979).

4. Coleman, J.D. 18th Forest Products Research Conference Proceedings (1977).

5. Desch, H.E. Timber Its Structure and Properties. MacMillan, London, 1938.

6. Sterner, P.R., Chow, S. and Vadja, S. F. Prod. J. 30 (7) 21-33.

7. Kelly, M.W. USDA Tech. Rep. FPL 10 (1977).

# APPLICATIONS OF COMPOSITE PAPER-WRAPPED YARNS

M. D. Campbell
CSIRO Division of Chemical Technology

## ABSTRACT

A new wool pack and energy absorbing materials are being developed from bicomponent reinforcing yarns. Both projects are being carried out in collaboration between the CSIRO Divisions of Textile Industry and Chemical Technology. The new wool bale is made from bicomponent yarns comprising a high strength nylon core with a helical wrap of paper tape, and is the subject of a joint patent application by the Divisions. The yarn if fractured will not contaminate the finished wool product, and has novel load/extension characteristics which make it well suited for use in wool packs. Several thousand packs have been produced for evaluation in the field.

Composite materials reinforced with bicomponent yarns are both strong and tough. This combination of properties is unusual in a fibre composite in which toughness and strength generally are mutually exclusive. Normally, in order to achieve high stiffness and strength the bond between the reinforcing fibre and the matrix must be strong. However, high toughness is obtained when the matrix-fibre interface is weak. Both high strength and toughness can be achieved in a composite material if the load transfer across the matrix-fibre interface is controlled by the net stress acting on the composite. A method has been developed whereby this can be achieved. The Division is collaborating with industry in investigating the production of demonstration samples of these composites. The energy adsorbed by the materials at failure is large, making them suited to energy attenuation applications such as highway railings, containment structures, bumper bars, etc.

Mr R E Belin of the Division of Textile Industry is carrying out work on yarn spinning and other aspects of the two projects.

# CHEMICALS FROM WOOD

A.A. Sioumis

Division of Chemical Technology, CSIRO,
P.O. Box 310, South Melbourne, Victoria,
Australia 3205.

## ABSTRACT

The highly-sophisticated conversion technology based on petroleum has provided us with a great variety of products. Most of these can also be derived from conversion technology based on forest biomass. The plant kingdom furnishes a large array of silvichemicals and the anticipated shortage of petroleum in the not too distant future has brought forward the prospects of using wood as a chemical feed stock.

## INTRODUCTION

Following the recent and rather frequent increases in the price of oil, a great deal of work has been published on the possibilities of using wood as a raw material for the production of chemicals (1-4). The concept of a forest-based chemical industry has been the dream of wood chemists for many years, and in recent times is gaining momentum as petroleum reserves decrease.

Chemicals from trees can be used either as synthesized by the trees (Table 1) or by converting them into compounds which are needed in the chemical industry (Table 2).

TABLE 1.

Chemicals present in wood

| | |
|---|---|
| Cellulose | Tall oil |
| Wood resins | Tannins |
| Turpentine | Essential oils |
| Pine oil | Pharmaceuticals |

TABLE 2.

Chemicals and materials derived from wood

| | |
|---|---|
| Sugars | Charcoal |
| Ethanol | Tars |
| Methanol | Kraft lignin |
| Cellulose derivatives | Lignin sulphonates |
| Phenolic compounds | Dimethyl sulphide |
| Furfural | Dimethyl sulphoxide |
| Vanillin | Carboxylic acids |

The complex biochemical reactions which are carried out by the plants produce a large number of organic compounds, some of which defy the ingenuity of the synthetic organic chemist. Despite the large variety of chemical constituents present in plants many classes of organic compounds are associated with specific families. It is this property of each species to manufacture unique organic compounds that led to the development of chemotaxonomy.

Industries such as the pharmaceutical, the rubber and the naval stores industries have used plant chemicals for many years. The chemicals in the above industries were used as they are manufactured by the trees or were modified to produce suitable components for specific purposes. Usually these products were only minor constituents of the tree. Recently wood chemists have put greater emphasis on developing products which are derived from the principal constituents of the tree, the cellulose and lignin. The vast amount of solar energy which is fixed photosynthetically as organic matter can thus contribute to the production of chemical feedstocks.

## METHODS FOR PRODUCTION OF CHEMICALS

The production of bulk chemicals from wood is not a new concept.

Charcoal and wood methanol were well known products from wood many years ago. The naval stores industry is still operating. Although many scenarios have been proposed for the conversion of biomass to chemicals and fuels, at this stage the chemical industry is still relying heavily on oil because of favourable economics. Wood is a mixture of cellulose, lignin, hemicelluloses and extractives. It is this heterogeneity which creates problems, and therefore higher costs, when wood is considered for conversion to chemicals and fuels. The extractives are relatively low molecular weight compounds whereas the cellulose, hemicellulose and lignin are polymeric compounds. In this paper the methods available for converting the high molecular weight materials into useful low molecular weight compounds will be discussed. The utilization of lower molecular weight extractives as commercial products will also be considered.

## THERMAL DEGRADATION PROCESSES

Pyrolysis, gasification and hydrogenation at elevated temperatures are well known methods of wood treatment and produce a large variety of products depending upon the conditions of the process. Pyrolysis is defined as the incomplete thermal degradation of wood, usually in the absence of air. The products are char, condensible liquids or tars and gases. The relative quantities of the above products will depend upon variations in temperature and oxygen supply. Higher temperatures, generally in the presence of oxygen, produce predominantly gaseous products.

A summary of the most common chemicals obtained by wood pyrolysis is given in Figure 1.

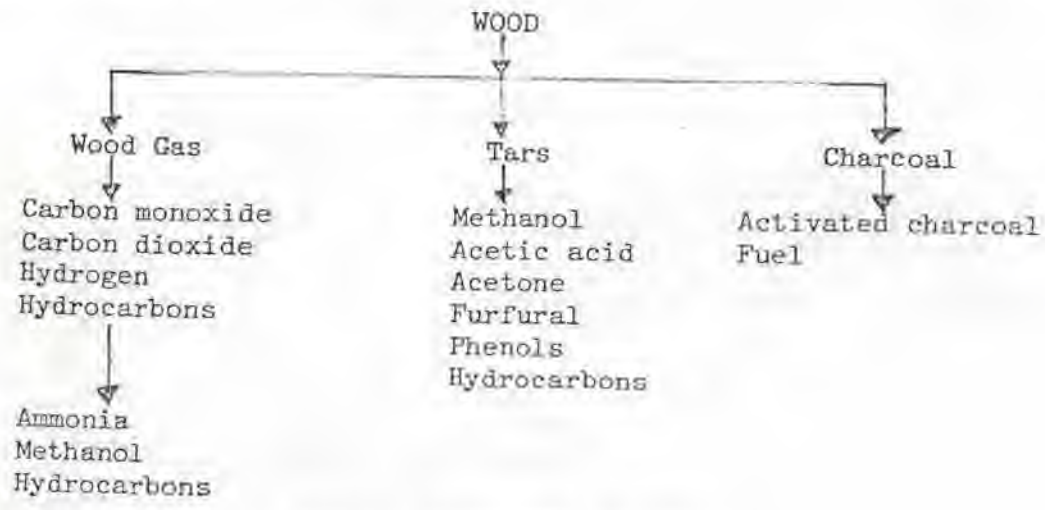



FIG.1. PYROLYSIS OF WOOD

Catalytic hydrogenation at high temperatures and under high pressure converts wood into low molecular weight hydrocarbons, phenols and cyclohexanol derivatives. Hydrogenation is an expensive process and it is unlikely to attract commercial interest.

HYDROLYSIS

The cellulosic and hemicellulosic components of wood can be hydrolysed to sugars for further conversion to chemicals. Although processes for the acid hydrolysis of wood have not gained widespread acceptance outside the Soviet Union, they are being actively investigated elsewhere.

Enzymatic hydrolysis is also receiving attention but it is handicapped to some extent by the inaccessibility of the cellulose to the enzyme, because of the presence of lignin and the crystallinity of cellulose. For this reason, acid prehydrolysis followed by enzymatic hydrolysis is considered as an alternative route to wood saccharification.

The most common products which can be obtained from the hydrolysis of wood are given in Figure 2. One fermentation product which has attracted a great deal of interest is ethanol, because of the ease with which can be converted to ethylene and butadiene; thus most chemicals produced by the petrochemical industry can also be derived from ethanol, which has the added advantage that it can be used as a liquid fuel for transport.

The wood availability and the economic aspects for the production of chemicals and fuels from lignocellulosic materials in Australia have been dealt with in two recent publications (5,6) by CSIRO officers.

An alternative biological route is that of digestion or anaerobic fermentation, in which the organic matter is broken down by bacteria, at relative low temperatures 20-60°C under oxygen free conditions, to produce biogas rich in methane. By varying the conditions the composition of the gas mixture can be changed and, by selection of appropriate bacteria, volatile fatty acids may be produced. However lignin is not digested anaerobically by bacteria.

BY-PRODUCTS FROM PULPING PROCESSES

Chemical pulping of wood furnishes a variety of organic by-products. Chemicals such as lignin, tall oil, turpentine, carboxylic acids and phenols are obtained from kraft pulping whereas sulphite pulping provides by-products such as lignin sulphonic acids, sugars, acetic acid and other compounds. Herrick and Hergert (2) have described the sulphite pulping

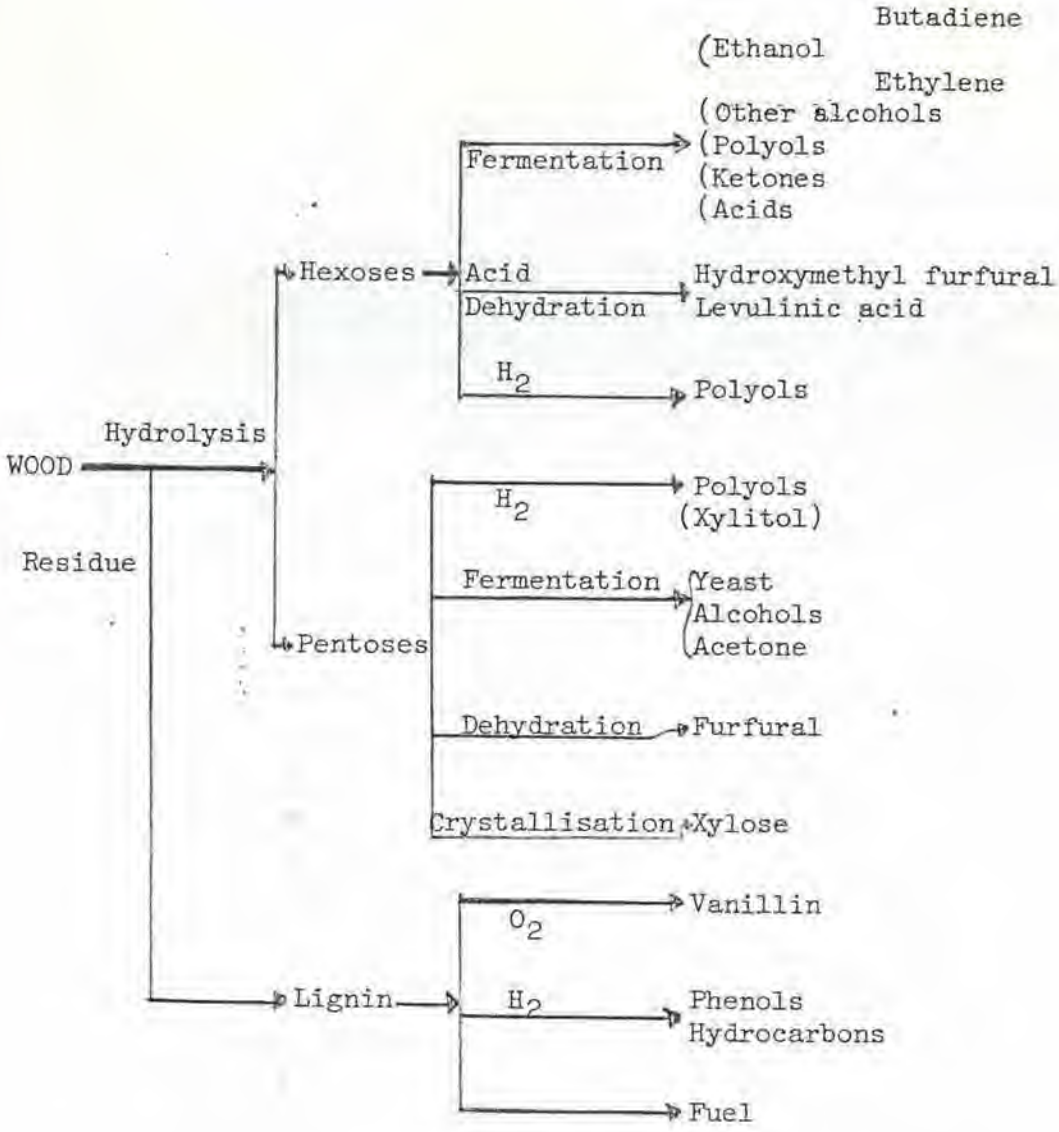



FIG.2. HYDROLYSIS PRODUCTS FROM WOOD.

route in terms of potential for the production of chemicals from wood and Myerly and his co-authors in a recent publication (4) proposed a system for the total utilization of biomass based on organosolv pulping.

SILVICHEMICALS

Many silvichemicals have found applications in industry, although many others so far are only of academic significance. Chemicals derived directly from trees are obtained by steam distillation, solvent extraction, and tapping, depending on their chemical nature.

The production of chemicals from trees in Australia is limited to eucalyptus oil, sandalwood oil from *Santalum spicatum*, sandarac resin from *Callitris columellaris*, methyl eugenol from *Dacrydium franklinii*,

and rutin from Eucalyptus species. Hillis (7) has recently reviewed the potential of eucalypts for the production of chemicals. The tannins are a large group of water-soluble organic compounds which are widely distributed throughout the plant kingdom and have a long history in the manufacture of leather and other uses. In Australia *Eucalyptus wandoo* was used commercially for the production of vegetable tanning material, but the operation ceased some five years ago. Also, the polyphenols from the bark of *Acacia* species, *Pinus radiata* and the wood of *Schinopsis lorentzii* have received attention for the production of wood adhesives. The use of tannins for adhesives in Australia has been under investigation for some time (8).

Rosin and turpentine derived from pines and often referred to as naval stores, have the largest volume and value of all silvichemicals and the naval stores industry has managed to survive the challenge from petrochemicals. In Australia there is no naval stores industry and all rosin and turpentine for industrial use is imported. In New Zealand there is an annual production of 10,000 tonnes of tall oil and 3000 tonnes of sulphate turpentine. It has been announced recently that a major wood chemicals plant will be built in New Zealand to fractionate crude tall oil and crude sulphate turpentine.

There are three types of naval stores: gum naval stores obtained from the oleoresin exudate of the living pine tree, wood naval stores obtained from pine stumps from which the sapwood has rotted away and sulphate naval stores which are produced as by-products in kraft pulping. The production of gum rosin and turpentine in western countries is decreasing because of labour costs and the same applies to wood rosin and turpentine because the industry is faced with a source problem as the pine stumps become exhausted. The production of crude tall oil is increasing. Oleoresin is essentially a solution of resin acids in turpentine, while wood rosin consists of resin acids, fatty acids and a neutral fraction. Tall oil is fractionated into tall oil rosin, tall oil fatty acids and other minor fractions. The major constituents of the turpentine fraction are α-and β-pinene. Minor constituents include other terpenes depending on the source.

Rosin, tall oil and turpentine are used in various industries (Table 3) and one can confidently assume that the great variety of products derived from petrochemicals can also be derived from turpentine and rosin. In a paper on the feasibility of petrochemical substitution by oleoresin, Collier (9) reported possible new areas for large volume industrial

TABLE 3.
Uses Of Naval Stores

| Rosin | Tall Oil Fatty Acids | Turpentine | |
|---|---|---|---|
| Paper sizing | Protective coatings | Organic syntheses | Vitamins E and A |
| Synthetic rubber | Soaps | Perfumes | Synthetic pine oil |
| Adhesives | Detergents | Polyterpene resins | Sealants |
| Coatings | Flotation agents | Adhesives | Inks |
| Inks | Intermediate chemicals | Rubber cements | Varnishes |

chemicals. Oleoresin is a particularly promising source of alternative chemical raw materials in areas such as synthetic lubricants used to produce engine oils, polyurethane foams for rigid coatings, isoprene for synthetic rubber and pressure sensitive adhesives.

*Pinus radiata* is unique amongst commercially grown pines in that its turpentine fraction consists mainly of α-and β-pinene in the approximate ratio 1:2. In most pines α-pinene is the principal constituent of turpentine and usually the turpentine fraction is somewhat more complex because of the presence of minor constituents. β-pinene is always in demand because it is particularly good as a starting compound for the synthesis of many commercial products. The application of small amounts of paraquat to *P. radiata* brings about a large increase in oleoresin production. In studies on paraquat-induced resinosis in *P. radiata* at the CSIRO Division of Chemical Technology (10-14), investigations were carried out on the effect of paraquat application, the distribution and chemical composition of oleoresin, the methods of application, the dose effect of paraquat, the dominance and age of trees, the seasonal effects and duration of resinosis, and on the oleoresin yields. The oleoresin yields obtained from *P. radiata* trees in Mt. Macedon, Victoria are given in Table 4. Special equipment has been manufactured in U.S.A. for the application of chemical stimulants to pines, and the application of paraquat to pines, in order to increase oleoresin yields, has become a commercial operation in U.S.A. (15).

TABLE 4.

Oleoresin, rosin and turpentine yields* (odb) (From Ref.13)

| Tree-Section | | Oleoresin (%) | Rosin (kg) | Rosin (%) | Turpentine (l) | Turpentine (ml/100g) |
|---|---|---|---|---|---|---|
| A1 | A | 14.6 | 3.99 | 9.7 | 1.97 | 4.9 |
| | B | 3.1 | 1.18 | 2.0 | 0.68 | 1.1 |
| | C | 7.8 | 5.17 | 5.2 | 2.65 | 2.6 |
| A18 | A | 14.4 | 3.00 | 9.7 | 1.43 | 4.7 |
| | B | 3.1 | 1.00 | 1.9 | 0.61 | 1.2 |
| | C | 7.3 | 4.00 | 4.8 | 2.04 | 2.5 |
| A22 | A | 19.1 | 3.10 | 13.2 | 1.39 | 5.9 |
| | B | 4.7 | 1.07 | 3.1 | 0.58 | 1.6 |
| | C | 10.5 | 4.17 | 7.1 | 1.97 | 3.4 |
| A38 | A | 16.1 | 1.17 | 10.0 | 0.72 | 6.1 |
| | B | 3.2 | 0.38 | 2.0 | 0.23 | 1.2 |
| | C | 8.1 | 1.55 | 5.0 | 0.95 | 3.1 |
| A40 | A | 13.3 | 2.28 | 8.7 | 1.20 | 4.6 |
| | B | 2.7 | 0.86 | 2.0 | 0.30 | 0.7 |
| | C | 6.8 | 3.14 | 4.6 | 1.50 | 2.2 |
| A47 | A | 16.2 | 2.14 | 11.6 | 1.25 | 4.6 |
| | B | 3.5 | 0.73 | 2.5 | 0.30 | 1.0 |
| | C | 9.2 | 2.87 | 6.0 | 1.55 | 3.2 |
| B5 | A | 13.7 | 1.81 | 9.2 | 0.88 | 4.5 |
| | B | 2.1 | 0.56 | 1.7 | 0.14 | 0.4 |
| | C | 6.4 | 2.37 | 4.5 | 1.02 | 1.9 |
| B6 | A | 19.9 | 3.21 | 12.7 | 1.81 | 7.2 |
| | B | 4.2 | 1.35 | 2.8 | 0.67 | 1.4 |
| | C | 9.6 | 4.56 | 6.2 | 2.48 | 3.4 |
| B7 | A | 10.4 | 2.40 | 7.1 | 1.13 | 3.3 |
| | B | 3.1 | 1.68 | 2.3 | 0.56 | 0.8 |
| | C | 5.4 | 4.08 | 3.8 | 1.69 | 1.6 |
| B8 | A | 21.2 | 3.00 | 13.7 | 1.64 | 7.5 |
| | B | 4.0 | 1.28 | 3.1 | 0.36 | 0.9 |
| | C | 10.8 | 4.28 | 6.8 | 2.00 | 3.2 |

* A series trees are 12 years old.

B series trees are 27 years old.

Sections: A(-)0.2m to 2m; B 2m - 8m and C (-)0.2 to 8m.

Distances in m from treated area.

odb - oven dry basis

1. Goldstein, I.S., 1975. Potential for converting wood into plastics, Science, 189, 847-852.

2. Herrick, F.W., and Hergert, H.L., 1977. Utilization of chemicals from wood, in Recent Advances in Phytochemistry, (Ed. F.A. Leowus and V.C. Runeckles), 11, 443-515.

3. Soltes, E.J., 1980. Pyrolysis of wood residues, Tappi, 63 (7), 75-77.

4. Myerly, R.C., Nicholson, M.D., Katzen, R, and Taylor, J.M. 1981. The forest refinery, CHEMTECH, 186-192.

5. Morse, R.N., and Siemon, J.R. 1976. The role of forests as a source of solar energy. J. Inst. Wood Sci. 7 (4), 37-42.

6. Stewart, G.A., Nix, H.A., Gartside, G., Rawlings, W.H.M., Gifford, R.M. and Siemon, J.R., 1979. The potential for liquid fuels from agriculture and forestry in Australia. CSIRO, Australia.

7. Hillis, W.E. 1978. Chemicals, in Eucalypts for wood production (Ed. W.E. Hillis and A.G. Brown), CSIRO, Australia.

8. Plomley, K.F., Gottstein, J.W. and Hillis, W.E. 1957. Tannin-formaldehyde adhesives for wood. CSIRO For. Prod. Newslett. No.234: 6-8.

9. Collier, T.J. 1977. Feasibility of petrochemical substitution by oleoresin, L.R.C.C., Proceedings, 172-186.

10. Sioumis, A.A. and Lau, L.S. 1976. Paraquat-induced resinosis in *Pinus radiata* Part 1. The effect of paraquat on *P. radiata*. Appita, 29 (4), 272-275.

11. Sioumis, A.A. 1976. Stimulation of resin formation in *Pinus radiata*. CSIRO Div. Chem. Tech. Res. Review, 58-67.

12. Sioumis, A.A.,Tham, S.H. and Lau, L.S. 1977. Paraquat-induced resinosis in *P. radiata*. Part 2. Distribution and chemical composition of the resin. Appita 30 (5), 401-404.

13. Sioumis, A.A., Smelstorius, J.A. and Lau, L.S. 1979. Paraquat-induced resinosis in *P. radiata* Part 3. Factors Influencing oleoresin yields. Appita, 33 (3) 189-194.

14. Davies, G.W. and Carrodus, B.B. 1978. Anatomical studies on paraquat treated *Pinus radiata* Appita 31 (5), 359-364.

15. Fajans, R.G. 1980. Hercules Pinex Program. Naval Stores Review, 90 (6) 11-13.

# LIQUID FUELS FROM WOOD

H. G. Higgins

CSIRO Division of Chemical Technology

## ABSTRACT

Lignocellulose in the form of wood and agricultural residues is attracting increasing interest as a possible source of liquid fuels and chemicals for various reasons: the impending depletion of crude oil supplies, the advantages of using renewable plant material in relation to arresting the serious rise in atmospheric carbon dioxide levels, and the abundance of lignocellulose compared to substrates such as sugar or starch, which can also be used as food. The two principal routes to liquid fuels are gasification followed by catalytic conversion of carbon monoxide and hydrogen to methanol, and acid hydrolysis of the polysaccharides followed by yeast fermentation to ethanol. In terms of current technology, the economics of producing ethanol from wood sources appears to be unfavourable, but a considerable number of new possibilities are emerging for process improvement and cost reduction. These include pretreatments to facilitate enzyme hydrolysis or direct fermentation, bacterial enzyme hydrolysis, utilization of pentosans, bacterial fermentation, the use of immobilized enzymes, application of recombinant DNA technology, thermophilic fermentation, new ethanol/water separation processes and the production of lignin byproducts. A strategy is outlined for research on ethanol from lignocellulose.

## CONTENTS

| | Page |
|---|---|
| Introduction | 2 |
| Broad approaches | 4 |
| Gasification and pyrolysis | 4 |
| Hydrolysis/fermentation | 5 |
| Direct fermentation | 6 |
| Conventional hydrolysis/fermentation routes to ethanol | 7 |
| Acid hydrolysis | 7 |
| Enzyme hydrolysis | 9 |
| Yeast fermentation | 10 |
| Possibilities for process improvement and lower costs in ethanol production | 10 |
| Pretreatments | 10 |
| Bacterial enzyme hydrolysis | 11 |
| Utilization of pentosans | 12 |
| Bacterial fermentation | 12 |
| Immobilized enzymes | 12 |
| Thermophilic bacteria | 13 |
| Recombinant DNA | 13 |
| New ethanol/water separation processes | 13 |
| Utilization of lignin | 13 |
| Research strategy for ethanol from lignocellulose | 13 |
| References | 15 |

## INTRODUCTION

The use of biomass as a source of liquid fuels is rapidly emerging as a real possibility for meeting, or helping to meet, the shortages which will inevitably develop as the world's annual production of oil begins to dwindle. It was estimated in 1978 that, as quoted by Stewart et al. (1), 12 million PJ of crude oil still remained ($\sim 2 \times 10^{12}$ barrels), 7 million PJ of which had still to be discovered, and that the decline in production would start around the turn of the century. The world's oil is a resource which is both finite and non-renewable (at least against the scale of human existence), and it is probable that the discovery of new reserves can only alter the time-scale of depletion by a generation, at the most.

Coal is often portrayed as a potentially cheap solution to the problem of providing a suitable substrate for conversion to liquid fuels. However the accelerated use of fossil fuels, whether coal, oil or natural gas, is fraught with a possibly disastrous environmental hazard in that it will undoubtedly lead to further increases in atmospheric carbon dioxide levels. Renewable plant resources, on the other hand, produce on burning the same amount of carbon dioxide as they have withdrawn from the atmosphere during photosynthesis. With coal, the carbon released has been fixed a very long time ago, more than 200 million years for the higher grade deposits. Should the suspected consequences of rising carbon dioxide levels be confirmed by research now in progress, e.g. within the CSIRO Division of Atmospheric Physics, it may be necessary for the industrial nations to enter into a moratorium on the accelerated use of fossil fuels. Of course this problem is a world-wide one, which Australia alone could do little to solve. However it should be more widely realized that the possible consequences of rising carbon dioxide levels are taken extremely seriously by a large body of expert scientific opinion. The possible role of biomass as an alternative to fossil fuels should also be more widely appreciated.

Carbon dioxide can also be produced in processes for the production of liquid fuel from biomass, e.g. fermentation, but again it is formed from carbon fixed by photosynthesis.

In assessing the potential for liquid fuels from biomass in Australia, both agriculture and forestry must be taken into account. As far as

the abundant lignocellulose resource is concerned, only residues need to be considered in the agricultural scene. The potential surplus resources available in Australia, in Mt(dry weight)/year, as estimated by G A Stewart (personal communication) are: cereal straw (wheat, barley, sorghum, oats, rice, maize) - 15.8; sugarcane bagasse - 0.6 (at present), 1.6 (improved technology); sugarcane field residues - 2.7; rice hulls - 0.1; oilseed straw - 0.4; cotton stalks - 0.1; fruit tree and vine prunings - 0.3; fruit stones - 0.002.

In the forest industries, both residues and plantation-grown trees can be considered for energy production. Residues embrace a wide variety of materials, including thinnings, logging wastes such as tops and branches, sawmill offcuts, sawdust, hardwood bark, and chipping rejects, to which certain secondary products such as wastepaper can be added. The survey by Stewart et al. (1) indicated that the following amounts of wood could be available as a fuel source, in Mt(dry weight)/year: intensive plantations - 11, logging residues - 3.5, mill residues - 1.

Published assessments of the economics of producing liquid fuels from wood or other lignocellulosic materials have necessarily been based on well established technology, so that possibilities for cost reduction which will be mentioned later in this paper have not been taken into account. Various assumptions have been used, leading to a wide range of estimated production costs, e.g. NZ 26¢/litre of gasoline equivalent (1977 costs) for ethanol from radiata pine plantations in New Zealand (2), compared with A57¢/litre of gasoline equivalent (1975-76 costs) or A73¢/litre (1978-79) for ethanol from existing logging and mill residues and proposed fuel plantations in Australia (1). The economics of producing methanol from wood has been the subject of considerable study, and with conventional technology its cost appears from Australian estimates (1) to be only about half that of ethanol, whereas on New Zealand estimates the costs are similar (2).

The introduction of new technology can drastically change the production economics. At present there is perhaps more scope for radical improvement in the processes leading to conversion to ethanol than in other areas. Two further points should be borne in mind: (a) agricultural residues and wood should be considered together in any conversion scheme; (b) the possibilities for producing useful chemicals should be given as much

consideration as those for producing liquid fuels. A research strategy which embraces these and other points will be outlined later in this paper.

## BROAD APPROACHES

Wood and other forms of lignocellulosic biomass can be converted to liquid fuels or chemicals by the following routes: (a) gasification and/or pyrolysis, (b) hydrolysis followed by fermentation, (c) direct fermentation.

## GASIFICATION AND PYROLYSIS

The processes of thermal degradation include a variety of pyrolytic and gasification techniques, with and without the addition of gases such as oxygen, hydrogen or steam. Products include char, oils, tars, hydrogen, carbon monoxide and methanol, and process heat. Producer gas formed by pyrolysis-gasification of relatively dry biomass may eventually offer a possible alternative to liquid fuels for vehicles. It has been shown that carbon in biomass is much more reactive than carbon in coal, and the hydrogen and oxygen content of biomass is so high that steam or oxygen do not need to be added. Rapid heating of finely ground biomass in a carrier gas stream can achieve nearly complete gasification in milliseconds, and G A Stewart has recently concluded that conceptually it appears possible to build small clean gasifiers operating on finely ground biomass for use with diesel, spark ignition or Stirling engines.

Methanol can be produced from biomass by gasification and subsequent catalytic conversion of the synthesis gas - a mixture of carbon monoxide and hydrogen. The technology of gasification and pyrolysis of biomass, including the route to liquid fuels, has been discussed recently by Gartside, Smith and Playne (3). If required methanol can be further converted to hydrocarbons (4) by the use of a special zeolite catalyst (the Mobil process). Alternatively synthesis gas can be converted to a mixture of hydrocarbon fuels by FischerTropsch reactions, using iron catalysts at medium pressures.

Oils produced by pyrolysis have been considered (5) as diesel substitutes. However modification is required to improve fuel volatility and to overcome corrosive and gumming tendencies. Phenolic materials may be extracted for adhesive applications.

HYDROLYSIS/FERMENTATION

Hydrolysis of wood polysaccharides to sugars can be carried out by acids or enzymes, and the sugars can be fermented to ethanol and a variety of other products, such as isopropanol, acetone, butanol, acetic acid, propionic acid, butyric acid, higher fatty acids, 2,3-butanediol and methane. Acid hydrolysis has been regarded as the more economically attractive method for converting cellulose and hemicelluloses to hexoses and pentoses (6), but it normally has the disadvantage that degradation products (primarily furfural and hydroxymethyl furfural) are formed during the reaction. Dilute acids may be employed at elevated temperatures, or concentrated acids at lower temperatures. Enzymes can also be used to hydrolyse cellulose, but the presence of lignin is often a barrier to the enzyme action.

Fermentation of the sugars to ethanol is traditionally accomplished by yeast, but other possibilities are emerging which may prove to be more efficient.

The production of ethanol from lignocellulosic materials, although still quite expensive, may eventually prove to be attractive for the following reasons.

(a) Lignocellulosic materials, including wood and agricultural residues, are far more abundant than the more easily fermented substrates such as sugar or starch, which also have the disadvantage that their use as fuel or chemicals competes with their use as food.

(b) As a liquid fuel aqueous (95%) ethanol can be used satisfactorily in blends with petrol in spark-ignition engines without engine modification, possibly in proportions up to 20% ethanol with super grade petrol (7).

(c) The high octane rating of ethanol fuels can contribute to the elimination of lead additives from ethanol-petrol blends.

(d) Ethanol is a convenient feedstock for conversion to chemicals, including ethylene, which forms the basis of the plastics industry.

(e) Even with diesel engines, anhydrous ethanol could possibly be used (7) in low concentrations (less than 10%); a better approach is to incorporate, in addition to ethanol, a bridging additive, such as ethyl acetate, to provide blend stability in the presence of the minute quantities of water which are inevitably present (8).

(f) A considerable number of new possibilities are emerging for reducing the costs of conversion of wood or other lignocellulosic materials to ethanol. These include: pretreatments to facilitate hydrolysis, bacterial hydrolysis, conversion of pentosans, utilization of lignin byproducts, simultaneous hydrolysis and fermentation, bacterial fermentation, thermophilic bacteria, application of recombinant DNA techniques and improved ethanol/water separation processes.

DIRECT FERMENTATION

Another approach to the production of liquid fuels from biomass is being pursued in the Division of Chemical Technology (9). This involves the anaerobic bacterial fermentation (10) of cellulosic materials to volatile fatty acids (VFA), separation of the VFA from the fermenter effluent by carrier-mediated transport through synthetic polymer membranes (11) and subsequent conversion to ketones, e.g. by pyrolysis of calcium salts of VFA. Anaerobic fermentation has a greater potential than conventional fermentation to ethanol to convert biomass energy to a useful form. Three steps can be identified (10) in the anaerobic fermentation process: (i) the cellulase enzymes of cellulolytic bacteria hydrolyse the cellulosic materials to sugars, (ii) the sugars are fermented to VFA and carbon dioxide, and (iii) methane is formed by slow-growing methanogenic bacteria. The VFA may include acetic, propionic, butyric, valeric and hexanoic acids, and a study using pure cultures of Clostridium species is being carried out in collaboration with the Department of Microbiology, University of Melbourne to devise a commercially viable scheme to produce hexanoic acid. Means of overcoming product inhibition of microbial growth during VFA fermentations are also being investigated. Playne (10) has shown that the biochemical pathways leading to propionic acid as the major product have the highest conversion efficiencies, the thermodynamics of the overall reaction are the most favourable and the energy value of the product, propionic acid, is greater than that of acetic acid.

Many factors influence the yield of VFA and the proportions of the various acids, e.g. nutrient supply, loading rate, retention time, pH, temperature, the presence of methane inhibitors or antibiotics, osmotic pressure, feeding pattern, sporadic oxygenation and liquid flow rate (10). VFA production is not limited to hexose fermentation, as in conventional yeast fermentation to ethanol, it does not require aseptic

conditions, and as the nature of the VFA is determined by environmental conditions which can be controlled, the process has considerable flexibility.

The major cost factors, and uncertainities, seem to lie in the separation process (11), and to be critically dependent on the assumptions made regarding membrane cost per unit area, membrane life, and the average transfer rate of acid. The possibility of modifying conventional processes such as solvent extraction is also being explored.

## CONVENTIONAL HYDROLYSIS/FERMENTATION ROUTES TO ETHANOL

The first step in producing ethanol from wood or other lignocellulosic materials is to degrade the polysaccharides to fermentable sugars, mainly glucose. A recent brief review of wood hydrolysis by Goldstein (12) gives an excellent summary of the present state of the art under the following headings.

- Acid hydrolysis
  - Dilute acid
  - Concentrated acid
    - Hydrochloric acid
    - Sulphuric acid
- Enzymatic hydrolysis
  - Mechanism
  - Production of cellulases
  - Saccharification
- Barriers to cellulose hydrolysis

This breakdown covers the conventional possibilities, including the routes which have been most used commercially, viz. dilute sulphuric acid at elevated temperatures and concentrated hydrochloric acid at lower temperatures.

### ACID HYDROLYSIS

The dilute acid hydrolysis of cellulose is a heterogeneous reaction and its rate is normally orders of magnitude lower than that of the cleavage of 1-4β linkages in oligosaccharides or simple glycosides. Intermolecular hydrogen bonding between the linear cellulose chains, associated with the presence of crystalline regions, is usually regarded as the reason for resistance to hydrolysis. Starch is much more readily

hydrolysed than cellulose, not because of any great difference between the chemical reactivity of 1-4α and 1-4β linkages, but because α-glucose in the pyranose chair conformation, with its axial hydroxyl group at $C_1$, cannot form linear polymers as β-glucose can, with its equatorial hydroxyl group at $C_1$. Hence lateral association of amylose chains, and crystallinity, is prevented; the presence of amylopectin with its chain branching probably contributes further to starch hydrolysability.

Glucose can be readily fermented to ethanol through a variety of biochemical pathways involving the formation by ATP of glucose-6-phosphate as the first step. $C_5$ substrates, however, only enter pathways which do not lead to ethanol production (13). For this reason the nature of the hemicelluloses is highly relevant to the ethanol yield by the hydrolysis/fermentation route. A prehydrolysis may be used to remove hemicelluloses which, being both non-crystalline and of lower DP than cellulose, are more easily hydrolysed to sugars. For angiosperms the main sugar obtained by prehydrolysis is xylose; for gymnosperms, mannose (the $C_2$ epimer of glucose), glucose itself and some galactose (the $C_4$ epimer) are the principal components of the prehydrolysate.

Glucose formed during slow dilute acid hydrolysis is subject to significant degradation, but higher temperatures favour the hydrolysis rather than the glucose degradation (14) so that higher yields are obtained. However the use of concentrated acids at lower temperatures eliminates degradation reactions. The cellulose is rapidly dissolved, so that random cleavage of the 1-4β glycosidic linkages takes place as a homogeneous reaction to give an almost quantitative yield of glucose. The disadvantages of concentrated acid hydrolysis are the need for corrosion-resistant equipment and higher costs associated with the recovery and replacement of acid (12). Both concentrated hydrochloric and sulphuric acids have been used in commercial processes for wood hydrolysis, but hydrochloric has been preferred on account of its volatility and greater ease of recovery than sulphuric acid.

The following is a list of some of the main features of commercial or near-commercial processes for acid hydrolysis of wood, adapted from Goldstein (12).

| PROCESS | ACID | TIME (s) | TEMPERATURE (°C) | YIELD | OPERATION |
|---|---|---|---|---|---|
| Scholler | 0.5-0.8% $H_2SO_4$ | | 140-190 | | Successive percolations, with cooling |
| Madison (15) | | | | | As for Scholler, but continuous |
| Grethlein (16) | 1% $H_2SO_4$ | 15 | 230 | 50 | Continuous; plug-flow reactor |
| Bremmer (17) | 0.5% $H_2SO_4$ | 20 | 230 | 60 | Twin-screw extruder |
| Bergius | 41% HCl | | ambient | 30 | Countercurrent |
| | HCl gas | | | | Various types; pilot plants only |
| Hokkaido (18) | 80% $H_2SO_4$ | | ambient | | Recovery by diffusion dialysis (ion-exchange membrane) |
| Riga (19) | conc. $H_2SO_4$ | | | | Mechanochemical treatment |
| Tsao et al. (20) | conc. $H_2SO_4$ | | | | Solution, precipitation, hydrolysis |

ENZYME HYDROLYSIS

The study of the preservation of wood against decay has given impetus to the understanding of the mechanisms involved in cellulose degradation by fungi. Recent work by Eriksson et al. with the white rot Sporotrichum pulverulentum (21) suggests that the rate limiting steps in fungal degradation of wood are the enzymic reactions for degradation of the polymeric wood components rather than the rate of growth of the fungal hyphae. The enzyme mechanisms responsible for cellulose degradation have been studied in S. pulverulentum and in the mould Trichoderma reesei (T. viride QM6a and strains derived from it). It is now well established (21) that the hydrolytic attack is carried out by three different types of enzymes viz. endo- and exo-1,4β-glucanases and 1,4β-glucosidases. Crystalline cellulose is not attacked by either endo- or exoglucanases alone, but they can cooperate to degrade highly crystalline cellulose, even when the glucanases originate from different organisms (21).

The T. reesei enzyme system has hitherto been considered as a promising means of enzyme saccharification of cellulose because the enzymes are produced in higher amounts than other organisms so far studied (21). Under optimum conditions of substrate concentration, pH, temperature and oxygen content more than 2% soluble protein, mostly cellulase, can be produced in a culture broth with cellulose as substrate. At present hydrolysis by fungal enzymes appears to be far from economic. Difficulties encountered in the process include the low rate of hydrolysis of crystalline regions of the cellulose, compared to the amorphous regions, the presence of lignin, which may inhibit hydrolysis completely, inhibition by cellobiose formed during the reaction, inhibition of cellobiase activity by glucose, thermal inactivation of the cellulases, the adsorption of enzymes on solid hydrolysis residues, leading to difficulties in recycling (12), and the cost of enzyme production.

### YEAST FERMENTATION

Traditional sugar fermentations use strains of the yeast Saccharomyces cerevisiae in low-temperature batch processes. This is considered (22) to be too inefficient for large scale fuel production, and continuous processes have been designed with fast-flow fixed-bed reactors. Glucose can yield theoretically about half its weight in ethanol, but less is obtained in practice because of yeast growth and the formation of side products such as glycerol and organic acids. Fermentation is usually carried out near 30°C and with an initial pH of 4 to 5 (23).

## POSSIBILITIES FOR PROCESS IMPROVEMENT AND LOWER COSTS IN ETHANOL PRODUCTION

### PRETREATMENTS

Wood or other forms of lignocellulose may be treated in various physical, chemical or biological ways to increase accessibility to acids or enzymes. Work by V P Puri in this laboratory, in association with G Pearce of the Faculty of Agriculture and Forestry, University of Melbourne, has been concerned with pretreatment of wheat and rice straw, sugarcane bagasse, a hardwood (Eucalyptus regnans) and a softwood (Pinus radiata). Particular attention has been paid to the application to this problem of the explosion digester system developed by Mamers et al. (24,25) with extremely promising results, both in relation to the

VFA project mentioned earlier (10) and in enhancing cellulase digestibility in vitro. Other systems involving explosive depressurization are the Iotech (26), Stake (27) and General Electric (28) processes. In the Iotech process lignocellulosic residues are heated for 20-80 s at 210-240°C and pressures up to 5.1 MPa. The Stake process operates continuously at lower temperatures and pressures, 200-210°C and 1.5-1.7 MPa, and requires a longer time, 5-20 min. The General Electric process is similar to the Stake process, but a batch reactor is used, and chemicals may be present. A substrate may be produced from hardwood which is fermented directly to ethanol at 60°C by a mixed culture of the thermophilic bacteria Clostridium thermocellum and C. thermosaccharolyticum. The first of these solubilizes cellulose and converts cellobiose to ethanol, while the second enhances the rate of cellulose degradation and allows xylose formed during pretreatment to be fermented also. The cost of 95% ethanol produced in a 30 million gallon(US)/year plant was estimated to be US$1.05/gallon (1979). A cost for pure ethanol of about $US1.25/gallon was considered to be achievable. Favourable as these estimates are, it was pointed out that ethanol yield and tolerance of microorganisms would have to be increased to justify the assumptions made in the cost estimates.

After explosive treatments of wood and agricultural residues, the yield of glucose in enzyme hydrolysis is very high, exceeding 95% (6).

Treatment with dilute sulphuric acid (0.09 N) at 120°C for 1 hour has been used (6) to remove pentosans without affecting the cellulose significantly. The treatment sterilizes the material prior to enzyme hydrolysis and improves the yield and rate of hydrolysis.

Physical pretreatments other than explosive depressurization, including various types of milling, have been used to enhance enzyme saccharification at the US Army research establishment at Natick, Massachusetts (6). With a hardwood (poplar) two-roll milling appeared to be the most effective.

## BACTERIAL ENZYME HYDROLYSIS

Most work on enzyme hydrolysis of cellulose has been concerned with enzymes from the fungus Trichoderma reesei. However recent studies (29) with a highly cellulolytic Cellulomonas bacterium subjected to a

series of mutation and selection procedures has shown considerable promise. Mutants have been isolated with increased ability to form both endo- and exoglucanases and β-glucosidases, and hence to decrystallize and saccharify cellulose. Experiments with bagasse showed a four-fold increase in the rate of enzyme production, compared with T. reesei.

## UTILIZATION OF PENTOSANS

G Tsao and his colleagues at Purdue University are leaders in the field of xylan utilization. One approach is to convert xylose, produced by hydrolysis of xylan, to xylulose, which is then fermentable. Various hydrolysis schemes have been developed for extracting pentose sugars from the hemicelluloses of agricultural residues, and somewhat similar methods should be applicable to hardwoods.

Xylose can be used as an energy source for ethanol production by certain thermophilic bacteria, such as Clostridium thermohydrosulfuricium (30), for which optimum growth takes place at 65°C, and C. thermosaccharolyticum, which was mentioned above.

In wood, the hemicelluloses can yield about half as much sugar as the glucose derived from the cellulose fraction, so their utilization can have a very large effect on production costs.

## BACTERIAL FERMENTATION

In ethanol fermentation, the use of suitable strains of the bacterium Zymomonas mobilis was found by Rogers et al. (31) to lead to higher specific rates of glucose uptake and ethanol production than the yeasts used at present. The rates are stated elsewhere to be two to three times greater than for yeast (32).

## IMMOBILIZED ENZYMES

Attaching yeast to a support can result in a rate of conversion from sugar to ethanol that is up to nine times greater than when the yeast is free to move (32). Columnar reactors containing immobilized cells of Zymomonas mobilis have also been employed for the continuous production of ethanol from glucose (33). Cells were immobilized by flocculation and by glass fibre pads, the greater productivity of ethanol being observed in the flocculant type of bioreactor.

THERMOPHILIC BACTERIA

Apart from the value of specific thermophilic bacteria in fermenting pentoses, as discussed above, thermophilic fermentation, in the vicinity of 60°C, offers other potential advantages over mesophilic reactions. Direct fermentation of both cellulose and hemicellulose from delignified biomass without depolymerizing treatments can be achieved with some organisms, which can also possess high growth and metabolic rates and lower cellular growth yield (30). The enzymes tend to show higher physical and chemical stability than in metabolically similar mesophilic species. The possibility is presented of a more stable process, with increased production rates and facilitated product recovery.

RECOMBINANT DNA

Molecular genetics, particularly recombinant DNA technology, interacts with microbial fermentation (34) and the possibilities for strain improvement are considerable. So, apparently, are the difficulties. However we may look forward, in due course, to the prospect of gene cloning being applied to the production of organisms and enzymes which may be applied to improved processes of fermentation, and perhaps, also, of hydrolysis.

NEW ETHANOL/WATER SEPARATION PROCESSES

The distillation of ethanol from aqueous mixture is an expensive and energy-consuming step in ethanol production. A novel approach to ethanol recovery from fermentation liquors is being studied in this laboratory by A A Sioumis. The results obtained so far are encouraging, and indicate that anhydrous ethanol may be obtained. The multiple distillation and fractionation steps normally involved in the production of anhydrous ethanol are avoided.

UTILIZATION OF LIGNIN

Lignin, either removed before hydrolysis of the polysaccharides, or remaining after hydrolysis, is available as a residue of the hydrolysis/fermentation process. Its beneficiation and use would have a very significant effect on the economics of the whole process of polysaccharide conversion. The hydrolysate lignin has the advantage,

for many purposes, of being sulphur-free, unlike lignin residues from kraft or sulphite pulping. Processes of lignin oxidation, pyrolysis and hydrogenolysis have the possibility of producing useful chemicals at a cost which will become more attractive as oil prices rise. Lignin polymers, preferably modified for specific purposes, also have a number of possible practical applications. These questions are being studied in this laboratory by A F A Wallis.

## RESEARCH STRATEGY FOR ETHANOL FROM LIGNOCELLULOSE

The strategy proposed for the development of a viable process for the production of ethanol from wood and other lignocellulosic materials available as agricultural residues involves the following elements.

1. Recognition of the nature of the Australian resource as being largely composed of angiosperms (hardwoods and agricultural residues) with the consequent necessity of also utilizing the xylan fraction of the polysaccharides available. Such an approach does not negate the real possibility of also utilizing gymnosperms where they are available, e.g. thinnings from softwood plantations.

2. Recognition of the economic desirability of including one or more lignin byproducts in the total production scheme.

3. Conscious drawing on the vast store of available knowledge in wood chemistry, accumulated internationally over a century and a half, and in Australia over the last sixty years, in the attainment of the above objectives.

4. Recognition that the nature of cellulose requires appropriate pretreatments to render it suitable for enzymatic hydrolysis, in relation both to its intermolecular hydrogen bonding pattern, or crystallinity, and to the effects of the presence of lignin.

5. Application of our experience in mechanical, chemimechanical, thermomechanical and chemithermomechanical pulping of wood to the problems of simultaneous or consecutive physical treatment and hydrolysis.

6. The closest collaboration with microbiologists, within the Division or the new Industrial Microbiology Unit or in outside centres, e.g. the Department of Biotechnology, University of New South Wales, particularly in relation to (i) the use of bacterial enzymes for hydrolysis, (ii)

bacterial fermentation, (iii) the use of thermophilic bacteria, (iv) recombinant DNA methodology.

7. The possibility of developing a novel, inexpensive process for separating ethanol in an anhydrous form from water, as an alternative to distillation.

## REFERENCES


1. Stewart, G. A., Gartside, G., Gifford, R. M., Nix, H. A., Rawlins, W. H. M. and Siemon, J. R. "Liquid Fuel Production from Agriculture and Forestry in Australia". CSIRO, Australia, 1979.
2. Harris, G. S. In "Proc. Fuel Ethanol Research and Development Workshop", Canberra, February 1980. Dept. Nat. Dev. and Energy, Canberra.
3. Gartside, G., Smith, B. R. and Playne, M. J. In "Proc. Nat. Conf. Fuels from Crops". Melbourne, 1981.
4. Heinemann, H. and Maziuk, J. In "Proc. Nat. Conf. Fuels from Crops". Melbourne, 1981.
5. Soltes, E. J. Tappi 63(7):75 (1980).
6. Blanch, H. "A Review of Ethanol Research at UC Berkeley and Elsewhere in the USA". Fourth Australian Biotechnology Conference, Melbourne, 1980.
7. Barnfather, E. E., Birrell, J. S. and Giannini, R. D. In "Proc. Nat. Conf. Fuels from Crops". Melbourne, 1981.
8. Meiring, P., Allan, R. S. and Lyne, P. W. L. In "Proc. Nat. Conf. Fuels from Crops". Melbourne, 1981.
9. Weiss, D. E. CSIRO Division of Chemical Technology Research Review, 1976.
10. Playne, M. J. CSIRO Division of Chemical Technology Research Review, 1978.
11. Smith, B. R. CSIRO Division of Chemical Technology Research Review, 1979.
12. Goldstein, I. S. Tappi 63(9):141 (1980).

13. Wood, W. A. In "Trends in the Biology of Fermentation for Fuels and Chemicals" (Ed. A. Hollaender et al.) Plenum Press, New York, 1981.

14. Saeman, J. F. Ind. Eng. Chem. 37:43 (1945).

15. Lloyd, R. A. and Harris, J. F. Report No 29, USDA Forest Products Laboratory, Madison, Wisconsin, reprinted 1963.

16. Thompson, D. R. and Grethlein, H. E. Ind. Eng. Chem. Prod. Res. Dev. 18(3):166 (1979).

17. Chem. Eng. News 57(41):19 (1979).

18. Oshima, M. "Wood Chemistry Process Engineering Aspects", Noyes Development, New York, 1965.

19. Karlivan, V. P. In "Proc. World Conf. on Future Sources of Organic Raw Materials", IUPAC, CIC, ACS, Toronto, 1978.

20. Tsao, G. T., Ladisch, M., Ladisch, C., Hsu, T. A., Dale, B. and Chau, T. In "Ann. Repts. in Fermentation Processes" Vol.2 (Ed. D. Perlman), Academic Press, New York, 1979.

21. Eriksson, K.-E. In "Trends in the Biology of Fermentations for Fuels and Chemicals" (Ed. A. Hollaender et al.) Plenum Press, New York, 1981.

22. Rabson, R. and Rogers, P. "The Role of Fundamental Biological Research in Developing Future Biomass Technologies". Submitted to "Biomass".

23. Haggett, K. In "Proc. Nat. Conf. Fuels from Crops". Melbourne, 1981.

24. Mamers, H. and Rowney, J. E. US Patent 4,163,687, August, 1979.

25. Mamers, H., Menz, D. and Yuritta, J. P. Appita 33(3):201 (1979).

26. Jurasek, L. "Developments in Industrial Microbiology, Vol.20", 1979 (Chem. Absts. 91:176850v 1979).

27. Bender, R. US Patent 4,126,267, January, 1979; Taylor, J. D. In "Energy from Biomass". Proc. Int. Conf. on Biomass, Brighton, England, 1980.

28. Brooks, R., Su, T.-M., Brennan, M. and Frick, J. In "Proc. 3rd Ann. Biomass Energy Systems Conf." 1979.

29. Gray, P. P. and Dunn, N. W. In "Proc. Fuel Ethanol Research and Development Workshop", Canberra, February 1980. Dept. Nat. Dev. and Energy, Canberra.

30. Zeikus, J. G., Ben-Bessat, A., Ng, T. K. and Lamed, R. J. In "Trends in the Biology of Fermentation for Fuels and Chemicals" (Ed. A. Hollaender et al.) Plenum Press, New York, 1981.

31. Rogers, P. L., Lee, K. J., Scotnicki, M. L. and Tribe, D. E. Fourth Australian Biotechnology Conference, Melbourne, 1980.

32. Clyde, R. In "Trends in the Biology of Fermentation for Fuels and Chemicals" (Ed. A. Hollaender et al.) Plenum Press, New York, 1981.

33. Arcuri, E. J., Worden, R. M. and Shumato, S. E. In "Trends in the Biology of Fermentation for Fuels and Chemicals" (Ed. A. Hollaender et al.) Plenum Press, New York, 1981.

34. Jackson, D A. In "Trends in the Biology of Fermentation for Fuels and Chemicals" (Ed. A. Hollaender et al.) Plenum Press, New York, 1981.

# WOOD AS A HEATING FUEL - SOME GENERAL OBSERVATIONS

R.M. Liversidge and P.Y.H. Fung
Division of Building Research, CSIRO

The rapidly escalating costs and predicted future shortages of petroleum based furnace fuels have led to a resurgence of interest in the use of wood as a fuel for both industrial and domestic purposes. As a result, there has been a world-wide mushrooming of developmental work on wood fired combustion systems and a wide range of commercial equipment is now available to handle wood fuel in its various forms and to suit most capacity requirements. In addition, developmental work on gasification and carbonization systems has also been re-stimulated and appreciable effort is being expended in these areas.

In Australia, while wood fuels are not likely to be "The answer to the energy problem" in many cases they could well represent "An answer to an energy problem". They certainly constitute an asset which can contribute to our overall energy requirements and assist in conserving our fossil fuels. In this context and in the light of the currently spiralling energy costs and the environmental consciousness of society, it is timely to reassess the role wood residues can play in providing energy for:

(a) the sawmilling industry

(b) other industries located within an economic transport distance from sawmilling areas

(c) the domestic market.

## (a) Energy for the sawmilling industry

Unlike most industries, the sawmilling industry is potentially well endowed with energy which is available from the residue it produces. To illustrate this point, a materials and energy balance has been calculated for a generalized hardwood mill of typical size (with kiln drying and planing facilties) (1). Details are given in the Appendix. Account was taken of all the material and energy that enter and leave over a given time interval of operation by all sawmilling, seasoning, planing and chipping processes. This showed that the 'typical' hardwood mill could provide all of its own

heating and electrical energy requirements by burning only 15 tonnes of residue a day out of the total residue generation of 33 t a day excluding wood chips, or 72 t a day if no woodchip outlet existed. In other words, all energy requirements could be met by burning 20-45% of the total residue production.

Hence, hardwood and softwood mills with an availability of bark and sawdust residues, are in the fortunate position of being capable of providing for much more than all of their energy needs from their residues.

(b) Energy for other industries

A number of industries other than those which are forest based also rely on sawmill residues as a fuel for all or part of their heating and steam requirements.

Currently, in Australia, these include sections of the dairy, brick, sugar and textile industries as well as a large hospital. Such usage can be expected to increase in the future where logistics permit, given the wide range of wood fired equipment now available and the fact that most of the new, wood fired equipment can be operated automatically, an option which was not generally available in the past.

Table 1 shows the relative cost per megajoule for a number of fuels based on May 1981 fuel prices and adjusted for assumed combustion efficiencies.

Wood residues are bulky and have a low calorific value. Hence the transportation costs play a very significant part in the overall cost to the user as can be seen in Table 1. Increases in calorific value and bulk density for such fuels could reduce the transport cost component in some cases, and reduce the storage and volume handling requirements. Bulk densities and energy per cubic metre for some wood residues and upgraded wood fuels are shown in Table 2.

One recent and specialized industrial use of wood residues of particular interest is the firing of modern brick kilns. Appreciable savings are already being effected in brick kilns fired with fine, dry wood particles in Tasmania, Western Australia and New South Wales. In these kilns, the dry wood fuel is metered into the ports previously used for the oil burners and the kilns can be almost entirely converted from oil to wood firing with very considerable cost savings.

(c) Energy for Domestic Uses

In recent years there has been a marked increase in the number of wood burning appliances available on the Australian domestic market. While in the city many of these units are installed for their social aspects rather than as the major source of home heating, nevertheless there are indications of an increasing demand for wood fuels in both country and city areas.

Solid wood fuel is likely to remain the most widely used domestic wood fuel in areas near forests and forest-based industries. Elsewhere, there is likely to be an increase in the domestic market for "improved wood fuels" such as briquettes or fuel logs formed from dry wood particles.

Investigations on domestic wood fired systems are being conducted at the University of Tasmania (3).

Current Research on Wood Residue Fuels and Technology
by the Forest Conversion Engineering Group, CSIRO

Work in the Forest Conversion Engineering Group has mainly centered on the conversion of timber mill residues into a suitable energy source both for the industry from which it is produced as well as for other industries wishing to use this fuel resource to reduce their oil fuel costs. Although the systems under development and the fuels being tested are based on mill residues, these could be adapted to other wood resources such as forest residues or tree cropping sources.

Three projects currently being undertaken are:

(a) Fluidized bed carbonization with heat recovery
(b) Gasification of wood in a simple close-coupled unit
(c) Charcoal/oil composite fuel.

The first of these DBR projects has the threefold purpose of residue disposal, supplying the energy requirements of the mill in both heat and electricity and upgrading the wood residue into charcoal, a valuable byproduct which can be sold. By combining these functions in the one plant, the economics becomes more attractive and the logistics of transportation are vastly improved since charcoal is a relatively high priced commodity with a calorific value three times that of green wood. When used as a fuel, it is smokeless and clean burning. These factors are important for decentralized

mills from which transport of raw residue becomes non-competitive with fossil fuels over distances in excess of 100-200 km.

The second and third projects are aimed at the replacement of part of the fuel currently being used in oil-fired installations by complementing the liquid petroleum fuel with a wood-based component. Oil is an excellent fuel having a high calorific value, being convenient for storage and enabling good control to be maintained to satisfy plant heat requirements. The ever-escalating costs of liquid fuels, however, is causing great concern to people operating oil-fired units.

The possibilities of using the energy available from wood in forms whereby it could be utilized to complement rather than replace oil in existing installations led to an examination of the following alternatives:

The use of gas generated from wood in a simple close-coupled, in-line, gas producer and burned in conjunction with a reduced quantity of fuel oil.

The use of finely powdered charcoal mixed with oil to form a composite slurry fuel capable of being handled and burnt in much the same manner as the oil alone.

(a) Fluidized bed carbonization with heat recovery (4,5)

The first project involves the development of a fluidized bed combustor for the production of charcoal from wood particles (sawdust, chips, hogged bark, etc.) while at the same time providing heat and steam for drying and other processes, and for power generation.

The material to be carbonized is fed into the hot sand bed where the volatile constituents are released and burnt leaving charcoal which can be removed from the unit by a means suited to the type of particles being carbonized. Once at operating temperature, the unit is self sustaining as the heat released by the combustion of the volatiles is sufficient to maintain the required temperature in the bed. By fitting a heat exchanger in the sand bed, heat can be extracted by circulated oil and used directly for process heating or steam generation in an unfired boiler.

Data obtained from an experimental laboratory unit were incorporated in the design of a pilot plant now under construction. This is expected to carbonize 0.5 t/h of sawdust

and chipped wood to produce both lump charcoal and charcoal fines. The plant is also designed to produce steam for kiln drying and electricity generation.

It has been estimated (5) that potential markets for charcoal in Australia, other than for heating or cooking purposes, could total some 750,000 tonnes a year.

(b) Gasification of wood in a simple close-coupled unit) (6)

One approach to complement oil in existing oil- fired installations is to add gas generated from wood into the furnace. While studies overseas suggest that gas can be used to completely replace oil in existing installations, and generally without excessive modification, in many cases it is necessary to include a dryer in the system to reduce the moisture content of the feedstock as well as a scrubber to clean the gases before they are piped to the burner thereby increasing overall costs.

Close-coupled gasifiers could overcome the need for precleaning the gases since, in such units, any condensible components of the raw gases given off are burnt before they can condense and cause fouling of pipes, burners, etc. It might be necessary in some cases, however, to remove particulate matter from the gas stream.

Work in this Division area has been aimed at developing a simple gas producing unit which would operate with either dry or green fuel and assist operators of small oil-fired equipment such as packaged boilers to economically extend the life of such equipment. Many small firms are finding the oil costs to be a major cost factor in their operations, but nevertheless would like to continue to use their existing and convenient installations, provided the overall fuel costs could be reduced or at least maintained at the present level. The unit produces gas in what is basically a hopper with a firetube fitted through it. The firetube, heated by the combustion of the oil as it is directed to the boiler, promotes the production of gas from the wood. This gas is bled into the firetube and burned along with the oil. The furnace is controlled by varying the rate of oil supply. The unit has been demonstrated in the laboratory and is soon to be tested in an industrial situation.

(c) Charcoal/oil composite fuel

Charcoal/oil slurry fuels were burnt successfully in short term trials at two plants in Australia and Papua New Guinea. Similar tests have been carried out in the USA. In the PNG tests, a 2500 kW boiler was operated on charcoal/oil mixtures in the ratios of 10:90 and 20:80 by mass (7). The slurry fuel was kept agitated by means of a mechanical

stirrer in the fuel tank and was also recirculated through the main fuel feed pump to ensure good mixing and prevent settling of the charcoal particles.

The trials conducted suggest that charcoal/oil composite fuels could be used commercially provided that some modifications were made to existing plant. Good burnout of the carbon was achieved and the plant was able to handle the charcoal/oil fuel during the short term trials with only slight modification to the control valves. However, the trials also indicated that, because of the abrasive properties of the charcoal particles, further modifications would be required if plant was to operate on the slurry fuel continuously.

It is possible that modifications might be minimized if clean oil only is fed through the normal piping and control system and combined with a heavy char/oil 'paste' just prior to the fuel reaching the burner nozzle.

The gasification and charcoal/oil composite fuel projects outlined above are mainly aimed at using residues from the timber industry to assist other industries in reducing their overall oil consumption.

## CONCLUSIONS

The forest-based industries, which are the major users of wood residue fuel should also be the suppliers of surplus fuel to other sections of industry. Residue disposal which creates pollution and represents a wasted energy resource should be discouraged. Where supplies of wood residue fuel are available, potential users should be encouraged to make as much use of it as possible thereby reducing the dependence on non-renewable fossil fuels.

Technological developments in Australia are continuing to be made in the various areas indicated in this paper.

## REFERENCES

(1) Fung, P.Y.H., Liversidge, R.M. and Lhuede, E.P. (1978). Timber industry residues as an energy source. Sixth National Chemical Engineering Conference, Surfers Paradise, 6-8 November. DBR Reprint 862.

(2) Fung, P.Y.H. and Liversidge, R.M. (1981). Wood as an industrial fuel in Australia: State of the art in wood to energy technology. NERDDC-CSIRO R&D Workshop "Production of energy from the combustion of crop and forest residues", Canberra, 7-8 July.

(3) Todd, J. (1981). The use of wood fuel for domestic purposes; The research programme ot the Univ. of Tas. NERDDC-CSIRO R&D Workshop "Production of energy from the combustion of crop and forest residues", Canberra, 7-8 July.

(4) Fung, P.Y.H. (1979). Carbonization of timber industry waste and heat recovery in a fluidized bed. Seventh Australian Conference on Chemical Engineering, Newcastle, 22-24 August. DBR Reprint 896.

(5) Fung, P.Y.H. (1981). Fluidized bed charcoal: Production, uses and energy recovery potential. Fuelwood Cropping Investment Seminar, Melbourne, 13 March.

(6) Liversidge, R.M. (1981). Wood as a fuel - some of the options available. Fuelwood Cropping Investment Seminar, Melbourne, 13 March.

(7) Blowers, M.J., Fussy, D.E., Liversidge, R.M. (1980). Evaluation of char-oil slurry combustion in a commercial boiler. Report No. 1/80, Energy Planning Unit, PNG Dept Minerals & Energy.

TABLE 1

Estimated cost of energy from various fuels*

| Fuel | Basis for costing | Gross Calorific Value kJ/kg | Assumed Combustion Efficiency | Fuel Cost c/MJ |
|---|---|---|---|---|
| Wood residue | Sawdust (green) | | | |
| | (a) Ex mill at $3.50/tonne | 10 000 | 0.60 | 0.06 |
| | (b) plus 100 km cartage+ | | | 0.15 |
| | (c) plus 200 km cartage+ | | | 0.24 |
| | Wood fuel chips (green) | | | |
| | (a) Ex mill at $6.00/tonne | 10 000 | 0.60 | 0.10 |
| | (b) plus 50 km cartage+ | | | 0.15 |
| | (c) Plus 150 km cartage+ | | | 0.24 |
| Bituminous steaming coal | At $32/tonne | 28 000 | 0.80 | 0.14 |
| Brown coal | Briquetted $31/tonne | 21 000 | 0.75 | 0.20 |
| Distillate | Duty free $337/tonne | 42 900 | 0.80 | 0.98 |
| Fuel oil | Low sulphur $240/tonne | 40 600 | 0.80 | 0.74 |
| LPG | Bulk price $252-340/tonne | 50 000 | 0.75 | 0.67-0.91 |
| Natural gas | Melb. industrial tariff: 0.17-0.45c/MJ | | 0.75 | 0.23-0.60 |
| Electricity | Melb. industrial tariff: 2.02-19.4c/kWh | | 0.95 | 0.59-5.68 |
| | (4.74c/kWh typical) | | | (1.39) |

* Adapted from Fung et al., (1978) & updated May 1981 (1,2)

\+ Assumed cartage cost 5.5c/tonne/km

TABLE 2
Bulk densities of some wood residues and upgraded wood fuels
(adapted from (2))

| Material | Bulk Density kg/m³ | Calculated Energy per cubic metre (bulk) (MJ/m³) |
|---|---|---|
| Sawdust - *P. radiata* 138% MC | 380 | 2,770 |
| - *E. regnans* 115% MC | 348 | 2,710 |
| Wood chips - Hardwood 52% MC | 389 | 4,680 |
| - " dried 3% MC | 322 | 6,090 |
| - " dried 2% MC and rumbled smooth | 398 | 7,610 |
| Charcoal - red gum, lump 8% MC | 343 | 10,100 |
| - red gum, ground 9% MC | 625 | 18,220 |

Gross calorific values for wood and a number of upgraded wood-based fuels are listed in Table 3.

TABLE 3

Gross calorific value of various wood-based fuels

| Fuel | Quantity | Gross Calorific Value (MJ) |
|---|---|---|
| Wood - Green (100% MC*) | 1 tonne | 10 000 |
| - air dry (10% MC*) | " | 18 200 |
| - oven dry | " | 20 000 |
| Charcoal | " | 32 000 |
| Pyrolytic oil | " | 23 000 |
| Char/oil** (10% char) | " | 42 500 |
| (20% char) | " | 41 600 |
| Reconstituted wood (10% M/C*) | | |
| - compacted briquettes and pellets | " | 18 000 |
| - 1:1 petroleum wax/wood logs | " | 34 900 |
| Methanol | " | 23 900 |
| Ethanol | " | 30 700 |
| Wood gas - air blast | 1 $m^3$ | 3.7- 5.6 |
| - oxygen blast | " | 11.0-14.0 |

* Moisture content, oven dry basis

** Fuel oil calorific value = 43 400 kJ/kg

Appendix

Calculated materials and energy balance for a generalized hardwood mill with kiln drying and planning facilities.

For an assumed "typical" mill over one day's operation, the log input was 94 $m^3$ (TLV under bark) with a sawn recovery of 45 $m^3$ (48%). Half the sawn output was seasoned giving a green sawn production of 22.5 $m^3$ and a seasoned, dressed board output of 16.9 $m^3$. The slabs and edging were chipped providing a woodchip production of 35.6 $m^3$ (39 tonnes). The corresponding residue production was calculated to be:- bark 13 $m^3$, green sawdust 11 $m^3$, chipper waste 2 $m^3$ and dry waste (shavings, sawdust, dockings) 6 $m^3$, giving a total of 32 $m^3$ or 33 tonnes.

Calculated energy requirements were:- sawmilling 1280 kWh, planing mill 370 kWh, chipping 186 kWh and seasoning 864 kWh for the kiln fans. Additional heat and steam for seasoning air-dried material were:- drying from 30% m.c. to 12% m.c. requiring 25,800 MJ of heat and reconditioning consuming 3420 kg of steam (8000 MJ). The overall energy requirement for the mill was therefore 2700 kWh electricity and 33,800 MJ heat.

On the other hand, energy available in the available residues has been calculated to be 311,000 MJ/day. If there is no outlet for the woodchip component, an additional 333,000 MJ would be available giving a total 644,000 MJ/day.

In order to supply the mill's total energy requirements, the residues would be burnt to raise steam to run a steam turbine generator. Additional electrical energy is needed by the combustor-boiler-power plant and depending on the system used, may amount to some 688 kWh. Furthermore, a system of bark handling may be needed such as mechanical debarking and hogging which could add a further 137 kWh thereby giving a total mill energy requirement of 3525 kWh. If exhaust steam from the steam turbine was used for seasoning then no additional boiler capacity would be required. Now assuming steam was produced at 1.48 MPa, 315°C driving a turbine operating on a Rankine cycle with a combined turbine-generator efficiency of 60% (mechanical), the steam requirement would be 28,600 kg to provide the necessary electricity. Since a combustor-boiler efficiency of about 60% can be expected, the amount of primary energy required to run the mill would be 138,400 MJ or 14.7 tonnes of residue (combined net calorific value 9410 MJ/tonne). The residue production was 33 tonnes excluding woodchips or 72 tonnes if no woodchip outlet existed (1).

# FOREST RESIDUES FOR ENERGY AND FIBRE

C.M. Kerruish,* R. Wingate-Hill* and W.H.M. Rawlins**

*Division of Forest Research, CSIRO, PO Box 4008, Canberra, ACT 2600
**Division of Chemical Technology, PO Box 1666, Canberra City, ACT 2601

## ABSTRACT

Potential sources of wood for energy and fibre are identified as: accessible 'non-merchantable' species and stands; thinnings from regrowth eucalypts and residues from existing logging operations. This paper reviews recent overseas technological innovations which are thought to be most appropriate for harvesting these un-utilised resources and for making them economically accessible.

## INTRODUCTION

Forest 'residues' exist principally because they are expensive to collect or qualitatively unsuited to a market. Increases in energy prices and perhaps different quality standards of wood for energy are encouraging the consideration of these residues for energy. From the supply side of the demand-supply equation, developments in harvesting technology are similarly encouraging the use of 'residues' for both energy and fibre. This paper describes these developments in harvesting technology which will influence residue availability.

## RESIDUES AVAILABLE

Using some gross approximations (1) estimated that total forest residues equal to 14 $Mm^3$/yr (7Mt(DW)) might be available in Australia. This volume actually equals the estimated removal of roundwood from the forest in 1978-79 (2). Stewart *et al.* (1) put these quantities of residues into an energy perspective by assuming that half might be available for conversion to methanol. As such, the methanol would contribute 2% of Australia's liquid fuel use. Thus residue utilisation might have a major impact on the logging industry and traditional forest industries but a relatively minor effect on the national energy supply or bulk chemicals.

## POTENTIALLY ACCESSIBLE RESOURCES

The major sources of additional wood for fibre or energy production are seen to be:

- non merchantable species accessible to large mills
- thinnings
- logging residues from plantations and wood chip operations in native forests.

## NON MERCHANTABLE SPECIES ACCESSIBLE TO LARGE MILLS

Probably the lowest cost sources of wood for energy are the stands or components of stands which are not used for fibre or wood. Low costs are feasible because stumpages are low or non-existent and reduced chip specification eliminates debarking and permits whole tree chipping. Because they are unmerchantable, substantial resources may be available close to mills.

## THINNINGS

Currently most of the plantation pulpwood cut is harvested as thinnings and is used for particleboard or pulp production. However, some reduction in demand for thinning can be anticipated as a result of the rapid increase in the wood available from plantations (Table 1) and the very considerable volume of mill wastes that will be generated.

Very little thinning of the native forests is currently done; pulpwood is largely obtained by the clearfelling of overmature eucalypts, but it is likely that this position will change in the future due to a number of factors including:

The relatively higher pulping properties of young eucalypt wood compared with old, overmature wood (3).

The declining availability of old growth material and the greater distance from mills of the remaining resource.

Silvicultural (4, 3), hydrological (5) and wildlife (6) reasons for manipulating the stocking of some naturally regenerated eucalypt stands.

Most of these thinnings are likely to be used for pulp and board manufacture.

The introduction of whole tree chipping and chip separation and segregation techniques, (see later sections) would be likely to change these situations, producing both coniferous and hardwood chips for pulping in substantial volumes - probably in the vicinity of 30% of the total chipped material - which would be available at the mill.

Since 1970 about a quarter of a million hectares of eucalypt forest has regenerated after clearcutting for wood chips. The previous pulp, saw logging

and unsuccessful agricultural and grazing ventures have generated further substantial areas of regrowth eucalypt forest which are potential sources of fibre and energy.

## LOGGING RESIDUES

Logging residues are generally defined as those components of the tree remaining in the forest after harvesting. Residues most likely to contribute to energy production will come from plantations and those native forests managed for woodchip production, where the residues can be harvested and transported via systems used for conventional wood products.

The predicted adoption of centralised processing by the plantation-based mills (see a later section) will generate substantial volumes of residues largely because of the expansion of softwood plantations. Table 1 gives the most recent estimates of the plantation resource and an indication of the residue which could be generated assuming various proportions of the plantation resource are processed by central processing stations. This increases the volume of residues available as logged limbs and waste wood.

TABLE 1

Potential Volumes of Plantation Pulpwood, Sawlogs and Logging Residues Recoverable at Mill $10^6$ $m^3/y$) (2)

| Year | Pulpwood & sawlogs (1) | Residues (% of 1) | | | |
|---|---|---|---|---|---|
| | | 5 | 10 | 15 | 30 |
| 1985 | 6.8 | 0.3 | 0.7 | 1.0 | 2.0 |
| 1990 | 9.7 | 0.5 | 1.0 | 1.5 | 2.9 |
| 2000 | 12.6 | 0.6 | 1.3 | 1.9 | 3.8 |

These residues would be available at the mill for the production of fibre and/or energy.

Considerable scope exists for the recovery of eucalypt stem and crown wood by small wood harvesting techniques in conjunction with mobile chippers. The volumes likely to be so recovered are difficult to predict because of the lack of data on the future native forest resource which can be expected to change substantially as younger and smaller regrowth material replaces the large overmature stands currently being logged and with no clear indication of whether bark will be removed in the forest or at the mill. However, the figures in Table 2, below, indicate the projected level of pulpwood production from native forests and four different levels of residue recovery associated with these operations.

TABLE 2

Potential Volumes of Pulpwood* and Residues from Native Forests ($10^6$ $m^3$/yr) (2)

| Year | Pulpwood (2) | Residues (% of 2) | | | |
|---|---|---|---|---|---|
| | | 5 | 10 | 15 | 30 |
| 1985 | 6.3 | 0.3 | 0.6 | 0.9 | 1.9 |
| 1990 | 6.2 | 0.3 | 0.6 | 0.9 | 1.9 |
| 2000 | 6.2 | 0.3 | 0.6 | 0.9 | 1.9 |

* includes some posts, poles, etc.

## TECHNOLOGICAL DEVELOPMENTS LIKELY TO RESULT IN INCREASED UTILISATION

A number of technological developments have occurred during the last few years which can increase the proportion of a stand which may be economically harvested. The following describes the more important developments.

### MECHANISED SMALL TREE HARVESTING AND HANDLING SYSTEMS

The harvesting of individual pieces of material less than approx. 0.2 $m^3$ in size results in a progressively steep decline in the productivity of conventional harvesting systems. Mechanised systems which can, to varying degrees, harvest and/or handle several stems at a time, have been introduced into our coniferous plantations to produce roundwood for pulp and particleboard. The major units of these systems are:

- feller-bunchers, which shear trees and place them in bunches
- processors which remove the limbs and cut stems to length
- harvesters which combine both these functions
- forwarders which are self-loading, terrain going transporters and commonly carry large loads of small logs and occasionally forest residues and chips
- grapple skidders which are used to drag bunches of small trees or stems from stump to roadside

These machines have increased labour productivity in harvesting early thinnings rather than reduced the costs of producing roundwood to the specifications demanded by traditional users. More radical processes involving changes in product specification are essential if wood is to be produced at an acceptable cost for energy use, whether from plantations or native forests (7).

When working with relatively small diameter wood the use of forwarders generally results in more efficient extraction and cleaner wood than that collected by skidders because of the shorter loading time and the larger loads which can be moved. Moore and Kerruish (8) in a recent study of three systems

for salvage logging crown and limb material in Karri after logging for pulpwood concluded that forwarder productivity was approximately twice that of the cable skidders.

An interesting machine for harvesting wood from residue crown material is being developed by the USDA Forest Service (9) to cut and bunch large hardwood tops into a compacted form more suitable for extraction. Compaction equipment is also being developed for unlimbed smallwood and similar residues (10). Also, of specific interest are the whole tree handling systems being developed in Scandinavia where bunches of small trees are transported from the forest to the mill with minimal processing (11).

## MOBILE CHIPPING

Depending on conditions and equipment chipping may be done directly at the stump, at roadside, or at a central processing plant.

The introduction of mobile chippers has increased the potential for harvesting residues and thinnings because several pieces can be processed simultaneously. Whole tree chipping in particular involves the use of top branches and trees which were formerly not commercially useful. There is also a potential opportunity to segregate the better quality chips for pulping from lower quality material suitable for energy production.

A wide range of mobile chippers are available (12, 13). Large self-propelled machines which carry their own chip bin have now been developed. They are fitted with a long-reach knuckleboom crane intended for retrieving bunched small wood material from the stand. In a study of a Finnish 'terrain' chipper Kalaja (14) quotes outputs of 9.0 to 11.2 $m^3$/h for whole tree volumes ranging from 0.38 to 0.48 $m^3$.

In North America over the last few years there has been a steady increase in the use of semi-mobile chippers which operate at roadside or on a large landing. For example a recent survey report (15) showed an increase from 483 to 732 machines in operation in the USA in 1975 and 1979, respectively, with corresponding production figures of 12.4 m tonnes and 18.6 m tonnes. As with the fully mobile chipping operations capital investment in equipment is very large and can make this form of wood harvesting uneconomic unless, for example, lower stumpage rates apply to the residue wood, some value is placed on a cleaner harvesting site or proportionate costs of forest roads are not charged to the residue harvesting operation (16). Two recent Canadian studies emphasise these points and the need for skilled organization to maintain a high level of output (17, 18).

The first semi-mobile chipper was imported into Australia some years ago (19) and there is now one in South Australia and two in Tasmania. The chips from two of the machines are being used for chipboard manufacture, but those from the third originate from hardwood logging residues and are being utilised for energy production.

## SEPARATION AND SEGREGATION PROCESSES

The use of wood residues for energy and fibre production in the form of chips may require some form of separation and/or segregation process. This process may be required to remove bark, leaves, twigs, knots, dirt, grit and fines from various mixtures of materials depending upon the input product and the way in which the segregated components are to be utilised.

Leaf seasoning, that is, delaying chipping a number of months after felling to allow the leaves to die and fall off is one method which has been tried in northern European species to reduce the leaf content in chips (20), but the authors are not aware of the technique having been used in eucalypts. Chain flails are fitted to the inlet of some mobile chippers as another means of reducing foliage intake.

Various types of screens are now used on the semi-mobile chippers and at central processing plants; these include rotary disc, rotary drum, gyrating and vibrating screens (12).

A combination of separation (detaching bark from wood), and segregation (partitioning components of the mixture), processes is required for removal of all contaminants from whole tree chips. Two of these combined processes have now reached the mill application stage in North America.

A joint study by PAPRICAN and FERIC (21) in Canada has lead to the development of a three stage process, viz.

(i) Conditioning by storing the chipped mixture in piles for about six weeks or steaming for 6-10 minutes at atmospheric pressure to weaken foliage and bark and the bark/wood bond.

(ii) Agitation of the conditioned mixture in water at a 13-19% consistency to detach bark and then break it and the foliage into small pieces.

(iii) Segregation of bark particles and foliage from woodchips by washing over a screenplate with water.

The mixture of comminuted bark and foliage after passing over a de-watering screen and being pressed to a solid content of 50% can, the authors claim, be used as a fuel.

The second combined process consists of steaming-compression debarking and vacuum-airlift segregation as separate operations or in combination depending upon the materials to be segregated (22). The compression debarking procedure involves three stages. Pre-steaming the unbarked chip mass; passing the chips through a compression debarker and screening the compression debarker output to remove bark fines.

Vacuum airlift segregation involves spreading the mixture on a wire mesh conveyer belt which moves slowly under vacuum hoods. The air currents generated by the vacuums typically remove foliage, then clean woodchips and finally 'middlings' which contain 30-50% of the total input including a high proportion of bark which may need to be removed by compression debarking. Fines, that is small pieces of bark, foliage, dirt and grit fall through the mesh conveyor belt. It is claimed by Sturos and Dickson (22) that the value of foliage as an animal food supplement and the fuel product more than covers the cost of up-grading the whole tree chips, but this may not be true in Australia.

## CENTRALISED TREE PROCESSING STATIONS

Owing to increased wood and energy values in Europe and North America processing and segregating plants are now being located at a central site or mill. Whole trees, or partly or fully delimbed long lengths are transported (23, 11) to the central site, delimbed if required, debarked and electronically scanned to establish dimensions and form. This information along with the values for different products is processed by computer and the stem is then automatically cut into the most profitable product assortment. Designed principally to ensure maximum value recovery of roundwood products, these systems do, however, generate residues in the form of limbs, bark and roundwood, ranging from an estimated 15-30% by weight of plant input. In Europe such materials are hogged and used for direct energy production in small industrial processes and heating. A number of the German installations are described by Becker and Grammel (24).

A study of plantation thinning operations in the ACT by Backen (25) indicated that both volume and value yields would be increased substantially by the introduction of centralised processing. However, published Swedish work and other overseas experience suggests that logging costs may be increased if the centralised station is remote from the mills requiring additional transportation.

Australia's larger plantations offer a concentration of forests and short haulage distances that favour such installations. With its wood industries at a formative stage in many regions, the opportunity exists to integrate plants producing forest products concentrating them near a suitable centralised log processing site. In the short term, our commitment to the shortwood system, relatively low stumpage and energy costs and limited diversity in both the demand and the value of different log products will, however, limit the application of centralised tree processing.

## CONCLUSIONS

Apart from cereal straws, forest residues represent the largest un-utilised source of biomass in Australia. A major constraint to their use is the cost of harvesting and transportation, this in particular applies to the young eucalypt resource.

Developments in four areas are likely to have an important bearing on the increased use of residues. These include:

- The mechanisation of small wood harvesting.
- Whole or part tree chipping.
- Centralised tree processing stations.
- Chip/bark segregation processes.

## REFERENCES

1. Stewart, G.A., Nix, H.A., Gartside, G., Rawlins, W.H.M., Gifford, R.M., and Siemon, J.R. 1979. The potential for liquid fuels from agriculture and forestry in Australia. CSIRO, Aust.

2. Anon. 1981. Aust. forest resources. Forestry Branch, Dept of Primary Industry, Canberra.

3. Hillis, W.E., and Brown, A.G. 1978. Eucalypts for Wood Production. CSIRO, Aust.

4. Brown, A.G., and Hall, N. 1968. Growing Trees on Australian Farms, p218-29. Comm. of Aust.

5. Water Supply Catchment Hydrology Research 1980. Report No. MMBW-W-0012 Summary of technical conclusions to 1979. Melbourne and Metropolitan Board of Works.

6. Recher, H.F., Rohan-Jones, W., Smith, P. 1980. The effect of the Eden woodchip industry on terrestrial vertebrates. Research Note No. 42, NSW For. Comm.

7. Schneider, C., and Kluender, R. 1980. Fuel harvesting systems: 'What are we really trying to do?' 80-P-58 Am. Pulpwood Assoc.

8. Moore, G.A., and Kerruish, C.M. 1981. Salvage logging in Karri: a comparison of three methods. Div. of For. Res., CSIRO, Harvesting Research Group Internal Report.

9. Mattson, J.A., Arola, R.A., and Hillstrom, W.A. 1978. Recovering and chipping hardwood cull trees having heavy limbs. Paper presented at a symposium 'Complete-Tree Utilisation of Southern Pine' New Orleans, Louisiana, April 17-19.

10. Danielsson, B.O., Marks, J., and Sall, H.O. 1977. Compressing small trees and tree components. Skogshogskolan, Sweden. Rept No.119.

11. Larsson, M. 1980. Development of transport systems for logging residues stumps and trees in Sweden. Skogsarbeten, Ekonomi No. 3E.

12. Anon. 1976. Woodchips : production, handling, transport. FAO 2nd ed.

13. Anon. 1980. Skogen's review of energy - machines in the forest. Skogen p67-71.

14. Kalaja, H. 1978. Harvesting small-sized trees with Terrain Chipper TT 1000F. Folia Forestalia, No. 374.

15. Mills, C.F. 1980. Whatever happened to whole tree chipping? TAPPI, 63(9), p39-42.

16. Stuart, W.B., Wallbridge, T.A., and O'Hearn, S.E. 1978. Whole tree chipping and conventional harvesting systems - economic and productivity comparisons on a variety of stand types. TAPPI, 61(6), p60-4.

17. Folkema, M.P. 1977. Whole tree chipping with the Morbark model 22 chip-harvester. FERIC Tech. Note No. TN-16.

18. Blakeney, K.J. 1980. Development and testing of a field treatment system for logging residues. Canadian Forestry Service, Pacific Forest Research, ENFOR Project No. P-36.

19. Crowe, M. 1976. Morbark Total Chipharvester. Div. of For. Res., CSIRO, Harvesting Res. Group, Machine Evaluation No. 14.

20. Simola, P., and Makela, M. 1976. Leaf-seasoning method in whole tree logging. Folia Forestalia, No. 273.

21. Berlyn, R., Hutchinson, J., and Gooding, R. 1979. A method for upgrading chips from full trees. Pulp and Paper, Canada 80(8), p56-60.

22. Sturos, J.A., and Dickson, R.E. 1980. Fiber, fuel and food from whole tree chips. Trans. Am. Soc. Agric. Engrs 23(6), p1353-8.

23. Lavoie, J.M. 1980. The transport of full trees from stump area to mill wood yard. Tech. Rep. No. TR-44 FERIC.

24. Becker, G., and Grammel, R. 1979. Technologie der zentralen Aufarbeitung von Rundholz. Univ. of Freiburg.

25. Backen, P. 1979. The effects of a proposed log merchandiser on utilisation of logs from thinning. Div. Forest Res., CSIRO, Harvesting Research Group Report.

# INSECTICIDES FOR THE PROTECTION OF WOODEN COMPONENTS OF SHIPPING CONTAINERS

C.D. HOWICK

## INTRODUCTION

Australia is an island continent with reasonable control of goods entering through its ports by sea or by air. Thus, by enforcing strict quarantine regulations, it is in the fortunate position of having a reasonable chance of preventing the accidental importation of unwanted pests or diseases from overseas. It must be accepted however, that some undesirable pathogens were introduced during the early development of Australia and some have since become so firmly established that they must now be regarded as indigenous.

Australian quarantine aims at the complete exclusion of any insect or diseaselikely to be detrimental to living trees or to any forest products in Australia. At ports of entry, the Quarantine officer is empowered to order into quarantine any vegetable material ..... "being or likely to be, in his opinion, infected with a disease affecting animals or plants, or which contain or appear to contain any insect or pest or disease agent". (Section 55a, Australian Quarantine Act).

## CARGO CONTAINERS

With the introduction and growth of containerised shipping in the 1960's and its subsequent acceptance and expansion, the Australian Department of Health (Plant Quarantine) drew up quite stringent regulations pertaining to sawn timber and plywood components of cargo containers. These regulations were aimed at the total exclusion of wood inhabiting insects and laid down preservation specifications which, if followed, should guarantee that any timber components offered harbourage to no such pests.

These regulations apply only to those containers whose owners or agents wish them to be excused from mandatory inspection on arrival in Australia. If owners or agents are agreeable to their containers being emptied for inspection, then there is no obligation for the preservative treatment. However, as such inspections would, in many cases, negate advantages of containerisation, it has so happened that container manufacturers generally attempt to conform to Australian requirements for registration of individual containers for immediate delivery, unless they can be completely certain that such containers will never enter Australian ports.

Because Australian cargo container treatment requirements are the most stringent in the world, it has evolved that the majority of container manufacturers, no matter in what country they may be located, make a serious attempt to conform to the requirements of the Australian Department of Health (Plant Quarantine). Regulations and requirements are published in a booklet "Cargo Containers and Unit Loads" which is frequently amended to update approved treatment chemicals and treatment techniques.

## PENETRATION REQUIREMENTS

Under the regulations, the requirements for the penetration of preservatives into the timber components of cargo containers are intended to ensure lifelong immunity from infestation - both when the container is new and the freshly-treated surface is intact and later, when the origianl surface may have become abraded or broken. In conformity with Australian Standards for preservative-treated sawn timber, the Quarantine regulations require that at least two-thirds of the cross-section of each piece of timber (including all sapwood) shall be penetrated with the required retention of preservative.

## APPROVED PRESERVATIVES

Approval of the various wood preservatives is based on their ability to prevent the establishment of infestations by wood destroying insects whether they be wood wasps, wood boring beetles, termites or even insects which may bore into wood for shelter such as carpenter ants or certain hide beetles. It is for this reason that requirements for copper-chrome-arsenic (CCA) preservatives are based on their elemental arsenic content. Similarly, approvals for many commercial formulations have been granted on the basis of their insecticidal component.

## ORGANOCHLORINE INSECTICIDES

Commercial formulations having organochlorine compounds as their active ingredient and indeed, the compounds themselves, have been approved both as impregnants of sawn timber components and as glue-line additives for plywood components. Acceptance of aldrin, dieldrin, heptachlor and lindane at specified retentions is based on laboratory termite bioassay work on these compounds as glue-line additives and in sawn timber in the early 1970's (1 and 2). Subsequently chlordane was accepted on the basis of its proven comparative efficacy.

## WITHDRAWAL OF APPROVAL

Early in 1981, the Assistant Director-General (Plant Quarantine) of the Australian Department of Health issued a statement to the effect that research work in Britain and Australia had indicated that, under certain circumstances, migration of organochlorine insecticides could occur in containers with treated sawn floors. He foreshadowed that recommendation for the use of organochlorine insecticides for treating sawn timber would not appear in the 1981 edition of "Cargo Containers - Quarantine Aspects and Procedures". This means that as from January 1982, *new* containers will not be registered for immediate delivery in Australia if the exposed sawn timber components are treated with aldrin, chlordane, dieldrin, heptachlor or lindane.

In the short term it is important to recognise that no withdrawal of approval for the use of these compounds as glue-line additvies has been foreshadowed. However, it is known that local research has shown that insecticide migration does occur from glue-lines but as yet, this has not been detected at unacceptable levels (3). Thus approval for the use of organochlorines for the protection of plywood as glue-line additvies continues, pending further investigations.

In contrast, however, insecticides used for direct treatment of plywood veneers must conform to the quarantine recommendations for sawn timber and so organochlorines will be proscribed for this application after January 1982.

## ALTERNATIVE INSECTICIDES

(a) Sawn Timber Treatment:

As an alternative to the organochlorine insecticides, the use of synthetic pyrethroids must be seriously considered.

Work in Australia (4) has shown that the protection threshold against Australian termites is, for permethrin below 0.08 kg/m$^3$, and for fenvalerate below 0.12 kg/m$^3$ in pine and hardwood. These recommendations are based on detailed laboratory work with *Coptotermes acinaciformis* and *Mastotermes darwiniensis*, and were carried out after severe weathering of the test specimens.

Laboratory work in Australia with European House Borer, *Hylotrupes bajulus* (4) has shown the protection threshold to be between 0.01 and 0.006 kg/m$^3$ for both permethrin and fenvalerate.

Preliminary screening work against termites with deltamethrin, cypermethrin and CRC 15000 (5) shows that all have potential as protectants for timber, but further work is necessary before specific protection thresholds can be determined.

Organophosphate insecticides may also represent an economically viable and environmentally acceptable alternative to the organochlorines. For example, chlorpyrifos has been shown to afford satisfactory protection at 0.64 kg/m$^3$ (6).

(b) Plywood Treatment:

The acceptance of glue-line additives is largely based on their performance in *Pinus radiata* plywood. Recent laboratory investigations with organochlorines as glue-line additives in plywood of *Ceratapetalum apetalum* (coachwood) and *Eucalyptus sieberi* (silvertop ash) have shown a marked species effect. It would seem that their effectiveness is a function of their ability to migrate into the veneer and that this ability may decrease with increasing wood density.

Alternatively, preliminary work with some synthetic pyrethroids as glue-line additives, indicates that their comparative stability may cause them to be locked up in the glue and therefore be inefficient in the protection of plywood against termites. Extension of this work is currently in progress to determine whether this is so. With such suspicion however, it may be safer to recommend the use of waterborne synthetic pyrethroids to treat veneer during plywood production.

## SAFETY FACTORS

It is probable that the most serious wood-destroying insects that quarantine measures are attempting to exclude from Australia are the European House Borer *Hylotrupes bajulus*, the West Indian Drywood Termite *Cryptotermes brevis* and the Formosan Subterranean Termite *Coptotermes formosanus*. Of these, *C. formosanus* would, almost certainly be the most tolerant and require the highest insecticidal retention to prevent attack.

It is the author's opinion that this retention would not be higher than that required to give protection from *Mastotermes darwiniensis* attack, but may be higher than that required for *C. acinaciformis*.

## CONCLUSION

The aim of Australian quarantine requirements is the complete exclusion of unwanted pests imported from other countries. To achieve this aim, Australian requirements may appear to the uninformed to be unnecessarily high. However, as Tamblyn (7) has so appropriately explained:

*"The need for an uncompromising attitude in quarantine matters is not always understood, though on consideration it should be obvious that a risk taken only once or a single mistake made, may cause irreparable harm on a national level and nullify all the vigilance of the past".*

## REFERENCES

1. Howick, C.D., Tamblyn, N. and Creffield, J.W. (1975). Termiticidal effects of insecticidal glue-line additives. Proc. 17th Forest Prod. Res. Conf. Topic 2/25, 1-4.

2. Howick, C.D. and Creffield, J.W. (1975). The development of a standard laboratory bio-assay with *Mastotermes darwiniensis* Froggatt (Isoptera: Mastotermitidae). Z. Angew. Entomol. 78, 126-138.

3. Paton, R. personal communication.

4. Howick, C.D. and Creffield, J.W. (198-) Australian evaluations of synthetic pyrethroids for protection of wood and wood-based panel products against subterranean termites and some other wood destroying insects (in preparation).

5. Howick, C.D. and Creffield, J.W. (1981). Further information on the efficacy of some synthetic pyrethroids in wood preservation. Proc. 20th Forest Prod. Res. Conf. Topic WP 2, 1-8.

6. Howick, C.D. and Creffield, J.W. (1977). Laboratory studies of the termiticidal effectiveness of chlorpyrifos. Proc. 18th Forest Prod. Res. Conf. Topic 2/28, 1-5.

7. Tamblyn, N. (1963). Quarantine measures as a means of reducing the danger of spreading wood destroying insects to non-infected areas. F.A.O. 5th Conf. Wood Technol. Madison Wis. Section WP, Paper No. 6.

# FURTHER INFORMATION ON THE EFFICACY OF SOME SYNTHETIC PYRETHROIDS IN WOOD PRESERVATION

C.D. HOWICK and J.W. CREFFIELD

This paper describes a series of laboratory bioassay experiments with wood blocks treated with FENVALERATE and with ALDRIN against attack by two species of Australian termites. The assessments were carried out at the Highett laboratory of CSIRO Division of Building Research during the latter part of 1980. The necessity for this investigation was foreshadowed in a previous paper (1) and it was primarily conducted to evaluate insecticidal efficacy, to consolidate information from previous evaluations and to determine recommendations regarding retentions for protection of wood against termites.

In addition to the establishment of retentions for the protection of a softwood and a hardwood with FENVALERATE, the bioassays included a preliminary investigation to determine the potential of three other pyrethroids, CYPERMETHRIN, EXP. S.P.* and DELTAMETHRIN (=DECAMETHRIN) against termites.

## MATERIALS AND METHODS

### (1) Treated Blocks

(a) Timber: Blocks were of the sapwood of *Pinus radiata* D. Don and of the heartwood of *Eucalyptus regnans* F. Muell. For each timber species, specimens (15 x 25 x 50 mm) were prepared from strips of similar radial position in a single board and were then assigned at random for insecticidal treatment.

(b) Treatment: Blocks were treated to pre-determined retentions by vacuum-pressure impregnation with the various pyrethroid-insecticides and for comparison with ALDRIN. The retentions were 0.02, 0.04, 0.08, 0.12 and 0.16 for FENVALERATE, 0.008, 0.04 and 0.20 for CYPERMETHRIN, 0.002, 0.01 and 0.05 kg/m$^3$ for EXP. S.P. and DELTAMETHRIN and 0.8 kg/m$^3$ for ALDRIN. Control blocks were treated with solvent only (mineral turpentine plus 0.5% paraffin wax) and untreated control blocks were also prepared.

* Experimental Synthetic Pyrethroid.

(c) Preparation for assessments: Before being used in the bioassays, all specimens were subjected to a rigorous leaching/volatilisation schedule to ensure removal of all solvent and to more realistically simulate several years of service life. This schedule comprised five days vacuum oven-drying (11 kPa) at 50°C; vacuum-pressure impregnation with water; one day water soaking at 50°C; one day oven-drying at 50°C followed by a further 5 days vacuum oven-drying at 50°C, a second vacuum-pressure impregnation with water, soaking and drying and finally another 5 days in the vacuum oven at 50°C. During this preparation each treatment was kept entirely separate from all others as were the untreated control specimens. After removal from vacuum ovens, at the conclusion of the leaching schedule, specimens were allowed to cool in a desiccator for 1 hour before weighing to obtain initial mass before their bioassay against termites.

## 2. Termite bioassays

Specimens were subjected to bioassays against two species of Australian termites viz. *Coptotermes acinaciformis* (Froggatt) and *Mastotermes darwiniensis* Froggatt.

Five replicate specimens of each retention of each insecticide as well as solvent and untreated controls were tested separately against 10 g groups of termites for each of the two timber species. However, only the pine was used in the screening of CYPERMETHRIN, EXP. S.P. and DELTAMETHRIN.

(a) The bioassay against *C. acinaciformis* was conducted basically according to the techniques described by GAY *et al.* (2) but with those modifications customarily adopted by the authors (3). Because of the low mass loss and high termite survival experienced during previous bioassays with similar compounds, the assessment period for the *P. radiata* specimens was extended to 12 weeks, while that for the *E. regnans* specimens was kept at 8 weeks for direct comparison with earlier work. Details of layout and test methods are shown in Table 1.

(b) The bioassay against *M. darwiniensis* was conducted in accordance with the technique described by HOWICK and CREFFIELD (4). Full details are shown in Table 1.

## RESULTS

At the conclusion of the bioassays, or when termites in any one jar had all died, specimens were removed from jars, cleaned and subsequently dried in a vacuum oven for 5 days at 50°C to obtain their final mass. This was then compared with initial mass and expressed as a percentage thereof to facilitate comparisons.

(a) Amount of termite attack: Details of the amount of termite attack to insecticide-treated blocks are given in Table 2. This information is also given for the solvent-treated and untreated control blocks. Mass losses (mean of five replicates) are shown as a percentage of the initial mass of the blocks. The Standard Deviation (SD) within each group of five replicates is also shown.

(b) Survival of termites: Table 3 shows details of termite survival. For the bioassay with *C. acinaciformis*, termites surviving at the conclusion of the assessment period were preserved in alcohol and subsequently oven dried. Termite survival calculations have been based on their oven-dry mass, expressed as a percentage of that of 10 g groups similarly preserved since the installation day after the addition of a 10% growth correction factor.

For the bioassay with *M. darwiniensis*, termite survival is assessed on the basis of the percentage of the original 10 g group surviving at the conclusion of the assessment period. For those groups which died before the conclusion of the test, survival is shown as the mean number of days before total death of the 10 g groups.

## DISCUSSION

This study presents new information concerning the efficacy of some synthetic pyrethroids in the protection of sawn timber from attack by subterranean termites.

(a) Amount of termite attack: A major criterion of the efficacy of a chemical in protecting materials against termite attack is specimen mass loss during termite bioassays. The protection threshold for a chemical may be defined as the amount which permits only sufficient attack to cause death of termites eating toxic material and no more than that amount of attack to repellent material. The protection limits are the highest retention permitting an unacceptably high level of attack and the lowest retention achieving an acceptable level of protection. The actual protection threshold obviously lies somewhere between the two, but must be taken as that retention shown to give protection. Thus, screening assessments usually involve only a few, widely spread retentions, whereas, more detailed bioassays use several retentions between protection limits determined by previous screening.

In this evaluation (see Table 2) the mass loss results with *M. darwiniensis* show the effects of increased retentions quite clearly. The extent of attack to blocks treated with FENVALERATE at the three lowest retentions was substantial

and comparable with the amounts of untreated and solvent-treated control blocks eaten by *M. darwiniensis*. The profound change as insecticide retention increased from 0.08 kg/m$^3$ to 0.12 kg/m$^3$ leaves no doubt as to where the protection limits lie. The relatively low attack of the *P. radiata* solvent control blocks was an unexpected effect for which no satisfactory explanation has yet been determined.

The screening of three additional compounds has provided useful preliminary data (see Table 2). In the bioassay with *M. darwiniensis* the highest retention of CYPERMETHRIN (0.20 kg/m$^3$) and DELTAMETHRIN (0.05 kg/m$^3$) afforded protection similar to that conferred by ALDRIN at 0.8 kg/m$^3$. Against *C. acinaciformis* however, CYPERMETHRIN at 0.04 kg/m$^3$, EXP. S.P. at 0.05 kg/m$^3$ and DELTAMETHRIN at 0.002 kg/m$^3$ afforded satisfactory protection, similar to that of ALDRIN at 0.8 kg/m$^3$.

(b) Survival of termites: Under the conditions of the bioassays used in this study, termites will avoid a repellent or distasteful material and will eventually die of starvation unless they are able to obtain nourishment from an alternative source.

The mound material matrix used with *C. acinaciformis* is that of *C. lacteus* and is known to be nutritious. Unfed control groups are able to obtain quite sufficient food from this matrix for significant survival at the conclusion of a 12-week bioassay (see Table 3). Consequently all groups, even those exposed to treated blocks at high retentions were able to feed on the matrix in preference to the repellent or less acceptable treated specimens and thus also record high survival.

The vermiculite matrix used with *M. darwiniensis* is not nutritious. Unfed control groups usually die of starvation towards the conlusion of a 4-week bioassay (see Table 3). However *M. darwiniensis* groups feeding on untreated control blocks recorded a high level of survival at the conclusion of the test period, indicating satisfactory conditions and normal vitality. Groups feeding on blocks treated with low retetnions of FENVALERATE and EXP. S.P. (see Table 3) also obtained sufficient nourishment for good survival from the amounts of treated wood eaten. However, even the very small amounts of wood eaten at the higher retentions of those compounds and at all retentions tested of CYPERMETHRIN and DELTAMETHRIN were sufficient to cause accelerated death of all groups feeding thereon. Alternatively, mere contact with blocks treated with 0.8 kg/m$^3$ of ALDRIN killed termites within only a few days.

## CONCLUSIONS

Under compulsion conditions of a severe termite hazard such as that encountered in the bioassay with *M. darwiniensis*, CYPERMETHRIN performed satisfactorily at 0.2 kg/m$^3$, EXP. S.P. at 0.05 kg/m$^3$ and DELTAMETHRIN at all retentions evaluated in *P. radiata* test blocks. However, because of the wide range between retentions assessed in this screening, it is not yet possible to determine at which point between 0.04 kg/m$^3$ and 0.2 kg/m$^3$ the desired protection threshold may lie for CYPERMETHRIN or at which point between 0.01 kg/m$^3$ and 0.05 kg/m$^3$ it may lie for EXP. S.P. In comparison, even at retentions as low as 0.002 kg/m$^3$, DELTAMETHRIN conferred protection similar to that conferred by ALDRIN at 0.8 kg/m$^3$. Thus, although the three pyrethroids screened show great promise for the protection of wood against termites, a more accurate and detailed evaluation of retention relationships is recommended before their real potential can be assessed. However, the bioassays described in this report show that FENVALERATE can confer adequate protection against two of the most economically significant species of Australian termites to both hardwood and softwood timbers. The results indicate quite dramatically that the protection threshold lies between 0.08 kg/m$^3$ and 0.12 kg/m$^3$.

Commercial retentions recommended on the basis of this information depend on factors outside the scope of this report.

## REFERENCES

1. HOWICK, C.D. and CREFFIELD, J.W. (1979). Synthetic pyrethroids and wood preservation. Proc. 19th Forest Prod. Res. Conf. Topic 3/12, 1-5.

2. GAY, F.J., GREAVES, T., HOLDAWAY, F.G. and WETHERLY, A.H. (1955). Standard laboratory colonies of termites for evaluating the resistance of timber, timber preservatives, and other materials to termite attack. - Bull. Commonw. Scient. Ind. Res. Org. No. 277, 60 pp.

3. HOWICK, C.D. (1975). Influences of specimen size, test period and matrix on the amounts of wood eaten by similar groups of laboratory termites - Proc. Br. Wood Preserv. Assoc. Annual Conv. 51-63. 174 pp. Southwick Sussex, England, Grange Press.

4. HOWICK, C.D. and CREFFIELD, J.W. (1975). The development of a standard laboratory bioassay technique with *Mastotermes darwiniensis* Froggatt (Isoptera: Mastotermitidae). - Z. Angew. Entomol. 78, 126-138.

TABLE 1. Experimental details for bioassays

| TERMITE SPECIES: | *Coptotermes acinaciformis* | *Mastotermes darwiniensis* |
|---|---|---|
| GROUP MASS | 10 g | 10 g |
| MATRIX<br>(a) Type | *C. lacteus* mound material | Grade 4 vermiculite |
| (b) Amount per jar | 150 g | 35 g |
| MOISTURE: | 75% | 250% |
| TEMPERATURE: | 26° | 32° |
| HUMIDITY: | 80% RH | 80% RH |
| CONTAINERS: | 1 L glass jars | 1 L glass jars |
| VENTILATION: | Vented lid (9mm) | Loose lid |
| SPECIMENS:<br>(a) Type | *E. regnans, P. radiata* | *E. regnans, P. radiata* |
| (b) Size | 15 x 25 x 50 mm | 15 x 25 x 50 mm |
| NO. OF JAR REPLICATES: | 5 | 5 |
| ASSESSMENT PERIOD: | 8 weeks for *E. regnans*<br>12 weeks for *P. radiata* | 4 weeks |

TABLE 2. Amount of termite attack (mean of 5 replicates)

| Insecticide | Nominal Retention kg/m$^3$ | *C. acinaciformis* | | *M. darwiniensis* | |
|---|---|---|---|---|---|
| | | *P. radiata* % (SD) | *E. regnans* % (SD) | *P. radiata* % (SD) | *E. regnans* % (SD) |
| FENVALERATE | 0.02 | 11.4 (5.7) | 7.6 (1.5) | 49.8 (7.7) | 52.3 (4.1) |
| | 0.04 | 3.9 (0.6) | 3.1 (1.0) | 13.3 (3.8) | 47.3 (3.3) |
| | 0.08 | 3.9 (0.3) | 2.2 (0.1) | 11.7 (3.0) | 45.2 (6.8) |
| | 0.12 | 2.6 (0.1) | 1.7 (0.9) | 1.1 (0.3) | 1.3 (0.3) |
| | 0.16 | 2.5 (0.2) | 1.0 (0.0) | 0.7 (0.1) | 3.0 (0.8) |
| CYPERMETHRIN | 0.008 | 10.8 (11.1) | | 8.6 (4.8) | |
| | 0.04 | 2.6 (2.5) | | 7.1 (3.8) | |
| | 0.20 | 1.5 (0.4) | | 0.6 (0.8) | |
| EXP. S.P. | 0.002 | 4.5 (2.8) | | 47.3 (4.8) | |
| | 0.01 | 3.4 (0.4) | | 30.6 (2.6) | |
| | 0.05 | 3.0 (0.4) | | 3.1 (0.8) | |
| DELTAMETHRIN | 0.002 | 1.7 (0.8) | | 1.9 (0.4) | |
| | 0.01 | 1.3 (0.2) | | 1.4 (0.8) | |
| | 0.05 | 1.5 (0.6) | | 0.0 ( - ) | |
| ALDRIN | 0.80 | 2.0 (0.7) | 0.3 (0.1) | 0.0 ( - ) | 0.0 ( - ) |
| SOLVENT CONTROLS | | 74.5 (10.6) | 49.4 (4.7) | 15.3*(2.1) | 47.7 (2.6) |
| UNTREATED CONTROLS | | 92.1 (8.5) | 61.4 (4.6) | 53.9 (3.6) | 49.0 (3.5) |

* See text.

TABLE 3. Termite survival (mean of 5 replicates)

| Insecticide | Nominal Retention kg/m$^3$ | *C. acinaciformis* | | | | *M. darwiniensis* | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | *P. radiata* | | *E. regnans* | | *P. radiata* | | *E. regnans* | |
| | | % | (SD) | % | (SD) | % | (SD) | % | (SD) |
| FENVALERATE | 0.02 | 86 | (3.5) | 89 | (2.0) | 70 | (5.4) | 76 | (0.6) |
| | 0.04 | 84 | (3.1) | 91 | (1.1) | 26 | (2.7) | 72 | (11.1) |
| | 0.08 | 87 | (2.0) | 88 | (3.6) | 26 days | (1.9) | 65 | (14.2) |
| | 0.12 | 81 | (3.8) | 85 | (1.5) | 15 days | (0.7) | 17 days | (0.7) |
| | 0.16 | 71 | (10.3) | 88 | (2.1) | 17 days | (1.1) | 20 days | (1.8) |
| CYPERMETHRIN | 0.008 | 78 | (6.6) | | | 23 days | (2.2) | | |
| | 0.04 | 74 | (3.0) | | | 22 days | (2.9) | | |
| | 0.20 | 74 | (7.1) | | | 18 days | (3.0) | | |
| EXP. S.P. | 0.002 | 81 | (6.3) | | | 73 | (6.4) | | |
| | 0.01 | 82 | (6.4) | | | 54 | (3.8) | | |
| | 0.05 | 80 | (6.0) | | | 21 days | (1.6) | | |
| DELTAMETHRIN | 0.002 | 77 | (4.7) | | | 20 days | (1.3) | | |
| | 0.01 | 73 | (4.9) | | | 19 days | (0.4) | | |
| | 0.05 | 71 | (5.7) | | | 18 days | (0.0) | | |
| ALDRIN | 0.80 | 48 | (6.1) | | | 6 days | (0.0) | | |
| SOLVENT CONTROLS | | 94 | (4.8) | 88 | (1.5) | 27 days | (1.5) | 76 | (7.4) |
| UNTREATED CONTROLS | | 98 | (2.1) | 92 | (2.9) | 81 | (4.7) | 75 | (7.3) |
| UNFED CONTROLS | | 89 | (3.7) | | | 27 days | (1.5) | | |

# TERMITICIDAL EFFICACY OF ALKYL AMMONIUM COMPOUNDS IN WOOD

C.D. HOWICK, J.W. CREFFIELD, H. GREAVES and J.A. BUTCHER

## INTRODUCTION

The potential of various alkyl ammonium compounds (AAC's) for use as wood preservatives has been clearly established by a comprehensive series of fungal and insect bioassays (1,2,3), treatment process trials (4) and studies concerned with the physical and chemical properties of these compounds (5).

In 1978, this potential was realised when two types of AAC (alkyldimethylbenzyl ammonium chloride and alkyldimethylamine acetate) were approved by the New Zealand Timber Preservation Authority for commercial use (6). The approvals were limited to treatment of *Pinus radiata* D. Don by full cell (Bethell) or modified empty cell (Lowry) processes and were restricted to those commodities which are exposed, but not in ground contact. Subsequently, a dip treatment process was approved for green veneers destined for plywood manufacture. These approvals were made in New Zealand in recognition of the relatively broad spectrum activity in the laboratory against both wood-destroying basidiomycetes and the common furniture borer *Anobium punctatum* (De Geer). Work is now in progress at the Forest Research Institute (NZ) to widen approvals for use with other wood species and commodities, and elsewhere to confirm laboratory data by field exposure tests (7).

As a result of the commercial acceptance of AAC in New Zealand and of earlier screening work in Australia and elsewhere, there is interest as to their suitability for protection of *P. radiata* and other wood species against a wider range of wood-destroying organisms. Cross (2) demonstrated high activity of the two approved AAC formulations against *Ambiodontus tristis* (F.) in addition to *A. punctatum*. However, more recent work in Australia has shown that much higher retentions are necessary to protect hardwoods from attack by the powderpost beetle *Lyctus brunneus* (Stephens) (Rosel and Greaves unpublished data). This is possibly because these compounds become highly fixed to cellulose which Lyctids, unlike Anobiids and Cerambycids, do not utilise (8).

In all the various studies undertaken with AAC's to date, little detailed attention has been given to the efficacy of these compounds to protect softwoods and hardwoods from termite attack. On the other hand some early screening trials against the drywood termite *Cryptotermes brevis* (Walker) (Yule, pers. comm.) and against subterranean species (French, pers. comm.) have indicated that AAC-based formulations may have some potential as termiticides, certainly for the Australian timber market.

From this viewpoint, a detailed laboratory study was devised, and we now report general results and conclusion on the efficacy of two AAC formulations in protecting both *P. radiata* and *Eucalyptus regnans* F. Muell. from attack by subterranean termites of economic importance in Australia.

## LABORATORY BIOASSAYS

The formulations evaluated were the quaternary ammonium compound BIOQUAT 501 (benzalkonium chloride) and the tertiary amine salt ADMA 246-451 (cocodimethylamine acetate). Blocks of each of the two timber species were treated with either of each of the two chemicals at four retentions. These retentions were nominally (i) 3.0, (ii) 4.5, (iii) 6.0 and (iv) 7.5 kg/m$^3$ of active ingredient. Before being used in the bioassays, all specimens were given a volatilisation schedule of five days vacuum oven drying (11 kPa) at 50$^{o}$C. Specimens were then subjected to bioassays against three species of Australian termites viz. *Mastotermes darwiniensis* Froggatt, *Coptotermes acinaciformis* (Froggatt) and *Nasutitermes exitiosus* (Hill).

The bioassay against *M. darwiniensis* was in accordance with the technique described by Howick and Creffield (9). The bioassays against *C. acinaciformis* and *N. exitiosus* were conducted basically according to the techniques described by Gay *et al.* (10) but with those modifications customarily adopted by the authors. *P. radiata* blocks were not subjected to the *N. exitiosus* bioassay because of the known inability of these termites to attack *Pinus* species.

## RESULTS

Results may be summarised as follows:-

(a) BIOQUAT in *E. regnans* was effective at all loadings against *N. exitiosus*;

was fair against *M. darwiniensis* but at retentions iii and iv only; and was unsatisfactory at all levels against *C. acinaciformis*.

(b) BIOQUAT in *P. radiata* was effective at all loadings against *M. darwiniensis* and at retentions ii, iii and iv against *C. acinaciformis*.

(c) ADMA in *E. regnans* was unsatisfactory at all loadings against both *N. exitiosus* and *M. darwiniensis*, but was effective at all loadings against *C. acinaciformis*.

(d) ADMA in *P. radiata* gave fair protection against *M. darwiniensis* at retentions iii and iv, only, and it gave fair protection at all loadings against *C. acinaciformis*.

## CONCLUSIONS

On the basis of these bioassays, the suitability of the two AAC's tested for protection against termite attack appears to be restricted to benzalkonium chloride for the protection of *P. radiata*. Neither formulation gave sufficient protection to *E. regnans* at the retentions assessed. Commercial feasibility would, of course, be dependent (among other things) on cost-effectiveness and this has not yet been fully established.

The authors are aware however, that the two AAC formulations approved for commercial use in New Zealand may not necessarily represent the most biologically active compounds in this broad chemical group. In the knowledge that other alkylammonium compounds could have more specific termiticidal efficacy (with or without additional insecticides), further cooperative work in this area is planned.

## REFERENCES

1. Butcher, J.A., Preston, A.F. and Drysdale, J. (1977). Initial screening trials of some quaternary ammonium compounds and amine salts as wood preservatives. Forest Prod. J. 27, 19-22.

2. Cross, D.J. (1979). Alkylammonium compounds as insecticidal wood preservatives. Material und Organismen 14, 105-116.

3. Hedley, M.E., Preston, A.F., Cross, D.J. and Butcher, J.A. (1979). Screening of selected agricultural and industrial chemicals as wood preservatives. Internat. Biodeterior. Bull. 15, 9-18.

4. Hulme, M.A. and Thomas, J.F. (1979). Control of fungal sap stain with alkaline solutions of quaternary ammonium compounds and with tertiary amine salts. For. Prod. J. 29,26-29.

5. Butcher, J.A., Preston, A.F., Hedley, M.E. and Cross, D.J. (1978). Current research with new chemicals for protection of wood. Proc. N.Z. Wood Pres. Ass. 17, 36-45.

6. Butcher, J.A. (1980). Current status of AAC preservatives in New Zealand. Internat. Res. Group on Wood Preservation Document No. IRG/WP/3141, 1-9.

7. Ruddick, J.N.R. (1981). Testing of alkylammonium compounds. Internat. Res. Group on Wood Preservation Document No. IRG/WP/2152,1-12.

8. Cross, D.J. (1980). Future insecticidal treatments for wood products. Internat. Res. Group on Wood Preservation Document No. IRG/WP/3140, 1-7.

9. Howick, C.D. and Creffield, J.W. (1975). The development of a standard laboratory bioassay technique with *Mastotermes darwiniensis* Froggatt (Isoptera: Mastotermitidae). - Z. Angew. Entomol. 78, 126-138.

10. Gay, F.J., Greaves, T., Holdaway, F.G. and Wetherly, A.H. (1955). Standard laboratory colonies of termites for evaluating the resistance of timber, timber preservatives, and other materials to termite attack. Bull. Commonw. Scient. Ind. Res. Org. No. 277, 1-60.

# A RAPID FIELD ASSESSMENT OF INSECTICIDE-TREATED WOOD AGAINST TERMITES.

J.R.J. French and P.J. Robinson

## ABSTRACT

A method developed for rapidly assessing the wood feeding preferences of subterranean termites in the field was adapted for use in evaluating insecticide-treated wood against termites. Two sites were selected, namely, Oakdale (N.S.W.) and Walpeup (Vic.). At Oakdale insecticide impregnated blocks of *Pinus radiata* and *Eucalyptus regnans* were stapled onto wire-frames and placed around mounds of live *Coptotermes acinaciformis* and *Nasutitermes exitiosus* respectively. Whereas at Walpeup, similarly treated *P. radiata* blocks were placed around steel drums, packed with toilet rolls, heavily infested with *C. acinaciformis*. The termites on both sites attacked the treated wood blocks on the wire-frames in the following order of decreasing preference - fenthion > quatramine and aldrin > permethrin.

## INTRODUCTION

Recently (1) a rapid and selective method of test was developed for assessing the wood feeding preferences of the subterranean termite, *Heterotermes ferox* (Frogg). Since that experiment, we have aggregated large numbers of termites at Walpeup, with emphasis on *Coptotermes acinaciformis* (Frogg) in steel drums packed with moistened toilet rolls (2). On placing small wood-blocks on wire frames around these drum baits, *C. acinaciformis* readily visited and attacked the wood specimens.

This present study describes the experimental layout adopted in assessing the susceptability of small wood blocks of *Pinus radiata* D. Don and *Eucalyptus regnans* F. Muell., impregnated with four commercially available insecticides to termite attack in two locations.

## MATERIALS AND METHODS

Site descriptions: Two sites were chosen, (a) Oakdale (N.S.W.) and (b) Walpeup (Vic.). Several termite species are found at each site.

Preparation of small wood-blocks: Small wood blocks (100 x 20 x 20 mm) were cut from two trees of *Pinus radiata* D. Don and two trees of *Eucalyptus regnans* F. Muell, and sufficient blocks selected at random for insecticidal treatments.

Insecticides used in the test, their loadings and solvents:

| Insecticide | Mean loading kg/m$^3$ | | Solvent used |
|---|---|---|---|
| | High | Low | |
| Aldrin | 0.80 | 0.10 | Mineral turps. |
| Fenthion | 0.20 | 0.02 | " " |
| Permethrin | 0.08 | 0.008 | " " |
| Quatramine 80 | 5.00 | 0.50 | Water |

After treatment the blocks were air dried for three months and randomly positioned on the wire frames (300 x 300 mm, with 7 x 7 mm squares of galvanised wire). Each frame contained 20 blocks, representing the four insecticide treatments, both high and low loadings. Duplicate blocks were treated each of the two trees, that is *P. radiata* or *E. regnans*. A water control and a mineral turpentine control were included for each tree. The blocks were stapled onto the wire frame in two rows of 10 blocks, with the 100 x 20 mm surface uppermost.

Installation of baits: (a) Oakdale (N.S.W.)
The experimental layout around each mound is shown in Table 1. Each wire frame comprised 20 blocks, treated as previously mentioned and fully randomized in position. The wire-frames were randomized and placed around the

TABLE 1. Experimental layout at Oakdale

| Termite Species | Total number mounds | Number of mounds* with feeder strip | with no feeder strip | with toilet rolls |
|---|---|---|---|---|
| *C. acinaciformis* | 6 | 2 | 2 | 2 |
| *N. exitiosus* | 4 | 2 | 2 | NT |

* 5 wire frames per mound with 20 randomized treated small wood-blocks
NT = Not tested due to limited supply of suitable *E. regnans*.

respective mounds and each wire-frame was covered with an inverted galvanized steel tray, held in position with two L-shaped steel pegs. As the intention was to verify if feeder strips commonly used in the Gay et al (3) method were necessary or not for the termites to quickly locate the baits. Two mounds of each termite species were selected, with and without feeder strips. Following the success of the toilet roll baits (1) a third category was selected. A toilet roll bait was placed just below the soil surface, and onto each was placed a wire frame. Baits were installed on 9th September, 1980, and inspected on 20th March, 1981.

(b) Walpeup (Vic.)

The method for installing the steel drum baits is described by French and Robinson (2). Five wire-frames (each with 20 wood-blocks were randomly placed around each of three drums when all drums were infested with *C. acinaciformis*. The wire frames were covered as previously mentioned (2). Baits were installed on 4th February 1980, and inspected on 8th April, 1981.

Damage rating of wood-blocks

At each site damage to each block was visually rated. The visual grades were: 1 - no damage; 2 - termite visited; 3 - termite nibbled; 4 - slight damage; 5 - moderate damage; 6 - severe damage.

## RESULTS

(a) Oakdale (N.S.W.)

The percent of total wood blocks per treatment attacked around the *C. acinaciformis* mounds during the period of test (6 months) and rated between 3 to 6 are shown in Table 2. Fenthion impregnated wood blocks were attacked more readily, irrespective of loadings, than any other insecticide treated block. Lack of activity around *N. exitiosus* mounds over the test period prevents any meaningful evaluation at this stage.

(b) Walpeup (Vic.)

The total number of small wood-block baits that were not attacked and attacked (i.e. rated 3 or more on the visual scale) by *C. acinaciformis* from the three steel drum baits during the 14 month test period are shown in Table 3. The majority of the blocks (60%) were not visited by the foraging *C. acinaciformis*, though about a quarter of the blocks showed evidence of termite visits.

TABLE 2 Percent of total wood-blocks per treatment attacked by *C. acinaciformis* at Oakdale (NSW) after 6 months. Attacks are rated to include termite nibbles to serve attacks.

| Insecticide | Loading | Experimental arrangement around mounds | | |
|---|---|---|---|---|
| | | No feeder strip | Feeder strip | Toilet roll |
| Fenthion | High | 6.7 | 2.2 | 13.3 |
| | Low | 5.6 | 3.3 | 10.0 |
| Quatramine | High | 0 | 0 | 1.1 |
| | Low | 1.1 | 0 | 4.4 |
| Permethrin | High | 1.1 | 0 | 0 |
| | Low | 1.1 | 0 | 5.6 |
| Aldrin | High | 2.2 | 0 | 1.1 |
| | Low | 4.4 | 0 | 6.7 |
| Control (water) | | 4.4 | 1.1 | 10.0 |
| Control (mineral turps) | | 5.6 | 1.1 | 13.3 |

TABLE 3 Number of insecticide-treated wood-blocks and controls not and attacked during the 14 months test by *C. acinaciformis* at Walpeup

| Insecticide | Treatment regimes | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Low loadings | | | | | | High loadings | | | | | |
| Damage Rating | 1 | 2 | 3 | 4 | 5 | 6 | 1 | 2 | 3 | 4 | 5 | 6 |
| Fenthion | 16 | 8 | 4 | 2 | 0 | 0 | 15 | 7 | 5 | 1 | 1 | 1 |
| Quatramine | 19 | 7 | 2 | 1 | 0 | 1 | 22 | 6 | 2 | 0 | 0 | 0 |
| Aldrin | 12 | 13 | 2 | 3 | 0 | 0 | 21 | 7 | 2 | 0 | 0 | 0 |
| Permethrin | 22 | 4 | 4 | 0 | 0 | 0 | 23 | 7 | 0 | 0 | 0 | 0 |
| Control (water) | 18 | 6 | 2 | 1 | 1 | 2 | | | | | | |
| Control (turps) | 19 | 5 | 3 | 0 | 1 | 2 | | | | | | |

Termites attacked about 16% of the wood blocks impregnated with low loadings of insecticides, whereas in the high loadings, only about 10% of the blocks were attacked. On average the insecticide impregnated blocks most prefered by *C. acinaciformis* were in decreasing order as follows:- fenthion > quatramine and aldrin > permethrin

## DISCUSSION

*C. acinaciformis* visited and attacked the insecticide-treated small wood-blocks on the wire-frames at both sites. *N. exitiosus* exhibited less foraging activity than *C. acinaciformis* for the same period at Oakdale. Examination of the controls for each baiting system suggest that there are differences in termite activity between the mounds. Whether this pattern was due to the presence of the different baits or simply the differences between the mounds, is not clear. But irrespective of baiting system, there was a trend indicating that fenthion treated wood-blocks were attacked more than any other insecticide treated block.

*C. acinaciformis* attacked the insecticide treated blocks on both sites in approximately the same order of decreasing severity, viz: - fenthion > quatramine and aldrin > permethrin. The data indicated that such a choice could be estimated within a year of installing the baits. Assessments regarding insecticide performance could be improved upon with later field inspections.

Notwithstanding the seasonal variations in foraging activity by both termite species examined, we consider the present assessment allows for a rapid evaluation of potential termiticides in wood. This field technique is faster and more easily installed and replicated than the Gay et al (1) method. Also, our findings clearly show that a "connecting strip" was not required using the present baiting techniques. All wire-frames were readily visited by the termite species selected for test except the *N. exitiosus*. Finally, we are of the opinion that this method of test will prove fruitful in evaluating the economic threshold of potential termiticides, particularly if only one or two insecticides are used, both with several levels of concentrations and with adequate replication.

## REFERENCES

1. French, J.R.J., Robinson, P.J. and Bartlett, N.R. (1981). A rapid and selective field assessment of termite wood feeding preferences of the subterranean termite *Heterotermes ferox* (Frogg.) using toilet roll and small wood-block baits. Sociobiology (in press).

2. French, J.R.J. and Robinson, P.J. (1981). Baits for aggregating large numbers of subterranean termites. J. Aust. ent. Soc. 20: 75-76.

3. Gay, F.J. Greaves, T., Holdaway, F.G. and Wetherly, A.H. (1957). The development and use of field testing techniques with termites in Australia. CSIRO Australia Bulletin No. 280.

WP 5

# A FIELD TEST OF THE NATURAL DURABILITY OF THE HEARTWOOD OF AUSTRALIAN TIMBERS IN GROUND CONTACT

J.D. Thornton, N.E.M. Walters and I.W. Saunders[1]
Division of Building Research, CSIRO.

## ABSTRACT

A test of heartwood stakes, of dimension 50 x 50 x 450 mm, was installed in 1968-69. The test was set up to determine the reliability of the present Australian classification for natural durability in ground contact. Five exposure sites, containing a total of 3700 specimens, were chosen with two sites each in Queensland and Victoria and one in New South Wales. There have been four inspections so far. This paper lists the ranking after more than 10 years in test of the 80 species, separately for decay and termite hazards, at each site. Though this test requires many more years of exposure before yielding conclusive data, the information presented here would appear to question the validity of those classifications originally allocated to certain timbers. Furthermore, some timbers will show markedly varied durabilities with respect to the two biological hazards.

## INTRODUCTION

Our current assessment of the natural durability of Australian timbers, though much used (AS 1604-1980; AS 2209-1979; Boyd, 1961; Kloot, 1965) is still very much dependent on a consensus of opinion gathered in the early 1950's from the experiences of foresters, timber users and members of the former CSIRO Division of Forest Products. In order to provide a rapid evaluation of the relative durabilities of species of commercial interest a series of laboratory tests was set up (Da Costa and Aplin, 1959; Da Costa, Aplin and Tamblyn, 1957). The results were at the time considered sufficiently objective to enable precise durability ratings to be stated

[1]Division of Mathematics and Statistics, CSIRO.

for timbers in service (Da Costa and Aplin, 1959).

It was recognised that outdoor, in-ground exposure was needed to provide a true test of the relative and absolute life of the timbers. Therefore a field test was devised for the purpose of providing direct information on the natural durability, against in-ground decay and termite hazards, of important timbers.

This paper reports on the progress of the field test installed in 1968-69 comprising 80 timber species at 5 sites. A total of some 3700 stakes was exposed.

## MATERIALS AND METHODS

A range of the most common Australian timbers was chosen, representing both softwood and hardwood species. Exotic species were included to give direct comparison with oversea timbers of well known durability.

Between-tree variability was allowed for by testing, wherever possible, five trees of each species from five different localities representing the geographical range of the species (see AS 02-1970). Within-tree variation was minimized by testing the outer heartwood of the butt log.

Timber species represented are shown in Table 1. Common names are given but, if required, scientific names can be obtained by noting the given standard number and referring to either AS 02-1970 (for Australian timbers) or AS 1148-1971 (for oversea timbers). Durability ratings (Table 1) are those published by Da Costa and Aplin (1959) and include the use of 'plus' and 'minus' qualifications in order to separate timbers within any one of the four durability classes. The classes are based on untreated heartwood of 'reasonable dimensions' (at least 40 mm thickness). For those not familiar with durability ratings, those values accorded by Tamblyn (1966) are given below (in ground ratings for "average conditions"):

Class 1 - Timbers of the highest natural durability which may be expected to resist both decay and termite attack for at least 25 years and sometimes 50 years.

Class 2 - Timbers of high natural durability which may be expected to have a life of about 15 to 25 years.

Class 3 - Timbers of only moderate durability which may be expected to have a life of about 8 to 15 years.

Class 4 - Timbers of low durability which may last about 1 to 8 years. These timbers have about the same durability as untreated sapwood, which is generally regarded as Class 4, irrespective of species.

TABLE 1

Timbers under test at each site

| DBR Code No. | Common Name | Standard Number (a) | Given durability class (b) |
|---|---|---|---|
| Australian hardwoods | | | |
| Myrtles (*Eucalyptus*, *Syncarpia* and *Tristania* spp) | | | |
| 00 | Grey box | 120 | 1 + |
| 01 | Grey ironbark | 304 | 1 + |
| 02 | Wandoo | 708 | 1 + |
| 03 | Red ironbark | 307 | 1 |
| 04 | Swamp box | 138 | 1 |
| 05 | Tallowwood | 655 | 1 |
| 06 | Coast grey box | 121 | 1 - |
| 07 | Gympie messmate | 412 | 1 - |
| 08 | Yellow box | 143 | 1 - |
| 09 | Yellow gum | 290 | 1 - |
| 10 | Forest red gum | 265 | 2 + |
| 11 | Jarrah | 319 | 2 + |
| 12 | Red mahogany | 363 | 2 + |
| 13 | River red gum | 267 | 2 + |
| 14 | Yate | 744 | 2 + |
| 15 | Red tingle | 678 | 2 |
| 16 | Salmon gum | 272 | 2D, 3T |
| 17 | Southern mahogany | 366 | 2 |
| 18 | Sugar gum | 281 | 2 |
| 19 | Woollybutt | 738 | 2 |
| 20 | Wilkinson's stringybark | 647 | 2 |
| 21 | White mahogany | 370 | 2 |
| 22 | White stringybark | 647 | 2 |
| 23 | Yertchuk | 752 | 2 |
| 24 | Yellow stringybark | 648 | 2 |
| 25 | Yellow tingle | 679 | 2 |
| 26 | Satinay | 604 | 2 |
| 79 | Red box | 131 | 2 |
| 27 | Turpentine | 688 | 2 |
| 28 | Tuart | 685 | 2 |
| 29 | Blackbutt | 82 | 2 - |
| 30 | Scribbly gum | 274 | 2 - |
| 31 | Spotted gum | 280 | 2 - |

| DBR Code No. | Common Name | Standard Number[a] | Given durability[b] class |
|---|---|---|---|
| 32 | Yarri | 85 | 2 - |
| 33 | Broad-leaved peppermint | 480 | 3 + |
| 34 | Brown stringybark | 638 | 3 + |
| 35 | Marri | 409 | 3 + |
| 36 | Maiden's gum | 255 | 3 + |
| 37 | Mountain grey gum | 253 | 3 + |
| 38 | Red stringybark | 643 | 3 + |
| 39 | Silvertop ash | 39 | 3 + |
| 40 | Southern blue gum (Tasmanian) | 241 | 3 + |
| 41 | Sydney blue gum | 240 | 3 + |
| 42 | Brush box | 116 | 3D, 1-2T |
| 43 | Long-leaved box | 127 | 3 |
| 44 | Brown mallet | 391 | 3 |
| 45 | Black peppermint | 479 | 3 |
| 46 | Karri | 322 | 3 |
| 47 | Manna gum | 256 | 3 |
| 48 | Messmate stringybark | 411 | 3 |
| 49 | NSW Messmate (narrow-leaved peppermint) | 482 | 3 |
| 50 | Rose gum | 270 | 3 |
| 51 | River peppermint | 485 | 3 |
| 52 | Brownbarrel | 155 | 3 - |
| 53 | Bullich | 157 | 3 - |
| 54 | Candlebark | 166 | 3 - |
| 55 | Mountain ash | 29 | 4 |
| 82 | White box | 141 | |
| Other (Australasian) hardwoods | | | |
| 56 | Bull oak | 435 | 1 |
| 57 | Kwila | 330 | 1 |
| 58 | New Guinea rosewood | 332* | 2 + |
| 59 | Brigalow | 152 | 2 |
| 60 | Raspberry jam | 318 | 2 |
| 61 | Garawa | 121* | 3 + |
| 62 | Bollywood | 104 | 3 |
| 63 | Blackwood | 86 | 3 - |
| 64 | Myrtle beech | 64 | 4 |
| Exotic hardwoods | | | |
| 65 | Teak | 369* | 1 |
| 66 | American white oak | 240* | 4 |
| Exotic softwoods | | | |
| 69 | Redwood | 326* | 1 |
| 70 | Western red cedar | 73* | 1 |
| 71 | Douglas fir | 114* | 4 + |
| 72 | Radiata pine | 528 | 4 - |
| Australian softwoods | | | |
| 73 | White cypress pine | 513 | 2 |
| 74 | Celery-top pine | 503 | 2 |
| 75 | Black pine | 498 | 4 |

| DBR Code No. | Common Name | Standard Number (a) | Given durability class (b) |
|---|---|---|---|
| 76 | Kauri pine | 517 | 4 |
| 77 | Huon pine | 515 | 2 |
| 78 | King William pine | 518 | 2 |
| 80 | Brown pine | 499 | |
| Treated radiata pine sapwood | | | |
| 67 | CCA | | |
| 68 | Creosote | | |

(a) Standard numbers given are those in AS 02-1970, except those denoted by *, in which case their standard numbers are as given in AS 1148-1971.

(b) D, decay; T, termites.

Where sufficient trees were available, two stakes from each of five trees were allocated to each site. As a comparison with treated timber, creosoted radiata pine sapwood (175-210 kg $m^{-3}$ K55 formulation) and copper-chrome-arsenic treated radiata pine sapwood (12 kg $m^{-3}$) were also included.

Stakes were cut to give a finished size of 50 x 50 x 450 mm.

No single site could be expected to represent adequately the full range of hazards to which timber in the ground in Australia may be exposed in service. For this test five sites, all selected to offer both decay and termite hazards, were chosen as follows:

Queensland: at Jolly's Lookout near Brisbane; at Innisfail.
New South Wales: at Pennant Hills, near Sydney.
Victoria: at Walpeup, near Ouyen; at Mulgrave, Melbourne.

Stakes were installed approximately 600 mm apart with a distance of approximately 900 mm between adjacent rows. The 450 mm stakes were buried vertically approximately 300 mm deep in the soil. The installation of the test was completed at four sites between May and July, 1968, although the fifth site (Mulgrave) was not completed until July 1969. There have been four inspections so far, but in future it is hoped to carry out inspections at intervals of two years.

At each inspection, each stake is lifted from the ground, examined for the incidence and extent of both decay and insect attack (using a sharp knife), and replaced. Each stake is separately assessed for decay and termite damage on a scale ranging from '4' (sound) down to '0' (failed) in half points.

## RESULTS AND DISCUSSION

Although some 11 years' exposure is generally insufficient to achieve meaningful data on the most durable timbers, some trends are emerging by this time. Actual scores obtained at the last inspection will not be presented here, neither will the 'estimated specimen life values' of those few species whose replicates at any one site have all become unservicable. A progress report to be published will give both mean scores and, where so far available, estimated specimen life (Thornton, Walters and Saunders, in preparation).

Based on the scores at the inspections,computer analysis has enabled relative rankings of all species to be presented for each site. Table 2 presents ranking of timbers by decay score while Table 3 gives rankings by termite score.

Despite the known widespread distribution of subterranean termites in Melbourne, no termites have been detected attacking stakes at the Mulgrave site.

Those timbers with a low number value are the ones currently showing most resistance to the decay or the termite hazard (Tables 2 and 3). From a quick glance at these tables it can be seen that there is considerable between-site variability in terms of either the relative decay attack rankings or the relative termite attack rankings.

Timber Rankings with Respect to Decay Score (Table 2)

Showing relatively good resistance to decay are many of the timbers originally designated Class 1. These are grey box - 00 (except at Mulgrave), grey ironbark - 01 (except at Walpeup), wandoo - 02 (except at Walpeup), red ironbark - 03 (except at Sydney and Walpeup) and bull oak - 56 (except at Walpeup and Mulgrave). Also white box - 82 is performing very well (except at Walpeup) and two timbers rated Class 2 are performing equally well, brigalow - 59 and raspberry jam - 60 (except at Innisfail). However, of the Class 1 timbers, tallowwood - 05, coast grey box - 06, gympie messmate - 07, yellow box - 08 are all showing some problems at more than one decay site, with swamp box - 04 and yellow gum - 09 probably so far being the worst performers among the Class 1 myrtles. Additionally kwila - 57 and teak - 65 are not performing well against decay.

Amongst those timbers of original Class 2 rating, there is much variation in decay resistance. Salmon gum - 16 is performing well (except at Walpeup) as are woollybutt - 19 and tuart - 28. Red box - 79 is, however, performing by far the best (except at Innisfail) of this class of myrtles. With the possible exception of forest red gum - 10, none of those timbers of given rating 2+ appear to justify the presence of the plus sign, including New Guinea rosewood - 58. Some of the Class 2 timbers appear to be performing worse than expected, including red tingle - 15, southern mahogany - 17, Wilkinson's stringybark - 20, white stringybark -22, yellow stringybark - 24 and scribbly gum - 30. Of the Class 3 timbers, brown mallet - 44 is only justifying this reputation at the Walpeup and Brisbane sites. At the other three sites this species is performing better than expected. The one Class 4 eucalypt in test, mountain ash - 55, appears to be performing no worse than such Class 3 timbers as brush box - 42, manna gum - 47, red peppermint - 55 and candlebark - 54.

Neither of the exotic softwoods (redwood - 69 and western red cedar - 70) justifies its high world rating when compared with the best Australian hardwoods in this test. Radiata pine - 72 appears to be the least durable timber in this test. Though white cypress pine - 73 performs slightly better than redwood - 69, again none of the Australian softwoods is particularly good beside the better hardwoods.

Timber Rankings with Respect to Termite Score (Table 3)

There appears to be much variation in a particular timbers performance between the four sites which present a termite hazard. For example, see brush box - 42, mountain ash - 55, celery top pine - 74 and brown pine - 80. Timbers performing best overall with respect to termites appear to be wandoo - 02, white mahogany - 21, red box - 79, bull oak - 56, brigalow - 59 , redwood - 69 and (with the exception of Sydney) river red gum - 13.

It is clear from these results that some timbers resist termites and decay quite differently. For example, coast grey box - 06 ranks quite well against decay (Table 2) but is far worse against termites (Table 3) whilst river red gum - 13 ranks well against termites but is far worse against decay.

This test is still in its early stages and we must wait for the availability of 'estimated specimen life values' before we can produce new durability classifications based on it.

TABLE 2.

Species ranking based on resistance to decay. (Note: timbers listed in same order as in Table 1)

| DBR Code No | SITE | | | | |
|---|---|---|---|---|---|
| | Brisbane | Innisfail | Sydney | Walpeup | Mulgrave |
| 00 | 13 | 9 | 15 | 11 | 29 |
| 01 | 9 | 13 | 4 | 36 | 10 |
| 02 | 3 | 8 | 3 | 21 | 3 |
| 03 | 5 | 7 | 20 | 18 | 7 |
| 04 | 27 | 55 | 23 | 6 | 23 |
| 05 | 14 | 17 | 18 | 37 | 15 |
| 06 | 19 | 4 | 21 | 9 | 20 |
| 07 | 17 | 24 | 16 | 30 | 24 |
| 08 | 10 | 15 | 6 | 12 | 8 |
| 09 | 21 | 12 | 53 | 22 | 16 |
| 10 | 20 | 20 | 13 | 25 | 9 |
| 11 | 55 | 43 | 33 | 34 | 26 |
| 12 | 25 | 38 | 27 | 43 | 13 |
| 13 | 33 | 32 | 26 | 44 | 33 |
| 14 | 23 | 26 | 25 | 55 | 43 |
| 15 | 71 | 61 | 73 | 65 | 63 |
| 16 | 8 | 14 | 17 | 39 | 11 |
| 17 | 52 | 40 | 41 | 48 | 44 |
| 18 | 22 | 16 | 12 | 26 | 27 |
| 19 | 15 | 10 | 8 | 24 | 12 |
| 20 | 45 | 25 | 57 | 54 | 53 |
| 21 | 16 | 30 | 11 | 38 | 4 |
| 22 | 62 | 27 | 65 | 53 | 49 |
| 23 | 36 | 33 | 46 | 57 | 39 |
| 24 | 47 | 63 | 55 | 46 | 52 |
| 25 | 24 | 5 | 37 | 35 | 38 |
| 26 | 43 | 34 | 38 | 27 | 36 |
| 79 | 4 | 29 | 9 | 8 | 17 |
| 27 | 28 | 31 | 28 | 29 | 28 |
| 28 | 18 | 11 | 24 | 23 | 21 |
| 29 | 48 | 21 | 31 | 19 | 48 |
| 30 | 61 | 47 | 36 | 49 | 57 |
| 31 | 32 | 36 | 39 | 31 | 30 |
| 32 | 35 | 28 | 32 | 32 | 40 |
| 33 | 60 | 58 | 51 | 64 | 61 |
| 34 | 64 | 59 | 60 | 59 | 58 |
| 35 | 57 | 41 | 34 | 61 | 59 |
| 36 | 59 | 66 | 29 | 63 | 54 |
| 37 | 58 | 56 | 42 | 45 | 60 |
| 38 | 30 | 35 | 40 | 33 | 51 |
| 39 | 44 | 57 | 47 | 42 | 55 |
| 40 | 40 | 78 | 35 | 13 | 56 |
| 41 | 68 | 53 | 49 | 66 | 37 |
| 42 | 69 | 68 | 69 | 78 | 66 |
| 43 | 34 | 19 | 44 | 50 | 34 |
| 44 | 37 | 22 | 14 | 62 | 22 |
| 45 | 65 | 67 | 56 | 40 | 72 |
| 46 | 41 | 70 | 30 | 68 | 45 |
| 47 | 76 | 75 | 67 | 79 | 77 |
| 48 | 54 | 64 | 74 | 47 | 70 |
| 49 | 63 | 62 | 66 | 69 | 73 |
| 50 | 51 | 37 | 58 | 51 | 62 |
| 51 | 79 | 69 | 77 | 71 | 74 |
| 52 | 67 | 39 | 70 | 73 | 69 |
| 53 | 39 | 72 | 45 | 60 | 41 |
| 54 | 66 | 60 | 75 | 72 | 71 |
| 55 | 74 | 74 | 68 | 56 | 68 |
| 82 | 11 | 2 | 22 | 52 | 18 |
| 56 | 6 | 3 | 7 | 67 | 46 |
| 57 | 46 | 42 | 52 | 41 | 42 |
| 58 | 49 | 50 | 59 | 20 | 50 |
| 59 | 12 | 18 | 10 | 15 | 6 |
| 60 | 7 | 23 | 5 | 5 | 5 |
| 61 | 56 | 54 | 72 | 75 | 75 |
| 62 | 70 | 48 | 63 | 77 | 65 |
| 63 | 80 | 77 | 43 | 80 | 82 |
| 64 | 73 | 71 | 62 | 10 | 67 |
| 65 | 26 | 44 | 19 | 17 | 19 |
| 66 | 77 | 73 | 71 | 28 | 76 |
| 69 | 53 | 52 | 64 | 4 | 35 |
| 70 | 42 | 49 | 76 | 14 | 47 |
| 71 | 72 | 79 | 79 | 81 | 64 |
| 72 | 82 | 81 | 82 | 82 | 80 |
| 73 | 29 | 46 | 48 | 16 | 14 |
| 74 | 31 | 65 | 61 | 70 | 32 |
| 75 | 81 | 76 | 80 | 74 | 78 |
| 76 | 75 | 80 | 81 | 76 | 81 |
| 77 | 38 | 45 | 50 | 58 | 31 |
| 78 | 50 | 51 | 54 | 3 | 25 |
| 80 | 78 | 82 | 78 | 7 | 79 |
| 67 | 1 | 1 | 1 | 1 | 1 |
| 68 | 2 | 6 | 2 | 2 | 2 |

(Note: the lower the ranking value the greater the resistance to decay).

TABLE 3. WP 5

Species ranking based on resistance to termites. (Note: timbers listed in same order as in Table 1)

| DBR Code No. | SITE | | | |
|---|---|---|---|---|
| | Brisbane | Innisfail | Sydney | Walpeup |
| 00 | 20 | 18 | 46 | 23 |
| 01 | 30 | 11 | 10 | 17 |
| 02 | 17 | 6 | 6 | 13 |
| 03 | 21 | 7 | 9 | 29 |
| 04 | 19 | 4 | 32 | 3 |
| 05 | 27 | 14 | 16 | 18 |
| 06 | 55 | 25 | 52 | 46 |
| 07 | 53 | 31 | 11 | 21 |
| 08 | 38 | 12 | 18 | 28 |
| 09 | 22 | 26 | 28 | 22 |
| 10 | 28 | 16 | 35 | 14 |
| 11 | 42 | 42 | 30 | 32 |
| 12 | 54 | 27 | 12 | 27 |
| 13 | 15 | 17 | 34 | 16 |
| 14 | 43 | 43 | 56 | 60 |
| 15 | 71 | 61 | 64 | 76 |
| 16 | 31 | 40 | 45 | 52 |
| 17 | 13 | 48 | 25 | 35 |
| 18 | 36 | 13 | 14 | 20 |
| 19 | 39 | 38 | 29 | 39 |
| 20 | 70 | 49 | 57 | 63 |
| 21 | 11 | 9 | 19 | 19 |
| 22 | 51 | 57 | 50 | 43 |
| 23 | 44 | 46 | 23 | 50 |
| 24 | 61 | 66 | 48 | 55 |
| 25 | 75 | 47 | 27 | 53 |
| 26 | 40 | 24 | 38 | 8 |
| 79 | 14 | 10 | 2 | 4 |
| 27 | 49 | 20 | 21 | 34 |
| 28 | 24 | 44 | 49 | 49 |
| 29 | 68 | 45 | 36 | 38 |
| 30 | 65 | 50 | 22 | 40 |
| 31 | 52 | 34 | 37 | 44 |
| 32 | 63 | 52 | 33 | 31 |
| 33 | 59 | 63 | 63 | 54 |
| 34 | 50 | 60 | 59 | 62 |
| 35 | 60 | 41 | 55 | 58 |
| 36 | 58 | 65 | 65 | 48 |
| 37 | 34 | 59 | 62 | 64 |
| 38 | 67 | 35 | 47 | 45 |
| 39 | 66 | 62 | 70 | 61 |
| 40 | 69 | 80 | 68 | 70 |
| 41 | 25 | 37 | 61 | 42 |
| 42 | 1 | 30 | 60 | 9 |
| 43 | 56 | 51 | 41 | 41 |
| 44 | 62 | 36 | 43 | 56 |
| 45 | 7 | 68 | 66 | 65 |
| 46 | 35 | 71 | 42 | 66 |
| 47 | 78 | 74 | 79 | 77 |
| 48 | 74 | 70 | 71 | 68 |
| 49 | 72 | 67 | 58 | 59 |
| 50 | 46 | 39 | 26 | 51 |
| 51 | 76 | 64 | 72 | 75 |
| 52 | 18 | 56 | 69 | 67 |
| 53 | 73 | 73 | 75 | 69 |
| 54 | 12 | 58 | 73 | 73 |
| 55 | 4 | 72 | 74 | 78 |
| 82 | 48 | 33 | 39 | 30 |
| 56 | 3 | 3 | 3 | 26 |
| 57 | 2 | 22 | 17 | 24 |
| 58 | 47 | 28 | 20 | 10 |
| 59 | 9 | 5 | 13 | 25 |
| 60 | 26 | 15 | 8 | 15 |
| 61 | 41 | 29 | 67 | 57 |
| 62 | 33 | 54 | 53 | 37 |
| 63 | 80 | 82 | 76 | 82 |
| 64 | 23 | 78 | 77 | 80 |
| 65 | 32 | 8 | 24 | 6 |
| 66 | 77 | 77 | 31 | 74 |
| 69 | 5 | 32 | 7 | 11 |
| 70 | 10 | 23 | 54 | 36 |
| 71 | 8 | 79 | 78 | 81 |
| 72 | 81 | 81 | 82 | 79 |
| 73 | 37 | 19 | 44 | 7 |
| 74 | 45 | 55 | 1 | 47 |
| 75 | 82 | 75 | 81 | 33 |
| 76 | 57 | 76 | 80 | 71 |
| 77 | 64 | 53 | 51 | 72 |
| 78 | 16 | 21 | 40 | 12 |
| 80 | 79 | 69 | 5 | 5 |
| 67 | 6 | 1 | 4 | 1 |
| 68 | 29 | 2 | 15 | 2 |

(Note: the lower the ranking value the greater the resistance to termites)

However, from values presented in this paper it is likely that some timbers will require a change of durability class. Furthermore it does seem likely that at least some of the timbers will need class separation in respect of the termite and the decay hazards.

## REFERENCES

1. Australia, Standards Association: (1970).Nomenclature of Australian Timbers. Stand. Assoc. of Australia, Sydney, N.S.W. AS 02-1970.

2. Australia, Standards Association: (1971). Nomeclature of Commercial Timbers Imported into Australia. Standard. Assoc. of Australia, Sydney, N.S.W. AS 1148-1971.

3. Australia, Standards Association: (1980). Preservative-treated Sawn Timber, Veneer and Plywood. Stand. Assoc. of Australia, Sydney, N.S.W. AS 1604-1980.

4. Australia, Standards Association: (1979). Timber Poles for Overhead Lines. Stand. Assoc. of Australia, Sydney, N.S.W. AS 2209-1979.

5. Boyd, J.D.: (1961). Efficient Engineering with Round Timbers. J. Inst. Eng., Australia, 33, 27-36.

6. Da Costa, E.W.B. and Aplin, T.E.H.: (1959). The Resistance to Decay in Laboratory Tests of Twenty-three Durable or Moderately Durable Australian Timbers. CSIRO Aust. Div. For. Prod. Proj. P 13-5, Prog. Rep. No.2.

7. Da Costa, E.W.B., Aplin, T.E.H. and Tamblyn, N.: (1957). The comparative resistance to decay of eight Australian timbers under different conditions of testing. CSIRO Aust. Div. For. Prod. Proj. P 13-5, Prog. Rep. No.1.

8. Kloot, H.: (1965). Revised Strength Grouping System. CSIRO For. Prod. Newsletter, No. 324.

9. Tamblyn, N.: (1966). Natural Durability Ratings. CSIRO For. Prod. Newsletter, No. 335.

10. Thornton, J.D., Walters, N.E.M. and Saunders, I.W.: A Natural Durability Field Test of Australian Timbers, Including Exotic Reference Species. 1. Progress Report after more than 10 years exposure (in preparation).

WP 6

# ACCELERATED "FUNGAL CELLAR" TESTING OF THE NATURAL DURABILITY OF THE HEARTWOOD OF AUSTRALIAN TIMBER IN GROUND CONTACT

J.D. Thornton, G.C. Johnson and I.W. Saunders[1]

Division of Building Research, CSIRO.

## ABSTRACT

A "fungal cellar" is employed to provide temperature and moisture regimes which will enhance fungal decay, thereby accelerating the testing of timber (with or without preservatives) in ground contact. This paper reports on the installation of a test to compare the natural durability of timber species in both a fungal cellar and in the field. Eighty timber species have now been exposed for over 10 years at 5 sites around Australia. From the Mulgrave (Victoria) test site, the upper 100 mm of the out-of-ground portion of replicate stakes of 32 species was removed. Each was cut to form "ministakes" 22 x 22 x 100 mm. The soil used in the cellar is from the Mulgrave site. The cellar test was installed in March 1981, and will be inspected at 28-day intervals. The main purpose of this test is, ultimately, to see if the order of failure of species in the cellar is the same as that order eventuating in the field test at the Mulgrave site. It is hoped this type of experimentation will soon provide an indication as to whether fungal cellar testing can, in the future, reliably replace requirements for long-term field testing against decay hazards.

## INTRODUCTION

The testing of decay resistance and of timber preservatives has, in the past, commonly been performed by either short-term laboratory testing using small wood blocks or by long-term field exposure using stakes or pole rounds. Recently, there have been two modifications to these approaches, arising from the desire of researchers to be able to form some quantitative comparison between laboratory and field performances. In order to attempt this comparison one can:-

---

1 Division of Mathematics and Statistics, CSIRO.

(a) set up an experiment in the laboratory (using laboratory-size specimens and fungal monocultures) then expose the test outside under field conditions, or

(b) set up a field-type test under controlled environmental conditions.

The latter is receiving much attention in the world's research laboratories, undoubtedly because of the desire to obtain reliable field performance data without having to wait the many years required by conventional field testing. This controlled environment type of testing is referred to here as "accelerated fungal cellar testing". Though this testing is not new, having been performed with monocultures of decay fungi in German laboratories for many years, it is only in the last few years that cellar testing with a natural, soil organism population (including the soft rot decay microorganisms as well as the "white rot" and "brown rot" decay fungi) has been undertaken.

This paper reports the initiation of an accelerated fungal cellar test of the natural durability of timber in ground contact. The Division of Building Research has in progress a field test of heartwood stakes of some 80 timber species exposed at 5 sites in Australia (see Thornton, Walters and Saunders, 1981). At one of these sites, Mulgrave (Melbourne), termites have not been detected since the installation of this field test in 1969. It was decided to select a number of timber species and remove a length of the out-of-ground portion of replicate stakes from the Mulgrave site. These were then cut to form "ministakes" approximately one quarter of the cross-sectional area of the original field stakes. The cellar itself contains soil removed from the Mulgrave site, and no addition of decay organisms has been attempted. The cellar is maintained in an environment of suitable temperature and humidity for enhanced growth of decay organisms and the soil is frequently watered. The test was set up in March 1981 and will be inspected in the same manner as a conventional field test, except that the inspection intervals will be of 28 days' duration.

Our ultimate aim is to see if the order of species failure due to decay in the fungal cellar is the same as that in the field test site at Mulgrave.

## MATERIALS AND METHODS

The Division's fungal cellar is a temperature and humidity controlled room housing metal troughs each 1800 x 600 x 800 mm deep. A single trough containing a bottom layer of coarse screenings 150 mm deep is being used for this test. One cubic metre of subsoil, including stones, was placed in the trough on top of the screenings. Half a cubic metre of topsoil was sieved (4 mm x 4 mm square-holed mesh). Material not passing through the sieve was placed directly on top of the subsoil and the fine, sieved topsoil placed over this. The total depth of soil in the cellar was 400 mm. After levelling, the soil was carefully watered at regular intervals until it was moist - without free water draining into the screenings. The air temperature was maintained at 27°C and the relative humidity at 85 per cent.

It was decided to represent each timber species by three ministakes produced from each of three replicate stakes (that is, 9 replicates of each species). With ministakes of cross-section 22 x 22 mm and with 25 mm spacing between stakes, this meant selecting a total of just under 40 species for test. In all, 32 species (plus CCA-treated radiata pine) were selected for removal from the test site at Mulgrave. Unfortunately stakes which had failed during previous field inspections (obviously of the less durable species) were not available. This meant that, with only 2 exceptions, the 32 species selected were of Class 1 (highly durable), Class 2 (durable) and Class 3 (moderately durable). The actual species selected depended on many factors such as the desire to have:-

(i) as many Class 1 timbers as possible in test

(ii) as many of those timbers which inspection data showed to be not performing according to their present durability classification. (Thornton, Walters and Saunders, in preparation).

(iii) sufficient replicate stakes free of serious splits and mechanical damage.

(iv) a preservative-treated yardstick.

The timber species selected are shown in Table 1. The top 100 mm was removed from the replicate stakes at the Mulgrave site (cross-section approximately 50 x 50 mm). From these, four ministakes (approximately 22 x 22 x 100 mm) were produced which were then numbered and photographed. The fourth specimen was stored for comparison during test inspections and as a permanent record.

TABLE 1 TIMBERS UNDER TEST IN THE FUNGAL CELLAR

| Test number | Common name | Standard number[1] | Given durability[2] |
|---|---|---|---|
| Australian myrtle hardwoods (*Eucalyptus*, *Syncarpia* and *Tristania* spp) | | | |
| 00 | Grey box | 120 | 1 + |
| 01 | Grey ironbark | 304 | 1 + |
| 02 | Wandoo | 708 | 1 + |
| 03 | Red ironbark | 307 | 1 |
| 04 | Swamp box | 138 | 1 |
| 05 | Tallowwood | 655 | 1 |
| 08 | Yellow box | 143 | 1 - |
| 09 | Yellow gum | 290 | 1 - |
| 11 | Jarrah | 319 | 2 + |
| 17 | Southern mahogany | 366 | 2 |
| 18 | Sugar gum | 281 | 2 |
| 19 | Woollybutt | 738 | 2 |
| 21 | White mahogany | 370 | 2 |
| 26 | Satinay | 604 | 2 |
| 79 | Red box | 131 | 2 |
| 28 | Tuart | 685 | 2 |
| 29 | Blackbutt | 82 | 2 - |
| 30 | Scribbly gum | 274 | 2 - |
| 35 | Marri | 409 | 3 + |
| 36 | Maiden's gum | 255 | 3 + |
| 37 | Mountain grey gum | 253 | 3 + |
| 41 | Sydney blue gum | 240 | 3 + |
| 52 | Brownbarrel | 155 | 3 - |
| Other hardwoods | | | |
| 57 | Kwila | 330 | 1 |
| 59 | Brigalow | 152 | 2 |
| 60 | Raspberry jam | 318 | 2 |
| 61 | Garawa | 121* | 3 + |
| 64 | Myrtle beech | 64 | 4 |

| | | | |
|---|---|---|---|
| Exotic hardwood | | | |
| 65 | Teak | 369* | 1 |
| Exotic softwoods | | | |
| 69 | Redwood | 326* | 1 |
| 71 | Douglas fir | 114* | 4 + |
| Australian softwood | | | |
| 73 | White cypress pine | 513 | 2 |
| Treated radiata pine sapwood | | | |
| 67 | CCA (copper-chrome-arsenic, 12 kg $m^{-3}$) | | (1 +) |

---

| | | |
|---|---|---|
| Additional, freshly cut timbers | | |
| Radiata pine sapwood | 528 | 4 - |
| Radiata pine heartwood | 528 | 4 - |
| Mountain ash heartwood from original forest | 29 | 4 |
| Mountain ash heartwood from regrowth forest | 29 | 4 |
| Messmate heartwood | 411 | 3 |

---

1 For botanical names of timber species use listed number in reference to Australian Standard AS 02-1970 or * AS 1148-1971.

2 see Thornton, Walters and Saunders, Topic WP 5 of this Conference.

In addition to the 32 species, 3 non-durables were selected (Table 1), to be included in this test as fresh material. These were messmate heartwood, mountain ash heartwood (both original forest and regrowth material) and both heartwood and sapwood of radiata pine. In the latter case both the heartwood and sapwood were cut from the same three pine trees. In accordance with the original field test procedure, all heartwood specimens were cut from the outer heartwood of the butt log.

An experimental design incorporating 9 randomised blocks was selected and the ministakes were installed in March 1981. The top of the original stakes was buried to a depth of 75 mm in the soil. The frequency of watering was accelerated to moisten the specimens sufficiently to allow microbial colonization to take place.

Inspections have been and will continue to be performed at 28 day intervals. For every inspection each specimen is temporarily removed and scored for decay on a scale '4' (sound) to '0' (failed) in half-point gradations. Only the two freshly cut faces of those 32 species removed from the Mulgrave site are inspected.

## DISCUSSION

Though there will have been 8 inspections of this test by the time of this Conference, at the time of writing only one inspection has been completed. At that inspection, surface colonization of below ground portions of the ministakes was evident, with visual evidence of both decay fungi and soft rot microorganism colonization on many replicates. Despite the presence of some surface attack, all specimens were rated '4' (i.e. sound) at this first inspection.

Computer analyses of the scores of the ministakes in the fungal cellar, and ultimately analyses of the scores of the parent stakes still under test at the Mulgrave site, will enable comparison between cellar and field testing of ground-contact natural durability. This will indicate whether fungal cellar testing can, in the future, reliably replace requirements for long-term field testing against fungi. There are no reasons, however, why similar cellar tests also including termites should not be undertaken in the near future.

If early inspections indicate the likelihood of useful data coming from the present test, the authors would wish to repeat this type of test with preservative-treated stakes removed from field exposure (initially only for decay resistance).

Ultimately, research may possibly enable "service lives" of either timbers of unknown durability or timbers treated with new wood preservatives to be quickly predicted. This could be performed by conducting a cellar test along with timbers and/or preservatives for which reliable "field to cellar life correlations" have already been calculated.

REFERENCES

Australia, Standards Association: AS 02-1970. Nomenclature of Australian Timbers. Stand. Assoc. of Australia, Sydney, N.S.W. 1970.

Australia, Standards Association: AS 1148-1971. Nomenclature of Commercial Timbers Imported into Australia. Stand. Assoc. of Australia, Sydney, N.S.W., 1971.

Thornton, J.D., Walters, N.E.M. and Saunders, I.W. (1981). Field testing of natural durability of the heartwood of Australian timbers in ground contact. 20th Forest Products Research Conference, Melbourne, November 16-20, 1981. Topic WP 5.

Thornton, J.D., Walters, N.E.M. and Saunders, I.W. A natural durability field test of Australian timbers, including exotic reference species. 1. Progress Report after more than 10 years' exposure (in preparation).

# PROGRESS ON INVESTIGATIONS OF THE TRUE DRY ROT FUNGUS *SERPULA LACRYMANS* IN RELATION TO THE RENOVATION AND PRESERVATION OF BUILDINGS

J.D. Thornton
Division of Building Research, CSIRO.

## INTRODUCTION

The wood destroying fungus *Serpula lacrymans* Gray is nowadays normally referred to as "the true dry rot fungus". Many persons continue to use its former scientific name of *Merulius lacrymans*.

This paper will briefly present Australian data gathered by the author, and will discuss its relevance to current improvement measures for established buildings.

## RESULTS AND DISCUSSION

Recorded outbreaks in Melbourne buildings are presented in Figure 1, which includes one recent case from Ballarat. All these outbreaks are instances of attack of flooring timbers within buildings containing masonry. No attacks have been reported for weatherboard buildings. The records are authenticated either by the author or by a former taxonomist of this Division, Mr. Neville Walters, over a number of years. Cases come to light through owner enquiries and the full extent of the distribution of this fungus in Melbourne is not known. The fungus is not found free-living in the forest and its association with buildings makes it a "private fungus". The distribution of this fungus in the rest of Australia is, therefore, not known. However, there have been cases in New South Wales (Glenorie, 1968 in a mushroom shed; Kogarrah, 1970 nursery hardening frame; and a likely case in a Sydney house; John Walker personal communication).

The fungus is a typical "brown rot" causing basidiomycete, in that it removes cellulose leaving timber in a state where it will become cuboidally-cracked (across the grain) when dry. However, the first symptoms apparent to the homeowner are normally one of the following; extensive deposits of the red-

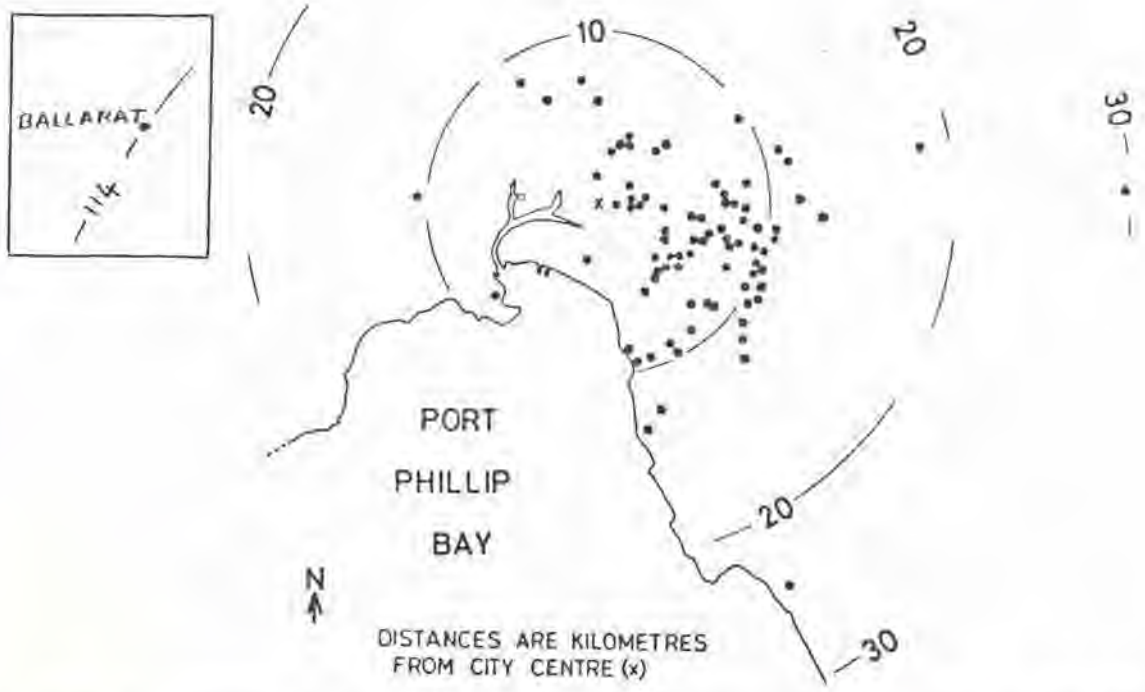



Fig. 1 Location of confirmed outbreaks of *Serpula lacrymans* in the buildings of Melbourne. Insert: One confirmed case in Ballarat.

brown "dust" of fungal spores on all internal horizontal surfaces, intense "mushroomy" smell, flooring collapse under human load. The fastest attack known to the author is a case of flooring collapse followed just three months later by collapse of the replacement flooring. A number of other cases have shown this cycle in six to twelve months. Naturally, these unfortunate cases (where the fungus was not successfully eradicated before replacement of flooring) do not indicate how quickly the fungus destroyed the flooring in the first instance. However, we can conclude that decay must proceed rapidly once begun, under conditions in the subfloor spaces of certain Melbourne buildings.

The fungus has an optimum growth rate at 18-22$^{o}$C and ceases growing at 26$^{o}$C. These optimum and maximum temperatures, although characteristic of this fungus, are unusually low for a wood decay fungus. Because of these "low" temperature requirements, European researchers have until recently been sceptical about our findings of this fungus in what they would describe as "the unfavourably hot Australian climate". However, the rapidity of successive failures, stated above, shows that this fungus is capable of working much faster in some Australian buildings than in the European buildings. This observation was deemed to justify further research to answer the following question; can *S. lacrymans* grow throughout the year in Melbourne? To answer this question the subfloor space of an asbestos-cement (AC) clad building, with only one small subfloor ventilator,

was selected for use as an experimental incubator. Jars containing non-nutrient agar and lengths of *Pinus radiata* D. Don sapwood predecayed with *S. lacrymans* were set up in the laboratory. Fresh, weighed blocks of radiata pine sapwood were introduced. Jars were set up in this fashion every month and incubated for a two-month period within the subfloor space of the AC-clad building. A duplicate set was always incubated in the laboratory at 20°C. The resulting mass loss of the blocks after each two-month exposure period is shown in Table 1. Data for the summer season only is presented, though the experiment continued for a full year. Results (Table 1) show that the fungus caused decay throughout the summer period, although the rate of decay was not as high as that occurring under the favourable (optimum), laboratory temperatures. In fact the fungus not only caused decay throughout the year under the subfloor space, but the fungus was always found to be viable at the end of the twelve incubation periods. Therefore it seems that not only can *S. lacrymans* survive throughout the year, but it can

TABLE 1

Mass loss of test blocks of *Pinus radiata* exposed to *Serpula lacrymans*

| Conditions of Exposure | Mean mass loss (per cent) | | |
|---|---|---|---|
| | Months of exposure to decay test | | |
| | November plus December | December plus January | January plus February |
| Poorly ventilated, subfloor space of AC-clad building | 13.2 | 10.4 | 9.8 |
| Laboratory incubator, at 20°C. | 14.8 | 14.6 | 13.9 |

cause decay throughout the year in the subfloor spaces of some badly-ventilated, masonry buildings in Melbourne. However, for the fungus to survive within even a badly-ventilated subfloor space it is necessary to have a source of moisture available to the fungus. In practice, water can arrive from many sources and by a variety of building malpractices and almost all the cases shown in Figure 1 had a moisture problem in the flooring region. For example, many Melbourne suburbs are low-lying and site drainage is often difficult. On the other hand leaking plumbing, broken roofing tiles, rusted guttering can each result in water becoming available in the basal area of the building, as can defective or non-existent damp courses.

The investigations on the ability of *S. lacrymans* to survive the year round went hand in hand with some experimental temperature monitoring within subfloor spaces of Melbourne buildings. The question looked at was; can the warm summer air outside the building enter the subfloor space to make the environment within that space unsuitable for growth by either *S. lacrymans* or other wood decay fungi? The maximum and minimum termperatures were measured at weekly intervals under the floor of the badly-ventilated AC-clad building mentioned earlier (see Table 1). Currently, a brick veneer house ventilated to the Victorian Uniform Building Regulations and a weatherboard building are both being monitored in a similar fashion. In all cases the weekly extremes of temperature are also being recorded for the outdoor shade environment of each building.

Values show there to be, under all three constructions, a reduction from the outdoor shade maximum. This is the case even beneath the weatherboard, where the maximum temperature reached would be expected to temporarily stop any surface growth of *S. lacrymans*, but would not kill the fungus. However, the maximum subfloor temperatures for the weatherboard would not even stop the growth of most other species of decay fungi. The maximum temperatures under the brick veneer would not even stop the growth of *S. lacrymans*. Maximum temperatures under the AC-clad building were near optimum for the growth of this fungus. Therefore, the temperatures attained, under the Melbourne buildings used in this study, are suitable for fungal decay despite Australia's generalised reputation as "an unfavourably hot climate for the growth of, and decay by, *Serpula lacrymans*". The outside air temperatures may be unfavourable, but subfloor temperatures are very favourable and must go a long way to explaining why this fungus causes far more rapid destruction here than it does in its "native" European environment; it must also explain why we have so many decay problems in the flooring area of buildings (and very rarely indeed do we have decay problems in roofing areas - in contrast to European buildings).

If subfloor ventilation is not beneficial from the point of view of introducing air with sufficient heat to kill decay fungi, then the sole benefit of ventilation must be for the removal of moisture. That moisture is more difficult to remove from masonry than from timber must help explain why *S. lacrymans* is limited to masonry buildings. (However, many other species of decay fungi can attack the timber of weatherboard buildings).

# ASPECTS TO CONSIDER IN EVALUATING A NON-DESTRUCTIVE METHOD FOR TESTING UTILITY POLES

J.D. Thornton and G.C. Johnson
Division of Building Research, CSIRO

## INTRODUCTION

Several methods for non-destructive pole inspection are being evaluated by various authorities around the world. It is not our intention here to discuss the relative merits of the instruments involved. We simply wish to express certain opinions regarding non-destructive testing, and to document our concern over one of the destructive methods currently being used for comparison with non-destructive methods.

## DISCUSSION

We believe that a method suitable for routine pole inspection should be:

(a) capable of distinguishing between sound wood, defects caused by decay and insects, and internal physical defects such as splits and checks;

(b) capable of distinguishing active biological action (by fungi or termites) from that which is dormant or has been completed;

(c) reasonably quick and inexpensive;

(d) reliable.

Items (b) and (d) are of particular concern to the authors and will be discussed in greater detail.

White rot and brown rot fungi can cause centre rots in pole heartwood as well as degrade in the sapwood and outer heartwood. On the other hand, degrade by soft rot organisms may usually be expected in the sapwood only (a case of soft rot in pole heartwood has been reported

by Barnacle and Beesley in 1980). If we look at the general characteristics of wood affected by these types of fungi (Table 1), the features vary markedly not only between types of rot but also between decaying or decayed wood.

Table 1: Characteristics of decay-affected wood. (1)

| Causal organisms | Condition of wood | Description of affected wood |
|---|---|---|
| Brown and White Rot Fungi (Basidiomycetes) | Decaying | Wood is moist and soft.<br>Wood is showing its original shape.<br>Wood shows less strength loss than for decayed wood. |
| | Decayed | Wood is dry (2) and crumbly or fibrous.<br>Wood cracks across the grain (brown rot) or becomes fibrous (white rot).<br>Wood shows more strength loss than for decaying wood. |
| Soft Rot Microorganisms | Decaying | Wood is moist, soft and usually discoloured.<br>Wood is showing its original shape.<br>Wood shows some strength loss. |
| | Decayed | Wood is dry and hard, particularly at low moisture content.<br>Wood may have cracking (small and cuboidal) but cracking may be absent.<br>Wood shows detectable strength loss which may apparently be less than was apparent in the decaying state. |

(1) No mention is made here of 'dry rot'. Since wood which is kept continually dry cannot support fungal growth, the term is to avoided.

(2) Decay-affected wood dries out faster than does sound wood of the same original moisture content.

It is obvious from Table 1 that, for wood affected by white or brown rot fungi, it is far easier to detect decayed wood than decaying wood*. However, unless environmental conditions change, decaying wood will

* The authors strongly suggest the adoption of the terms decaying and decayed for fungus-affected wood, since the terms 'rot', 'decay' and 'attack' are too vague and, as in the case of 'dry rot', may be misleading.

continue to decay whereas the decayed wood will not. It is equally obvious that degrade by soft-rotting microorganisms is relatively difficult to detect macroscopically unless a brash fracture is seen. Soft rot-decaying material is often easier to detect with a knife test than is soft rot-decayed wood.

With a non-destructive instrument capable of differentiating wood that is sound, decayed or decaying, the inspector would be able to evaluate the existing internal condition of the pole and make a reasonable estimate of its future condition at the time of next inspection.

When comparing methods, or when determining the reliability of a proposed inspection method for research purposes some comparison to a destructive method is always required. Several researchers in the U.S.A, Europe and Australasia are employing 'the ability to culture wood decay fungi from a sample core' as the 'destructive' yardstick. This sounds simple and though some success may be had from attempts at culturing from decaying wood, in practice recovering the decay-causing fungi from decayed wood is very difficult. Decaying and decayed wood invariably contain moulds, which do not themselves cause decay, but these moulds grow faster on culture media than do the wood-decaying fungi. Hence, growth of the decay fungus is masked or stopped. Special culture media, containing antibiotics to suppress mould growth, are recommended. Despite the assistance of an antibiotic medium, in 74 attempts to culture white or brown rot fungi from decayed or decaying pole segments all of which were visibly decay-affected, no basidiomycetes were recovered. If this work had been performed on cores as a check for some instrumental technique then the poles may have been assessed falsely as sound. From this experience the authors believe that verification that the wood is decay-affected cannot be carried out by culturing alone. Microscopic examination is necessary, in order to look for evidence of the degradation of wood cell wall components.

In the previous case the decay-causing fungi could not be isolated in 74 attempts. Culturing, if used carelessly, can be so misleading that the converse may also be seen; one could obtain decay fungi where decay-affected wood is not apparent. For example, while the authors were examining a SECV pole which failed mechanically it was noticed that the heartwood core broke with a brash fracture. That type of fracture is used often to indicate the presence of soft rot-affected wood.

However, microscopic examination of the wood does not confirm that soft rot caused the failure of the pole. No soft rot cavities have been seen. In fact, the brash fracture was due to brittle heart - not soft rot. Nevertheless, we will attempt isolating 'wood decay fungi' from the timber to see whether soft rot causing organisms are present. If present, it would provide further evidence of the misleading value of culturing as a true indicator of decay-affected wood either when inspecting poles or when destructively evaluating a non-destructive instrument.

## REFERENCE

Barnacle, J.E. and Beesley, J. (1980). A test of pole treatments in dry tropical Queensland after 21 years. Proceedings of the ESAA Pole Symposium, Surfers Paradise, Queensland, April 22-24, 1980, Topic 9, 24 pp.

# PENETRATION OF CREOSOTE INTO STAINED KARRI (*EUCALYPTUS DIVERSICOLOR* F. MUELL.) HEARTWOOD

J.E. Barnacle, G.C. Johnson, M.A. Tighe, A. Antonovsky
Division of Building Research, CSIRO

## ABSTRACT

Preliminary investigations have shown that certain stained karri heartwood can be readily penetrated with creosote at 1380 kPa whereas unstained heartwood is refractory at this, and higher pressures.

Similar material from each of four trees ex Big Brook Western Australia is currently being studied to determine its susceptibility to impregnation. Attempts to isolate cultures and identify the permeability - causing micro-organism/s are in progress. In addition microscopic examination of both stained and unstained heartwood is being done to better estimate the means whereby penetration of the stained heartwood is achieved.

This work is considered to have potential in that it could provide a means of improving the preservative treatment of wood used as poles and/or railway sleepers.

## PRELIMINARY RESULTS AND DISCUSSION

The current series of studies was undertaken because it was considered that stained permeable heartwood, rather than being a quality defect, could be a means whereby commodities obtained from karri such as power poles or rail sleepers could be given a more adequate preservation treatment than is presently possible.

That stained heartwood of karri could be very permeable, to creosote at least, was first observed by Barnacle and Christensen in an unpublished study in which green karri pole stubs were conditioned by the Boulton process and then pressure treated at 1380 kPa. An assessment of penetration pathways derived from

microscopic examination of material from these poles was, however, published (Greaves and Barnacle, 1971).

Preliminary studies of the penetrability of stained karri heartwood have indicated that brown stained heartwood absorbs creosote much more readily than the unstained. Although unstained heartwood has proved to be refractory in other studies at 7000 kPa treating pressure, the stained material examined so far has treated readily at 1380 kPa. Penetration appears to be mainly confined to vessels but volumetric uptake of creosote is still substantial. Four logs containing stained heartwood were obtained from trees selected from a pole stand of karri regrowth in the Big Brook area of W.A. Selection was done by felling trees having fire scars, overgrown branches or broken branches.

Despite the use of several media and incubation in aerobic and anaerobic conditions, few microorganisms (fungi, bacteria or actinomycetes) were initially isolated from the heartwood of the four karri logs. Furthermore none of the organisms isolated in this series was consistently associated with the stained, but not with the unstained heartwood. It is possible that inappropriate culture media or growth conditions were used. However, from preliminary examination (with the light microscope) of sections from stained and unstained heartwood, it seems that only one log has significant microbial colonization of the stained heartwood. In this case one or more dark coloured fungi can be seen in the ray cells of the stained heartwood near where it meets the unstained heartwood. However - and particularly because the penetration appears to be confined mainly to vessels - it is not known whether this organism is the factor causing the observed increased permeability.

Thus far, penetration studies have been conducted only on the log subsequently shown to contain the dark-coloured fungi. Specimens - including both stained and unstained heartwood - have been cut from another section of the same log and from each of the other three logs. These specimens are currently air-drying prior to pressure treatment.

Just how much of this stained material exists in the karri forests, or how frequently it occurs in any given stand is not known at this stage. However officers of the Forests Department of Western Australia were able to find, with little difficulty, the material currently being studied.

It should also be noted that there is some evidence (derived from preservative-treated sleepers removed after 22 years service in the Carnegie test track in Victoria) that stained heartwood permeable to preservative oils can be found in *E. regnans* and *E. eugenioides*. In these species, as in karri, the density of the heartwood rendered permeable by the particular staining factor (or factors) appeared to be little different from that of the unstained wood.

"Biological incising" - i.e. the inoculation of pieces of refractory heartwood with a microorganism with the intention of rendering the wood permeable without it undergoing substantial decay - has not yet proved to be a reliable means of increasing wood permeability. Nevertheless, it seems likely that such a permeable condition in otherwise solid wood is often achieved in standing trees of karri, at least. Thus, provided a permeability - causing organism can be isolated from the wood currently being studied and then cultured in the laboratory, some attempts will be made to "biologically incise" heartwood of living trees in the field and also sawn unstained heartwood in the laboratory.

As all isolation attempts, microscopic examinations and preservative treatments should be completed by the end of August, a full report on the results of this preliminary study will be available for the Forests Products Conference in November 1981.

ACKNOWLEDGEMENTS

The authors wish to thank Mr. I. Rotherham and other staff of the Forestry Department of Western Australia for their ready co-operation and assistance in obtaining the karri logs. The contribution of Dr. P. Dorling and the staff at Murdoch University in providing laboratory facilities and services is also gratefully acknowledged.

REFERENCE

Greaves, H. and J.E. Barnacle. 1970. A note on the effect of microorganisms on creosote penetration in *Pinus elliottii* sapwood and *Eucalyptus diversicolor* heartwood. Forest Products Journal 20 (8): 47-51.

# THE PERFORMANCE OF ONE-PIECE PRESSURE TREATED HARDWOOD AND SOFTWOOD RAILWAY SLEEPERS IN VARIOUS AUSTRALIAN STATES

C.W. CHIN and J.E. BARNACLE
Division of Building Research, CSIRO.

## ABSTRACT

Extensive rail sleeper tests were set up, mostly 25 years ago, by the then CSIRO Division of Forest Products in conjunction with the various rail systems. Data obtained from the tests show that oil treated sleepers of a number of hardwood species as well as those of radiata pine can give service lives of 25 years and in some cases probably more than 30 years. Creosote/tar oil, creosote/furnace oil, pentachlorophenol in furnace oil and, to a lesser extent, creosote are indicated as being the best sleeper preservatives.

## INTRODUCTION

Traditionally all Australian railway systems used wood sleepers cut from naturally durable timber in the construction and maintenance of their tracks. However, supplies of durable hardwood species are now seriously depleted. The practicality of using alternative species of lower natural durability for sleepers has been studied by the former Division of Forest Products and now the Division of Building Research for a period of nearly 50 years. In cooperation with the State and Commonwealth rail systems and the State Forestry Departments, the former Division of Forest Products designed the tests, treated and installed test sleepers at 24 sites over 6 states. Results of the major tests are discussed here.

## MATERIAL AND TREATMENTS

Approximately 5500 sleepers cut from 21 hardwood and one softwood species, and various combinations of 12 wood preservatives - 9 oil type and 3 waterborne - were used.

The pressure treatments of hardwood sleepers were carried out mainly at 7000 kPa. However for some readily treated sleepers of low density eucalypts, the treating pressure was limited to 4100 kPa. Hardwood sleepers were air-dried before treatment with the exception of 19 brush box sleepers which were

boultonized "green" before pressure treatment at 7000 kPa. Air-dried softwood sleepers were treated at pressures within the range of 280-1400 kPa. For hardwood and softwood sleepers the target retention for oil-type preservatives was 96-128 kg/$m^3$ (total volume basis) and for waterborne preservatives was 12 kg dry salt/$m^3$ (total volume basis). The test sleepers were progressively installed on, mainly, tangent (straight) track at 24 sites in 6 states between 1952-1961.

## RESULTS AND DISCUSSION

### 1. Hardwood sleepers

#### (a) Untreated controls

For the naturally durable species, it is evident from Table 1 that wandoo in the South Australia/Western Australia test, and jarrah and river red gum in the South Australia test are the only untreated naturally durable species that have achieved more than 25 years service life in any of our tests. Other instances where the durables reached an average life of 20 years or more were: Western Australian blackbutt - 23 years in South Australia/Western Australia; river red gum - 23 years in Victoria and 21 years in New South Wales, and grey box - 20 years in New South Wales. These species failed mainly due to splits and/or decay.

Species with moderate to low surability, as expected, performed poorly with the main causes of failure being decay and splitting. The only exceptions to this pattern were karri and marri in the Western Australia test which were severely attacked by termites (in lateritic gravel ballast). The average life of the untreated sleepers varied between 7 to 16 years (see Table 1).

#### (b) Oil treated sleepers

Out of the 71 species/oil treatment combinations tested, 42 have given excellent performance and are expected to exceed an average service life of 25 years, with some combinations likely to reach 30 years. This result is the more creditable for two reasons. First, some sleepers in some groups were initially split before treatment and, as a consequence, had to be removed prematurely with the causes of failure being splits and spike kill. Results obtained so far indicate that the importance of such splits is likely to be directly related to their location relative to spikes and their initial severity. The presence of such splits in any group of sleepers will no doubt depress to some extent the mean life and worsen the service life distribution as compared to a group of sleepers that has minimum splits. Secondly some sleepers were very much undersized for the weight/size of rail used. For instance in the New South Wales test, initially 50 kg rail was installed and four years later it was changed to 53 kg rail. This rail is approximately 160 mm high and some of the

test sleepers were only 95 mm thick. Despite the heavier rail loads and greater amount of traffic at this site as compared with others, recent inspection results indicate that a number of good quality, under-sized sleepers are still in excellent condition.

When comparing the service lives achieved for species tested in both the untreated and oil-treated condition it is evident that oil treatment under pressure greatly improves the performance even of a durable species like satinay. Under severe wet tropical conditions at Deeral, Queensland (1) an improvement in service life of 10 years is confidently predicted (compared with 15 years for the untreated satinay - see Table 1). In the drier cooler climate of south Western Australia, the value of treatment in sleepers of the durable jarrah species is also becoming apparent. After 25 years in test, 61 per cent of untreated sleepers of this species have failed with an average life of 23 years. On the other hand those pressure-treated at 7000 kPa with straight furnace oil could well exceed a 30 year service life as only 3 per cent of these sleepers had failed at 25 years.

The data presented in the table clearly show that adequate treatment with certain oil-type preservatives has most markedly increased the life of sleepers of the species with low to moderate natural durability. For instance for sleepers of mountain ash in Victoria, brush box and rose gum in Queensland and marri in Western Australia, service lives have been (or are most likely to be) increased from 11 to 28, 11 to 24, 12 to 25 and 14 to 28 years respectively by means of pressure treatment with any of a number of oil type preservatives. In other words the average life of sleepers of these species has been at least doubled; their service life distribution has been improved relative to those of durable species and, importantly, their service lives are all very similar despite their widely variable natural durabilities. From the cumulative failure figures shown in Table 1 it seems likely that the species/ treatment combinations that will give the best performance will be one of the treatments in which the percentage failure to date (i.e. after 19, 20, 22 or 25 years) is less than 25 per cent.

The performance of the untreated river red gum was generally poorer than the oil treated lower durability Victorian species such as mountain ash or messmate and in South Australia was slightly inferior to untreated jarrah. From these results, it seems fair to say that the lower durability Victorian species when treated with certain oil type preservatives are expected to perform as well as the untreated jarrah, at least under conditions similar to those in South Australia and Victoria. However, very collapse-prone material should probably be avoided.

TABLE 1. PERFORMANCE OF UNTREATED CONTROL SLEEPERS AND SLEEPERS WITH SPECIES/TREATMENT COMBINATIONS HAVING EXCELLENT PERFORMANCE

| State and Age (years of test when last inspected) | Timber Species | Preservative treatment | Number installed | Average life actual or estimated (years) | Cumulative failure (%) at last inspection |
|---|---|---|---|---|---|
| Victoria (25) | River red gum *(Eucalyptus camaldulensis)* | untreated | 143 | 23 | 68 |
| | | (no treated sleepers in test) | | | |
| | White stringybark *(E. eugenioides)* | untreated | 71 | 16 | 99 |
| | | 40/60 creosote*/coal tar oil | 60 | 28 | 23 |
| | | creosote/furnace oil+ | 126 | 29 | 15 |
| | | creosote | 120 | 27 | 32 |
| | | 2 or 3 % PCP+ in furnace oil | 93 | 27 | 34 |
| | | 80/20 naphthenic acid/diesel oil | 60 | 25 | 35 |
| | Mountain ash *(E. regnans)* | untreated | 71 | 11 | 100 |
| | | 40/60 creosote/coal tar oil | 60 | 28 | 30 |
| | | creosote/furnace oil+ | 170 | 28 | 25 |
| | | creosote | 120 | 26 | 48 |
| | | 2 or 3% PCP in furnace oil | 115 | 26 | 36 |
| | Narrow-leaved peppermint *(E. australiana)* | untreated | 71 | 15 | 100 |
| | | 40/60 creosote/coal tar oil | 60 | 27 | 40 |
| | | creosote/furnace oil+ | 104 | 28 | 30 |
| | | creosote | 119 | 24 | 63 |
| | | 2 or 3% PCP in furnace oil | 82 | 26 | 40 |
| | Messmate *(E. obliqua)* | untreated | 60 | 15 | 100 |
| | | 40/60 creosote/coal tar oil | 60 | 26 | 38 |
| | | 40/60 creosote/furnace oil | 60 | 26 | 43 |
| | | creosote | 120 | 25 | 53 |
| | Radiata pine *(Pinus radiata)* | (no untreated sleepers in test) | | | |
| | | 50/50 creosote/furnace oil | 132 | 26 | 28 |
| | | 3% PCP in furnace oil | 84 | 26 | 45 |
| Victoria (22) | Radiata pine | 50/50 creosote/furnace oil | 80 | 27 | 15 |
| Queensland (19)§ | Narrow-leaved red ironbark *(E. crebra)* | untreated | 34 | 18 | 59 |
| | | (no treated sleepers in test) | | | |
| | Spotted gum *(E. maculata)* | untreated | 35 | 14 | 94 |
| | | (no treated sleepers in test) | | | |
| | Satinay *(Syncarpia hillii)* | untreated | 17 | 15 | 88 |
| | | 50/50 creosote/furnace oil | 14 | 25 | 0 |
| | | creosote | 15 | 25 | 0 |
| | | 5% PCP in furnace oil | 13 | 24 | 11 |
| | Rose gum *(E. grandis)* | untreated | 19 | 12 | 100 |
| | | 50/50 creosote/furnace oil | 17 | 25 | 0 |
| | | creosote | 17 | 25 | 0 |
| | | 5% PCP in furnace oil | 17 | 24 | 6 |
| | Brush box *(Tristania conferta)* | untreated | 19 | 11 | 95 |
| | | 50/50 creosote/furnace oil | 10 | 24 | 10 |
| | | 5% PCP in furnace oil | 13 | 25 | 0 |
| | Turpentine *(S. glomulifera)* | untreated | 20 | 12 | 100 |
| | | (none of the treated sleepers exceed 20 years service life) | | | |
| South Australia 1st test (24) | River red gum | untreated | 80 | 25 | 44 |
| | | (no treated sleepers in test) | | | |
| | Jarrah *(E. marginata)* | untreated | 76 | 27 | 38 |
| | | (no treated sleepers in test) | | | |
| | Radiata pine | untreated | 240 | 4 | 100 |
| | | 60/40 creosote/furnace oil | 160 | 29 | 10 |
| | | creosote | 160 | 28 | 13 |
| 2nd test (22) | Radiata pine | (no untreated sleepers in test) | | | |
| | | 50/50 creosote/furnace oil | 134 | 28 | 0 |
| | | 30/70 creosote/furnace oil | 134 | 28 | 0 |
| | | 3% PCP in furnace oil | 135 | 28 | 0 |
| | | Greensalt K | 135 | 25 | 26 |

| | | | | | |
|---|---|---|---|---|---|
| South Australia/ Western Australia (Trans-Australian Railway) (25) | Wandoo *(E. wandoo)* | untreated (no treated sleepers in test) | 24 | 26 | 42 |
| | Jarrah | untreated (no treated sleepers in test) | 24 | 20 | 71 |
| | W.A. Blackbutt *(E. patens)* | untreated (no treated sleepers in test) | 48 | 23 | 48 |
| | Karri *(E. diversicolor)* | untreated | 48 | 16 | 56 |
| | | 30/70 creosote/diesel oil | 24 | 26 | 33 |
| | | Creosote | 74 | 27 | 38 |
| Western Australia (25) | Jarrah | untreated | 74 | 23 | 61 |
| | | 50/50 creosote/furnace oil | 77 | 29 | 15 |
| | | creoste | 45 | 28 | 33 |
| | | furnace oil | 38 | 30 | 3 |
| | | 3% PCP in furnace oil | 42 | 30 | 14 |
| | Marri *(D. calophylla)* | untreated | 16 | 14 | 100 |
| | | 50/50 creosote/furnace oil | 54 | 24 | 54 |
| | | creosote | 44 | 28 | 41 |
| | | 3% PCP in furnace oil | 22 | 28 | 32 |
| | Karri | untreated | 15 | 7 | 100 |
| | | 3% PCP in furnace oil | 25 | 24 | 48 |
| Tasmania (25)Π | Silvertop ash *(E. sieberi)* | untreated (treated sleepers achieved approx. 22 years service life) | 8 | 13 | 100 |
| | Alpine ash *(E. delegatensis)* | untreated (treated sleepers achieved 20-22 years service life) | 9 | 11 | 100 |
| | Messmate | untreated (treated sleepers achieved 20-22 years service life) | 9 | 11 | 100 |
| New South Wales (20)Π | River red gum | untreated (no treated sleepers in test) | 5 | 21 | 40 |
| | Grey box *(E. microcarpa)* | untreated (no treated sleepers in test) | 5 | 20 | 60 |
| | Narrow-leaved red ironbark | untreated (no treated sleepers in test) | 5 | 19 | 60 |
| | Brush box | untreated (treated sleepers did not achieve 20 years service life) | 10 | 15 | 100 |
| | Silvertop ash | untreated (treated sleepers did not achieve 20 years service life) | 10 | 11 | 100 |
| | Messmate | untreated (treated sleepers did not achieve 20 years service life) | 10 | 10 | 100 |
| | Mountain grey gum *(E. cypellocarpa)* | untreated (treated sleepers did not achieve 20 years service life) | 5 | 10 | 100 |

* Creosote in all cases obtained from vertical retort tar and conformed to specification AS-K55 (1936).

+ Mixtures used were 30/70, 40/60, 50/50.

† Pentachlorophenol.

§ Because the test is only 19 years old, the average lives could still exceed 25 years as most of these sleepers are still in excellent condition.

Π Many sleepers were lost due to track upgrading, track deviation and/or derailments, in most cases without record of their final condition.

For species/treatment combinations that failed to achieve 25 years service life, the major causes of their failure was splitting (including shelling) followed by spike kill and/or decay.

(c) Waterborne treated sleepers

With the 12 species/treatment combinations tested, only one achieved a mean service life of nearly 20 years (white stringybark treated with Greensalt K in Victoria). At the other end of the scale was messmate treated with copperized-chromated-zinc chloride (CuCZC) which managed a service life of only 10 years i.e. worse than species controls which had an average life of 15 years - see Table 1. The reason for such a poor performance can only be guessed at but probably due to the chemical reaction of preservative with the wood. In fact all or most species treated with this chemical in the tests gave shorter service life than the corresponding untreated controls.

The main causes of failure for sleepers treated with waterborne preservatives were decay and/or splitting. This may have been contributed to by low retentions in some cases. However the tendency of the treated sleepers to defibrate (from multitudinous surface cracks and splits) was characteristic of most sleepers treated with these preservatives. The test results clearly indicated that Tanalith C, Greensalt K and CuCZC are not to be used in treating Australian hardwood sleepers if life in excess of 20 years is desirable.

2. Softwood (radiata pine) sleepers

(a) Oil treated sleepers

In the first South Australia test installed in 1936 and terminated in 1960, the oil treated radiata pine sleepers gave an average service life of six times that of untreated controls (see Table 1). Out of a total of 9 oil treatments tested in radiata pine - in Victoria and South Australia - only one failed to achieve 25 years service life. The oil-treated pine sleepers in Victoria are performing as well as oil-treated hardwood sleepers in the same tracks. Rail cut in pine sleepers is more severe than that in hardwood, but at this stage very few sleepers have failed because of rail cut. Pine sleepers with rail plates were not cut as badly as unplated sleepers, and unplated pine sleepers could not be recommended for use in Australia.

(b) Waterborne treated sleepers

Radiata pine sleepers treated with Greensalt K, in the second South Australia test, are expected to achieve an average service life of 25 years. The remaining three waterborne treatments used in radiata pine sleepers failed to give service lives in excess of 20 years. Again it has been observed that all

waterborne treated pine sleepers developed wide and deep checks on the exposed surface. Such defects may have contributed to the premature failure of these sleepers due to decay and/or spike kill

The 25 year inspections of all CSIRO sleeper tests except New South Wales and Queensland have been completed. The performance of all treatments in each of these tests will be published in detail on an individual basis in Rail Track at a later date.

## CONCLUSIONS

From on-going Australian rail sleeper tests, the age of which ranged from 19 to 25 years when last inspected, the following conclusions can be drawn for the track and fastening conditions applicable.

1. Average service lives of at least 25 years and in some cases, 30 years or more, can be obtained from good quality, oil treated wood sleepers of a number of readily available timber species whose natural durabilities vary from very low to high. These treated sleepers have commonly proved superior to untreated sleepers of durable species, which are in any case becoming scarce.

2. It is already evident that failure-free service lives of at least 20 years in tangent track is a reasonable expectation from the best of these species/ treatment groups.

3. Increasingly, evidence indicates that initial physical condition is very important if treated sleepers are to provide average service lives in excess of 25 years.

4. Oils and oil mixtures that have proved most successful as sleeper preservatives are creosote/tar oil, creosote/furnace oil or pentachlorophenol in furnace oil and, to a lesser extent, creosote. Even furnace oil alone can be used successfully as a means of extending the service life of the durable species jarrah.

5. Many sleepers failed due to spike kill when dog spikes were used. It is nevertheless considered likely that, with improved fastners e.g. screw spikes, the average service life of good quality oil treated sleepers can be further improved.

6. None of the four waterborne preservatives tested proved adequate in protecting sleepers of Australian grown species apart from the single success of Greensalt K in radiata pine sleepers.

REFERENCE

1. Barnacle, J.E. and T.R. Weatherhead, 1979 - Pressure treated and untreated hardwood rail sleepers - some performance data from wet tropical Australia. Third International Rail Sleeper Conference, Proceedings Session 5 No. 3, 16 pp.

# PRELIMINARY INVESTIGATIONS INTO THE TREATMENT OF MESSMATE (*Eucalyptus obliqua* L'Herit.) BY A MODIFIED FORM OF DOUBLE-DIFFUSION

Kofi Ampong* and C.W. Chin†

## ABSTRACT

Round posts of messmate (*Eucalyptus obliqua* L'Herit.) were treated by a modified form of double-diffusion involving pre-heating the posts in water prior to their immersion in the first stage solution of copper sulphate. Half of the number of posts were then treated in a solution containing arsenic acid and sodium dichromate and the other half in a solution of arsenic acid and sodium chromate. Preliminary results indicate that (a) messmate sapwood can be penetrated by copper based on visual assessments; (b) the penetration of arsenic and chromium appears to be limited with the treatment schedule used; (c) penetration in messmate is largely end-grain.

## INTRODUCTION

The treatment of wood by double-diffusion involves soaking the wood in two separate aqueous solutions. The chemicals diffuse into the "green" wood and react to form relatively leach-resistant compounds toxic to a wide range of wood-destroying organisms. Copper sulphate is the chemical used in the first stage solution in most current double-diffusion treatments. The second stage solution generally contains sodium arsenate with, or without sodium chromate. The copper-chrome-arsenate combination is considered by Baechler and Roth (3) to be the most practical for posts to be treated by complete immersion in tanks.

Softwoods treated by double-diffusion have generally performed well in field tests. The best known test of this type of preservative treatment is probably that included in the Mississippi Post Study. The 1977 Progress Report of this study (6) gives an estimated average life of 50 years for round posts of southern yellow pine (*Pinus* spp) treated with copper sulphate and sodium arsenate by double-diffusion.

---

* Forest Products Research Institute, Kumasi, Ghana. (currently S.C.A.A.P. Fellow)

† Division of Building Research, CSIRO.

With hardwoods treated by double-diffusion field tests have given less promising results to date even though treatment has been reported to be adequate (2,4,10,12,13). This relatively poor performance of double-diffused hardwoods compared with that of softwoods similarly treated has been attributed to the greater tolerance in hardwood of rotting fungi (commonly white rots) to the inorganic toxicants (9) though it could also be due to attack by soft rot fungi to which hardwoods are known to be more susceptible than softwoods. Most workers in this field agree, that the manipulation of solution concentrations, treatment schedules and heating could produce effective treatment in hardwoods (10,15). Ampong (1) modified the double-diffusion method in 1976 by heating the posts of five tropical hardwoods in boiling water prior to their immersion in a first stage solution of copper sulphate and obtained adequate penetration of copper in three of the Ghanaian species. The performance of the three species in field trials was, after 30 months, comparable to that of the same species pressure-treated and slightly superior to most of the species creosote-heated by a modified form of the thermal process. After 18 months 9 out of 15 specimens of untreated controls of these species had been destroyed and four had been attacked by fungi.

The renewal of interest in Australia in non-pressure treatment methods such as double-diffusion has been attributed to the overall cost of pressure treatment facilities in this country (11). The potential value of double-diffusion to developed, hardwood-using countries like Australia lies in the thought expressed by Dale (5) that, depending, as the process does, on the molecular movement of solutes from an external treating solution to the interior of wet wood, the treatment of hardwoods by double-diffusion could conceivably result in a better micro-distribution of preservatives in hardwood fibres which are difficult to treat by conventional vacuum/pressure methods, and thus provide a possible solution to the soft-rot problem in CCA-treated hardwoods (7,8).

The primary aim of this investigation was to obtain data on:

(1) the efficacy of double-diffusion as a method of treatment for round posts of messmate in terms of depths of penetration of the toxic components of the chemicals used.

(2) the levels of chemical retention obtainable in messmate with varying concentrations of the treating chemicals.

(3) the degree of treatment achievable in the fibre cell walls of messmate, using a scanning electron microscope fitted with an X-ray micro-analyser to obtain a semi-quantitative measure of this treatment.

The investigation is in its early stages. Some preliminary results are discussed in this paper.

## MATERIALS AND METHODS

Wood Species: *Eucalyptus obliqua* L'Herit. (Messmate)

Sizes: Round posts one metre in length, varying in top diameters from 50-110 mm.

Chemicals: 1st stage solution 10% m/m copper sulphate ($CuSO_4.5H_2O$).

2nd stage solutions

(a) 5% m/m arsenic acid ($As_2O_5 2H_2O$) + 8% m/m sodium dichromate ($Na_2Cr_2O_7.2H_2O$).

(b) 5% m/m arsenic acid ($As_2O_5.2H_2O$) + sodium chromate ($Na_2CrO_4$). Formulated to contain the amount of chromium (m/m) as in solution (a).

Treatment: The green posts were debarked, immersed in water contained in a treatment cylinder and heated until the temperature of the water reached about 100°C. This temperature was maintained for two and a half hours. The heated posts were transferred into the first stage solution contained in a metal trough in which they were held submerged for 20 hours at room temperature. The solution was stirred continuously. Half of the number of posts were transferred into solution (a) and the other half into solution (b). The posts were held in these solutions for 48 hours at room temperature with continuous stirring and then removed and stacked for air drying. After drying, two matched 20 mm discs were cut from the centre of each post, one for the spray test for copper using chrome Azurol S, and the other for quantitative analysis for copper, chromium and arsenic using an atomic absorption spectrophotometer. Longitudinal sections were cut to determine the extent of end-grain penetration of copper based on visual assessment.

A pre-treatment investigation had been carried out to determine:

(i) the effect of boiling on the depth of lateral and longitudinal penetration by treating posts in the same copper sulphate solution without prior heating;

(ii) the main penetration paths (lateral or end-grain) in the posts by end-sealing some posts and sealing the surfaces of others prior to treatment;

(iii) the maximum depth of end-grain penetration obtainable in two-metre posts by sealing the top ends of such posts.

## RESULTS AND DISCUSSION

Only a few indications of the potential of the treatment of messmate using this modified double-diffusion schedule can be reported here. It must be stressed that these indications are as based on macroscopic observations at this stage. They can be summarised as follows:

(i) Preheating the posts greatly improves both lateral and longitudinal penetration. In end-matched posts not pre-heated, the average depths of penetration achieved were about two and 80 mm in the lateral and longitudinal directions respectively, copper did not appear to penetrate wound-affected wood e.g. wood in the vicinity of gum veins.

(ii) Full penetration of the sapwood by the copper component of copper sulphate is obtainable in two metre posts of messmate. There was little penetration in the heartwood in this trial.

(iii) Arsenic and chromium appear limited in their capacity to diffuse into messmate using the schedule described above. Most of the arsenic and chromium were detectable only within a lateral depth of a few millimetres in the mid-section of the posts as determined by atomic adsorption spectrophotometer.

The constraint on the ability of arsenic to diffuse to a significant depth in the wood could possibly be due to its fixation at an early stage by the chromium. Chromium is reported (14) to fix arsenic preferentially to copper. A greater penetration of arsenic may be achieved if the arsenic acid is included in the first stage solution assuming this hypothesis to be correct.

One of the major drawbacks of treatment by double-diffusion is the general lack of the control facilities normally associated with conventional vacuum/pressure impregnation. The concentration levels of unisalt treating solutions can be checked with the aid of specific gravity measurements using a hydrometer. The concentration levels of the individual components of multi-salt formulations are less easy to control without complicated analyses or the use of expensive chemical recovery systems. Quality control is therefore a major (and probably limiting) factor in double-diffusion and the adoption of this method as a commercial timber impregnation process in Australia will almost certainly depend not only on its possible efficacy in the treatment of wood fibres i.e. the microdistribution of

formulation, but also on the ability of commercial treatment establishments to institute control measures at economically acceptable costs.

## CONCLUSIONS

With the schedule used in this method of double-diffusion, the following preliminary conclusions may be drawn:

(i) the sapwood of messmate can be completely penetrated by copper; heartwood is practically impenetrable. In unheated end-matched samples there was little penetration of sapwood.

(ii) the penetration depths of arsenic and chromium are less than desired.

(iii) the total penetration of sapwood appears to depend on the longitudinal movement of the liquid.

## REFERENCES

1. Ampong, K.: Treatment of Fence Posts of Some Tropical Tree Species by a Modified Form of Double-Diffusion. (unpublished).

2. Boone, R.D., Gjovik L.R. and Davidson, H.L. (1976): Sawn Hardwood Stock Treated by Double Diffusion and Modified Double-Diffusion. U.S. Department of Agriculture 10 pp.

3. Baechler, R.H. and Roth, H.G. (1964): The Double-Diffusion Method of Treating Wood: A Review of Studies. Forest Prod. J. 14 (4) 171-178.

4. Chudnoff, M. and Goytia, E. (1972): Preservative Treatments and Service Life of Fence Posts in Puerto Rico. Progress Report, Forest Service Research Paper ITF-12. U.S. Department of Agriculture.

5. Dale, F.A. (1975): Preservation of Round Timbers in Ground Contact: General Considerations. Paper presented at the Tropical Wood Preservation Training Seminar, Port Moresby, P.N.G. 4-22nd July.

6. Davidson, H.L. (1977): Comparison of Wood Preservatives in Mississippi Post Study, Progress Report, 16 pp.

7. Greaves, H. (1974): The microdistribution of copper-chrome-arsenic in preservative treated sapwoods using X-ray microanlaysis in scanning electron microscopy. Holzforschung 28, 193-200.

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

9. Johnson, B.R., Gjovik, L.R. and Baechler, R.H. (1975): Preservative Treatment by 'Double Diffusion' and its Applicability to Tropical Hardwoods. I.U.F.R.O. Division V (S5.03). Group Protection Du Bois Réunion D'Abidjan 17-23 Feb.

10. Johnson, B.R. and Gonzalez T, G.E. (1976): Experimental Treatment of Three Tropical Hardwoods by Double-Diffusion Processes. Forest Prod. J. 26 (1). 39-46.

11. McCarthy, D.(1980): Double Diffusion of Wood. Rebuild, April.

12. Skolman, R.G. (1971): A Durability Test of Wood Posts in Hawaii - Third Progress Report, U.S. Forest Service Pacific Southwest Forest and Range Experiment Station. Res. Note 260. 4pp.

13. Smith, H.A. and R.H. Baechler (1961): Treatment of Hawaiian Grown Posts by the Double-Diffusion.Wood Preservation Process. U.S.A.D. Forest Serv. Res. Note No. 187. Pacific Southwest Forest and Range Expt. Sta. Berkeley, Calif. 8pp.

14 Smith, D.N.R. and Williams, A.I. (1973): The Effect of Composition on the Effectiveness and Fixation of Copper-Chrome-Arsenic and Copper-Chrome Preservatives. Part I: Effectiveness. Wood Sci. & Tech. Vol. 7 60-76.

15. Vick, C.B: Gaby, L.I. and Baechler, R.H. (1967): Treatment of Hardwood Fence Posts by the Double-Diffusion Process. Forest Prod. J. 17 (12) 33-35.

# PROTECTION OF WOOD POLES BY GROUNDLINE REMEDIAL TREATMENTS - INSPECTION OF POLE TEST SITE AT WEDDING BELLS S.F.

By R.S. Johnstone

Wood Technology and Forest Research Division
Forestry Commission of N.S.W.

## Introduction:

The work leading up to the selection of the pole test site at Wedding Bells State Forest (near Coffs Harbour, New South Wales) was reported at an earlier Conference by Edwards, Johnstone, and Pitt(1). In this report details were given of the selection of a suitable test site in New South Wales that was known to have (a) a high potential for soft rot attack, (b) subterranian termites in the vicinity, and (c) reasonable access for the installation of pole stubs.

A report of the installation of the test poles in November, 1976, was presented at the 18th Forest Products Research Conference by Johnstone(2) and the results of a preliminary investigation were reported to the E.S.A.A. Pole Symposium 1980(3), and the 19th Forest Products Research Conference by Johnstone, Gardner, and Pitt(4).

In the preliminary assessment basidiomycete attack in the untreated Eucalyptus maculata sapwood was used as a means of comparing the effectiveness of groundline treatments. While it is well known that attack by soft rot fungi operates by a different mechanism than basidiomycetes, it was considered that a barrier that would inhibit the initiation of basidiomycete attack would similarly act as a barrier to soft rot colonisation.

This preliminary inspection resulted in the following conclusions:

(1) Some protection of poles will be given by an envelope of a fungicide such as creosote or 5% pentachlorophenol in oil.

(2) A pole encapsulated in an impermeable material without a fungicide results in negligible pole protection.

(3) Where a bandage treatment is used in order to protect a pole, the fungicide must not only be effective but must completely cover the zone underneath the bandage.

(4) Concrete around the base of a de-sapped durable pole will probably increase the decay risk in the heartwood.

It has been emphasized repeatedly by Levy(5), Greaves(6) and others that for a toxicant to be completely effective in the prevention of soft rot attack, some penetration of the preservative into the cell wall must be achieved.

If a restraining barrier can be applied to prevent or reduce the initial colonisation by soft rot fungi in the primary stages then this could be of benefit in a power-pole situation.

Results of the preliminary inspection indicated that a barrier of toxicant could protect the timber from the entry of fungi. In many of the applications, once this envelope of toxicant was overcome there were no means of preventing subsequent fungal degradation. This inspection indicated that creosote, penta in oil, a C.C.A. gel and "Blue 7" had prevented primary colonisation of wood decay fungi. All other applications allowed some penetration of basidiomycetes and one could assume that these same applications would offer a similar lack of resistance of soft rot fungi.

Inspection Procedure:

Inspections were carried out to a depth of 0.5m below ground level. The degree of penetration of fungal attack was estimated visually by examining 4 replicates of each remedial system applied to untreated E. maculata and 4 replicates of each treatment applied to de-sapped durables.

Four replicates of the impregnated pole types were examined where there was no remedial treatment (control samples) and where polythene sheeting encased the pole at the groundline. This sampling procedure was based on the expectation that these samples were likely to show the greatest amount of fungal attack and this would be indicative of the performance of pressure-impregnated poles as a whole.

An estimate was made of the proportion of sound sapwood in each of the poles inspected.

The average of the proportion of sound sapwood in the pressure-impregnated poles with no remedial treatment was calculated. These results are shown in Fig.1.

The average of the replicates of individual remedial treatments applied to untreated E. maculata sapwood is also shown (Fig.2)

Discussion:

As indicated in Fig.1 there has been little fungal deterioration in the sapwood of poles impregnated with preservative.

Because of the anatomical structure of Pinus radiata, less fungal attack would be likely to be present in this species than in the hardwoods and as yet no visible fungal attack was present.

The remaining poles of preservative-impregnated hardwoods showed no significant difference between preservatives in the degree of fungal degrade at the time of the inspection. As the inspections proceed an indication of the difference in fungal resistance between the various preservative types should become apparent.

Fig.2 indicates that a number of the remedial treatments can be eliminated as being ineffective and that, with the methods of application of remedial treatment as used in the test, only the copper chrome arsenic gel and pentachlorophenol in oil were continuing in all samples to act as a barrier to fungal penetration in Eucalyptus maculata sapwood. All other treatments were therefore deficient to a degree in their methods of application and/or were not sufficiently effective toxicants to control all fungal attack.

It would be expected that to perform effectively in the protection of poles, the prevention of primary fungal colonisation would be a first objective. The ability of the toxicant to arrest the fungus at its source within the timber would also be an important function.

While all groundline treatments were applied by skilled technical personnel and, where applicable, to the manufacturer's instructions, there have already been significant advancements in the design of bandages used to contain toxicants.

In some cases the systems reported here could be classed as representing the early stages of experimental projects. Subsequent new designs in groundline pole protection, particularly by CSIRO, Koppers, and W.T. and F.R.D., could be expected to give an efficient and more permanent control of fungal attack than some of the systems examined at this inspection. These new types of pole protection have now been incorporated into the existing field trial and information on these more advanced techniques will be forthcoming over the years.

The major value of the test at this stage could be the elimination of some of the doubtful procedures that have been used in the past and their replacement by improved systems of groundline protection.

The use of a satisfactory diffusable concentrate could provide the answer but in view of the need for a complete inspection of the pole at the groundline every 3 to 5 years there is a need for a suitable bandage that can be removed with relative ease and replaced with simplicity.

High durability poles with concrete surrounds

The de-sapped poles of high natural durability with a concrete surround are, after 4 years, showing serious deterioration. Reference was made to the increased decay risk in these poles in previous reports (3) (4).

The results of this examination show that the penetration of fungal degrade in these poles was greater than three times the depth of degrade in free-standing durable poles with no concrete surround.

The rate of deterioration is also significantly greater in the high-durability de-sapped poles than in impregnated poles - no degradation being yet evident in preservative-treated poles encased in concrete.

Unfortunately the concrete surround invariably results in a less frequent and less detailed inspection of the pole so the additive effects of a less frequent inspection and accelerated decay could combine to produce a serious risk situation.

Conclusions:

(1) The sapwood of all preservative-impregnated poles is continuing to offer resistance to fungal attack after 4 years.

(2) Pentachlorophenol in oil and a copper chrome arsenic gel are providing a barrier to the entry of fungi into the untreated sapwood of Eucalyptus maculata.

(3) All mechanical barriers with no toxicants have increased the rate of fungal attack in untreated Eucalyptus maculata.

(4) Concrete applied to the base of high durability de-sapped poles has accelerated the decay risk.

Acknowledgements:

The authors wish to acknowledge the assistance given by Koppers (Australia) Pty Ltd, Rentokil Pty Ltd, Engery Authority of N.S.W. and Northern Rivers County Council. They also wish to thank for their advice and help Dr L Leightley and Messrs J Hunter, C J Edwards, G Baxter, and W Gabb.

References:

(1) Edwards D.W., R.S. Johnstone, and W. Pitt, Evaluation of soft rot field test sites in N.S.W. Proceedings of the 17th Forest Products Research Conference, Melbourne, 1975.

(2) Johnstone R.S. Remedial treatments to prevent soft rot in poles. Proceedings of the 18th Forest Products Research Conference, Melbourne, 1977.

(3) Johnstone R.S. Soft rot protection of poles by groundline remedial treatments. Proceedings of the E.S.A.A. Pole Symposium, Surfers Paradise, 1980.

(4) Johnstone R.S., W.D. Gardner, and W. Pitt, Evaluation of groundline maintenance alternatives against fungal degrade - Wedding Bells pole test site. Proceedings of the 19th Forest Products Research Conference, Melbourne, 1979.

(5) Levy J.R. Soft rot fungi : their mode of action and significance in the degradation of wood. Advances in Botanical Research 2:323-357 New York, 1965.

(6) Greaves H., Progress towards controlling soft-rot in treated hardwood poles. Proceedings of the 18th Forest Products Research Conference, Melbour 1977.

# *GLYPTOTERMES* IN TRANSMISSION POLES

R. H. Eldridge and W. D. Gardner
Wood Technology and Forest Research Division
Forestry Commission of New South Wales

## ABSTRACT

A brief review of the known biology of *Glyptotermes* (Isoptera:Kalotermitidae) is given, followed by a history of the records of occurrence in hardwood transmission poles in the Sydney region. The results of a recent survey of pole dressing plants and pole stands on the northern coast of New South Wales are presented. These results indicate that *Glyptotermes* infestations found in poles in service within the Sydney region were probably initiated in the growing tree and have survived the conversion to a transmission pole. The implications of these observations are discussed briefly in relation to the use of infested poles, forest operations in pole stands and the concept of compartmentalization of decay in trees.

## INTRODUCTION

Termites of the genus *Glyptotermes* (Isoptera:Kalotermitidae) are distributed throughout the tropical and subtropical regions of the world. They have been recorded from the Australian, Papuan, Oriental, Ethiopian, Malagasy and Neotropical regions (1). Generally they are considered to be of little economic importance, with attack confined to decaying logs, stumps, dead branches and damaged portions of living trees. An exception is *Glyptotermes dilatatus* (Bugnion), a serious pest of the tea plant in Ceylon (2).

Numerous species of tree are attacked and descriptions of attack are similar for most species. The colony exists within a network of small galleries which run both longitudinally and across the grain within timber having a high moisture content (Figure 1a and b). The timber is usually partially decayed or probably contains incipient decay.

The more significant Australian species appear to be *Glyptotermes brevicornis* (Froggatt), *G. tuberculatus* Froggatt and *G. iridipennis* Froggatt. All three species have been recorded from butts of Australian hardwood poles (*Eucalyptus* spp.), the latter two records in Hills 1942 monograph (3). *Glyptotermes tuber-*

*culatus* was also recorded from an Australian hardwood pole in New Zealand in 1940 (3). Records of *Glyptotermes* spp. attacking transmission poles in service within New South Wales, and more particularly the Sydney metropolitan area became more frequent as a result of a termite distribution survey initiated by the Forestry Commission of New South Wales in 1970 (4).

Several pole failures associated with the presence of *Glyptotermes* (Figure 2) have been recorded. Pole-using authorities within the Sydney are have become concerned because of the difficulties in detecting the presence of *Glyptotermes* and in determining residual strength and life expectancy of poles containing even small infestations. Any pole found to contain *Glyptotermes* is usually removed from service.

This paper reviews our present knowledge of the occurrence of *Glyptotermes* in hardwood poles within the Sydney region. Information presented was obtained from a survey of termite distribution within New South Wales and from a survey of pole producers on the N.S.W. north coast.

## METHODS

As part of a survey of the distribution and abundance of termites within New South Wales, pole-using authorities throughout the state were asked to obtain specimens of termites attacking transmission poles. Officers of the major authorities within the Sydney area, (Sydney and Prospect County Councils) were instructed in termite biology, detection, treatment methods and collection methods during the early stages of the survey. This approach yielded many hundreds of termite specimens from poles along with much valuable information on the biology of some species and the effectiveness of recommended control methods.

More recently, a survey of new Class 1 durability poles held in storage by the Sydney County Council, was undertaken to determine the incidence of defects attributable to wounds incurred by the growing tree. The presence of active *Glyptotermes* colonies within some of these poles resulted in a preliminary survey of pole dressing plants along the north coast of New South Wales to determine the incidence of *Glyptotermes* infestations in new poles.

## RESULTS AND DISCUSSION

In the first two years of the New South Wales termite survey (1971-72) there were 29 records of *Glyptotermes* from the Sydney region (4). Twelve of these were from transmission poles while the remaining 17 were taken from decaying stumps, dead branches and dead wood on living trees. *Glyptotermes brevicornis*, *G. iridipennis* and *G. tuberculatus* were all recorded from naturally occurring situations, as distinct from transmission poles, and are considered endemic to the Sydney area.

Seventeen of the 29 *Glyptotermes* records were of *G. brevicornis* with several records from poles in service and other records from living and dead trees. These included *Banksia serrata, Casuarina* sp., *Ceratopetalum apetalum, Erythrina* sp., *Eucalyptus bicostata, E. citriodora, Fraxinus velutina, Populus deltoides* and *Salix babylonica.*

The number of recorded instances of *Glyptotermes* in transmission poles increased following instruction given to County Council officers. In 1973 there were 32 records of *G. brevicornis* and in 1974 34 records from poles in service within the Sydney area. The survey was reduced in intensity in 1975 and only 10 records of *G. brevicornis* in poles were made. From 1975 to 1978 there were only 6 records due to cessation of the termite survey. Since early 1979 one officer of the Sydney County Council has been collecting some specimens of *Glyptotermes* from poles within the Council's northern establishment area and has supplied a further 32 records of *G. brevicornis.*

From 1971 to the present there have been a total of 125 records of *G. brevicornis* attack in poles in Sydney reported to and confirmed by the Forestry Commission of N.S.W. In this same period there have been only 17 records of *G. tuberculatus* and no confirmed records of *G. iridipennis* from poles. Pole species infested include bloodwood (*E. gummifera*), ironbark (*E. paniculata* or *E. siderophloia*), blackbutt (*E. pilularis*), grey gum (*E. propinqua*), red gum (*Eucalyptus* sp.), tallowwood (*E. microcorys*), stringybark (*Eucalyptus* sp.) and white mahogany (*E. acmeniodes*) (5).

A single occurrence of *G. brevicornis* was recorded from a spotted gum (*E. maculata*) pole which had been in service for 5 years, and had been poorly treated using a creosote hot-cold bath process. The inner sapwood of this pole was untreated and had been attacked by sapwood borers (Coleoptera:Bostrychidae and Lyctidae) and some decay was present. The record is of a small incipient colony which had gained access to the untreated sapwood through the emergence holes of the wood borers.

Infestations within poles in service are confined to the region near groundline. This is an area of high moisture content and the zone most susceptible to decay. It is also the part of the pole under most stress and therefore where most failures occur. After a few pole failures were confirmed to be associated with the presence of *Glyptotermes*, pole-users became concerned with detection and treatment of the problem. Unlike attack by the common subterranean termite *Coptotermes acinaciformis* (Froggatt), *Glyptotermes* do not create a well defined pipe or large voids caused by numerous enlarged longitudinal galleries within the pole. Detection by "sounding" or drilling techniques is very difficult and the most satisfactory method is to chip a small piece of wood from the pole to

expose the typical gallery formation (Figure 1b).

Conventional treatment methods such as injection of arsenic trioxide dust are totally ineffective due probably to the narrow damp galleries and sluggish movement of the species. A treatment method incorporating the use of solid or liquid fumigants introduced into the infested section of a pole could be readily devised but while this would kill the termites present the effect on decay fungi would still be minimal. At present there is no way of determining the residual strength or life expectancy of an infested pole, so such poles are usually removed from service.

Evidence of *Glyptotermes* is sometimes seen in old poles in the form of surface galleries exposed by the dressing process. These are often well above ground. The presence of active *Glyptotermes* colonies in new poles ready to be placed into service was confirmed in mid 1980 at the Sydney County Council's Strathfield pole store (Figure 3). Later a survey was undertaken of pole dressing plants on the New South Wales north coast in September 1980 to determine the incidence of *Glyptotermes* in new poles.

The survey included pole dressing operations at Stroud, Taree, Coffs Harbour and Grafton. A total of 466 dressed and 117 nondressed poles were examined (Table 1).

TABLE 1

Field Survey of *Glyptotermes* Infestation of New Durability Class 1 Poles on the New South Wales North Coast

| Locality | Poles examined* | *Glyptotermes* present |
|---|---|---|
| Stroud | 40 | 2 |
| Taree | 35 | 1 |
| | 117 (not dressed) | 3 |
| Coffs Harbour | 109 | 7 |
| Grafton | 282 | 8 |
| Totals | | |
| Dressed poles | 466 | 18 (3.9%) |
| Nondressed poles | 117 | 3 (2.6%) |

* Numbers refer to dressed poles unless specified otherwise.

Of the 466 dressed poles 18 were found to contain *Glyptotermes* infestations (3.9%). The level of infestations varied from minor, with a few galleries exposed close to the butt of the pole, to very severe with up to 6 m of pole exhibiting large numbers of exposed galleries. Because the poles were often

stacked it was difficult to quantify the distribution of attack within each pole. Most attack appeared to be within 2 m of the butt or in the vicinity of branch stubs and most records in the survey refer to the butt end of the poles. 117 nondressed poles were examined at Taree. Evidence of the presence of *Glyptotermes* could be seen only on freshly cut surfaces of the butts. Of these, 3 showed clear evidence of infestation (2.6%).

Precise determination of the extent of infestation in a dressed pole requires detailed destructive examination. A visual estimation of the severity of attack can be made by an examination of the dressed surface along the length of the pole. In the nondressed, or natural round state however, it is virtually impossible to make such an estimate, as the only visual evidence is that found on the cut surface of the butt (Figure 3). This is often difficult to recognise. It was apparent throughout the survey that foresters, timber inspectors and mill operators had noted damage consistent with that caused by *Glyptotermes*. Generally such damage was attributed to pin-hole borer or called "bull-ant" damage. It was rarely recognised as being caused by termites and was not considered significant unless a very severe infestation was present.

Pole stands where logging operations were taking place or had been recently completed were examined in the Taree, Coffs Harbour and Grafton areas. The Taree site was in Kiwarrak State Forest where tallowwood, grey gum and grey ironbark were being logged for poles. Stumps of two poles containing large infestations of *Glyptotermes* were located in the brief time available. Both stumps, a tallowwood and a grey gum, showed clear evidence of old butt wounds estimated to have occurred approximately 15-20 years earlier. The trees had taken several years to overgrow the wounds, allowing adequate time for the entry of decay fungi and termites.

The Coffs Harbour site was in Boambee State Forest where tallowwood was being logged for poles. Several stumps of recently felled trees containing *Glyptotermes* infestations were located. Each of these had received butt wounds at about the same time, an estimated 15-20 years ago. Many younger trees left after this current logging operation had received butt wounds of varying severity during the formation of snig trails and during the sniggling operation. It is probable that *Glyptotermes* infestations in the current pole crop from both the Coffs Harbour and Taree sites could be directly related to damage caused to standing trees during previous logging operations. The Grafton site examined was an area of flat open forest with no evidence of butt wounds in standing trees or stumps. No *Glyptotermes* infestations were found at this site.

A break in the bark immediately exposes new space and a new source of nutrients for many pioneer organisms such as bacteria, fungi, algae, small

invertebrates and so on (6). It is not long before the decay process begins and, while this may be confined in its development according to the concept of compartmentalization of decay in trees (6), the wound becomes an area of exposed partially-decayed wood, often having a constantly high moisture content, which will remain open for several years. Such a wound represents an ideal niche for the development of an incipient colony of termites, such as *Glyptotermes* or *Coptotermes*. By the time the tree has overgrown the wound it is very possible that a colony of termirs will be already well established within the tree. The presence of active termites within the damaged portion of the tree may lead to more rapid breakdown of the barriers formed by the tree around this decaying region due to the persistent formation of new galleries.

## CONCLUSIONS

While the species of *Glyptotermes* recorded from transmission poles within Sydney are considered to be endemic to the region, evidence suggests that most infestations are introduced with new poles. These infestations are probably related to butt wounds incurred by the younger standing crop during logging operations. Eradication of termites either at the dressing plant or in the user's storage yard should be relatively easy using fumigation techniques. Eradication of the termites could arrest the rate of breakdown but it should be remembered that incipient decay is probably already present.

Rejection by pole-users of new poles containing evidence of *Glyptotermes* infestations and the practice of docking the butts of poles to remove badly infested sections represents a waste of a valuable resource. A reduction of the incidence of butt wounds caused during logging operations would reduce the number of infested new poles.

Such an improvement in logging practice, particularly on steep terrain, would be a difficult and probably costly exercise. Quantitative data on the long term effects of wounding on the merchantable crop is required before a proper cost/benefit study could be undertaken.

## ACKNOWLEDGEMENTS

The authors wish to thank officers of the Prospect and Sydney County Councils for their willing co-operation during this survey. In particular K. Clarke, D. Hodge and V. O. Roimer.

## REFERENCES

1. Krishna, K. (1970). "Taxonomy, phylogeny and distribution of termites". [In Biology of Termites, *Vol. II*, 127-152. K. Krishna and F. M. Weesner Ed.] Academic Press, N.Y.

2. Danthanarayana, W. and Fernando, S.N. (1970). A method of controlling termite colonies that live within plants. International Pest Control

12(1): 10-14.

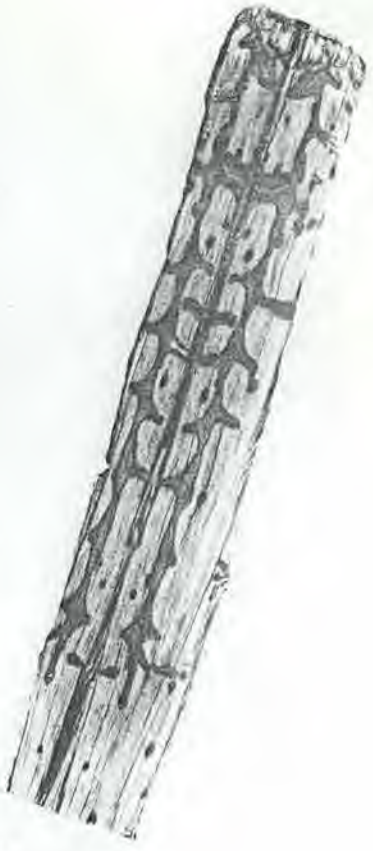
3. Hill, G.F. (1942). Termites (Isoptera) from the Australian Region. Council for Scientific and Industrial Research, Melbourne, 85-98.

4. Reynolds, J.L. and Eldridge, R.H. (1973). Distribution and abundance of termites attacking wood in service in the Sydney area. Proc. 16th Forest Prod. Res. Conf., Topic 3/39.

5. Standards Association of Australia (1970). Nomenclature of Australian Timbers. Australian Standard 02-1970. Standards Association of Australia, North Sydney.

6. Shigo, A.L. (1979). Tree decay - an expanded concept. U.S.D.A., Agriculture Information Bulletin No. 419.

1a



1b

Figure 1a. An advanced *Glyptotermes* infestation within a hardwood transmission pole. Longitudinal section showing a typical pattern of attack.

1b. Longitudinal section through a *Glyptotermes* gallery.

2a

2b

Figure 2a. Section of a hardwood transmission pole which failed in service as a result of *Glyptotermes* attack showing zone of failure.

2b. Details of failure zone. Note numerous transverse galleries.

Figure 3a, b. *Glyptotermes* galleries exposed near butt of a new dressed hardwood transmission pole.

# THE NEED FOR CARE IN THE PROMOTION OF WOOD FOR EXTERNAL USE ON BUILDINGS

K. R. Bootle
Wood Technology and Forest Research Division,
Forestry Commission of New South Wales

ABSTRACT

While wood checking occurs in some eucalypt hardwoods even when protected with a three-coat pigmented paint system, the problem is exacerbated when stain finishes are used. Radiata pine is often subject to very deep checking. Resin bleed can be serious with many softwoods, necessitating careful selection of stock for cladding and external trim. Knots are a problem substrate for all coatings. The enhanced performance of reconstituted wood products is discussed.

## INTRODUCTION

A major reason for the decline in the use of timber externally over the last thirty years has been the significant cost of maintenance of the surface coatings applied to it. In many instances renewal of the coating was found necessary at intervals as short as three or four years, whereas twice this interval is not difficult to achieve when a quality product is applied to a good substrate. The sale of timber products well endowed with knots and resin, or of species prone to surface checking, or inadequately seasoned, or their use without taking precautions to seal the end-grain against water penetration, must be important factors in this loss of market.

If this situation is to be reversed greater care in the selection of material for use in cladding and exterior joinery is essential. During the last twenty years I have used numerous wood-based substrates when assessing the performance of the many commercial and experimental products of the paint industry, so some comments on the behaviour of those substrates may be of interest.

## PROTECTIVE HOUSE PAINTS

In one series of tests recently concluded (1) a range of white house paints of both alkyd and acrylic type were exposed for over seven years on north-facing $45^{\circ}$ racks on substrates of blackbutt, brush box, western red cedar, cypress pine and radiata pine. Comments on the behaviour of these species follow:

(a) Blackbutt

Blackbutt is representative of those eucalypts which are very prone to surface checking when subject to full exposure to the weather. This tendency to check is so strong that even the application of a three-coat protective paint system is not sufficient to prevent the development of extensive wood checking after a couple of years of the severe 45° exposure. Once checking becomes well established it is impossible in practice to restore the surface to a suitable substrate for a durable paint film because the multitude of lines of weakness tend to rupture the renewed coatings. Such species should be avoided when paint-type coatings are required in positions of severe exposure to the weather. This does not preclude them from use under stain-type finishes, especially if a sawn rather than dressed surface is used, since such thinner systems are able to accommodate the factures in the wood surface without peeling away from then.

A comparative study of the checking tendencies of 24 myrtaceous eastern Australian species is in progress at the Division and should provide a helpful guide to paintability.

(b) Brush box

While brush box does suffer considerable shallow checking when exposed without protection or under stain systems, it behaved very well under paint and gave it a service life equal to that obtained over western red cedar. Material with very disturbed grain should be avoided.

(c) Western red cedar

This species has a reputation in North America as being one of the best substrates for coatings. Its suitability under paint was found to be on a par with brush box. While it did not have the same potential risk of surface checking it did suffer in the long term from erosion of the coating from the raised grain of the latewood bands on back-cut surfaces.

(d) Cypress pine

When its surface is free of knots and surface checks cypress pine is a very good substrate, attributable to its dimensional stability. However, knots are a usually inescapable feature while fine lines of surface checking often develop in the early

stages of drying, particularly in hot weather. A much better performance was obtained from panels of green cypress pine painted before such checks had a chance to develop but such a procedure is not a practical measure.

The surface checks in cypress pine usually tend to remain fine and in consequence there is less tendency for the coating to peel back from them and cause an extension of the checking. However these fine lines are hard to fill and they remain a continuing source of weakness in the paint system.

Knots present an especial hazard to the coating of cypress pine because there is often a considerable amount of bark encasement and bark is a most unsuitable base for paint; the paint fails over it and the whole of the surface of the knot may be laid bare while the remainder of the coating system is still in excellent condition.

(e) Radiata pine

The potential for good performance as a substrate for coatings is marred by the frequent presence of knots and resin streaks and by the occasional very resinous board. The latter type of material should be reserved for structural applications where coatings are not involved. The narrow bands of latewood are the major source of resin flow.

The increasing use of finger-jointing, enabling the exclusion of knotty material, will make radiata pine a much more acceptable timber for exterior trim but this process needs to be done with care, for the joining of quarter-cut to back-cut material can cause sufficient stress at the interface to crack the superimposed paint coating. Knotting compounds such as shellac and aluminium primer are seldom, if ever, used in commercial practice to-day. It should be noted that while shellac may have a beneficial role to play under paints it is worse than useless under stain finishes because their lack of waterproofing permits enough water penetration to cause the knotting plus finish to fall off in large segments.

Various preservative treatments (impregnation with copper-chrome-arsenic or light organic solvent-borne chemicals, dipping in pentachlorphenol solution) did not change coating

performance very significantly from that on the natural wood, except that impregnation involving hydrophobic solvents introduced the difficulty of spreading acrylic (water based) systems evenly on the surface.

STAIN FINISHES

In our assessment of the performance of the many commercial exterior stain finishes which have been marketed in New South Wales in the last 15 years brush box and radiata pine have been the most commonly used substrates, brush box because it is a good timber for painting and can satisfactorily represent the dense and difficult-to-penetrate hardwoods, radiata pine because of its rapidly increasing significance on the local timber scene (2).

Since the stain finishes are not a waterproof cover the wood substrate suffers a lot of penetration by dew and rain under the harsh conditions of 45° rack exposure, which is usual in testing coatings in order to expedite the assessment of their performance, so a considerable amount of checking was a normal occurrence in both species. Checking in the brush box was within acceptable limits from the viewpoint of appearance and serviceability, especially when sawn rather than dressed surfaces were used, but such severe exposure caused radiata pine to develop very deep checks which often continued to enlarge and occasionally penetrate right through the 20 mm thickness of the test panel. Such checking occurs on both radial and tangential cuts; on the radial surface the lines of failure are usually in the vicinity of the junction between earlywood and latewood, but on the tangential surface the checking is more randomly distributed and is apparently associated with breakdown of the parenchyma tissue of the rays and resin canals. It is more abundant in the latewood than in the earlywood.

It is important to point out that when radiata pine is applied to the vertical walls of a structure and has some protection from the normal roof overhang there is much less surface checking under these non-waterproof finishes.

RECONSTITUTED WOOD PRODUCTS

The greater uniformity of reconstituted wood products introduces the possibility of a more suitable substrate than is possible in the natural timber from which such products are formed.

This is particularly the case with exterior grade hardboard. Such a substrate made by the Masonite process using a range of N.S.W. north coast eucalypts is, for example, still holding on firmly to acrylic stain finishes after a period of 45° exposure exceeding 7½ years. Such finishes can develop

a blotchy "bloom" of chalk after such a long period of exposure but the original appearance is restored by washing down the surface.

Small scale testing of exterior grade fibreboard made from radiata pine is showing good promise with both paint and stain finish after two years of exposure.

Particleboard too has shown itself to be a suitable substrate for stain type finishes. Even current flooring grade material, with waterproof bond but with no attention to particle size in the outermost layer, has given a good performance. On a test hut without roof overhang the wall surface finished with an oil-type stain is still in good condition after $5\frac{1}{2}$ years exposure despite unevenness of the surface caused by moisture swelling the unevenly dimensioned particles. Another wall, clad in particleboard with a kraft paper overlay, and with coatings of paint, oil stain and acrylic stain is still in perfect condition after two years' service. As an alternative to a paper overlay one could consider a medium sized, evenly distributed outer chip such as is seen in the myrtle furnish particleboard made in Tasmania. This board starts out with a very definite woody texture and after $2\frac{1}{2}$ years of service on a northern wall is still of excellent appearance under an oil stain.

It is worthy of mention that phenolic bonded particleboard is very prone to black surface mould but tannin bonded board is virtually unaffected.

SUMMARY

Some myrtaceous hardwoods are prone to widespread surface checking if exposed to the full force of the weather, even when protected by the normal thickness of a paint coating, so care is needed when selecting suitable substrates. There is a need for more information on the checking susceptibilities of Australian hardwoods and some work on this aspect is in progress.

Radiata pine can present finishing problems when knots and resinous wood are present, especially if dark coloured, heat absorbent finishes are involved. It is also susceptible to deep surface checking from weathering if only stain-type finishes are used.

Cypress pine not only has the problem of an abundance of knots, often bark encased, but is also at risk from surface checking in the initial stages of drying. Material intended for external use under surface coatings needs special care to avoid this type of degrade.

Plywood surfaces will check extensively when fully exposed to the weather if not protected by a paper overlay before being painted or stained, but other reconstituted wood products can have considerable advantages over the natural

wood, since the problems of surface checking, resin bleed and knots are not present. Very good performance has been obtained from exterior grade hardboard made from eucalypts under both paint and stains. Exterior grade fibreboard made from radiata pine is still of only limited availability but one small scale trial over two years has shown a very favourable performance. Particleboard holds onto stain finishes very well but the water penetration of such finishes does cause some disturbance of the relatively large 'chips' in the surface layers, so further experimentation on particle size is needed before this material is promoted for external cladding.

REFERENCES

(1) Bootle, K. R. (1981): Determination of the service life of exterior alkyd and acrylic paints on a range of species representing good, average and poor substrates. Forestry Commission of N.S.W. Internal Report. pp. 83 + 50 illustrations.

(2) Bootle, K. R. (1978): Stain finishes for external wood surfaces. Forestry Commission of N.S.W. Tech. Pubn. 25. pp. 3.

# THE APPLICATION OF TIMBER POLE FRAME HOUSE CONSTRUCTION IN QUEENSLAND

J.L. Grimmett and W.T. Kynaston

Division of Technical Services
Queensland Department of Forestry
Brisbane

## ABSTRACT

Pole frame construction, previously used more for farm and industrial building, is being extended to house construction especially on steep building sites.

Protection against termites, other insects and fungi is satisfactorily provided for in conventional house design, but needs to be re-examined for pole-frame construction, particularly in tropical and sub-tropical environments.

The local use of C.C.A.-treated hardwoods poses a potential soft-rot problem not as consequential when treated softwoods are used.

Termite-proofing can be more complex than in conventional structures.

Conformity to house-standard pole grade, maintainable soil treatments, protection against end-splitting, and maintenance of joints are seen as necessary to satisfactory service.

The use of road base fill to poles in lieu of total soil fill or concrete collars is advocated.

High replacement cost merits earnest attention to the correct specification of pole species, graded quality, chemical treatments, pole placement and bedding and moisture proofing of the structure; also the specification of appropriate maintenance procedures for this high-investment application.

## POLE SPECIES

Some builders have used C.C.A.-treated hardwood for timber pole frame housing. This practice has been reviewed in the light of our experience of the often drastic deterioration due to soft-rot as seen in C.C.A.-treated power poles at and below ground line. Such a situation is unacceptable in a pole frame house where replacement of poles would be both difficult and

prohibitive in cost. Therefore a conservative approach should be adopted in the choice of poles for this purpose.

First choice is, without doubt, C.C.A.-treated indigenous or exotic pines treated to the recommended retention level and pattern throughout its sapwood. We would expect a life in excess of 50 years for this commodity.

As a second choice untreated Durability Class 1 hardwoods (Q.F.D. ratings) could be expected to have a life under similar service conditions of more than 25 years provided that (a) the pole is desapped from the butt to about 300 mm above ground line; (b) the sspwood is not lyctus susceptible and (c) the poles are completely protected within the building. However, if Durability Class 1 hardwood poles are to be located externally in the structure, C.C.A. treatment of the sapwood zone will be necessary to prevent destruction by decay and/or insects. Desapping of treated poles from the butt to about 300 mm above ground line will again overcome the soft-rot problem. This would also allow a lower preservative retention to be used as the remaining treated sapwood is exposed to the weather but is not in ground contact.

Because of the growing scarcity of suitable hardwoods and the rapidly increasing pine resource in Australia, these recommendations should be easy to comply with.

POLE QUALITY

Australia has not yet prepared a standard covering the use of poles in pole frame house construction. The closest we can get is with AS 2209-1979 "Timber poles for overhead lines" which specifies grade limits for pole species not requiring full length preservative treatment and for hardwoods and softwoods requiring full length treatment.

This application is covered in New Zealand where the quality of poles is defined in NZS 3609-1977 "Load bearing round timber piles and poles". This standard accepts timber species for which appropriate design stresses are available. It sets requirements for the maximum number of growth rings, straightness, and limits for defects such as checks, splits, knots and sprial grain. The methods of preparation of poles are also specified as well as seasoning and precautions to be taken in handling to prevent damage.

CHEMICAL TREATMENT

The current Australian Standard 2209-1979 "Timber Poles for overhead lines" calls for C.C.A. preservative retention of 25 $kg/m^3$ on a charge basis for hardwood poles and 20 $kg/m^3$ for softwood poles used in temperate climatic conditions while AS 1604 "Preservative-treated sawn timber, veneer and plywood requires a charge retention of 20 $kg/m^3$ for hardwoods and softwoods in tropical

conditions as compared with 12 kg/m$^3$ in temperate conditions.

Logs used for this specialised application would have to be treated with a fixed multi-salt preservative (C.C.A. type) to a retention of 24 kg/m$^3$ in the treated zone. Although this loading is not as high as that used in New Zealand, it does correspond with their practice of specifying a higher retention than that required for line poles.

An aspect that should be considered in Australia is the supply of a 'Certificate of Compliance' with all house poles at delivery. In New Zealand, this certificate is based on not less than two samples taken from every pole ordered which have been laboratory tested to check the actual retention of treatment salts. The supplier would be responsible for this confirmation of quality control. The certificate is required by some designers and lending institutions and is supplied free of charge if asked for when ordering.

POLE BEDDING

With an anticipated in-ground life of over 50 years, C.C.A.-treated softwood is our first choice for pole house construction. Our traditional hardwood pole species (C.C.A.-treated or desapped) should only be considered if ground contact can be avoided by supporting the pole by a metal stirrup embedded in concrete. This technique adds to building costs as greater engineering design input is required to handle the extra bracing needed.

When bedding poles, holes should be prepared with a diameter approximately twice that of the pole so as to permit pole adjustment after placing. The depth of holes will depend on soil type, prevalence of rock, and the bracing methods used and should be determined by the engineer at the design stage. If poles are bedded properly, pads or plugs at the base of holes appear not essential for bearing purposes as most of the pole support is obtained from side friction. Further, poured concrete plugs could lead to ponding of water within the hole.

The practice of concreting around the base of poles is inadvisable. Poles are always placed in the green condition and subsequent drying of both pole and surrounding concrete results in a gap which constitutes a high decay situation. We recommend that the hole be backfilled with earth, or better still with small diameter road base which will allow free movement of moisture away from the pole surface.

MOISTURE PROOFING

Penetrating the roofline with poles should be avoided as this causes flashing difficulties and, with metal roofing, corrosion problems. External framed walls should not be fitted between poles as this results in weather-proofing difficulties and finishing problems.

The ends of beams that extend past the outside walls should be capped to prevent water absorption into the end grain and to reduce the risk of splitting.

Decks should be stepped down from floor level to prevent water running in along the top of the joists.

## MAINTENANCE OF STRUCTURES

The tops of exposed poles should be bevelled and covered with a copper capping so that end grain moisture penetration is avoided. Better still is to design the house so that all poles are internally placed.

Although poles above ground do not require maintenance, they may be painted, stained or waxed to prevent rapid drying as this can result in unsightly splitting.

The embedded section of the pole and 300 mm above ground line needs initial protection and continued periodic maintenance. Barrel checking and splitting will occur in poles during drying and can expose untreated heartwood susceptible to degradation by fungi and termites. By employing the bedding technique of using small diameter road base material, the fungal problem will be minimised. Treatment of the hole before bedding and the zone around each pole by puddling the backfill with an approved termiticide and then periodically inspecting poles and saturating the soil within 200 mm of the poles to a depth of 300 mm with the same termiticide and a fungicide should keep termites and soft-rots away.

Poles should not be cut or drilled close to the ground. When untreated heartwood will be exposed, all cuts and notches must be brush coated with a water repellent preservative containing copper naphthenate or pentachlorophenol before proceeding.

We don't claim to be experts on pole house construction - we certainly do not have all the answers. However based on our experience of the behaviour of timber in the Queensland situation we feel that adherence to the principles discussed in this paper will minimise subsequent maintenance costs of this high investment application.

The preparation of an Australian Standard to cover pole framed house construction is strongly advocated.

## REFERENCE

Building Research Association of New Zealand. June 1978. Building Information Bulletin 206. 5 pp.

# DRYWOOD TERMITES IN QUEENSLAND - ERADICATION, CONTROL OR PREVENTION?

R.A. Yule and B.C. Peters*

## INTRODUCTION

Heather (1971) and Yule and Watson (1976) comment on the distribution of drywood termites in Queensland and give some data on timber susceptibility. However, the extent of the drywood termite problem and methods of control and prevention in Queensland, have not been reported.

As a result of the attempt to eradicate the exotic West Indian drywood termite (Cryptotermes brevis (Walker) ) reliable data on the extent of damage caused by drywood termites has been gathered.

This paper discusses that data, how it was aquired, and methods by which control and prevention may be achieved.

## C. BREVIS IN QUEENSLAND

During the period 1974 to 1976 our knowledge of the extent of infestation by C. brevis expanded substantially. In 1974 confirmation of its presence in Bundaberg occurred and in 1976 it was identified in the City of Brisbane. Without doubt Brisbane was the major focus of infestation in the State and has been the source of most other foci, primarily through the distribution of infested furniture and timber articles. Maryborough stands alone as a separate introduction. There is still no absolute solution to the source of the original introductions.

* Entomologists, Department of Forestry, Biology Laboratory, 80 Meiers Road, Indooroopilly, Qld. 4068

.../2

The extent of damage in some major City buildings fumigated in 1979 and since renovated e.g. Parliament House, has astounded foresters, builders, architects and engineers. The damage potential of the target pest is no longer confined to words about overseas experience. The expenditure on the eradication programme since its inception is now approaching $2 million. Although the project involves an exotic insect which poses a threat to the major domestic centres in Australia, it has been completely sustained by State funds alone.

The conclusion of the largest single fumigation contract the world has seen in September, 1979, has sparked a new direction in the eradication programme. The futility of reliance on chance findings was realised. It was decided to obtain Public support through an awareness campaign designed, for obvious reasons, to be eye-catching. The results of this aspect of the programme are discussed below and clearly illustrate its value. The information obtained extends beyond C. brevis and is based upon positive data aquired by the Public bringing or sending samples to the Laboratory. All records are sorted by using an electronic data processing system.

Other investigations included an attempt in 1974/75 to ascertain the state distribution of C. brevis. The surveys were restricted to all ports of entry with Staff from other Government Departments and Forestry coopted to do the work. Attempts to inform the Public were made by using radio talk-back programmes and feature articles in the press. The response was not substantial but proved that C. brevis was not found north of Bundaberg.

.../3

## C. BREVIS PUBLICITY CAMPAIGNS

Public assistance was sought through four publicity campaigns to identify sites of *C. brevis* infestation. The campaigns occurred in November (1979 and 1980) to coincide with the *C. brevis* flight season, and in February (1980 and 1981) to coincide with the return of holidaymakers. In each campaign three to five newspaper advertisements were used and a thirty second commercial run sixty times on each of two radio stations (see Appendix I). Unpaid advertising was also obtained on radio, television and in the press.

Since November 1979, 3,677 samples of suspected *C. brevis* evidence have been processed. These resulted from 3,473 enquiries (some containing several samples) either delivered personally or forwarded by mail. Many other enquiries were handled by telephone, up to 113 per day. The geographical distribution of enquirers is presented in Table I.

TABLE I

The geographical distribution of enquirers despatching suspected *C. brevis* samples since November 1979; grouping by post code. (Postcode Divisions after Australia Post, 1979).

| LOCATION | FREQUENCY |
|---|---|
| Brisbane Metropolitan | 2,982 |
| Gold Coast | 121 |
| Ipswich Region | 119 |
| Toowoomba Region | 20 |
| Western Queensland | 2 |
| North Coast 1 | 108 |
| Sunshine Coast | 68 |
| North Coast 3 | 4 |
| North Coast 4 | 22 |
| Rockhampton Region | 3 |
| Mackay Region | 6 |
| Townsville Region | 3 |
| Cairns Region | 9 |
| New South Wales | 6 |
| TOTAL | 3,473 |

55% of the samples were of ant origin and 29% of termite origin. The remainder contained a wide range of material including frog droppings and a rodent skull. Samples of termite origin were 11% subterranean termites, and 18% drywood termite (15% *Cryptotermes primus* (Hill), 2.9% *C. brevis* and 0.1% unidentified *Cryptotermes* spp.).

.../5

29 infested buildings and 33 infested furniture pieces were found as a direct result of advertising. Surveys around infested buildings resulted in the discovery of an additional 21 infested buildings and two infested furniture pieces. Annual reinspections around previously fumigated buildings and reports from householders in these areas yielded six infested buildings. 14 infested furniture pieces, all currently or previously Government owned, were also located (Table II). Most of the infestations were in Brisbane, but included two buildings in Bundaberg, two buildings in Maryborough, and a hotel in Childers. Two furniture infestations were found in Dalby, and one in each of Rockhampton, Maryborough and Gympie.

Both structural and furniture infestations were scattered in metropolitan Brisbane. Most structural infestations occurred as single or two adjacent infested houses, but 15, 8, 7 and 5 adjacent infested houses were found prior to 1981.

TABLE II

Type of C. brevis infestation and source of discovery from November 1979 until October 1980. Results from November 1980 until July 1981 in parentheses

| SOURCE | TYPE OF INFESTATION | |
|---|---|---|
| | Structural | Furniture |
| Advertising | 19(10) | 19(14) |
| Surveys | 18( 3) | 1( 1) |
| Other | 3( 3) | 8( 6) |
| | 40(16) | 28(21) |

.../6

The results are encouraging in that the rate of finding infestations has decreased with time, and the structural infestations now appear to be either single buildings or two adjacent houses. Possibly, with further reinpsections some additional infested houses will be discovered adjacent to previously fumigated houses. As C. brevis becomes rarer the chances of finding an infestation are decreasing and the relative cost incurred in finding each new infestation is increasing.

Although isolated infestations will probably continue to be discovered for many years, the major threat posed by C. brevis in Queensland has been substantially diminished as a result of the current programme.

OTHER DRYWOOD TERMITES IN NORTH QUEENSLAND

Department of Forestry surveys in far northern centres produced the unexpected exotic species C. domesticus (Haviland) and C. cynocephalus Light reported by Yule and Watson (1976). The surprising absence of these species from the Cairns and Gordonvale region has been sustained by all recent investigations and public enquiries. These investigations have also shown that C. domesticus is established in the wild, infesting fence posts, dead branches etc., thus negating application of eradication as a control option.

The surveys and investigatory studies during the past five years have shown that drywood termites are a major pest of timber in-service in the North. The damage caused in structural timber (foundations, floors, wall framing, roofs) was not generally recognised because visual evidence of activity does not appear. When damage was seen it was inevitably confused with "borer" activity (lyctids and bostrychids) and believed to be confined to the sapwood. Unfortunately the structural timbers now used in the north contain drywood susceptible truewood and many examples of structural failure have been seen e.g. T & G flooring collapse

.../7

in Mossman, Cooktown, Thursday Island 10-15 years after erection; structural plywood flooring failure in Thursday Island after 7 years; roof framing collapse in Thursday Island after 20 years; floor bearers and joists destroyed in Cooktown (time indeterminant) etc.

The reasons why damage is so widespread and occurs so rapidly in the north are not entirely clear. Increasing utilisation of susceptible species, particularly for structural purposes, has allowed termite populations to expand. The invasion of new structures may occur rapidly. Where control was attempted, aqueous emulsions, which do not penetrate seasoned timber, were used and achieved nothing with regard to drywood termite control.

The species causing concern are the natives C. primus (confined to the coastal mainland) and C. secundus (Hill) (confined to the Torres Strait Islands in Queensland (Gay and Watson (in press)), and the exotics C. domesticus and C. cynacephalus. The distribution of these species in the main domestic areas is given in Table III.

TABLE III

Distribution of Infestations

| Locality | Premises Surveyed | Premises with Cryptotermes spp. | Premises with C. primus | Premises with C. domesticus | Premises with C. cynocephalus | Premises with C. secundus |
|---|---|---|---|---|---|---|
| Mossman | 59 | 40 | 22 | 24 | 7 | - |
| Port Douglas | 6 | 3 | 3 | 1 | - | - |
| Newell Beach | 10 | 4 | 2 | 2 | - | - |
| Daintree | 10 | 2 | 2 | - | - | - |
| Bloomfield | 12 | 11 | 6 | - | 5 | - |
| Cooktown | 12 | 9 | - | 9 | - | - |
| Yarrabah | 9 | 9 | 3 | 4 | 5 | - |
| Thursday Island | 15 | 10 | - | 9 | - | 1 |
| Tully/Innisfail/ Cardwell | 15 | 8 | 8 | - | - | - |
| Cairns/Gordonvale | 10 | - | - | - | - | - |
| Mt. Molloy | 7 | 4 | 4 | - | - | - |
| Irvinebank | 3 | - | - | - | - | - |

The current requirements for the protection of milled timber are those governed by the Timber User's Protection Act 1949-1972 (T.U.P.A.). In general, the need to protect timber in exposed and in-ground situations or against Mastotermes darwiniensis Froggatt is also recognised. However, the consequence is that species of timber not in the T.U.P.A. schedule of species with susceptible sapwood and used in protected situations (scantling and framing timber, flooring, mouldings etc.) are not treated to prevent insect attack.

Unfortunately the drywood termites infest species not in the T.U.P.A. Schedule and attack truewood as well as sapwood (Appendix II). An indication of the potential hazard may be gauged by comparing the annual milling timber removals (Table IV) with some preliminary data on Lyctus brunneus and C. brevis timber susceptibility (Appendix II).

It is estimated 50-70% of the species milled in northern Queensland are susceptible to drywood termites. The trend in Table IV of increasing annual timber removals will not continue because the sustained yield capacity of the forests is being exceeded. Pressure from conservation groups to "lock-up" rain forest areas may also have a future impact on this resource.

.../10

TABLE IV

Milling Timber Removals from Crown Land in the North Queensland District (cubic metres gross)

| | Forest Hardwoods | Rainforest Structural Timbers | Prime Cabinet Woods | Misc. Cabinet Woods | Hoop Bunya Kauri | Other Pines | Total Native Forests | Total Plantations | TOTAL |
|---|---|---|---|---|---|---|---|---|---|
| 78/79 | 9810 | 53773 | 36655 | 47779 | 6026 | 1228 | 155271 | 269 | 155540 |
| 79/80 | 10954 | 67322 | 38400 | 59086 | 10354 | 1360 | 187476 | 155 | 187631 |

Any deficit will in part be satisfied from clear-fall operations in the south Queensland Araucaria sp. and Pinus spp. plantations and also through overseas imports. Pinus spp. and Araucaria spp. are susceptible to drywood termites. Timber imports will be restricted to sawn timber ("ship dry" or seasoned) unless present Quarantine policy is changed. The primary sources of this timber will be North America, South East Asia and the Pacific, with the bulk of the species now entering the State being drywood termite susceptible (Table V).

TABLE V

Timber Imports into Queensland (Commonwealth Department of Primary Industries, Forestry Branch, 1981) (cubic metres)

| ORIGIN | Dec. quarter 1979 | Dec. quarter 1980 | Primary Species |
|---|---|---|---|
| North America | 7444 | 11925 | Pseudotsuga menziesii |
| Asia (primarily Malaysia) | 7276 | 7857 | Shorea spp. |
| Pacific Region | 3047 | 5322 | Mixed rainforest |

It is clear that the northern timber market is supplied with (and will continue to be) an enormous volume of untreated timber susceptible to drywood termites. In a region frequently devasted by cyclonic winds it is important to prevent biological agencies from contributing to potential catastrophies.

.../12

## CONTROL, PROTECTION, PREVENTION

### Control and Protection

Practices adopted overseas are discussed by Speare (1970) and Ebeling (1978). Tent fumigation is the most widely used technique in the United States. However, as Ebeling and Wagner (1964) have shown (Figure 1) the possibility of reinfestation from untreated neighbouring dwellings is substantial. Poor quality control is also a factor with fumigation as stated by Ebeling (1978), "much depends on the discretion and judgement of the fumigator".

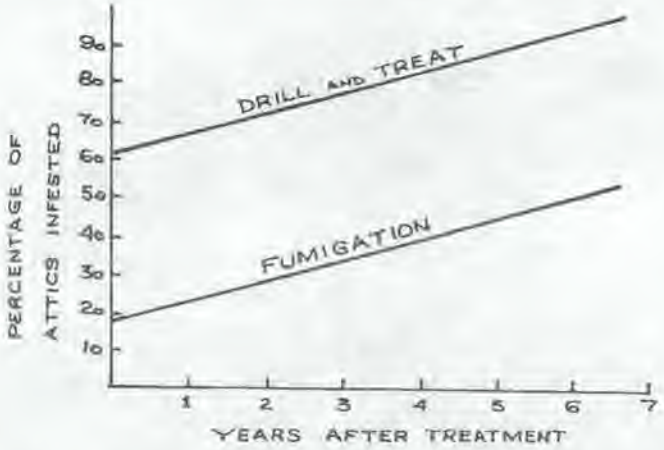



FIGURE 1.

Percentage of attics infested with drywood termites after fumigation or "drill and treat". (from Ebeling and Wagner, 1964)

In Queensland the position is different. Fumigation is applied only as an eradicative tool where strict supervision and specifications ensure set standards are maintained i.e. it is used in Quarantine and in the special action being taken to attempt to eradicate C. brevis. Its application for general timber pest control will be extremely rare because cheaper, safer and less distuptive alternatives are appropriate.

.../13

The risks of reinvasion in the circumstances prevailing in norther Queensland are such that temporary protection e.g. fumigation, is unrealistic. If the practical service life of a timber structure is 30-40 years as cited by Tamblyn and Rosel (1979) the need for infestation control will not arise. If, however, the service life of the average building is to exceed 50 years, as most owners would anticipate, control and prevention are necessary.

The control of active infestations and protection from reinfestation in existing structures is a two part operation:-

(i) the assessment of the extent of damage and the replacement (with pretreated timber) of any structurally damaged timber.

(ii) The application of suitable persistent insecticides to all exposed unpainted timbers (including roof voids). The use of oil solutions of insecticide is essential and a retreatment schedule of two treatments in the first six months and then each 4-5 years appropriate.

Alternative insecticidal techniques include the use of mayonnaise emulsions and aerogels. While both have been applied overseas (Ebeling, 1978) they have not seen wide use in Australia. Consumer and anti-pollution pressures will certainly result in the replacement of the chlorinated hydrocarbons by less toxic and less persistent chemicals in the future. It is therefore essential for research into new techniques and chemicals to continue in order to provide appropriate alternatives when the need arises.

.../14

Prevention

At present some of the timber marketed in north Queensland is immunised as a consequence of requirements under T.U.P.A. This position may improve when the revision of T.U.P.A. is completed and proclaimed. Most sawmillers appear to favour immunisation of all produce rather than sorting logs into susceptibles and non-susceptibles. If this occurs and quality control standards are maintained, all rough sawn timber will receive an envelope-type protection - an important first step to drywood termite control.

Immunisation will only be effective if the produce is not cut on the job thus exposing untreated zones, or machined in any way, thereby removing the treated envelope. It is normal practice to size timber on-site and it must become routine practice to apply suitable insecticides to protect cut surfaces on-site also.

In the case of machined timber, treatment after machining and sizing should be the objective. Beesley and Greaves (1981) have reported on the use of light organic solvent preservatives (LOSP) in Australia. It appears that the general use of LOSP is for protection against decay and wetting. This process, with suitable insecticides, offers a suitable and relatively cheap means of preventing drywood termite attack. Again the problem of an envelope treatment occurs and the need for treatment of cut ends on-site becomes essential.

Research work in this area is proposed in conjunction with alternative chemicals and processes for immunisation against lyctids and drywood termite attack.

.../15

## CONCLUSIONS

The information aquired on drywood termite distribution and damage in Queensland during the past few years, has provided a basis for assessing the future impact of these pests and necessitated a need to review their control and prevention.

There are two distinct problems and both involve exotic drywood termites viz.

(i) C. brevis in south Queensland

(ii) A complex of four species in north Queensland

Evidence supports the contention that the C. brevis eradication programme is succeeding. It has entered the "mopping-up" phase and the remaining infestations will be time consuming and difficult to locate.

In north Queensland there is a major drywood termite problem which will increase in the future unless preventative treatments are applied to susceptible timbers. Suitable pretreatments will depend on the end use of the milled timber. Immunisation, L.O.S.P.'s, glueline additives and on-site application of insecticides are appropriate methods which need urgent investigation to establish their efficacy.

Initiation of action to have the sawmilling and building industries make the recommended changes will require careful planning, coordination and Public awareness.

The problem in existing structures has no simple answer but timber replacement and repeated insecticidal treatment are more appropriate than tent fumigation.

.../16

APPENDIX I

Example of newspaper advertisement and text of radio commercial used in publicity campaigns.

Radio Text

The World's most destructive drywood termite; the West Indian Drywood Termite; at this moment, could be destroying your home, or building, or furniture; (especially second hand).

Look for telltale signs of small, light to dark brown, heaps of pellets. They're of similar colour, shape, and size, (about 10 on a pin head); hard and smooth; with a sandy feel.

If you find these pellets; or termite wings, dispatch a sample immediately, to C. brevis, - Department of Forestry, 80 Meiers Road, Indooroopilly, 4068.

Your Home's Survival, Could be Threatened!

.../17

## APPENDIX II

Comparison of timber species susceptibility to *Lyctus brunneus* (Stephens) and *Cryptotermes* spp. * Denotes record of attack. (The table consists of data, after Yule and Watson (1976) augmented by recent experimental data).

| Species of Timber | *Cryptotermes* spp. susceptibility | | *Lyctus brunneus* susceptibility |
|---|---|---|---|
| | Sapwood | Truewood | Sapwood |
| *Acacia melanoxylon* | * | * | * |
| *Acinena divaricata* | * | * | |
| *Agathis palmerstonii* | * | * | |
| *Alstonia scholaris* | * | * | * |
| *Araucaria cunninghamii* | * | * | |
| *Argyrodendron peralatum* | * | * | * |
| *Argyrodendron trifoliatum* | * | * | * |
| *Backhousia bancroftii* | * | * | |
| *Beilschmedia* sp. aff. *obtusifolia* | * | * | |
| *Callitris macleayana* | * | | |
| *Canaga odorata* | * | * | ? |
| *Cardwellia sublimis* | * | * | * |
| *Cedrela odorata* | * | * | * |
| *Cryptocarya angulata* | * | * | |
| *Elaeocarpus coorangooloo* | * | * | |
| *Endosperma myrmecophilum* | * | * | * |
| *Endiandra palmerstonii* | * | * | * |
| *Eucalyptus grandis* | * | * | |
| *Eucalyptus intermedia* | * | * | * |
| *Eucalyptus pellita* | * | * | * |
| *Eucalyptus staigerana* | * | | |
| *Eugenia gustavioides* | * | * | * |
| *Euroschinus falcata* | * | * | * |
| *Flindersia brayleana* | * | * | |

.../19

| | | | |
|---|---|---|---|
| Flindersia pimenteliana | * | * | |
| Geissois biagiana | * | * | * |
| Gmelina leichhardtii | * | * | * |
| Grevillea robusta | * | * | * |
| Mangifera indica | * | * | ? |
| Myristica muelleri | * | * | * |
| Palaquium galactoxylum | * | * | * |
| Pinus elliottii | * | * | |
| Pinus radiata | * | * | |
| Planchonella chartaceae | * | * | ? |
| Pseudotsuga menziesii | * | * | |
| Shorea spp. | * | * | * |
| Synoum muelleri | * | * | * |
| Toona australis | * | * | * |

REFERENCES

1. HEATHER, N.W. 1971 The Exotic Drywood Termite Cryptotermes brevis (Walker) (Isoptera : Kalotermitidae) and Endemic Australian Drywood Termites in Queensland. J. Aust. Ent. Soc. 10:134-141.

2. YULE, R.A. & WATSON, J.A.L. 1976 Two Further Domestic Species of Cryptotermes from the Australian Mainland (Isoptera : Kalotermitidae). J. Aust. Ent. Soc. 15:349-352

3. AUSTRALIA POST 1979 Numeric Post Code Directory. Queensland. 28 pp.

4. GAY, F.J. & WATSON, J.A.L. In Press. The Genus Cryptotermes in Australia. (Isoptera : Kalotermitidae). Aust. J. Zool. Supplementary Series.

5. SPEARE, P.J. 1970 Principles of Termite Control. In "Biology of Termites" Vol. II (K. Krishna and F.M. Weesner, eds.) pp. 577-604. Academic Press, New York and London.

6. COMMONWEALTH DEPARTMENT OF PRIMARY INDUSTRY 1981 Timber Supply Review 13 (4):14.

7. EBELING, W. 1978 Urban Entomology. 695 pp. University of California, Berkeley.

8. EBELING, W. and WAGNER, R.E. 1964 Built-in Pest Control. Pest Control 32(2):20-32.

.../20

9. TAMBLYN, N. & ROSEL, A. 1979 Comparative Tests of Spray and Dip-Diffusion Treatments for Protection of Eucalypt Building Timbers against Lyctus Borers.
Int. J. of Wood Preservation 1(1):11-14.

10. BEESLEY, J. & GREAVES, H. 1981 Light Organic Solvent Preservatives. CSIRO Division of Building Research. Information Service Sheet No. 10-77.

# A COMPARISON OF PRESERVATIVE RETENTIONS AS DETERMINED BY TWO DIFFERENT METHODS

J. Norton
Division of Technical Services
Queensland Department of Forestry
Brisbane

## ABSTRACT

One of the methods of establishing preservative retention in a small treated block of timber, is to determine the weight uptake of a preservative solution of known concentration. Results obtained by this method are compared with those obtained by chemically analysing the whole block.

A functional relationship is established between the two methods and from this, it is possible to predict a more accurate retention by analysis from the retention by weight.

When preservative retention is determined by weight the test specimen can then be exposed to degrade mechanisms to establish the efficacy of the impregnated preservative.

## INTRODUCTION

This study compares the chemical analysis of treated small block specimens with the uptake of preservative solution as a measure of the preservative retention in spotted gum (*Eucalyptus maculata* Hook.) and slash pine (*Pinus elliottii* Engelm. var. *elliottii*) samples.

The amount of copper-chrome-arsenic (C.C.A.) preservative in treated timber can be determined accurately by chemical analysis. Since it is seldom possible to analyse the whole of a piece of treated wood, various methods of sampling are used to establish the level of treatment achieved. Errors introduced by such sampling may be measured by statistical methods.

As a general rule, any specimen subjected to chemical analysis is so much changed or damaged that it is seldom possible to reinstate it in a biological test. Therefore, if changes are to be monitored progressively during a biological test, it is customary to use sufficient replications to permit progressive sampling. Alternatively, the preservative retention in treated timber may be ascertained, at the start of the test from the uptake of a preservative solution of known concentration.

MATERIALS AND METHODS

Test blocks were prepared from chemically determined sapwood of spotted gum and slash pine dressed to a consistent size of 30 x 15 x 5 mm. All blocks were conditioned to equilibrium moisture content before treatment and were treated to different nominal retentions by immersion in preservative solutions of predetermined concentration, to the following schedule:

1. Completely submerge the samples in C.C.A. solution for 90 minutes at 94 kPa below atmospheric pressure.
2. Break the vacuum and allow to soak for a further 60 minutes at atmospheric pressure while still completely submerged.

Retentions were determined by weight uptake for each block. Each block was also analysed to determine retention. Analysis was carried out on the whole block.

Basic density was calculated in each case and used for retention calculations.

The two sets of data, weight and analytical retention figures, could then be compared.

RESULTS

For both the spotted gum and slash pine sets of data, the loading by weight was compared with the loading as determined by analysis. In both cases the loading by weight was significantly different from the loading by analysis using a paired 't' test at the 5 per cent level.

Simple and multiple linear regression of the results was carried out providing the following results:

SPOTTED GUM

$$\text{Loading by analysis} = 1.46 + 0.94 \quad \text{(loading by weight)}$$
$$R^2 = 0.9641$$

Using the 't' statistic, the coefficient of the independent variable was found to be significant at the 5 per cent level. When the density variable was entered into a multiple regression system, it was found to be a non-significant variable at the 5 per cent level.

SLASH PINE

$$\text{Loading by analysis} = 0.29 + 1.05 \quad \text{(loading by weight)}$$
$$R^2 = 0.9938$$

Using the 't' statistic, the coefficient of the independent variable was found to be significant at the 5 per cent level.

The density variable was again found to be non-significant at the 5 per cent level.

Table 2 shows the 5 per cent confidence intervals over a range of loadings, for prediction of analytical loading from the loading as determined by weighting.

TABLE 1

Confidence interval for the prediction of actual loading from loading determined by weight

| Loading by weight (kg/cu m) | Predicted analytical retention (kg/cu m) | Confidence interval (kg/cu m) | % Confidence interval (as % of predicted retention) |
|---|---|---|---|
| Spotted gum | | | |
| 3 | 4.33 | ±2.90 | 66.97 |
| 6 | 7.15 | ±2.89 | 40.42 |
| 9 | 9.97 | ±2.89 | 28.99 |
| 12 | 12.79 | ±2.90 | 22.67 |
| 15 | 15.61 | ±2.91 | 18.64 |
| 18 | 18.43 | ±2.93 | 15.90 |
| 21 | 21.25 | ±2.96 | 13.93 |
| 24 | 21.07 | ±3.00 | 14.24 |
| 27 | 26.89 | ±3.04 | 11.31 |
| 30 | 29.71 | ±3.08 | 10.37 |
| Slash pine | | | |
| 3 | 3.44 | ±1.16 | 33.72 |
| 6 | 6.59 | ±1.16 | 17.60 |
| 9 | 9.74 | ±1.15 | 11.81 |
| 12 | 12.89 | ±1.15 | 8.92 |
| 15 | 16.04 | ±1.16 | 7.23 |
| 18 | 19.19 | ±1.17 | 6.10 |
| 21 | 22.34 | ±1.18 | 5.28 |
| 24 | 25.49 | ±1.19 | 4.67 |
| 27 | 28.64 | ±1.21 | 4.22 |
| 30 | 31.79 | ±1.23 | 3.87 |

DISCUSSION

Results for both spotted gum and slash pine show that there is a close relationship between the two methods of determining preservative retentions and that retentions established from absorption of preservative solution can be used to predict results which would be obtained by chemical analysis.

With both species, the error in prediction (per cent confidence interval, Table 1) decreases with an increase in the loading level.

Predictions based on these mathematical models, however, only hold true for specimens of similar dimensions. Larger dimensional specimens may require a different model because of variations in the actual movement of treatment solution within the block.

Table 1 shows that preservative loading in the pine may be more accurately predicted than loading in the hardwood. Testing of the density variable showed it was not a significant factor when applied in a multiple regression. This indicates that other variables such as cell size may have an effect on the treatability of the blocks.

# POOR PERFORMANCE OF HIGHLY DURABLE TIMBER SPECIES IN NON-FLOODED AREAS OF MECHANICAL DRAFT WATER COOLING TOWERS

B.N. Brown & L. Bolland
Department of Forestry
Indooroopilly, Queensland

Mechanical draft water cooling towers are used at a number of industrial installations in Queensland including thermal power stations and oil refineries. The authors have inspected a number of this type of cooling tower which have had timber structural members. This structural timber has been either CCA treated sapwood of coniferous species or untreated heartwood of *Eucalyptus* spp. (mostly but not always high durability species). The structural timbers in these towers are exposed to two different types of biological hazard. Most of the timber in the tower, including timber filling if used, is in the flooded area which consists both of the cascading down-flow zone and the water-filled basin at the base of the tower. Soft rot attack occurs in this area of the tower. The other type of hazard occurs in the non-flooded portion of the tower where severe white rot attack has been recorded.

Walters (1) reporting on 10-year in-service tests rated a number of important timbers for use as fill material. The best performance was shown by the only preservative treated timber in Walters' list (CCA treated radiata pine sapwood) which on average had retained 91% (range 72-100) soundness whilst the two high durability eucalypts (durability class 1 in (2)) in the study were reduced to 55% (10-92) soundness for wandoo and 49% (10-90) for tallowwood. Inspection of Queensland cooling towers with durability class 1 structural timbers (including tallowwood and iron-barks) has shown some surface erosion from soft rot of structural members in the flooded zone but this was considered to have had little effect on the strength of the structure.

There have been a number of instances of serious deterioration, in some cases collapse, of hardwood structural timber members in the non-flooded zone of mechanical draft cooling towers in Queensland. The cause of these failures has been white rot. *Fuscoporia livida* and *Xylaria* sp. have each been found fruiting in towers at two different locations.

Affected timbers have been identified as tallowwood (durability class 1), grey ironbark (class 1), spotted gum (classes 2,3), and blackbutt (class 2). The towers where serious timber deterioration occurred had been in service for between 8 and 15 years. By comparison, in cooling towers with similar service history to those where hardwood timbers have failed, CCA treated hoop pine sapwood generally has not deteriorated in either the flooded or non-flooded zones. One exception was brown rot activity in a non-flooded area but the preservative treatment pattern suggested that the decayed portion was untreated heartwood.

The Department is now recommending the use of pine, preferably pre-cut, treated with CCA to a minimum retention of 24 $kg/m^3$. Where treated timber is cut or drilled during fabrication, copper naphthenate in light fuel oil is to be applied to exposed surfaces. Monitoring of existing towers may reveal other suitable species but it may be necessary to test potential species, including cypress pine, in in-situ tests.

REFERENCES

1. Walters, N.E.M. 1970 Current results from Cooling Tower Tests. CSIRO Forest Products Newsletter No. 374. 1-3.

2. Pearson, R.G., Kloot, N.H. and Boyd, J.D. 1958 Timber Engineering Design Handbook. Melbourne. CSIRO in association with Melbourne University Press, Table 1.3.

# LIGHT ORGANIC SOLVENT PRESERVATIVES IN QUEENSLAND: A SHORT POSITION PAPER

A. Gardner
Division of Technical Services
Queensland Department of Forestry
Brisbane

## PROBLEMS WITH C.C.A.

C.C.A. preservatives are still recognised as extremely useful general purpose preservatives which have some shortcomings in particular applications.

The two problem areas are:

1. The incidence of soft rots in C.C.A. treated sapwood of a number of hardwood species when used in a ground-contact situation; and
2. The degradation due to weathering of some C.C.A. treated but unpainted sawn conifer claddings.

The solution to the first problem is seen as the use either of an alternative preservative yet to be proven in service or the use of supplementary treatments applied in addition to C.C.A.

The solution to the second problem is seen to lie in the provision of water repellancy and dimensional stabilisation, probably combined with use of the correct sawing pattern for conifer timber used as cladding.

Work by CSIRO and others is directed toward finding and proving chemicals which are environmentally and industrially acceptable, economically feasible and which will perform in the ground-contact situation.

## LIGHT ORGANIC SOLVENT PRESERVATIVES

The Queensland Department of Forestry has looked at solutions to the second problem and has at this stage concentrated on the use of copper and zinc naphthenates in light organic solvents because of:

1. reasonable performance of these chemicals as fungicides in exterior-not-in-ground-contact situations;
2. water repellancy;
3. penetration patterns able to be achieved;

4. reasonable stability to ultra-voilet radiation and absence of toxic break-down products; and

5. ease of analysis.

Some alternative light organic solvent preservatives have been 'avoided' because of doubts expressed on their stability and of adverse effects on the environment and on health from toxic break-down products.

CONCLUSIONS

Copper and zinc naphthenate treatments in conditions of subtropical or tropical exterior exposure cannot be considered as maintenance free; recommendations for their use embody periodic maintenance treatments where the preservative is not protected by a weatherproof opaque film (paint).

Neither copper nor zinc naphthenate alone can be recommended on present knowledge for use as a fungicide in ground-contact situations.

# THE DISTRIBUTION OF COPPER CHROME ARSENIC SALTS IN SLASH PINE

J. Norton
Division of Technical Services
Queensland Department of Forestry
Brisbane

## ABSTRACT

Sixteen, pole size slash pine logs, were sampled from each of the four major exotic plantation areas of south-east Queensland. All logs were treated commercially with Copper Chrome Arsenic (C.C.A.) preservative and discs were taken from each for analysis of preservative retention at various depths.

In each of four directions, analysis was carried out on blocks cut every 2 cm from the bark to the full depth of preservative penetration. The moisture content and density of each block was also determined.

Results were calculated for each of the four areas as well as for all the areas grouped together.

Analysis showed a definite distribution pattern of each of the C.C.A. components as well as a preservative gradient from the surface towards the centre of the log.

## INTRODUCTION

Softwood species, particularly slash pine (*Pinus elliottii* Engelm. var. *elliottii*) are currently being investigated as part of a research programme into their possible uses as alternatives to hardwoods.

The major objective of this study was to assess the distribution of compounds of copper chrome and arsenic in treated slash pine from the major plantation areas in S.E. Queensland.

## MATERIALS AND METHODS

The major exotic plantation areas in south-east Queensland are Beerburrum-Beerwah, Toolara and Tuan State Forests, and each area is represented in this study. The details of trees sampled are given below (Table 1).

TABLE 1

Sampling details of slash pine logs

| Source | No. of trees | Years Age | Present Stocking (stems/ha) |
|---|---|---|---|
| Tuan S.F. | 16 | 29 | 390 |
| Toolara S.F. | 16 | 27 | 750 |
| Beerburrum S.F. | 16 | 26 | 500 |
| Beerburrum S.F. | 16 | 38 | 300 |

Sample trees were randomly selected from the population of "select" stems with diameter breast high over bark ranging from 360 to 380 mm, and taken from a single compartment.

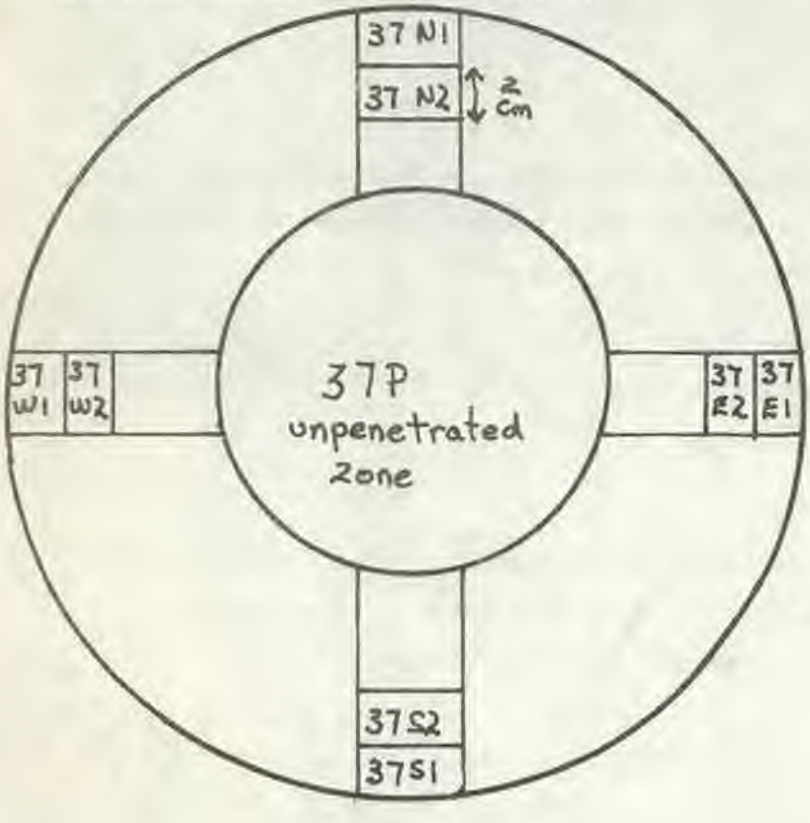
The 5.5 m section from the butt was taken as containing the test samples.

Each cut and debarked section was sprayed using a sodium pentachlorphenate and dieldrin mixture to inhibit fungal and insect attack.

All log sections were strip-stacked until the moisture content of two randomly selected sections from each of the four groups was below 40% at the 50 mm depth.

Log sections were then treated under commercial conditions (for Queensland) with copper chrome arsenic (C.C.A.) preservative.

Following treatment, logs were strip-stacked until equilibrium moisture content was reached. A disc was cut from the centre of each log section and each disc was cut as per figure 1.




e.g. 37 W4

indicates (37) log No. 37

(W) orientation west

(4) Sample 4 or sample 8 cm from bark.

In each direction, (North, South, East, West) two cm blocks were cut from the outside in, finishing at the untreated zone. On each of these blocks, the following determinations were carried out.

1. Moisture content - by oven drying.
2. Density - by volume displacement.
3. Preservative Content - by analysing for Copper, Chromium and Arsenic using standard Atomic Absorption Techniques.

A comparison was also carried out of the results on logs from each area.

RESULTS

For each sample the elemental components, density and moisture content, were determined - and from these, preservative retentions were calculated.

Results are summarised by the equations to the lines of best fit determined by simple and multiple linear regression.

Density Variable

| | Equation | $R^2$ |
|---|---|---|
| Total area | Density = 640.066 - 15.9397D | 0.4173 |
| Area 1 | Density = 641.12 - 13.8376D | 0.4227 |
| Area 2 | Density = 638.04 - 17.5975D | 0.4982 |
| Area 3 | Density = 637.60 - 18.9530D | 0.5264 |
| Area 4 | Density = 636.32 - 11.3226D | 0.2413 |
| | Where D = depth from surface. | |

% Moisture Content Variable (taken before analysis)

| | | |
|---|---|---|
| Total area | % M.C. = 19.05 + 0.6808D | 0.1436 |
| Area 1 | % M.C. = 18.814 + 0.7266D | 0.1547 |
| Area 2 | % M.C. = 18.513 + 0.6188D | 0.1983 |
| Area 3 | % M.C. = 19.998 + 0.6139D | 0.1317 |
| Area 4 | % M.C. = 18.571 + 0.8465D | 0.1327 |

% Copper Variable

| | | |
|---|---|---|
| Total area | % Cu = 0.408 - 0.0045D | 0.0202 |
| Area 1 | % Cu = 0.4326 - 0.0099D | 0.1112 |
| Area 2 | % Cu = 0.4039 - 0.0016D | 0.0025 NS |
| Area 3 | % Cu = 0.4338 - 0.0043D | 0.0175 |
| Area 4 | % Cu = 0.3652 - 0.0031D | 0.0108 NS |

| | | Equation | $R^2$ |
|---|---|---|---|
| **Chrome Variable** | | | |
| Total area | % Cr | = 0.684 - 0.0304D | 0.36 |
| Area 1 | % Cr | = 0.6801 - 0.033 D | 0.4801 |
| Area 2 | % Cr | = 0.7088 - 0.0298D | 0.3481 |
| Area 3 | % Cr | = 0.7298 - 0.0325D | 0.4262 |
| Area 4 | % Cr | = 0.6152 - 0.0266D | 0.2611 |
| **Arsenic Variable** | | | |
| Total area | % As | = 0.689 - 0.0064D | 0.0174 |
| Area 1 | % As | = 0.7192 - 0.0135D | 0.0951 |
| Area 2 | % As | = 0.6784 - 0.0019D | 0.0015 NS |
| Area 3 | % As | = 0.7235 - 0.0043D | 0.007 NS |
| Area 4 | % As | = 0.6408 - 0.0084D | 0.0369 |
| **Retention Variable** | | | |
| Total area | L | = 29.908 - 1.2411 D | 0.4422 |
| Area 1 | L | = 30.694 - 1.3541 D | 0.5090 |
| Area 2 | L | = 29.9195 - 1.1937 D | 0.4274 |
| Area 3 | L | = 31.568 - 1.4015 D | 0.5382 |
| Area 4 | L | = 27.235 - 0.99609D | 0.2991 |

On a total area basis, the following equations were obtained. This was done simply by manipulating variables to obtain a maximum "coefficient of determination".

$$\% \text{ Cu} = 0.09758 - 0.01224 \text{ Depth} + 0.00001604 \text{ Depth x Density} + 0.3142\%\text{Cr} + 255.78 \frac{\%\text{Cr}}{\text{Density}} - 381.41 \frac{\%\text{Cr}}{\text{Depth x Density}}$$

$$R^2 = 0.8239$$

and

$$\% \text{ As} = 0.2768 - 0.008361 \text{ Depth} + 0.3163 \%\text{Cr} + 409.21 \frac{\%\text{Cr}}{\text{Density}} - 501.38 \frac{\%\text{Cr}}{\text{Depth x Density}}$$

$$R^2 = 0.7584$$

It is pointed out that the possible number of equations from the data available, has by no means been exhausted.

Figure 2 shows the predicted curves for the C.C.A. components when data from each of the areas is grouped.

Figure 3 shows the preservative retention by depth. Again, data from all the areas is grouped. Density data for each block was used in the production of retention data.

DISCUSSION

A great deal more work must be done on interpreting the results obtained. It is clear however, that there is a decrease in the component concentrations of the preservative at increasing depth from the surface of the logs. There is a concentration gradient present in the timber with the higher concentrations being present towards the surface of the log.

This feature becomes important in specifying the retention level to be present in treated pine logs. The trend in Queensland is to specify a minimum that must be present in a core sample; the core sample being taken from the sapwood-truewood boundary.

If treated pine is dressed, because of the preservative concentration gradient, timber of lower retention may be exposed to degrade. Checking in pine poles would also expose "undertreated" wood to attack. Figure 3 shows quite a severe retention gradient.

Further equations are being calculated to better describe the results obtained. Space available in this paper does not permit presentation of some of the mathematical models already produced.

TOTAL AREA
predicted component concentration with depth from surface.

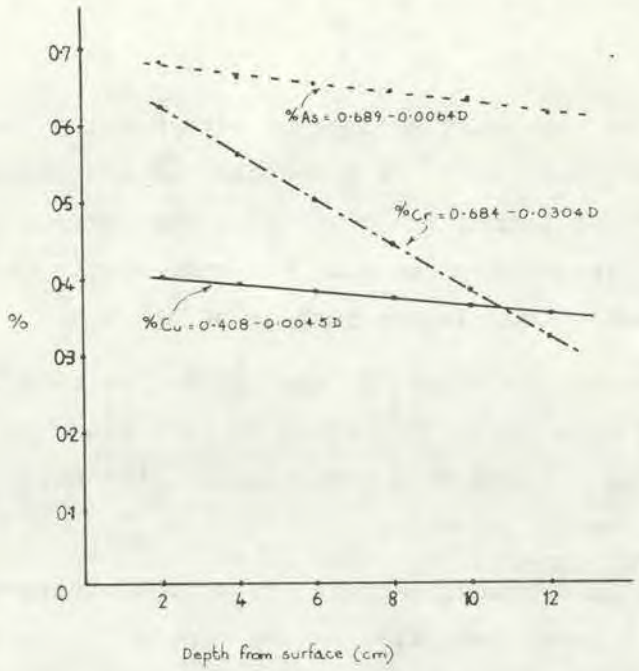



Figure 2

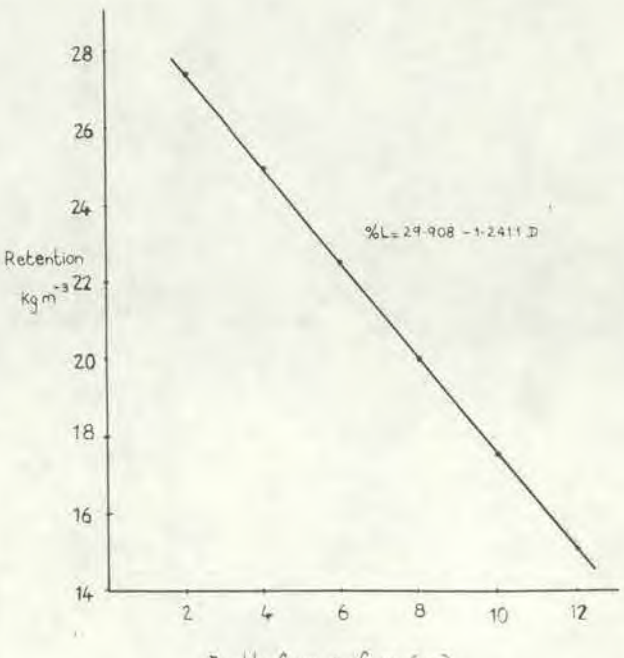



Figure 3

# BIOCIDES FROM TROPICAL RAINFOREST SPECIES - SOME RESULTS, PRACTICAL PROBLEMS AND CONCERNS

J.R.J. French

## ABSTRACT

Tropical forests represent an enormous source of chemicals, fibre and energy. Our particular interest is in obtaining biocidal extracts from durable wood species and synthesizing analogues that possess termiticidal properties. However it is arguable whether the sustained use of such material to protect wood and wood products is realistic in the long term. Serious concerns regarding the sustainability of materials from tropical forests are posed.

## INTRODUCTION

At a workshop on the biodeterioration of tropical woods in 1974, Bultman (1) presented an overview of the research at the United States Naval Research Laboratory on bioresistant tropical woods, and on the effect of their protective wood constituents on biological systems. Emphasis was given to obtaining vital information leading to the development of new, more effective, environmentally acceptable methods of wood protection. We have a similar concern in this Division in the need for developing biocides, particularly against termites, with low environmental hazards and that will serve as alternatives to organochlorides and arsenicals. This paper presents our current status in this research area, offers some suggestions as to the direction of future research and development, and enunciates concerns regarding the supply of such biocides from tropical rainforest species, and the sustainability of these tropical biomes.

## SOME RESULTS

Although there are numerous reports of termite resistant Australian timbers, and several laboratory sutdies have been published on the anti-termitic components of such timbers (2,3,4,5,6), information on biocides from torpical forest species, either from Australia or the Pacific region is scant (1). Except for the investigations at N.R.L. and United States Department of Agriculture, Forest Service, Gulfport, (1,7), there have been no major laboratory or field studies on this aspect of wood preservation.

Our preliminary laboratory bioassays on the termiticidal properties of extracts from the Queensland tropical hardwood scaly ash (*Ganophyllum falcatum* Bl.)

indicate the potential of some of these components (French *et al.* unpubl. data). Extracts of *G. falcatum* appear to be as toxic to the termite *Coptotermes acinaciformis* Frogg, as extracts from white cypress pine (*Callitris columellaris* F. Muell.) (6). However, there is a distinct advantage with the toxic extracts of *G. falcatum* compared to *C. columellaris*, as the former are water soluble, whereas the latter are organic solvent extracts.

Direct comparison is not possible to date, as these bioassays were not conducted at the same time, nor with the same groups of orphaned *C. acinaciformis*. Currently, we are examining extracts from greenheart (*Ocotea rodiei* (Schomb.) Mez, supplied from Guyana for their biocidal properties, and as yet, have no publishable data. However, when the bioassays are completed, the results willbe published elsewhere.

## SOME PRACTICAL RESEARCH PROBLEMS

As Beal (8) mentioned at the N.R.L. workshop (1), many of the rainforest species that appear resistant are not of sufficient size or abundance to provide wood for general construction purposes. Nor is it practicable or economic in many cases to obtain adequate quantities of extracts from these timber species merely by logging (L. Jurd, pers. comm. via J.E. Barnacle). Nevertheless, their extractive components, or synthesized chemical analogues, may prove of economic value as termiticides or non-toxic repellents, particularly as damage by termites in Australia to timber-in-service is estimated to cost the consumer over $40 million annually. Whatever biocides one examines, it is important to conduct highly replicated, repeatable bioassays, that allow the researcher to perceive the difference between termite repellancy and toxicity. Also, all antitermitic substances identified by laboratory bioassays (both in choice and no-choice feeding tests) should be evaluated in the field, both in ground, and in above ground situations.

Although our results are in the preliminary stages the whole question of utilizing tropical rainforest species, such as *G. falcatum*, for the production of antitermitic extracts, poses practical long-term problems. Whilst it is reasonable to cut down a small number of trees for experimental purposes, and hopefully to synthezise chemical anti-termitic analogues, it is questionable whether these tropical rainforests are sustainable under commercial development (9,13,18,22). These biomes have never undergone even one rotation under such a regime, yet already there is mounting evidence indicating that tropical biomes are limited and non-renewable (9,18).

## CONCERNS REGARDING SUSTAINABILITY OF RESOURCES FROM TROPICAL BIOMES

The world's tropical rainforests cover about 16% of the earth's surface and lie in a belt centred on the equator and extending 23½° north and south to the Tropics of Cancer and Capricorn. In 1976 the area of these forests was estimated at 935 million hectares (equivalent in size to the USA); comprising about 30% of all the

world's forest (9). Tropical moist forests include the tropical rain forest and tropical moist deciduous forest. The former, famous for ebony and mahogany cover about 568 million hectares, the latter make up the remainder. About 80% of the world's tropical rainforests have already disappeared, the remainder are being felled and burned at the rate of 40 hectares per minute. "If this continues, these forests may cease to exist as usable forests in 40 to 50 years. On these figures we lose an area of tropical moist forest the size of a football pitch almost every second" (FAO). The Asia-Pacific region (187 million hectares) will find themselves short of sawlog timber before the end of this century. Worldwide, there is a decline in natural forest biomass due to deforestation. The ratio of deforestation to reforestation is 8 to 3 (10).

Webb (11) and Webb and Higgins (12) offered the notion that development and conservation are not irreconcilable concepts in tropical rainforests. After examining the pulpwood developments in Papua New Guinea they considered the exploitation operations should be directed unequivocally towards maximum benefit for the indigenous people. These authors list the many values of tropical rainforests, such as termiticidal extracts from durable timber, and appeal to foresters and others concerned in the development process to seriously consider the ecological implications of development and devise appropriate solutions to the problem of trying to match ecological and economic realities. As Leslie (13) and others (14) point out, studies on tropical forest wildlife for instance have hardly started, so that evaluation of the economic implications is sheer guesswork. The same could be said for other non-commercial values (15).

The main factors responsible for the disappearance of tropical rainforests are a combination of population growth, and opening up of new areas for economic development (16). New programs for economic development are based upon mining, timber harvesting, fuel-wood gathering and cattle-raising operations (15) (eg. Daniel Ludwig's Jari Forestry and Ranching Company in Amazonia). It is arguable whether or not these developments will sustain and renew tropical rainforests. The difference between a renewable and nonrenewable resource is in fact more a question of socio-economic context than one of the natural ecology of the resource itself. Renewable resources are considered to be those for which utilisation and replacement can fit into our social or economic time scale, and all other resources are unrenewable (17). It is possible to completely use up a so-called renewable resource (e.g. cedar, huon pine, Douglas fir, etc.). Grainger (18) considers the tropical rainforests as a limited and non-renewable resource which is certainly not going to be the salvation of developed nations who have not taken care of their own forests.

If we wish to sustain our tropical rainforests on this planet, and their potentially renewable products which are so vital for present and future civilizations, then we need to appreciate that diversity and variety are the keys to sustaining this life. Renewability of resources must not be implicitly assumed by the forestry planners and developers, and there is a wealth of information to testify against such assumptions (9,12). It's one thing to talk about using 'appropriate technology' to sustain these forests. However, technology, the fruit of science, is not a neutral commodity, and depends on the rich and powerful (19). For instance, in 1973 some US $96 billion were devoted annually to R & D worldwide - but less than 3% was spent in developing countries. Present military expenditure is $331 billion, or $907 million daily (20). There is a distinct touch of unrealism in this exercise when one views how to understand and modify a sustained yield from tropical rainforests. Others (21,22) urge that a more holistic approach is required for the harvests of these forests ecosystems to be made available for the needs of the indigenous peoples. Leslie (13) considered that in evaluating the natural management of tropical moist forests, either from an economic or social perspective, the data are clearly not good enough to provide definitive cost/benefit relationships. He maintains that tropical foresters, like foresters almost everywhere, are forced to look too far into the future for them to be sure enough about their assumptions for them to be dogmatic about their decisions. There must be a strong international commitment for conservation of tropical rainforests under the Man and Biosphere (MAB) programme, a pledge by tropical countries to exploit native rainforests under the sustained-yield principle while abstaining from their exploitation for the benefits of the ruling faction, and much more effective foreign aid for the development of sound tropical, and appropriate, agro-ecosystems (24).

## REFERENCES

1. Bultman, J.D. (1974). Proceedings of a workshop on the biodeterioration of tropical woods: chemical basis for natural resistance. Workshop held on October 17-18, 1974. Naval Research Laboratory, Office of Naval Research, Wash. D.C.

2. Rudman, P. (1965). The causes of natural durability in timber. XVII. The causes of decay and termite resistance in *Callitris columellaris* F. Muell. Holzforschung. 19: 52-57.

3. Rudman, P. and Gay, F.J. (1961). The causes of natural durability in timber. V. The role of extractives in the resistance of tallowwood (*Eucalyptus microcorys* F. Muell.) to attack by the subterranean termite *Nasutitermes exitiosus* (Hill). Holzforschung. 15: 117-120.

4. Rudman, P. and Gay, F.J. (1967). The causes of natural durability in timber. XXI. The anti-termitic activity of some fatty acids, esters and alcohols. Holzforschung 21: 24-26.

5. Yazaki, Y. and Hillis, W.E. (1977). Components of extractives from *Callitris columellaris* F. Muell. heartwood which affect termites. Holzforschung. 31: 188-191.

6. French, J.R.J., Robinson, P.J., Yazaki, Y and Hillis, W.E. (1979). Bioassays of extractives from white cypress pine (*Callitris columellaris* F. Muell.) against subterranean termites. Holzforschung 33: 144-148.

7. Bultman, J.D. and Southwell, C.R. (1976). Natural resistance of tropical American woods to terrestrial wood-destroying organisms. Biotropica 8: 71-95.

8. Beal, R.H. (1974). Resistance of tropical woods to subterranean termites pp 67-74. In - (see Ref. 1).

9. Grainger, A. (1980). The state of the world's tropical forests. Ecologist. 10: 6-55.

10. Odum, E.P. (1977). The life support value of forests. pp 101-105. In - Forests for people. Proc. Soc. Amer. For. 1977 Nat. Conv. Albuquerque, New Mexico.

11. Webb, L.J. (1977). Ecological considerations and safeguards in the modern use of tropical lowland rain forests as a source of pulpwood. Example, the Madang area PNG. Office Environ. & Conserv. Dept. Nat. Resources, PNG pp 36.

12. Webb, L.J. and Higgins, H.G. (1978). The impact of the "new ecology" in the development of the tropical rainforest. pp 23. 8th World For Congr. Jakarta.

13. Leslie, A.J. (1977). Where contradictory theory and practice co-exist. Unasylva. 29: 2-17.

14. Brünig E.F. (1977). The tropical rainforest - a wasted asset or an essential biospheric resource? Ambio. 6: 187-191.

15. Routley, R. and Routley, V. (1980). Destructive forestry on Melanesia and Australia. Ecologist. 10: 56-67.

16. Ehrlich, A.H. and Ehrlich P.R. (1978). Hope for the tropical forests? The Mother Earth News. Sept/Oct. 110-111.

17. Kimmins, J.P. (1973). The renewability of natural resources. Implications for forest management. J. For. 71: 290-292.

18. Grainger, A. (1981). Reforesting Britain: A special report. Ecologist 11: 56-81.

19. Nader, R. (1975). Who benefits? The Center Mag. 8: 32-37.

20. Biswas, M.R. (1980). UNCSTD in retrospect. Mazingira. 4: 36-53.

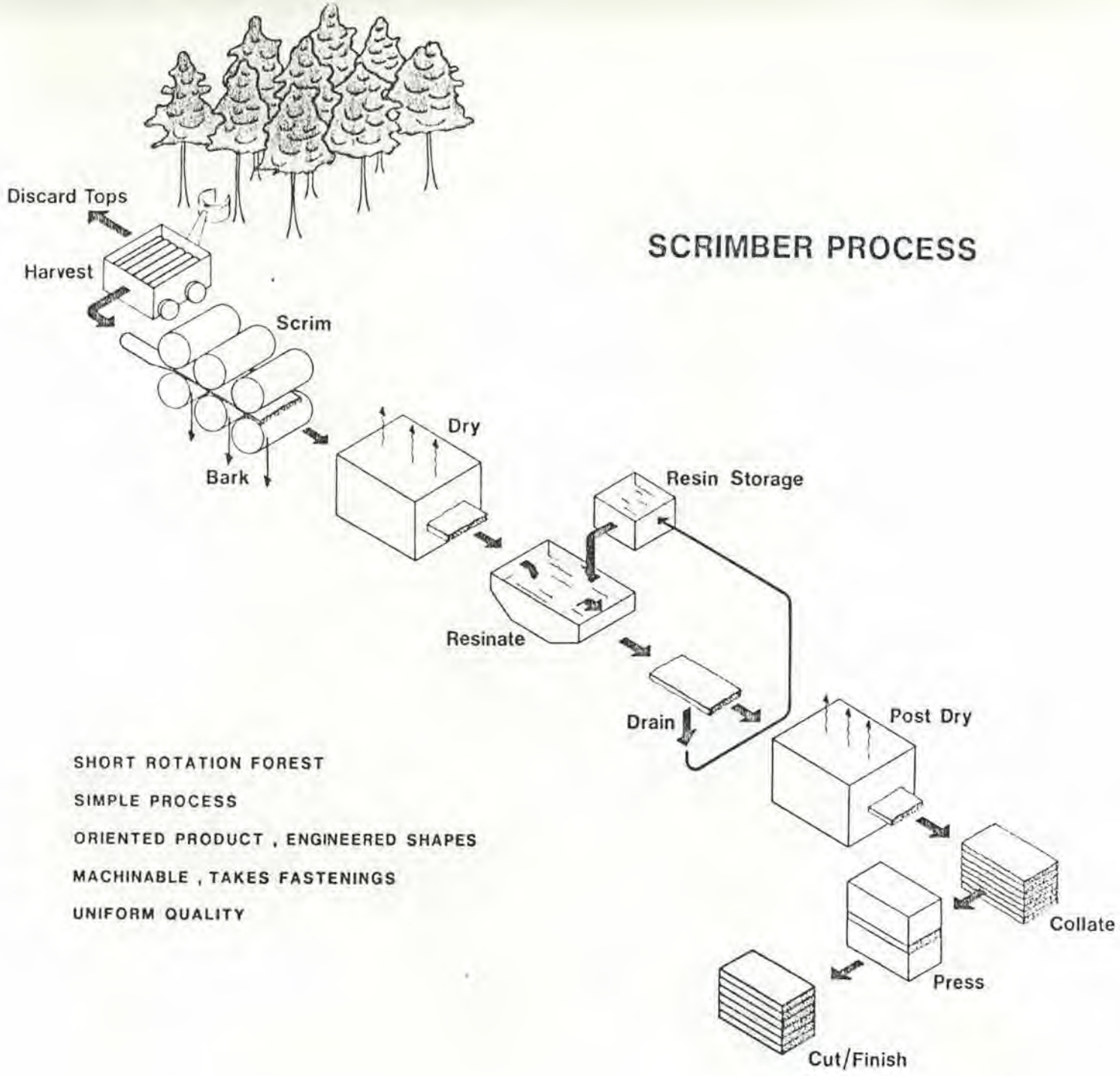
21 Francois, J.H. (1980). Harvesting tropical natural forests. 11th Commonw. For. Conf. Trinidad-Tabago, Sept.: 14.

22. Myers, N. (1980). The present status and future prospects of tropical moist forests. Environ. Conserv. 7: 101-114.

23. Eckholm, E. (1979). Planting for the future: forestry for human needs. Worldwatch Paper No. 26, Wash. D.C. pp 64.

24. Meijer, W. (1980). A new look at the plight of tropical rainforests. Environ Conserv. 7: 203-206.

# SCRIMBER PROCESS




SHORT ROTATION FOREST

SIMPLE PROCESS

ORIENTED PRODUCT , ENGINEERED SHAPES

MACHINABLE , TAKES FASTENINGS

UNIFORM QUALITY

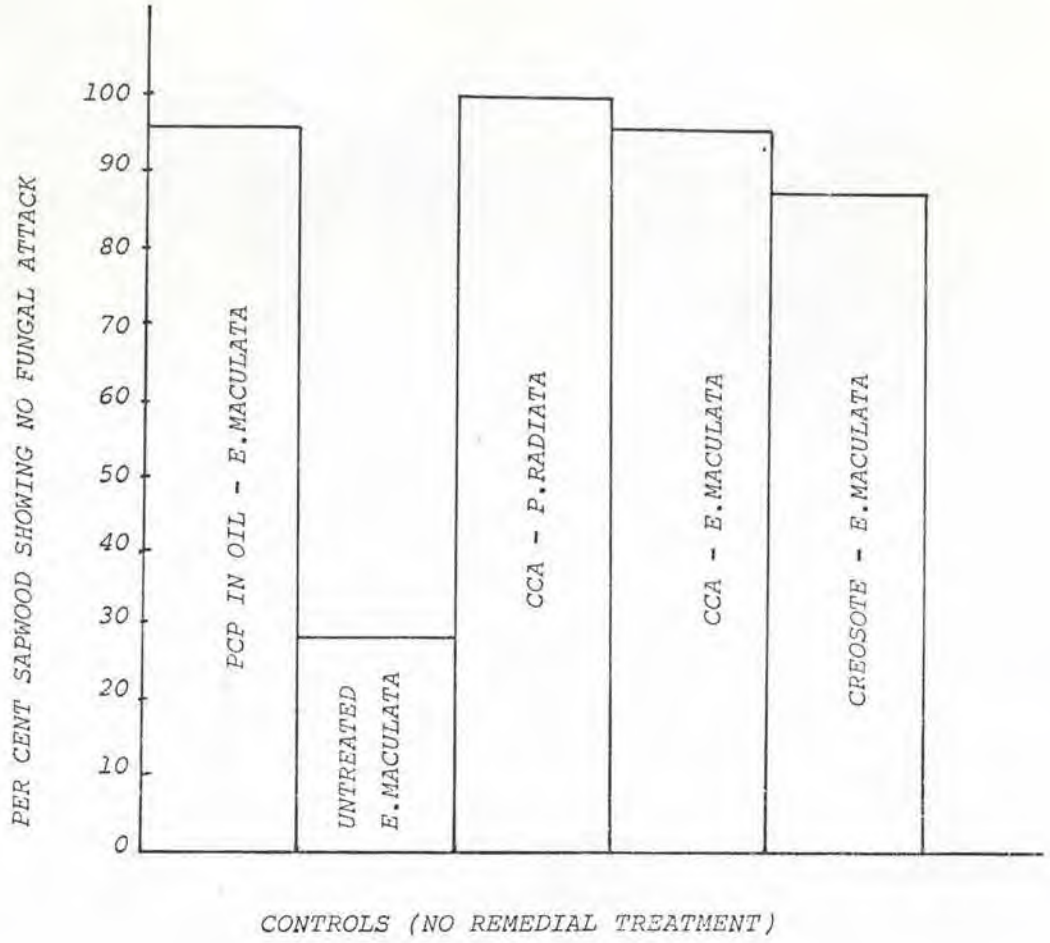
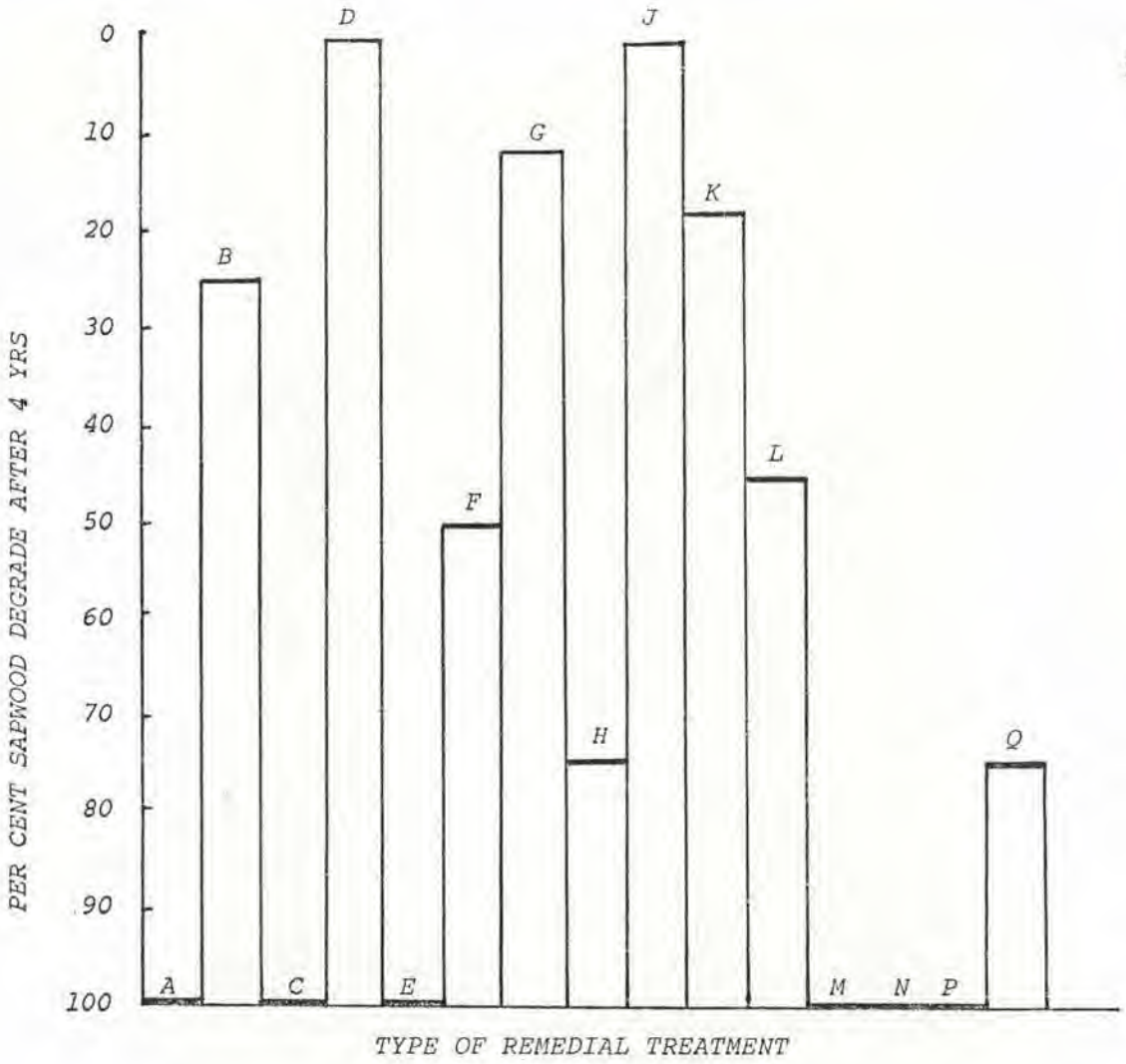



FIG.1 PERFORMANCE OF CONTROLS AFTER 4 YEARS




KEY:

A CONCRETE COLLAR
B BLUE 7 (MARK I)
C TAR ENAMEL
D C.C.A. GEL
E POLYURETHANE FOAM
F H.T. CREOSOTE
G H.T. CREOSOTE + ALDRIN
H CONTROL
J 5% PCP IN OIL
K POLE-NU
L H.D. CREAM
M POLYTHENE
N BASILIT BFB (MARKI)
P POLYURETHANE + ADDITIVE
Q AMMONIUM SULPHATE

FIG.2 - FUNGAL DEGRADE - REMEDIAL TREATMENTS APPLIED TO UNTREATED E.MACULATA SAPWOOD