22nd FOREST PRODUCTS RESEARCH CONFERENCE

17-20 NOVEMBER 1986

HELD AT

CSIRO

DIVISION OF CHEMICAL AND WOOD TECHNOLOGY
CLAYTON, VICTORIA,
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Clayton, Victoria

VOLUME 1

*Keynote Address:** *Dr D.I. Bevege*
(10.30 a.m., 17 November)

Session 1. Biodegradation and Chemical Treatments (1.30 p.m., 17 November)

Chairman's Lead Paper: 1/L Environmental Aspects of Wood Preservation - *Dr H. Greaves, CSIRO*

Other Invited Papers

1/1 Recent advances in oil-based preservative emulsions in Australia - *C.W. Chin, J.B. Watkins and H. Greaves*

1/2* Current fire retardant research and future markets - *D. Gardner*

1/3 Research and development for the preservation of panel products - *G.C. Johnson and J.W. Creffield*

1/4 The potential for the expanded use of treated softwood poles - *L.E. Leightley*

1/5 Performance of wood rail sleepers in Australian and their potential - *J.E. Barnacle and J. Costello*

Session 2. Structural Applications (9.00 a.m., 18 November)

Chairman's Lead Paper: 2/L Timber Structures and Fire - *Dr R.H. Leicester, CSIRO*

Other Invited Papers

2/1 Market opportunities for timber through engineering - *R.S. Beckett*

2/2 Research on Timber Connectors in CSIRO - *E.P. Ihuede*

2/3 Design for high wind areas - *C. McKenzie*

2/4* The engineering use of timber in large industrial buildings - *G.B. Walford (N.Z.)*

2/5 The structural response of a Tongan hurricane house to simulated cyclone loading - *G.F. Reardon*

Session 3. Primary Conversion and Drying† (2.00 p.m., 19 November)

Chairman's Lead Paper: 3/L Continuous Production and Technological Trends - *F.J. Christensen, CSIRO*

Other Invited Papers

3/1 Seasoning research in Western Australia
- *P. Shedley*

3/2 Sawing small diameter eucalypts in Australia
- *G. Waugh*

3/3 A model to correlate measurements directed towards reducing drying degrade in sawn eucalypt timber - *Professor A. Oliver*

3/4 Coping with wood from young fast-grown eucalypts
- *R. McKimm*

3/5 Quality control and the use of electronics in the forest products industries (sawn timber) - *W. McCullock*

Session 4. Preparation for Use as a Reconstituted Product

(2.00 p.m. 18 November)

Chairman's Lead Paper: 4/L Laminated Veneer Lumber
- *K. Lyngcoln, Plywood Association of Australia*

Other Invited Papers

4/1* Scrimber - commercial aspects
- *R. Cowan*

4/2* Glued structural timber products
- *J. Carson*

4/3 Performance testing of structural composite products
- *M. O'Halloran (USA)*

4/4 Recent developments in the Australian plywood industry and their likely influences on future raw material needs - *B. McCombe*

4/5* The durability of bonded wood structural components
- *R. Palmer*

Session 5. Growth for End-Use (9.00 a.m., 20 November)

Chairman's Lead Paper: 5/L Influence of Site Quality, Management and Genetic Factors on Plantation-Grown Wood - *A.G. Brown, CSIRO*

Other Invited Papers

5/1 Towards non-destructive measurment of growth stresses in living trees - *A. Krilov*

5/2 Raw material requirements for the pulp and paper industry - *F. Phillips*

5/3* Density as a factor in tree breeding - *Christine Deane*

5/4 Increased yields of high quality veneer and sawn timber from cuttings of radiata pine - *D. Spencer*

5/5 Young eucalypt project - *W.H. Rawlins and C.M. Kerruish*

Session 6. Fibre and Chemicals from Wood† (2.00 p.m., 19 November)

Chairman's Lead Paper: 6/L Fibre and Chemicals from Wood - *A.F.A. Wallis, CSIRO*

Other Invited Papers

6/1 Structure/activity relationships in carbon from wood - *K.J. Harrington*

6/2 Activated carbon and gold extraction - *P. Fung*

6/3 Pulping developments - *P.J. Nelson*

6/4 Review of rayon processes old and new - *A.A. Sioumis*

6/5 Commercial production of oil from eucalypt foliage - *P. Abbott*

† Concurrent Sessions * See Volume 2

ENVIRONMENTAL ASPECTS OF WOOD PRESERVATION

H. Greaves

Division of Chemical and Wood Technology, CSIRO, Highett, Victoria 3190

ABSTRACT

The preservation industry employs a wide range of chemicals and processes to provide timber commodities capable of resisting biodeterioration and degradation. The public often perceives the chemicals as health hazards and treatment plants as potential threats to the environment. This paper attempts to place in proper perspective the value of wood preservation. It presents a brief history of the industry and discusses aspects of health and safety of the treatment chemicals and the treatment operations. CCAs, creosote and PCP, TBTO, copper naphthenate, boron and fluoroborates, and organochlorine insecticides are all reviewed. Where appropriate, precautions are presented for handling both treated wood and the chemicals. Guidelines for treatment plant operations are also provided. These aim at minimising the potential for pollution and at promoting worker safety. It is suggested that preservative-treated wood - as opposed to the unreacted treatment chemicals - does not represent a hazard to health or the environment.

INTRODUCTION

The use of chemicals in our everyday life is taken for granted; indeed the general public seldom recognise the integral part that chemicals play in their lives. Some chemicals, however, particularly pesticides, are closely scrutinised from the health and safety point of view, and almost everybody is aware, in one way or another, of the use of these chemicals in their environment.

In Australia, and also in many other countries, wood preservatives are classified as pesticides or agricultural chemicals for the purposes of registration and clearance. The manufacture, packaging, sale, distribution, possession, transport, use, and disposal of wood preservatives is regulated under a wide variety of State and Federal Legislation. These Acts and Codes are aimed at ensuring minimum risk to

the consumer, the environment, and the workforce employing the chemicals.

The use of timber in both the urban and rural scenes would be substantially curtailed without the judicious application of chemicals to the wood. Alternative materials, such as plastics, concrete, steel, are generally more expensive, certainly less readily and economically produced, non-renewable, and not always as suitable or flexible in use. Preservative-treated wood may offer many advantages over competing alternative materials.

Almost by definition, the wood preservation industry is dependent upon the use of chemicals. Its products must resist biodeterioration and physical degradation from agencies such as fire and the weather - and to do this the wood has to be treated with chemicals. In the case of naturally resistant timber species, the growing tree achieves its own treatment as it ages and produces heartwood. In non-durable species, the chemicals are introduced into the wood by a variety of processes, some capital intensive, others less so and relatively unsophisticated.

The risks associated with the preservation industry's chemicals are far outweighed by the benefits of the final product. Clearly, the fact that chemicals are used and that, in most cases, they are expected to be toxic to one life-form or another, means that they should be handled and employed with due consideration to the users and the environment. The legislation referred to earlier plays a vital role in this. In addition the industry itself should employ codes of good practice, consumer awareness schemes, and other means of achieving a safe image for its products. However, not all producers of treated wood consciously pursue such an image, and even in well-run operations accidents may happen, e.g. spills of preservative solutions. Unfortunately, public attitudes are more often influenced by the bad operators and the publicised accidents, than by the good procedures.

This presentation examines some of the above problems, focusing on aspects of wood preservation and the enviornment, including the risks, if any, of using treated wood.

HISTORICAL PERSPECTIVE

The preservation of wood using chemical means has been practised for

well over two thousand years. The earliest known processes (not including Noah and his pitch-coated ark) employed naturally-occurring inhibitors of biological deterioration, e.g. oils of cedar, larch, juniper and even olive oil. Chemicals - in the sense we use today - arrived very much later on the wood preservation scene, at about the end of the seventeenth century. Some of the earliest formulations included products still in use, e.g. copper sulphate, zinc chloride, and creosote. The latter gained universal acceptance by the middle of the nineteenth century and knowledge of the various fractions of creosote and their preservative effects began to be collated. At about the same time chlorination of some of the fractions was proceeding and this ultimately led to the production of chlorinated phenols. During this period, water soluble preservative chemicals were largely overshadowed in a development sense. The earliest, mercuric chloride, had ceased to be used on a large scale in the Kyanising process about a decade before the extensive work on creosote fractions and chlorination. Interestingly enough it was many years later, in 1935, that mercuric chloride became one of the first of the preservation industry's chemicals to be withdrawn.

Fluorides were proposed as wood preservatives in Britain during the mid-1800s, and they were developed extensively during the early part of the present century despite their lack of permanence in wood - their potential risks to health appear not to have been recognised until the 1940s.

The dominance of copper salts in biocidal preparations for wood preservation took almost 100 years to emerge, but by the 1920s, copper, chromium and arsenic had all been suggested and used in various forms and combinations.

During all this development activity, the industry had given little or no attention to environmental and health-related matters. It was not until the post-World War II period that such issues received serious consideration by wood preservers; industries using related chemicals, e.g. coal-tar and pitch industries, sectors of the agricultural industry employing certain pesticides, etc., were already concerned with health aspects of their operations. In recent times, of course, the disasters of Seveso and Bhopal have highlighted the hazards of industrial chemical production.

Public awareness of the potential hazards associated with putting

chemicals into wood is now greater than at any other time during the preservation industry's history. The US EPA notices of rebuttable presumption against registration (RPAR) for wood preservatives (1) assisted in bringing the industry's operations into the limelight of public scrutiny. During the past decade, other countries, particularly within the European Economic Community (EEC) have also turned their attention to preservatives. In Australia, the ACTU and the Victorian Trades Hall Council drew worker interest to wood preservative chemicals in their 1982 Health and Safety Bulletin, No. 8. This publication attempted to list all preservatives used in Australia, and cited some of the data against creosote, inorganic arsenicals, and pentachlorophenol which were contained in the US EPA RPAR proceedings.

The impact in this country of both the RPAR notices and the Health and Safety Bulletin No. 8 has been significant; it has brought pressure on the industry to improve its operations and become more conscious of health-related matters, and it has resulted in industry, its work force, and consumer groups coming together with the common goal of achieving a safer environment for preservative chemicals.

THE TREATMENT CHEMICALS

It is not possible in this review to cover in detail all of the various environmental aspects associated with the preservation industry's chemicals, nor indeed to consider each and every chemical. Thus attention will be focussed on the major chemical types and some of the main features of their usage.

1. Copper-chrome-arsenates (CCAs)

These formulations are probably the most widely used preservatives in the world although the oil-borne treatments, creosote and pentachlorophenol would account for the greater volume production of treated commodities.

Most of the concern related to the use of CCAs is about the arsenic and, to a lesser extent, the chromium. Both elements are viewed as potentially harmful to human health, either as poisonous substances or as carcinogenic chemicals. As far as the public is concerned, these views

usually relate to the use of treated wood, whereas during the production of treated commodities the work force is necessarily concerned with the CCA chemicals themselves.

There have been a number of reviews of both of the above aspects. Two such reviews presented to British Wood Preserving Association annual conventions cover an enormous body of literature on the subject (2,3). In addition, the proceedings of the RPAR process referred to above produced further documentation on health and safety aspects of CCAs and their use (4,5). Various studies, surveys, etc. dealing with CCAs, as well as specific monographs on arsenic and chromium provide further appraisals (e.g. 6-11). This body of information can be summarised as follows:

- CCA solutions represent hazards to workers at the treatment plant. The unreacted ingredients, notably pentavalent arsenic and hexavalent chromium are the major risk and protective clothing and glasses should be worn during mixing operations and in handling freshly-treated timber. This is to protect the skin from soluble hexavalent chromium and soluble arsenic. Although concentrations of the former in freshly-treated timber will be low, contact dermatitis and sensitization may occur without the recommended handling precautions.
- The CCA ingredients and the fully formulated CCA preservative present different poisoning risks. It is highly unlikely that a plant worker would ingest CCA solution, or its separate ingredients (particularly where concentrates rather than separate powders are now the preferred form for CCAs in Australian plants). However, should this happen, a fatal dose in 50% of instances would be about 450 ml of a 3% CCA solution.
- CCA reacts in timber to become substantially insoluble and fixed in the wood. Hexavalent chromium is reduced to the less toxic trivalent form, and the arsenic is fixed as insoluble pentavalent arsenates. The dry surfaces of CCA-treated wood can yield from 0.006-0.04 mg/cm^2 of arsenic, figures below the levels of As found in some food stuffs and not regarded as a potential health hazard.
- Exposure to dust and small particles as a result of working with CCA-treated timber (or indeed untreated timber) should be minimised. In the short term the amount of respirable arsenic and

chromium from such work has been regarded as harmless. Longer term, occupational exposure may require attention to work practices and worker protection.

- It is extremely difficult to prove cause and effect for human carcinogens. In the case of the fixed, reacted CCA ingredients, as they appear in the treated wood, neither the arsenic nor the chromium have been shown to be carcinogenic. The copper has never been in doubt in this context.
- CCA-treated wood fed, in relatively large doses, to sheep, pigs, cattle, and dogs has not proved to be toxic.

It will be seen that the evidence - a mixture of experimental data, animal tests, epidemiological surveys, expert opinion, and varying lengths of experience -, suggests that CCA treatment is not a threat to human life. However, no amount of data can alter some entrenched views and it will continue to be a prudent investment to study chromium - and arsenic-free formulations as future replacements to CCA in the event that they are removed eventually from the industry's list of preservatives.

2. Creosote and Pentachlorophenol (PCP)

These essentially oil-borne formulations (note their modern use in emulsions and water dispersions) are employed worldwide and account for the biggest volume of treated timber, particularly heavy-duty commodities.

The US RPAR proceedings produced substantial and relatively recent information about creosote and pentachlorophenol (1,5,12,13). The reader is also referred to a number of other key sources of information on these preservatives (14-18).

The major concern about the health hazards of PCP is related to the presence of chlorodioxins and dibenzofurans in commercial preparations of the chemical. In particular, hexachlorodibenzo-p-dioxin (HxCDD) has been claimed to be teratogenic in rats. The more potent dioxin, 2,3,7,8 tetrachlorodibenzo-p-dioxin (2,3,7,8-TCDD) has not been found in PCP according to the US EPA (19). The preservative is readily absorbed through the skin, and this pathway has given rise to fatal accidents in the past, where unprotected workers have been extensively exposed - arms and hands immersed - during open tank dipping operations, and in crop spraying and herbicide application. In the short term, skin and respiratory tract

irritation can occur following brief direct contact with PCP, either as dust, spray or liquid, and it is clear that work practices should be aimed at minimising, or even eliminating this possibility. In some countries PCP (and its salt, NaPCP) is banned, while here in Australia the ACTU has recommended that member unions cease to work with PCP-treated poles and sleepers.

There is a greater risk of toxic side-effects during the actual manufacture of PCP than during its use as a wood preservative (20), and there are few reports of it causing health problems in the modern preservation industry. Nevertheless, PCP must be viewed as one of the industry's higher risk chemicals and a reduction in the HxCDD levels in PCP is desirable, as recommended in the final determination of the RPAR proceedings (19).

Assessments of environmental and health risks associated with creosote are hampered by the confusing chemistry of the preservative itself. There is a considerable variability between the world's creosotes, and conservative estimates suggest that several hundred chemicals make up this, the oldest, of man's preservatives. Much of the data on health hazards of creosote is further confused by the wrongful and misleading inclusion of coal tars, pitches, bitumen, and other coal derivatives in the assessments.

The primary cause for concern with creosote seems to be associated with certain polycyclic aromatic hydrocarbons (PAH's) found in the preservative, notably benzo-α-pyrene (BaP) which has been shown to be carcinogenic in animal experiments. PAHs occur very widely in our environment. They are produced, for example, during coal burning, in running our cars, from barbecues, cooking, fires, smoking, etc. In particular, BaP has been shown to be present in car exhausts at levels up to a thousand times higher than levels of BaP found in the air at creosote treatment plants (21). Attention in Europe has focussed in the BaP levels found in both heavy-duty creosotes and the lighter brushing grades. These levels range from less than 50 ppm to 2000 ppm; our own Australian high temperature creosote contains very much less than 50 ppm BaP. A creosote with BaP levels of 50-1000 ppm is labelled by the EEC in Europe as "harmful but not toxic", and member countries of the Western-European Institute of Wood Preservation are examining the possibilities of producing creosotes below even 50 ppm BaP contents.

Many epidemiological surveys have been carried out on creosote treatment plants and the associated work force. The results have been reviewed in various publications (e.g. 12-16), and it is apparent that creosote does not pose the severe health risks popularly perceived. Indeed the surveys indicate that no workers exposed to creosote have suffered from an increased risk of cancer. Primary concern is clearly the skin irritation, and increased photosensitisation i.e. susceptibility to sunburn from UV exposure; brought about by contact with liquid (and in some individuals, vapour of) creosote. These adverse health effects can be reduced by the use of protective clothing, barrier creams, etc. In addition creosote formulations have been studied in attempts to eliminate the fractions thought to be responsible for the irritancy. Our own PEC (22), an emulsion of high temperature creosote, represents a significant breakthrough in reducing the handling difficulties and health risks associated with creosote and creosote-treated commodities.

The following points summarise some of the environmental and health aspects of using PCP and creosote:

- Commercial grade PCP as used by the preservation industry may be contaminated with the dioxin HxCDD. The more potent dioxin, 2,3,7,8-TCDD is not present in preservative grade PCP.
- Surface deposition of PCP on treated wood can be minimised by the use of cosolvents and influenced by formulation procedure. Protective clothing should be worn when handling PCP treatment solutions, and PCP-treated wood.
- PCP preservatives may be toxic to aquatic organisms and are persistent in the environment, and therefore their use in dip tanks for sapstain control should be carefully controlled.
- The possible chronic toxic affects of prolonged exposure to PCP should be monitored by routine medical checks of plant workers.
- In the most unlikely event that a worker actually ingested PCP preservative, the oral lethal dose (based on animal studies) would be about 50-200 mg/kg body weight.
- Various types of creosote have a number of therapeutic uses, notably as antiseptics, expectorants, and even in tonics. In the latter area creosote is employed in Australia at recommended ingestion levels of up to 33 mg/day. Approximately 5500 times this

level would be a lethal dose!

- There are no validated published epidemiological studies that indicate workers exposed to creosote have suffered from an increased risk of cancer.
- Benzo-α-pyrene is present in Australian creosote at levels which are many times less than the levels found in car exhaust gases.
- Creosote is known to cause skin irritation and increased sensitivity to sunlight in some individuals, and workers handling creosote and creosote-treated commodities should wear protective clothing and/or barrier creams.
- Both creosote and PCP preservatives are highly effective in protecting timber from biodeterioration and weather degradation. Weathered treated wood does not represent a health hazard and free creosote and PCP deposits should not be present on surfaces when the commodities leave the treatment plant.

Improving the environment and public acceptability of both creosote and PCP is essential if these preservatives are to remain as options for the future. The recent developments in emulsions and water dispersions (e.g. 22,23,24) have led to substantially improved characteristics from the health and safety points of view for timber treated with creosote- and PCP-based preservatives.

3. Other preservative chemicals

This catch-all section is not intended to be exhaustive, but provides comment on environmental aspects of some of the more widely used chemicals employed by today's preservation industry.

a) Tributyltin oxide (TBTO)

TBTO is used mainly in light organic solvent preservatives for the treatment of joinery, and other above-ground timber. It is also a major active ingredient in occasional water-based preparations, e.g. Permapruf T.

There have been a number of reviews dealing with health and safety aspects of TBTO and other organotin compounds used in wood preservation

(e.g. 25,26). Generally speaking, the toxicity of the various organotins is a function of the organic moiety and its degree of substitution, and unlike some of the other triorganotins, e.g. trimethyltin compounds, TBTO is not perceived as a potent health hazard. However, in direct contact with the skin, it may give rise to adverse reactions. TBTO can be absorbed through the skin from liquid contact producing the risk of gastrointestinal upset. As a poison, TBTO is about as toxic as PCP, i.e. a lethal dose would be about 14 g for the average 73 kg person. The vapour toxicity of TBTO and other tributyltin wood preservatives is negligible, while recent studies (24) indicate that TBTO is neither carcinogenic nor mutagenic.

In summary:-

- Direct skin contact with liquid TBTO should be avoided, and it may be advisable to wear gloves in handling fresh TBTO-treated timber.
- TBTO-treated timber in service, particularly around the home does not present a health hazard.

b) Copper naphthenate

Copper naphthenate is employed in light organic solvent preservatives mostly for application to above-ground timbers. In addition, some ground contact commodities particularly overseas are treated with copper naphthenate in heavier oil preparations. The preservative is used extensively in "preservative-in-a-can" formulations and sold to the D-I-Y market. Copper naphthenate is also used in Australia for industrial remedial preservation. It is primarily a fungicide with little to no insecticidal properties.

Copper naphthenate as used in wood preservation is non-toxic, for all practical purposes; based on rat oral toxicities, a lethal dose would be about 420 g, or twice as much as the figure for common salt! Copper naphthenate has not been shown to be carcinogenic or mutagenic.

To summarise:-

- Copper naphthenate is a non-toxic wood preservative.
- Timber treated with copper naphthenate does not require special handling precautions and is not a health hazard.

c. Boron and fluoroborates

A range of preservatives containing these chemicals is employed by the world's preservation industry. In Australia, as in many other countries, the boron-based formulations are dominant. They are used primarily against insects, but preparations containing both borates and fluorides are also fungicidal. Most of the products are used in simple treatment processes and many for *in situ* remedial treatments, as liquids, pastes, or solids.

There are relatively minor differences in the toxicity of the various B- and F-B- containing preservatives. Studies with rats have indicated that borax ($Na_2B_4O_7$) has a lower oral toxicity (5 g/kg) than boric acid (H_3BO_3 - 3 g/kg) which in turn is slightly less toxic than the commercial preparation, Timbor ($Na_2B_8O_{13}.4H_2O$) at 2 g/kg body weight. Fused boron in the form of Impel rods lies somewhere between Timbor and boric acid at 2.5 g/kg, while preparations of boron in glycol such as Boracol 10 (15 g/kg) or Boracol 40 (6 g/kg) are even less hazardous than borax. Clearly these boron-based preservatives would not be considered toxic in a poisonous sense. There are indications that some preparations of boron may cause irritations to the eyes and mucous membrane. In terms of the treated wood, however, no special handling precautions are necessary.

Some preservatives containing fluoroborates are available in Australia, e.g. Blue 7 an alkaline CuFB mixture, Basilit BFB an aidic CuFB, Formula 7 a preparation of boron, fluoride, chromium and arsenic. In the latter case, the elements Cr and As would need to be considered in toxicity assessments, and in use Formula 7 represents a severe skin hazard since it is applied by dipping and then block-stacking the chemically-wet timber. Clearly, special handling precautions are necessary.

The F-B complex in Blue 7 and Basilit BFB is somewhat more toxic - as shown by animal experiments - than the B component alone; the LD50 in rats for a Blue 7 gel containing 70% active ingredients ranges from 0.5 to 1.0 g/kg. Extrapolated to humans, these figures do not indicate a substantial health risk and Blue 7 is not scheduled as a poison by the Department of Primary Industry Technical Committee on Agricultural Chemicals. However, since Blue 7 contains fluorine and is formulated with ammonia to assist its solubility and diffusion characteristics, care must be taken in handling the chemical.

In summary:-

- Boron-based wood preservatives are relatively non-toxic to humans, with the various preparations requiring from 140 g to >1000 g to act as a poison.
- Timber treated with boron-based preservatives requires no special handling precautions although it is recommended that gloves be worn when handling wet freshly-treated timber. In the case of multisalt diffusion preparations in which chromium, arsenic and fluorine are present in addition to boron, e.g. Formula 7, more stringent handling precautions are necessary.
- Fluoroborates are more toxic than borates alone, but the dry treated timber requires no special handling precautions.
- Blue 7 preservative is not a scheduled poison, as judged by the Federal Department of Primary Industry. Precautions should be taken in handling the chemical to avoid excessive exposure to the ammonia present in the preservative.

d) Organochlorine insecticides

A great deal of information has been produced about the health hazards and environmental risks associated with these insecticides. The specific chemicals used by the preservation industry to fortify preservatives particularly for termite control include, aldrin, dieldrin, chlordane and heptachlor. The first two are generally preferred in formulation work - the latter more for remedial application or soil treatments.

It is not proposed to present here a detailed appraisal of the various data on organochlorine insecticides. They have well known effects on health, their toxicity varying with formulation. In general terms dieldrin is more toxic than aldrin which is more toxic than chlordane, while heptachlor is the least toxic of the four. They all may be absorbed thorugh the skin and affect the central nervous system. Headaches, dizziness and nausea may result in the short term. Chronic exposure causes liver and kidney damage. The International Agency for Research in Cancer has concluded that there is too little evidence to suggest that dieldrin, aldrin, chlordane or heptachlor are carcinogenic (27). Clearly the handling risks and long-term pollution problems associated with these insecticides probably outweighs their undoubted benefits to the preservation industry.

In summary:-

- Organochlorine insecticides represent a health risk in wood preservation operations.
- Dieldrin, aldrin, chlordane and heptachlor in formulated preservatives used to impregnate building timbers will remain substantially in the wood.
- Particular care should be taken when handling freshly-treated wood containing organochlorines, and when working with the commodities which have been impregnated with them. Especially avoid inhaling quantities of treated wood dust.

The preservation industry is gradually phasing out the use of organochlorine insecticides. In a number of countries they have already been banned or restricted, either entirely or for selected treatment operations, e.g. remedial application to roof timbers in the UK in order to eliminate insect infestations; treatment of the solid wood components of cargo containers for shipment to and use in Australia. Their replacements, even the organophosphates, are more acceptable. Synthetic pyrethroids, though questioned in their early versions, are now environmentally attractive options which the preservation industry is rapidly adopting.

THE TREATMENT OPERATIONS

Concern about this aspect of the preservation industry has tended to be aimed at minimising environmental contamination - pollution by spills, run-off water, plant accidents, etc. The subject has been reviewed by a number of people (28,29,30). Less attention has been given to actual plant design and operation as a function of environmental safety, although CSIRO and individual State forestry departments have provided advice to would-be treaters.

The industry overall has not been active in guidance to its members on the establishment of treatment plants; of course individual companies implement their own design criteria for building new plants. In Australia, the publication last year by the Standards Association (SAA) of a "Timber Preservation Safety Code" was the first attempt at setting down national guidelines on plant design and plant operation (31). Previous to this, the Environment Protection Authority of Victoria (EPAV) had published its own

guidelines for CCA preservative plants (32). In the forward to their document, the Authority recognised that "although the industry had a satisfactory worker safety record there was a general need to pay more attention to pollution control". It went on to say that pollution problems were a result of inadequate attention to plant design and operation, as well as poor housekeeping.

The SAA Code (31) is aimed at "improving the occupational health and safety of plant personnel and controlling environmental contamination around and downstream of timber preservation plants by drawing attention to siting, design and layout procedures." The Code is intended to minimise the dispersion to the environment of the treatment chemicals and to reduce worker risks in handling both the preservatives and the freshly-treated wood. It sets out critical aspects of plant details which may result in unsatisfactory operations, such as formulation preparation, usage and storage and procedures for processing the treated timber; the requirements of bunding, drip pads, roofing and drainage are given particular attention. In addition to these guidelines, the SAA Code lists the various State and Territory Regulatory Authorities who may have some involvement in aspects of timber preservation, including the disposal of all types of plant wastes. Spillage is dealt with in this latter section of the Code, with cross reference where appropriate to the SAA cards on emergency procedures (AS 1678) and safe storage and handling (AS 2508).

The SAA Code and the EPAV guidelines are excellent documents having beneficial effects upon the preservation industry's operations (where necessary, of course). However, health and safety aspects associated with the chemicals and the treated wood are not dealt with in the documents. It was intended that the SAA Code would contain a third part dealing with such matters, and Part 3 was duly prepared. At the same time a similar document was being drafted by a sub-committee of the National Labour Consultative Council (NLCC), of the Committee on Occupational Safety and Health. This NLCC document contained some identical information to the SAA Code Part 3 draft, although the input was heavily biased towards some entrenched perceptions. A politically-based decision was taken late in 1985 that the SAA should not publish Part 3 of its Code; the National Occupational Health & Safety Commission took over the NLCC document and the responsibility of publishing it. At present there are no readily available, clear guidelines in Australia, which deal on a national basis

with the preservation industry's chemicals and chemically-treated wood. Other countries have prepared such documents, with the input of all concerned, including the industry and Government advisors as well as the unions.

The major risk of environmental contamination by the preservation industry's treatment processes can be significantly reduced if the following summarised points are considered:-

- Site location and details of soil types. In particular, proximity to watercourses, etc., potential for flooding, and permeability of the soil should be checked.
- The plant should be able to cope with leakage/spills of its total volume of treatment chemicals, such that full containment of the liquid is provided for without any quantity of liquid escaping into drains, watercourses, etc.
- The treatment plant - vessels, pumps, pipework, all tanks, and treated timber drip areas - should be bunded, and preferably roofed. There should be drainage under this area to an appropriate collecting sump.
- All plant equipment should be safe and serviceable with safety devices fitted where appropriate.
- Standard worker hygiene should be enforced, e.g. separate eating areas, instructions for hand washing, separate toilet facilities, provision of emergency showers, etc. In addition the use of protective clothing and footwear should be mandatory.
- Personnel should be instructed in the safe and efficient operation of their plant, and be made safety conscious. In addition medical monitoring should be carried out at regular intervals.
- The overall site should have adequate security to prevent deliberate acts of vandalism, sabotage, etc. Storage of treated timber should be such that it cannot give rise to contamination of soil and to water courses.
- Treated timber should not be removed from the site, nor sold to the public in such a state that treatment chemicals are either still wet, present in excessive quantities, or else representing some other hazard on the wood's surfaces; in the case of CCA the freshly-treated timber should be held for c. 3 weeks before removal and PEC until the surface wetness has dried as a result of

emulsion break.

- Disposal of waste chemicals, contaminated wood wastes, etc. should be undertaken in accordance with the requirements of local Regulatory Authorities.

Today's preservation industry is, for the most part, conscious of the need to improve its operations. Many members already are giving attention to the above points - and some not listed above, including detailed equipment assessments. There are operators, however, who consistently ignore the more obvious environmental requirements of their procedures: watercourses are still being polluted; waste chemicals are still being dumped; dripping wet treated timber is still finding its way onto the job site. These problems must be addressed and remedied.

CONCLUDING REMARKS

The wood preservation industry uses a broad range of chemicals to treat various timber commodities; clearly the selection of the most appropriate chemical is a function of the end use requirements. From the health and safety point of view for example, neither PCP nor creosote would be employed to treat timber used in food containers.

Chemically treated wood is a common, and often essential, feature of our environment. The benefits conferred by the preservatives far outweigh the risks. Indeed very little treated wood - as opposed to the raw, unreacted chemicals - represents a hazard to the public or the environment. Unfortunately, there is a clear lack of public understanding on these matters, and the industry must promote a consumer awareness programme. In its final determination on the RPAR proceedings, the US EPA specifically directed the industry to adopt such a programme (19). Complacency on environmental matters must be eliminated from the industry's approach to its' markets; plant hygiene, plant safety, and general level of plant housekeeping must meet the requirements of codes of good practice. A quality assurance scheme would attend to this and guarantee that the public gets a well-treated, safe-to-use product.

The future of the wood preservation industry is assured for as long as forest products are an integral part of both the urban and rural sectors. An investment in developing safe chemicals and processes will continue to support the industry's position in a world increasingly conscious of its

environment. In this regard, the future may see the development of preservatives with reduced biological toxicity but increased environmental acceptability - a theme espoused at the last Forest Products Research Conference (33).

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RECENT ADVANCES IN OIL-BASED PRESERVATIVE EMULSIONS IN AUSTRALIA

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ABSTRACT

The development and commercialisation of Pigment Emulsified Creosote (PEC) is reviewed. Some details relevant to the development of modified PEC formulations, including the addition of biocides, are also discussed. In addition the latest development of a petroleum oil/CCA emulsion (Protan) is presented.

INTRODUCTION

Conventional creosote is used in large quantities all around the world as a heavy duty wood preservative. It is claimed by some to be a health hazard, although extensive studies and surveys have not provided positive human evidence of this (e.g. 1,2,3). On the other hand, creosote-treated commodities undoubtedly can present handling problems; oily surfaces, tar-like deposits - referred to as 'crud' - and vapour emissions can cause skin sensitization (4) in some people which may lead to sunburn.

In order to reduce and possibly eliminate the handling problem we have developed creosote-based pigment stabilized emulsion formulations in which the oil is 'locked' into the treated wood. These novel and unique preservative emulsions belong to a family of formulations which are referred to as Pigment Emulsified Creosote (PEC) (5,6). Anionic PEC containing finely pre-dispersed, coated titanium dioxide pigment is now available commercially and is being utilized in vacuum pressure impregnation of hardwood commodities such as poles, marine piles and railway sleepers.

Recent research effort has concentrated on the development of a creosote-free petroleum oil-based preservative emulsion containing copper-chromium-arsenic (CCA) in the aqueous phase. Such an emulsion could conceivably provide treated products with good dimensional stability in-service and commodities exhibiting softer surfaces compared to that of

straight CCA treatment.

DEVELOPMENT AND COMMERCIALISATION OF THE 'SUPER-STABLE' ANIONIC PEC

The first creosote emulsion, Pigmented Emulsified Coloured Creosote (PECC) was developed and patented by Watkins (7) of Koppers Australia Pty. Ltd. (KAP) in 1977. It was an anionic oil-in-water emulsion consisting of High Temperature Creosote (HTC), pre-dispersed micronised pigment of up to 7%, emulsifiers, stabilisers and water. Two hundred full-sized hardwood poles were successfully pressure treated with PECC for the State Electricity Commission of Victoria (SECV). The surface quality of the treated poles was excellent and as a result PECC was manufactured in larger quantities for a commercial treatment run of 3000 SECV hardwood poles. However, PECC proved to be unstable during the treatment process; the concentration of pigment in the 'emulsion' increased after each charge causing retention and penetration problems. The treatment runs were terminated after some thirteen charges.

It was obvious that a super-stable emulsion was required to withstand the rigours of hostile treatment and environmental conditions when used repeatedly. CSIRO, KAP and the SECV conducted further research and development for "the stable" formulation. Factors that influence the stability and fineness of the emulsion were thoroughly investigated - globule/pigment particle sizes, distribution and surface charges; density differences between the continuous and dispersed phases; surface and interfacial tension; rheological nature and behaviour of the two phases, especially after the addition of emulsifiers, etc.; optimum ratio of both phases in the emulsion; distribution of the pigment within the two phases and at the interface; and the effect of pH. Numerous types of emulsifiers, surfactants, stabilizers and rheological structuring agents were tested for effect, interaction and compatibility within the emulsion systems. The methods and equipment used in processing of the emulsion, and order of addition and reaction duration of each component were found to be critical. The resultant formulations were tested for their stability against heating and during freeze/thaw cycles. In addition the effect on emulsion stability of wood extractives from green timber was also assessed.

A successful formulation must remain stable and retain its microscopic

integrity as determined by light microscopy. Furthermore, the emulsion must exhibit ultra stability during extended use, and when subjected to repeated temperature, pressure, vacuum cycles, shearing forces and contamination introduced into the treatment system (e.g. bark, extractives, clay, etc.). Such an emulsion must act as a hybrid one phase material.

After carrying out the above investigations, radical changes to the original PECC formulation were found necessary in order to improve the manufacturing process and treatment plant regime stability. This led to the development and patenting (5) of the 'super-stable' emulsified creosote called Pigment Emulsified Creosote (PEC).

PEC is prepared by simultaneously bringing together and emulsifying the prepared aqueous and oil phases under conditions of ultra high shear. The formulation is manufactured as an oil-in-water emulsion. This phase configuration will achieve very fine initial globule size and homogeneity, and its apparent viscosity will be high due to the ratio of creosote to water (nominally 65% creosote and 30% water). The emulsion is inverted to water-in-oil prior to its use in the treatment plant. This inverted emulsion is much less viscous but the globule sizes (water phase) remain the same as the oil-in-water emulsion. The pigment particles (less than 1 μm) remain homogeneously distributed throughout the emulsion.

The early extensive laboratory, pilot plant and semi-commercial trials of PEC were presented at the previous Forest Products Research Conference (8). PEC formulated with micronised pre-dispersed brown ferric oxide or coated white titanium dioxide pigment was found to exhibit the desired stability, as assessed before and after each treatment charge by analysis of its water content, surface tension, density, pigment level, pH, microscopic structure, viscosity and rheological behaviour over many shear rates/temperatures. The surfaces of PEC-treated samples and commodities are dry and more attractive with minimum or no 'crudding' when compared with HTC treatment. Retentions and penetrations of PEC in treated wood are in the main as specified.

The survey of 157 commercially PEC-treated poles in-service has clearly indicated the much improved surfaces of these poles over the HTC-treated poles (9). Evidence for the pigment's vital role in 'locking' the creosote component of the emulsion inside the wood structure has been obtained firstly by Murray and Brinkies (10) of SECV. Specimens treated with PECC

were carbonised to remove creosote from the cells but leave the pigment in position. Back-scattered electron imaging, X-ray mapping and energy dispersive X-ray microanalysis revealed that the pigment is dispersed upon treatment within the wood cells, coating the lumina. Further studies carried out by Sydney University on PEC-treated samples using scanning transmission electron microscopy (STEM) and X-ray microanalysis also revealed iron pigment particles coating cell lumina (11). Iron in a form too small to be seen as discrete particles has been identified inside the cell wall.

The general specifications for the commercially available PEC with white pigment are as follows:-

	% m/m
High Temperature Creosote	64 ± 2
Softened water	27 ± 2
Pre-dispersed pigment	min. 4
Surfactants/structuring agents/stabilisers	4.4
pH value	9-11
Denisty at 20°C	min. 1.08
Typical apparent viscosity at 50°C, $210S^{-1}$	11-21 mPa.s
Surface tensions at 20°C	<35 mN/M

Globule size:-	Size range (μm)	Mean distribution (%)
	<10	>70
	11-24	<20
	25-49	<5

To date some 1500 tonnes of PEC have been processed at two manufacturing plants and more than 14,000 poles and marine piles have been treated in four plants. In addition to national interest, PEC is being closely scrutinised in a number of overseas countries, including Sweden, New Zealand, parts of S.E. Asia, South Africa, France, Japan, USA, South America and UK. (Patent protection has been sought on a very wide basis). PEC treated indigenous species timber samples are under test in

Scandinavia and in Malaysia. Indonesia has purchased some 200 tonnes of PEC for sleeper treatment.

Our studies on the treatment of softwoods using PEC have been less successful than the hardwood treatments. Although adequate retention and penetration of PEC can be achieved in radiata pine specimens, the surface quality of the treated timber is generally below our expectations.

DEVELOPMENT OF A CATIONIC PEC (PECAT) AND ITS COMMERCIAL TRIAL

The cool and wet climate in southern Victoria, especially during winter, necessitates a drying period of at least three months for anionic PEC-treated poles, prior to handling by SECV staff. Since the commercialisation of PEC in northern NSW, we have noted that the treated poles dry much faster than those in Victoria. Instead of taking more than three months the poles are generally dry and safe to handle in a matter of weeks. So, the prevailing weather conditions markedly influence the rate of emulsion break and hence shorten the drying period.

In theory, a cationic emulsion coming in contact with a negatively charged substrate such as wood, should break electro-chemically. Subsequent surface drying may thus be accelerated. This theory led to the development and testing of a cationic PEC (PECAT) formulation. PECAT was formulated with a nominal 30% water phase and 5% predispersed titanium dioxide pigment. After the formulation had passed the heating and freeze/thaw tests, a 400 L batch was manufactured in the pilot plant. Twenty treatment charges of hardwood pole stubs and sawn timber were carried out with PECAT using Bethell and Lowry schedules. The retention results are summarised in Table 1.

TABLE 1
Summary of PECAT retentions obtained in CSIRO pilot plant trials

Commodity	Botanical name	Treatment schedule	Retentions (kg/m^3)[1]	
			Mean	Range
Blackbutt stubs	*E. pilularis*	L	318	302-334
Grey box stubs	*E. microcarpa*	L	258	227-305
Red ironbark stubs	*E. sideroxylon*	B	206	186-226
Spotted gum stubs	*E. maculata*	B	237	179-405
White stringybark stubs	*E. eugenioides*	L	316	272-367
Sawn hardwood boards	*E. obliqua/regnans*	L	145	72-264

B = Bethell; L = Lowry.
[1] Sapwood volume in the stubs; total volume in the sawn boards

The pole stubs accepted adequate formulation, while the sawn hardwood samples, with varying heartwood content, produced rather variable figures. The PECAT emulsion was used as a water-in-oil emulsion which exhibited excellent physical characteristics throughout the work but which tended to deposit on the surface of the timber. This mayonnaise-like deposit, however, dried within about three weeks on the pole stubs, to provide oil-free surfaces. The colour during this time changed from drab-olive to a cinnamon-brown if the treated wood was placed outdoors; indoors the same dry oil-free surfaces were produced but the wood colour remained drab-olive. Of the four packs of sawn hardwood, only two lost their mayonnaise-like PECAT deposits, while in the other two packs the emulsion remained wet between the timber samples. Breaking the packs and drying each piece of timber separately produced excellent surfaces.

An aborted commercial trial of PECAT proceeded from the CSIRO pilot plant runs, with KAP manufacturing some 60,000 L at their Thornton, New South Wales plant. The treatment of poles and a small number of sleepers appeared to proceed satisfactorily. However, it was noticed that there was gradual build up of pigment-concentrated emulsion on the end grain of the roundwood and between the surfaces of the sawnwood such that specified retentions became difficult to achieve. Apparently the highly charged pigment particles were attracted to any exposed areas of the longitudinal wood elements which carried a negative charge. This resulted in a reduction of emulsion uptake.

The PECAT trials led to the observation that in cationic formulations, the iso-electric point of the pigment particles is critical to emulsion performance in the treatment regime.

PEC + ADDITIVES, INCLUDING PECCA AND PECBUS

The addition of phase-specific biocides to PEC theoretically permits the production of emulsions with reduced HTC levels and which still retain overall preservative performance. One of the biocides incorporated into PEC was aqueous copper-chromium-arsenic (CCA). When HTC comes into direct contact with CCA solution, both will react chemically and exothermically to produce tar-like material. In order to successfully formulate such a polar active emulsion, a complex emulsifier/surfactant system was developed to inhibit chemically this antagonistic oxidation-reduction reaction.

Five litre batches of PEC + additive formulations, with the biocides incorporated into either the oil or water phase have been produced. 2-(thiocyanomethyl)thiobenzothiazole (TCMTB); Boracol 40; copper ethanolamine nonanoate (CEN); Quatramine 80; arsenic trioxide; Troysan Polyphase; and CCA (Tanalith C) were the biocides investigated. It is interesting to note that arsenic trioxide will not dissolve in either HTC or water, but readily dissolves into PEC. HTC was diluted with toluene prior to its use for treatments where low retentions of HTC were required in bioassay tests. In this way the low creosote retentions can be achieved in the treated specimens without sacrificing distribution.

A series of small stakes which were cut from two ash-type eucalypt trees were treated with the formulations and biologically assessed by soil-jar tests and Accelerated Field Simulator (AFS) testing. The results to date are summarised in Tables 2 and 3 respectively. The results, which have been presented elsewhere (12), indicated that relatively small amounts of selected biocides could be formulated with HTC to provide preservative capacity. Table 3 presents the most recent scores from the AFS tests of PEC + additive formulations, together with the results of earlier inspections. In interpreting the data, it should be remembered that the batches of PEC 30 used contained only 65% HTC, so that the highest loading of creosote obtained in the PEC + additives-treated blocks was 78 kg/m^3. This figure appears to be close to the toxic threshold for HTC (see Table 2), and the addition of biocides at this point should provide protection. This is proving to be the case with all additives particularly at the highest retention levels. Continued exposure in the AFS, which after 12 months produced significant decay in the controls, will of course provide more valuable data.

TABLE 2
Mean mass loss data from various decay tests of PEC emulsions and two conventional creosotes

Preservative	Nominal retention (kg/m^3)		Fungal species		
	Emulsion	Whole creosote	*Fomes lividus*	*Pycnoporus coccineus*	*Lentinus lepideus*
PECC	192	160	0.21	0.04	NT
	115	96	0.18	0.24	1.42
	77	64	3.61	0.66	1.32
	38	32	25.61	1.87	2.35
PEC	120	78	4.28	2.71	NT
	60	39	11.26	3.61	NT
	30	20	24.34	12.29	NT
HTC		160	1.67	0.00	NT
		120	2.12	1.98	NT
		96	1.13	0.02	1.12
		60	5.37	1.25	2.24
		30	17.10	1.62	3.80
K55 (low temp. creosote)		160	4.18	0.38	NT
		96	12.07	3.64	NT
		64	21.56	11.91	NT
		32	33.06	23.21	NT

NT = Not tested

TABLE 3
AFS scores of stakes treated with PEC plus biocidal additives

Formulation	Nominal Retⁿ (kg/m³)	Scores[1] 6 mo	12 mo	18 mo	24 mo
PEC[2] alone	120	4	4	3.83	3.67
	60	3.92	3.83	3.75	3.50
	30	3.75	3.58	2.92	2.50
HTC alone	120	4	4	3.83	3.75
	60	4	4	4	3.92
	30	3.92	3.67	3.58	3.42
PEC + TCMTB	120 + 0.30	4	4	3.83	3.75
	60 + 0.15	3.92	3.83	3.75	3.50
	30 + 0.07	3.83	3.67	3.42	2.92
PEC + Boracol	120 + 1.00	4	4	3.83	3.75
	60 + 0.50	4	3.92	3.83	3.67
	30 + 0.25	3.75	3.58	3.33	2.08
PEC + CEN (as copper)	120 + 0.30	4	4	4	4
	60 + 0.15	4	4	3.92	3.75
	30 + 0.07	3.58	3.42	2.92	1.83
PEC + Quatramine 80	120 + 1.00	4	4	4	4
	60 + 0.50	3.92	3.83	3.83	3.58
	30 + 0.25	3.92	3.58	3.50	3.08
PEC + As_2O_3	120 + 2.90	4	4	4	4
	60 + 1.45	3.92	3.92	3.92	3.83
	30 + 0.73	3.92	3.75	3.50	3.08
PEC + Polyphase	120 + 1.00	4	3.92	3.92	3.92
	60 + 0.50	3.83	3.92	3.75	3.58
	30 + 0.25	3.75	3.67	3.50	2.75
PEC + Tanalith C	120 + 4.00	3.92	3.92	3.92	3.83
	60 + 2.00	4	3.92	3.83	3.75
	30 + 1.00	3.92	3.92	3.75	3.50
Toluene controls		3.29	2.67	1.88	0.83
Water controls		2.81	2.00	0	-

[1] Mean of 6 replicates; 0 = destroyed, 4 = sound

[2] All PEC formulations contained 65% HTC, therefore 120 kg/m³ PEC ≡ 78 kg/m³ HTC, 60 kg/m³ ≡ 39 kg/m³ HTC, and 30 kg/m³ ≡ 19.5 kg/m³ HTC.

The encouraging results obtained from the PEC/additives work led to pilot-plant testing of 400 L quantities of the anionic PEC + TCMTB (referred to as PECBUS) and the cationic PEC + Tanalith C (referred to as PECCA). SECV pole stubs, 1.4 m long x 200-300 mm diameters were used in the treatment trials, which served to indicate how relatively large quantities of PEC/additives emulsions would behave during treatment cycling, as well as the quality of pole surfaces treated with them. Ten stubs of Victorian ash-type euclaypts were used together with ten stubs of the much denser red ironbark (*E. sideroxylon*). The PECCA formulation was also used to treat 36 radiata pine posts which measured 1 m x 100 mm diameter (nominal). In order to stress the emulsions in a practical manner a number of treatment schedules were used: Bethell, with 30 minute vacuums of -85 kPa and a 150 minutes pressure cycle of 1380 kPa; and a number of Lowry schedules employing different length pressure cycles at 1380 kPa, and a final vacuum of 30 or 60 minutes at -85 kPa. The range of retentions obtained during this pilot-plant run were as follows (hardwoods, sapwood volume; softwoods, total volume): ash-type eucalypt stubs 237-548 kg/m^3 PECCA and 312-468 kg/m^3 PECBUS; red ironbark stubs 240-373 kg/m^3 PECCA and 234-433 kg/m^3 PECBUS; radiata pine posts 124-383 kg/m^3 PECCA (PECBUS was not used with the posts). The CCA and TCMTB retentions can be calculated from the formulation contents (PECCA - 13% CCA, PECBUS - 0.3% TCMTB). The HTC content in the emulsions was down to 20% and therefore the creosote would function mainly against the weather rather than biodeteriogens (although some synergistic action might occur). Surface quality in the hardwoods was good - PECCA, with an initial mayonnaise-like deposit of emulsion on the stub surfaces drying to a hard, dry shiny finish, while the PECBUS emulsion dried to a thin layer leaving a yellowish colour which soon weathered to the appearance of the natural untreated timber. The PECCA emulsion did not produce good dry surfaces in the pine posts, which we believe to be due to a number of reasons, including surface charge phenomena. This aspect is being studied further, particularly in terms of the zeta potential of the emulsion droplets and the type of charge (positive or negative) on the pigment particles.

RESEARCH AND DEVELOPMENT OF A PETROLEUM OIL-BASED CCA EMULSION (PROTAN)

CCA-treated softwood commodities generally give excellent biological

field performance. However, weathering can cause severe checks/splits to develop and the wood may be embrittled by the preservative. Incorporating oil to produce an emulsion with CCA would provide the treated timber with better dimensional stability and general weather resistance. Treating CCA-treated timber with oil in a second vacuum pressure cycle would not achieve the same longlasting effect, and cell walls would not be 'bulked' against dimensional change brought about by water ingress and egress during weathering.

Numerous attempts failed to develop a PEC formulation, using HTC as the oil, which would not only result in adequately treated radiata pine posts, but also produce attractive surface finishes immediately after treatment and consequently upon weathering. Our next approach was to use a well defined petroleum oil instead of creosote. A very stable and extremely fine emulsion was developed and named Protan (13). Initially, 'creaming' of the emulsion was a problem.

The extremely reactive nature of copper, chromium and arsenic compounds, especially the chromium (Cr), have largely been overcome. However, it was observed that the inside walls of the glass jars containing Protan and exposed to the sun's radiation were rapidly and tenaciously coated with a greenish compound. X-ray microanalysis in the scanning electron microscope revealed that the compound contained mainly Cr. It would appear that at least some of the Cr present in the emulsion has been reduced from its original valency state of 6 to 3 based upon the greenish colour of the compound.

At this stage of Protan development no pigment is used. The emulsion consists of nominally 35% oil phase and 65% water phase. The CCA concentration can vary between 2% and 10% based upon total emulsion.

Protan emulsion and a petroleum oil emulsion without CCA were used to treat four sets of radiata pine posts; end-matched controls were also treated with the petroleum oil, and with straight CCA solution. The retention results are shown in Table 4. The Protan treated samples were covered with a thick layer of mayonnaise-like emulsion. The post treatment mass of each post was determined, for retention calculation, after removal of this excess emulsion. The results in Table 4 clearly indicate that posts treated with Protan have achieved the lowest retention with each matched set of specimens. The penetration of copper, determined by Chromazurol S indicator, in Protan treated samples was not satisfactory with patchy distribution.

TABLE 4
Retentions* achieved in radiata pine posts using base liquids and their emulsions

Sample**	A petroleum oil	A petroleum oil emulsion	Protan emulsion	CCA solution
1	271	407	95	496
2	509	476	272	671
3	302	443	123	671
4	401	527	263	700

* (kg/m^3) based upon total volume of the specimen

** Each post was 0.9 m long and end matched for the four types of treatments.

The results prompted a close investigation of the complex interaction and electro-chemical effect of the CCA itself, its individual components, and their interaction with the surfactants, emulsifiers and structuring agents used in the emulsion system. Surface tension, rheological behaviour, viscosity versus temperature, pH and density differences between the oil and CCA solutions were also studied. The size and distribution of the oil globules together with the charges on the droplets were measured using a light microscope and a Zeta meter. In addition, the interaction of the emulsion with the wood substrate was also investigated.

The early results of the above studies have been most encouraging from the point of view of surface quality. A modified Protan emulsion has produced excellent surface characteristics on pine rounds - and also on a limited sample of hardwood - but variable retentions and penetration. The retention in the softwoods have ranged from 220 to 380 kg/m^3 Protan which provides CCA loadings of 8.5 to 15.0 kg/m^3. The trend of decreased uptakes with continued use of the modified Protan is continuing to receive attention. It is hoped that Protan represents a significant new approach to the treatment of softwoods and that it can be discussed in more detail in the near future.

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RESEARCH AND DEVELOPMENT FOR THE PRESERVATION OF PANEL PRODUCTS

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ABSTRACT

Two projects in which CSIRO is collaborating with Australian panel producers are described. In one project, bioassay methods were developed that overcame certain problems encountered when exposing particleboard specimens in small chambers to either decay fungi or subterranean termites. For the second project, the results of laboratory trials to produce a preservative treated plywood by incorporation of biocides either in the glueline, veneer or both are presented.

INTRODUCTION

In 1983 Greaves presented data showing that the world-wide production of wood based panel products was increasing rapidly. Furthermore, he pointed out the overall lack of preservtion for this type of product. Recently CSIRO's research and development in the preservation of panel products has been concentrated in two areas:

(i) new laboratory bioassay methods, and
(ii) evaluation of preservatives applied to the timber, the adhesive, or both.

Our interest in laboratory test methods is not simply academic - methods such as these strongly influence preservative retentions to be used commercially. If the retentions chosen are inappropriately low, the product may be attacked and this may result in loss of consumer confidence. If the loadings are too high, the product although effective may not be competitive in the marketplace. If no attack takes place on the untreated control material, one is uncertain whether it doesn't need preservation or whether the result is an artefact of the test method.

DEVELOPMENT OF BASIDIOMYCETE BIOASSAY METHODS FOR PARTICLEBOARD

The assessment of the fungal degradation of panel products presents the bioassayist with difficulties not generally encountered when assessing solid timber specimens. The problems are largely associated with the slow release of free formaldehyde and uncondensed phenolic compounds which did not polymerize during manufacture of the panel. In small experimental chambers, and in voids in the panel, these compounds can accumulate in concentrations that inhibit fungal activity (Deppe and Gersonde, 1976). Such concentrations are unlikely to be attained in the built environment.

Accelerated weathering will remove much of this free formaldehyde and free phenolic material. However, further microbial activity may liberate the bound formaldehyde into the small bioassay chamber and retard or stop the attack.

Under the sponsorship of the Australian Particleboard Research Institute (APRI) new bioassay methods using both decay fungi and subterranean termites have been developed. These bioassays attempt to simulate the conditions under which biodeterioration of particleboard takes place in the built environment.

For one APRI project, it was necessary to develop a method that would allow rather large specimens (350 x 50 x 20 mm) to be bioassayed for determination of mass loss. The approach taken was as follows:

- Replicate specimens were either leached and then dried or remained unleached, before being sterilized.
- Three leached or three unleached specimens were placed in a decay chamber. Each specimen was placed on a feederstrip colonized by *Serpula lacrymans* (Shum. ex Fr.) S.F. Gray.
- Until this stage the chambers were enclosed in autoclaveable bags. However, once the test specimens were in place, half the replicate chambers were incubated in the autoclaveable bags and half were covered instead with a Goretex® membrane.

The results of the study are shown in Table 1. Whereas the autoclaveable bag allowed gas exchange to take place very slowly, the Goretex® allowed rapid exchange. When the autoclaveable bag was used very little mass loss was recorded even with leached material. However, when the Goretex® membrane was used both leached and unleached particleboard were attacked.

TABLE 1
Per cent mass loss of leached and unleached particleboard exposed to *Serpula lacrymans* for 12 weeks

Specimen Preparation	Chamber Cover	% Mass Loss (SD)
Leached	Autoclaveable bag	0.8 (0.2)
Not leached	Autoclaveable bag	-0.2 (0.8)
Leached	Goretex® membrane	12.6 (3.1)
Not leached	Goretex® membrane	8.9 (1.9)

The use of the membrane offers significant advantages. As the specimens do not have to be leached before the bioassay begins, preparation time is significantly shortened. Also, the panel specimens to be assessed undergo a minimum of mechanical and chemical degradation prior to evaluation. However, the most important benefit to the bioassayist, is that he has the option to work with greater volumes of particleboard and still expect to get significant attack by fungi causing white and brown rot.

DEVELOPMENT OF SUBTERRANEAN TERMITE BIOASSAYS FOR PARTICLEBOARD

The effect on termite activity of low atmospheric concentrations of formaldehyde and phenolic compounds from adhesives are not documented. However, particleboard is likely to be drier when attacked by termites in the built enviornment than when exposed in other commonly used bioassays. Therefore, the new bioassays provide adequate ventilation to reduce both the moisture content of the specimens and the concentration of any gases that may reduce or prevent termite attack.

In the bioassays developed for APRI, the timber specimens were exposed in a feeding chamber separated from the basal chamber where the termites were maintained. The feeding chamber had much greater ventilation than is provided in conventional bioassays. The chambers were linked together so the termites could move freely from one to the other. However, the linkage was sufficiently constricted that they could close off this passageway.

Two new bioassays were developed for *Coptotermes acinaciformis* (Froggatt) and two for *Mastotermes darwiniensis* Froggatt (see Figures 1 and 2). Results from these assays were compared with those derived from a modification of the commonly used Australian technique of Gay *et al.* (1955).

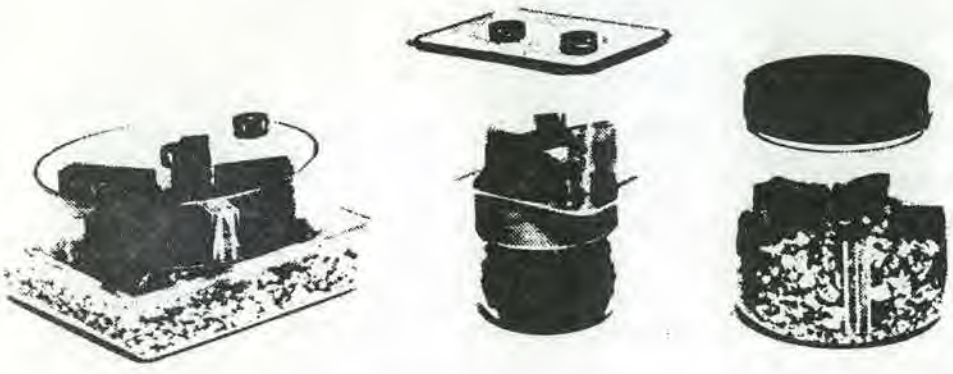

Figure 1. Bioassay types used for the assessment of five timber flooring products with M. darwiniensis (left to right: bioassay type M/a,M/b,M/c).

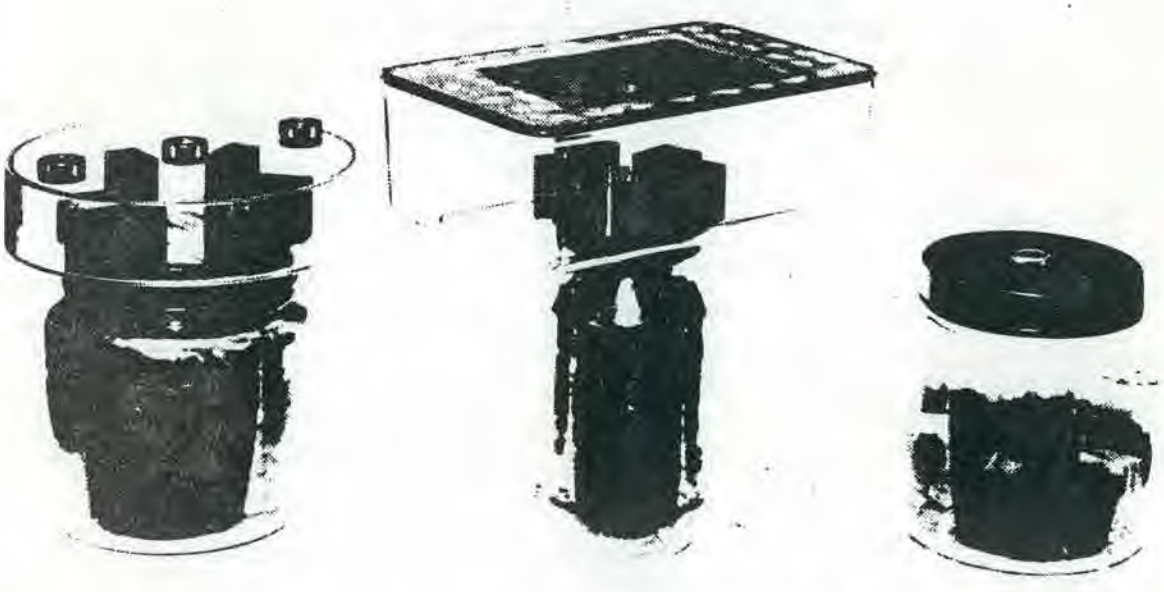

Figure 2. Bioassay types used for the assessment of five timber flooring products with C. acinaciformis (left to right: bioassay type C/a,C/b,C/c).

In order to evaluate these dual chamber bioassays, samples of five flooring products (heartwood of *Eucalyptus delegatensis* R.T. Bak., *E. pilularis* Sm. and *Pinus radiata* D. Don; *P. radiata* plywood and particleboard) were exposed after vacuum oven drying. The results presented in Table 2 are simply to assist in the evaluation of the bioassays and are not to be used to compare the products. Each of the flooring materials was taken from a single source which may not be representative of the material generally available on the market. Also, the termites were collected from one colony. In order to make generalizations, results from studies using the termites of at least three colonies would be required.

TABLE 2

Mass losses of five timber flooring products after exposure to termites in seven bioassays.

Flooring product	Mean percentage mass loss					S.E.* 1 [of differences]	S.E.** 2	S.E.***
	Heartwood of *E. delegatensis*	Heartwood of *E. pilularis*	*P. radiata*	*Pinus radiata* Plywood	*Pinus radiata* Particleboard			
M. darwiniensis								
M/a	81.0	45.3[a]	24.2	52.5[a]	52.5[a]	4.0	8.1	
M/b	83.2	-0.4	2.3	26.0	14.9	4.3		
M/c	74.6	20.8[b]	16.8[b]	31.3[b]	26.1[b]	2.8	5.2	
C. acinaciformis								
C/a	96.2	23.4	5.9[c]	9.0[c]	2.0[c]	4.1		
C/b	99.5	8.6[d]	23.9	18.9	6.9[d]	2.5	6.3	8.6
C/c	97.4	20.9	19.6	36.4	9.8	2.2	5.3	

*Standard errors of differences in means. These should be used for comparison of data within bioassay types only. The standard errors have been used to assign alphabetical symbols (a to d) to means which are not significantly different from particleboard at the 5% level.

**Where $S.E._2$ is given, it should only be used when comparing *P. radiata* heartwood means with the means of other flooring products.

***$S.E._3$ should only be used to compare *P. radiata* and plywood in bioassay C/b.

One of the dual chamber bioassays (C/a) using *C. acinaciformis* ranked the flooring types, according to amount of attack, similarly to the standard bioassay (C/c). The other dual chamber bioassay (C/b) ranked two flooring types rather differently. The main difference between the bioassays was that the flooring samples exposed in C/b were, at the end of the exposure period, much drier (20 to 26% moisture content) than those in C/a and C/b (31 to 71%).

The two *M. darwiniensis* bioassays in dual chambers (M/a and M/b) gave similar rankings to those derived from the standard method, M/c. However, *M. darwiniensis* had considerable difficulty in attacking under the dry conditions (flooring moisture content was 15 to 20%) offered in the M/b bioassay. This was the only dual chamber bioassay in which the vitality of the termites was reduced during the exposure period.

Three of the new bioassays were successful in the sense that the termites survived and consumed large amounts of wood. However, the results show that care must be taken to choose the appropriate bioassay that will best reflect the conditions under which termite attack takes place outside of the laboratory. From Table 2 it is apparent that the choice of bioassay can affect the results both qualitatively and quantitatively.

PRESERVATION OF PLYWOOD FOR ABOVEGROUND USE

At the last Forest Products Research Conference, a paper was presented by Johnson *et al.* (1984) that discussed the early work on a joint project with the Plywood Association of Australia and Wellcome Australia Ltd. The aim of the project was to preserve plywood from attack by subterranean termites and decay fungi. The preservatives were applied as:

(a) a glueline addition of permethrin* to control termites,
(b) a benzalkonium chloride (BAC) dip of the green veneers to control decay fungi and termites (some replicates of this treatment had permethrin added to the glueline), and as
(c) a BAC plus permethrin dip of green veneers to control decay fungi and termites.

*In this report permethrin refers to permethrin with a cis:trans ratio of 25:75.

The results of recent laboratory trials are presented in Table 3. The following three conclusions can be drawn:

(a) The glueline addition of permethrin failed to control the termites. However, only one veneer thickness (2.5 mm) and one loading were examined.

(b) A loading of between 8 and 12 kg/m^3 of BAC in dry veneers was required in order to prevent greater than 5% mass loss by all decay fungi tested. BAC at 12 kg/m^3 was nearly sufficient on its own to control the termites. Where permethrin was added to the glueline, control was achieved at 4 to 8 kg/m^3 of BAC in dry venner.

(c) A loading of between 8 and 12 kg/m^3 of the BAC plus permethrin formulation applied during dipping of the green veneers achieved control of both termites and decay fungi.

The most appealing approach was considered to be the one step treatment of veneers utilizing both fungicide and insecticide. BAC wasn't sufficiently effective that it could be used by itself, and so had to be fortified with permethrin. To this stage, the laboratory work was carried out with a 10:1 (BAC:permethrin) formulation. As permethrin is the more expensive component and is highly active, it was decided to modify the ratio to 67:1. This decision was based, in part, on other work with permethrin carried out in CSIRO. A target retention of 10 kg/m^3 of formulation was chosen. This formulation will be marketed as Wellply®.

A small trial was proposed to validate the lab-based recommendations. In this trial, which was carried out in early September 1986, green veneers of radiata pine and slash pine (*P. elliottti* Engelm.) were dip treated. Subsequently treated and untreated five-ply panels were manufactured. From each 2400 x 1200 mm panel the following specimens will be prepared:

- specimens for aboveground field exposure at Brisbane and Highett
- specimens for glue bond quality assessment and for chemical analyses
- specimens to be bioassayed.

TABLE 3

Preservative types and retentions required to control termites and decay fungi[1]

Treatment No.	Nominal Treatment Veneer BAC/Permethrin kg/m^3	Glueline Permethrin kg/m^3	Biodeteriogen[2] Termites C.a.	M.d.	C.ℓ.	Fungi G.a.	P.c.	S.ℓ.
1	0/0	0						
2a	1.0/0.1*	0	√		√			
2b	4.0/0.4*	0	√	√	√			
2c	8.0/0.8*	0	√	√	√	√		√
2d	12.0/1.2*	0	√	√	√	√	√	√
3a	1.0/0.1†	0	√ϕ					
3b	4.0/0.4†	0	√	√	√			
3c	8.0/0.8†	0	√	√	√	√		√
3d	12.0/1.2†	0	√	√	√	√	√	√
4a	1.0/0	0						
4b	4.0/0	0						
4c	8.0/0	0	√	√		√		√
4d	12.0/0	0	√	√	√ϕ	√	√	√
5	0/0	0.5*	√ϕ					
6a	1.0/0	0.5*	√		√			√
6b	4.0/0	0.5*	√	√ϕ	√			
6c	8.0/0	0.5*	√	√	√	√		√
6d	12.0/0	0.5*	√	√	√	√	√	√

[1] √ indicates that less than 5% mass loss was sustained
√ϕ indicates the mean was less than 5%, but that the upper 95% confidence limit ≥5%
* Nonionic permethrin formulation) permethrin 25:75
† Cationic permethrin formulation)

[2] C.a. is *Coptotermes acinaciformis*
M.d. is *Mastotermes darwiniensis*
C.ℓ. is *Coptotermes lacteus* (Froggatt)
G.a. is *Gloeophyllum abietinum* (Bull. ex Fr.) Karst.
P.c. is *Pynoporus coccineus* (Fr.) Bond. and Sing.
S.ℓ. is *Serpula lacrymans* (Schum. ex Fr.) S.F. Gray

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THE POTENTIAL FOR THE EXPANDED USE OF TREATED SOFTWOOD POLES

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ABSTRACT

Hardwood forests in Australia have supplied poles for overhead distribution systems and domestic construction for many years. In the near future the supply situation of hardwood timber poles will show a distinct shortfall against demand. The ability of exotic softwood plantations to supply poles to satisfy the predicted shortfall is discussed. In addition, comment is made on the increasing use of CCA treated softwood poles in pole frame construction.

INTRODUCTION

In Australia the native hardwood forests have been the traditional source for timber poles required for overhead reticulation of power and telecommunication. In the last decade the demand for small size telecommunication poles has disappeared. However, the current and future demand for poles in overhead power distribution indicates a critical supply situation from native hardwood forests. The shortfall in pole availability could be met by using treated softwood poles taken from the extensive exotic pine plantations which are now reaching maturity in Australia.

This paper reviews the current and future supply of hardwood poles and the potential for the expanded use of treated softwood poles to make up the expected shortfall. In addition comment is made on the increasing use of copper-chrome-arsenic (CCA) treated softwood poles in pole frame construction.

POWER TRANSMISSION POLES

Historically, the major source of power transmission poles in Australia has been from Eucalyptus spp. Initially the eucalypt forest resource was considerable and supplied large volumes of species possessing high durability

and strength. This resource became depleted as the rapid expansion of electricity reticulation led to an increased demand for power transmission poles. The preservative treatment of non-durable sapwood with CCA extended the availability of suitable pole species. However, doubts have been raised concerning the ability of the native forests to satisfy the continued increase in pole demands. There is very good potential for the use of CCA treated softwood poles to alleviate the demand on the hardwood pole resource.

Estimates for future pole requirements and available resources have been made by Mason (1981, 1985) for Queensland, New South Wales and Victoria. A long term forecast projected to the year 2050 and based upon 10 year periods from 1980, indicated an increase in the demand for poles. A summary of the forecast is presented in Table 1. Whilst increasing and decreasing estimates are apparent it is considered that the trend will be toward a consumption of more treated poles as the availability of highly durable species diminishes.

The hardwood forests in Queensland and New South Wales are not expected to satisfy future increased pole demands (Clough and Bragg, 1985; Mason, 1985). In Queensland the resource is dominated by poles available in the < 9.5 to 12.5 m lengths, with extreme limitations on poles 18 m to 23 m. Mason (1985) estimated the annual Eastern Australian availability of hardwood poles to the year 2050 to be some 15280 poles, based upon the following length classifications:-

TABLE 2
Estimated Annual Pole Availability in Queensland to the Year 2050, based on Length

Length (m)	Annual availability to the Year 2050
< 9.5 to 12.5	11810
14 to 17	2505
18.5 to 23	965
TOTAL	15280

The largest numbers of poles are required in the 11 m and 12.5 m lengths.

A steady increase in pole removal from Crown Land in Queensland was seen in the years 1977 to 1982. In the year 1981/1982 the number of poles cut was 15 400 based on an average length of 12.5 m. An estimated pole

TABLE 1
Future Pole Requirements from 1980 to 2050 (After Mason, 1981)

		TEN YEAR PERIODS							70 YEAR TOTALS
		1980/1989	1990/1999	2000/2009	2010/2019	2020/2029	2030/2039	2040/2049	1980/2050
QUEENSLAND:	TOTAL	342 230	325 455	354 215	378 105	404 235	432 960	465 690	2 702 870
	AVERAGE ANNUAL USAGE	34 220	32 540	35 420	37 810	40 420	43 290	46 570	
N.S.W.	TOTAL	573 731	620 201	657 956	720 106	767 226	770 306	734 456	4 843 982
	AVERAGE ANNUAL USAGE	57 370	62 020	65 790	70 010	76 720	77 030	73 440	
VICTORIA:	TOTAL	249 680	279 650	313 250	350 850	392 920	440 075	492 875	2 519 300
	AVERAGE ANNUAL USAGE	24 970	27 965	31 325	35 085	39 290	44 010	49 290	
BULK SUPPLY AUTHORITIES	TOTAL	8 350	8 350	8 350	8 350	8 350	8 350	8 350	58 450
	AVERAGE ANNUAL USAGE	840	840	840	840	840	840	840	
TOTAL: 3 STATES		1 173 991	1 233 657	1 333 771	1 457 411	1 572 731	1 651 691	1 701 371	10 124 512
	AVERAGE ANNUAL USAGE	117 400	123 370	133 380	145 740	147 270	165 170	170 140	

yield for all Forestry Districts revealed that a deficiency would occur in 11 m and 12.5 m lengths. Furthermore, treemarking rules applied under the Queensland Department of Forestry's Circular No. 2013 dramatically reduces the potential pole population. Many pole size stems will be retained for future sawlogs which reflects the Forestry Department's committment to the sawmilling industry.

In New South Wales, large numbers of hardwood poles are supplied to other states, especially Queensland and Victoria, to make up the shortfalls in supply. This movement has occurred for many years and is expected to continue for as long as the resource can sustain the demand.

The New South Walse Forestry Commission expects that the overall supply of durable and non durable poles will satisfy local demands for all sizes, in the long term future. Supply of poles surplus to requirements, into Queensland and Victoria will continue in all sizes, except 11 m and 12.5 m. After 1990 the availability of such sizes will only be sufficient to provide for the New South Wales demand.

The average pole supply and demand from 1980 to 2050 has been estimated by Mason (1985) and is presented in modified form in Table 3.

TABLE 3
Total New South Wales supply and demand, 1980-2050

Period	Supply Private Durables	Supply Crown Durables	Supply Private Non-Durables	Supply Crown Non-Durables	Supply Total	Demand NSW	Demand QLD Vic NSW
1980-89	118	364	116	627	1225	574	1174
1990-99	84	389	129	662	1264	620	1234
2000-2009	85	390	123	664	1262	658	1334
2010-2050	78	401	94	572	1145	748	1596

Pole authorities in Victoria require supply of untreated durable species only. The demand for these species by the State Electricity Commission of Victoria (SECV) represents 50% of current purchases. Victorian pole using authorities will not now accept preservative treated poles. At present the SECV requires 25 000 poles annually and this demand is expected to increase to 50 000 by the year 2050. The New South Wales durable pole resource will become depleted because of the Victorian demand, leading to a shortage of

the 10 m to 14 m length poles.

In Queensland and Victoria predictions for future pole usage and available resource indicate a shortfall. At present pole demand is supplemented in both States by supply from New South Wales. However, this supply will begin to decline in the short term future, especially in the 11 m to 12.5 m lengths. It will be necessary for Queensland and Victoria to utilise alternative sources of poles or alternative materials to make up the expected shortfall.

The demand for 11.5 m to 12.5 m length poles for distribution lines could be met by suitable size stems being made available from extoic pine plantations. In Victoria the large areas of pine plantations could supply pole size stems to pole using authorities. The availability and marketing of softwood poles has been discussed by Clough and Bragg (1985). The standing pole resource in exotic pine plantations in the South East of Queensland was considered to be very large, consisting of some 1 580 000 select stems and representing all pole classes. More recent figures indicate the availability of an annual supply of some 23 000 11 m and 17 000 12.5 m poles in all classes (except extra heavy), for the next ten years. As the plantations mature the standing resource of pole size stems is expected to double or treble. The estimates of Clough and Bragg (1985) indicated that the pine resource could easily supply Queensland's annual demand for poles up to 14 m in length. This pole resource will become very important since the hardwood forests can only supply about one-third of Queensland's current demand for poles and cannot meet any future increases. The larger plantation exotic poles are of course also prime sawlogs and market forces are expected to determine the volume of exotic pine diverted to pole production.

The Electricity Authorities in Queensland have expressed keen interest in CCA treated softwood poles. At the time of writing 500 softwood poles are being treated for use in a Statewide service trial. Each of the seven Electricity Authorities in Queensland, will take varying numbers of poles and monitor the in service performance. Previous experience with treatments, handling and performance of CCA treated power poles has been very favourable (Leightley, 1986).

In Western Australia the hardwood resource is rapidly becoming depleted. The current demand for poles is met from locally produced CCA treated

hardwoods and importation of large numbers from the Eastern States. The exotic softwood plantations in Western Australia are expected to contribute to the total resource and substantially alleviate the demand for timber. In response to the shortage of hardwood poles the State Energy Commission of Western Australia has commenced using CCA treated softwood poles in distribution systems. The current supply is for 5 000 11 m poles, which represents half of the number the Commission wish to obtain. However, faced with a shortage of total timber availability, there is a high demand for stems to be marked as sawlogs.

The potential for the use of CCA treated softwood poles by electricity authorities, appears to be very promising.

POLE FRAME CONSTRUCTION

Pioneer Australian timber house construction employed naturally durable hardwood foundation poles and supporting structures. The readily available supply of naturally durable foundation timber soon decreased as the resource became depleted. More recently, the pole frame house type of construction is increasing as a popular choice for new buildings. This increase is a direct result of the development and guaranteed performance of CCA treated softwood poles.

Pole frame house construction offers site and construction savings. Steeply sloping blocks of land are inexpensive to purchase, relative to level blocks. The unique pole frame construction utilises specifically sited poles which run from the roof down to concrete footings where they are deeply embedded in the soil. In comparison to traditional buildings, where the walls are load bearing, it is the poles that support the full weight of the house. This design enables siting on otherwise unacceptable blocks of land and cost savings, since minimal site clearance and levelling work is required. The speed of construction can also aid in cost savings.

A simple pole frame house can cost 30% less than a comparable cavity brick building of the same size. However, pole frame houses featuring unique designs with specialist materials can be costly. The major savings in pole frame construction lie in the purchase of a cheap block of land.

CCA treated softwood timber has shown excellent performance in experimental and in service field trials (Leightley, 1986). To ensure that such performance is obtained in pole frame housing, strict quality control

of CCA treated poles is required. A 100 percent compliance must be met for each pole used in a construction. Pole plugs taken from each pole should be chemically analysed for compliance with specifications for penetration and retention zone loadings. Certificates of analysis can be used to satisfy the compliance requirements of local building and finance lending authorities.

In Australia, pole frame building construction is increasing and reflects an international trend in using timber to produce environmentally pleasing dwellings. In the USA there are some 500 000 such buildings. A review of pole frame construction in New Zealand was made by Walker (1981). It was stated that in 1974 only 18 pole frame constructions were commenced in New Zealand. Current estimations are that 1 000 such buildings are being constructed per year. If a similar rate of increase in pole frame construction were to occur in Australia, a demand would be made on local softwood plantations for pole class stems.

Until recently pine poles were difficult to obtain in Australia because of immature plantations. As plantations matured it was considered that regular supplies of such material was assured. This assurance together with the cost savings and attractiveness in pole frame design, appeared to offer a very large potential market in Australia. However, recent market developments need to be considered.

In the early 1980's a pole frame market began to rapidly emerge in South Australia, especially in the Adelaide foothills. This activity, took the advantage of pole frame construction on steep slopes. The same cost advantage is not present in much of the readily available flat building land in the Adelaide area. A downturn in the commencement of pole frame houses has been experienced. More recently, a new factor has emerged which may limit the construction of timber structures in South Australia and Victoria. Legislation in these States is proposing to severely restrict the use of external timber poles and cladding in zones considered to be a high bush fire risk. Such legislation would affect the whole of the Adelaide Hills area. Pole frame design would be especially affected because of the liberal use of timber throughout the building.

In Victoria and South Australia the softwood plantation resource is limited in its supply of suitable pole material. This is especially because of recent major bush fires and the disastrous losses of the softwood resource. In addition, the Grade Specifications also limit pole supply in favour of sawlog supply. In the short to mid-term it is not envisaged that there will be a boom in pole frame housing in Victoria and South Australia.

A readily available supply of suitable size stems for pole frame construction is available from Queensland softwood plantations. At the present, CCA treated softwood poles are being produced in Queensland for an increasing local and interstate market. In particular, New South Wales purchases large numbers of CCA treated slash pine poles. If Queensland production trends continue some 8 000 poles may be produced on a per annum basis for pole frame construction in New South Wales. The lack of readily available pole size softwood stems in New South Wales causes the timber to be sourced interstate. The steady demand and willingness to pay premium prices is indicative of the market potential for CCA treated softwood poles for pole frame construction in New South Wales and Queensland.

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THE PERFORMANCE OF WOOD RAIL SLEEPERS IN AUSTRALIA AND THEIR POTENTIAL

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ABSTRACT

Attention is drawn to the continuing need for wood sleepers and to the fallacy of comparing sleepers of different materials on the basis of inadequate descriptions such as "wood" or "concrete" and/or inadequate data.

Wood sleeper service life data obtained from a series of service tests are presented in a summary form. The results show that a properly treated wood sleeper fitted with simple dog spike fasteners can give a service life greater than 25 years and in some cases will last 35 years. Excellent results of treated timber sleepers in a heavy haul iron ore railway after 11 years are also reported.

With the current shortage of durable timber available for sleepers, the alternative is to use non-durable timber treated with an oil-based preservative to overcome this shortage, while at the same time minimising the drain on the timber resource.

INTRODUCTION

Wood sleepers of various species have provided the support for rail tracks in Australia since their inception and today still constitute 93% of sleepers in the Australian rail system.

Despite an upsurge in the use of concrete (of various types) sleepers in main line and heavy haul tracks this material still provides only 18% of replacement sleepers in 1986. It is likely that concrete will never be used in many tracks in Australia because of the complete track rebuilding required and the high cost of machinery necessary to handle and lay them. Steel too has its problems (the maintenance of top and line) as a rail sleeper.

One thing is certain, sleepers produced from various species of wood are going to be <u>needed</u> in the hundreds of thousands each year by Government railways in most States for a long time to come. True, many

would claim that "wood" (a totally undefined material) is unreliable and unsatisfactory on the basis of accumulated experience. But because of the lack of definition of the material concerned in terms of species and quality this statement can neither be proved or disproved.

For instance, in an article written by a journalist in Ausrail in 1980, the staff magazine of Australian National (1) the following profound (?) comparison was made: concrete sleepers "have a 50 year life and cost $17 each. Wooden sleepers $10 and last 17 years". That may have been right for one or more types of concrete sleeper but it has never been proven, and which "wood" sleeper was under discussion is not known. Five years later another railway journal (Rail Track) contained an article discussing concrete sleeper performance (2). This time the prediction for the service life of wood sleepers was lowered to 12 to 15 years compared to a 50 year life for concrete sleepers (again still no evidence provided to support such a claim).

CSIRO data show that well treated radiata pine (*Pinus radiata* D. Don) can last 50 years and more, at least in a wheat line in South Australia. Untreated Cooktown ironwood (*Erythrophleum chlorostachys* (F. Muell.) Hennings ex Taub.) lasted more than 90 years in tropical northern Queensland.

Solid evidence should be acquired about the performance of the respective sleeper materials. The extravagant cliams for concete for example, are still based on speculation, and not established data. Furthermore, it is necessary to remember that like "wood", concrete is a generic non-definitive term and in fact there are many species of the same. Therefore performance must be related to particular types and designs.

In this paper our concern is with the actual performance of sleepers of various species of wood in different parts of Australia.

DATA

In co-operation with the State and Commonwealth rail systems, the former Division of Forest Products treated and installed more than 5500 sleepers spread between 24 sites throughout Australia. The annual gross tonneage at these sites ranged from ½ to 12 million tonnes. They included 21 hardwood and one softwood species treated with various combinations of

12 wood preservatives. A small selection of these species/treatment combinations along with their respective service performances is presented in Table 1. A complete list of sleepers with species/treatment combinations giving excellent performance (greater than 25 years) is presented in Chin and Barnacle (3).

The results show that average service lives of at least 25 years and in some cases, 35 years or more can be obtained from reasonable quality, oil treated wood sleepers of a number of readily available timber species. Most failures were due to end splitting and/or loose spikes, and premature failure due to the former cause was almost invariably related to the initial quality of the sleeper.

The untreated sleepers that have been traditionally used were those of high natural durability to termites and decay, e.g. River red gum (*E. camaldulensis* Dehnh.) in Victoria, New South Wales and South Australia. Narrow-leaved red ironbark (*E. crebra* F. Muell.) in New South Wales and Queensland, and jarrah (*E. marginata* Donn ex Sm.) in Western Australia and South Australia. According to our data the service lives achieved for the durable species were of the order 20 to 25 years. See Table 1.

Good performance was obtained with the waterborne preservative, Greensalt K, when used in radiata pine sleepers in the South Australian test (27 year average life). The same preservative-species combination in Victoria provided an average life of 15 years. Greensalt K was not effective in hardwood sleepers however, and we do not recommend waterborne treatments for preserving hardwood sleepers.

While these data relate to small groups of sleepers, the results have been analysed and sleeper life distribution characterized (5). Briefly, the results indicate that the life distribution curves for the best oil treated hardwoods differ little from that for concrete sleepers in the same track.

Indicated guarantee periods and subsequent failure rates suggest that the reliability of such treated sleepers would allow mechanical replacement strategies to be used. This would have obvious economic advantages in that it could eliminate the expensive spot replacement strategies that have been used in rail tracks since their inception.

Another study of the effectiveness of wood sleepers in rail tracks which should be of considerable interest, involved a test of oil treated unincised karri (*E. diversicolor* F. Muell.) sleepers fitted with Pandrol plates and fasteners installed in a 2^{o} curve in a heavy haul, iron ore

TABLE 1
Performance of untreated sleepers and a selection of sleepers of different species/treatment combinations having long service life

Species	Treatment	Location and age (years) of test	Estimated min. average life (years)	Cumulative failure (%) at last inspection
Radiata pine (*Pinus radiata*)	50:50 creosote:furnace oil	South Australia (30)	34	21
		Victoria (32)	28	75
	3% PCP in furnace oil	South Australia (30)	35	11
		Victoria (32)	28	79
	3% Greensalt K in water[a]	South Australia (30)	27	79
		Victoria (32)	15	100
	Untreated	South Australia (25)	4	100
White stringybark (*Eucalyptus eugenioides*)	40:60 creosote:coal tar oil	Victoria (32)	30	65
	Creosote oil	" (32)	25	95
	Untreated	" (32)	16	100
Mountain ash[b] (*E. regnans*)	40:60 creosote:coal tar oil	Victoria (32)	29	80
	Creosote oil	" (32)	28	85
	Untreated	" (32)	12	100
Jarrah (*E. marginata*)	Furnace oil	Western Australia (29)	34	10
	50:50 creosote:furnace oil	" " (29)	33	19
	Untreated	" " (29)	24	86
Karri (*E. diversicolor*)	3% PCP in furnace oil	Western Australia (29)	25	84
	Untreated	" " (29)	6	100
Silvertop ash (*E. sieberi*)	3% PCP in furnace oil	New South Wales (27)	23	77
	Untreated	" " " (27)	11	100
Brush box (*Tristania conferta*)	50:50 creosote:furnace oil	Queensland (25)	28	20
	Untreated	" (25)	11	100
Satinay (*Syncarpia Hillii*)	50:50 creosote:furnace oil	Queensland (25)	29	8
	Untreated	" (25)	16	100
Narrow-leaved red ironbark (*E. crebra*)	Untreated	Queensland (25)	19	73
	"	New South Wales (27)	21	100
River red gum (*E. camaldulensis*)	Untreated	Victoria (32)	23	90
	"	New South Wales (27)	23	60

Note: This is a selection of species/treatment combinations and a larger number of treatments are presented in Chin & Barnacle (3).

[a] Greensalt K is the proprietary name for a waterborne salt type preservative.

[b] These were air dried sleepers. The same performance could not be guaranteed if these or other collapse-susceptible species were dried by accelerated methods using high temperatures, as this would enhance fibre collapse.

track in the north west of Western Australia (4). This site was located in an area having an arid-sub tropical climate, and very high termite activity. The pressure treatment schedules used gave low average charge retentions of 15, 21 and 42 kg/m^3 for the three groups used. (Note current recommended retentions are 80 kg/m^3 in incised sleepers.) At the most recent inspection this test had been in service for 11 years and the sleepers had carried 548 million gross tonnes of 32 tonne axle load traffic. The results in Table 2 show that despite the severe track conditions, these poorly treated, karri sleepers have maintained good track quality indices and less than one per cent of the better treated sleepers have failed over this period. Most sleepers are rated as having at least a further 5 years life.

It is pertinent to note that these sleepers replaced untreated jarrah sleepers which failed after only 6 years service in a curve which had the next-to-worst rail corrugation problem in the entire Hamersley track. Corrugation was finally eliminated through repeated rail grinding and other track work. In the time span of this test the sleepers had survived through 3 high leg and 2 low leg replacements together with some rail transpositions.

TABLE 2
Performance of oil treated karri sleepers in a well maintained heavy haul railway after 11 years service

Charge retention (kg/m^3) and original number of sleepers	Percentage of sleepers having estimated further life (years)				
	>5	=5	<5	Fail	Previously Failed
42 (400)	90	7.3	2.8	0	0
21 (200)	76	16	7	0.5	0.5
15 (200)	27.5	32	36	5	0

Note: These karri sleepers were treated with a mixture of 60 per cent furnace oil, 39.5 per cent high temperature creosote and 0.5 per cent dieldrin.

DISCUSSION

First, we would stress that no meaningful discussion of sleeper performance can be had without:

(i) proper definition of the material, i.e. its species

(ii) the quality of the timber, i.e. the part of tree from which the sleeper is cut, namely outer or inner heartwood, and the condition of same in respect of end splits, loose gum rings, knots, etc.

(iii) its preservative treatment, level and/or quality

(iv) the types of rail fasteners used, and the frequency of traffic carried

(v) the type of ballast, the periodicity of tamping and drainage conditions of the track.

As a corollary to the foregoing, it can be said that if "wood" of extremely variable quality is used for sleepers, extremely variable results in terms of life are likely. And it is our view that it is inadequate definition of the material used in past years that has led to the reputation of "wood" as an unreliable sleeper material.

As the traditional durable species used for sleepers is now in short supply, other species have to be employed because the rail authorities advise that they must continue to use wood sleepers at the rate of about 2.5 million units each year.

This leaves only two options:

First, install low durability species untreated (this is not an option with pine), or

Second, install low durability species treated with an oil preservative.

From our data the lives of untreated low durability sleepers, i.e. the first option, would be from only one-third to three-quarters that of the service lives of traditional durable species. But if properly selected and preservative treated, any of a wide range of species can be expected to achieve a similar or better average life with a "guarantee" period (time to first failure) longer than the traditional sleeper.

Since the resource is now in short supply, the second is the only option if the drain on the resource is to be reduced.

In the case of pine we know that the amount of wood becoming available will double within 10 years and this must be peservative treated to be an option for use as rail sleepers. Also the pine resource can probably be expanded by the production of dowel or glue laminated sleepers, thereby allowing 125 mm square sections - which could be cut from very small trees - to produce sleepers.

Another problem that has occurred as a result of the reduced supply of logs for sleepers is that the quality of sleepers now being installed has fallen with the consequent result of a reduction in service life. A way to avoid this situation is instead of purchasing these sub-standard sleepers use the funds available to purchase a smaller number of better quality treated sleepers each year. This would allow a gradual improvement in the standard of tracks, and benefits would occur in a few years when less track maintenance would be required.

CONCLUDING REMARKS

(i) Oil treated wood sleepers of reasonable quality fitted with simple fasteners can give service lives in excess of 25 years with good consistency of performance.

(ii) Such lives would be an improvement over the untreated durable species now used. This improvement would show in a better guarantee period, i.e. time to first failure and more predictable performance overall, providing a sound foundation for improved track maintenance strategies.

(iii) With a diminishing resource of durable timber, or even an expanding pine resource, an improvement in service life and reliability is essential if the drain on the timber resource is to be reduced.

(iv) If the potential for wood sleepers is to be realized, it has to be recognized that the quality of the wood used must be commensurate with the life expected, i.e. firewood quality is not aceptable.

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TIMBER STRUCTURES AND FIRE

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1. INTRODUCTION

The combustibility of timber, the potential of timber to fuel a fire, has been a stumbling block to the rational development of procedures for assessing the fire safety of timber structures. The basis for this probably lies in past history when cities of timber buildings were devastated by major fires. Well known examples of this are the fire of London in 1666 and the burning of the Ginza district in Tokyo in 1872. In London the response was to double the premium of houses having timber frames; in Tokyo the governor ordered the area to be rebuilt in brick.

A legacy of these past disasters is that in most countries today the building regulations provide no rational approach to the use of combustible materials, (such as timber) for structural purposes. Usually the regulations will either prohibit or accept (without question) the use of such materials for a given end use.

However during the past few decades there has been a keen interest among fire research scientists to develop rational procedures for designing timber structures to resist fire. It is probably largely for this reason, more perhaps even than reasons related to economic pressures of the building industry, that have led to a review of the situation by building authorities.

In the following, a discussion is given on several significant aspects of the behaviour of timber structures in a fire.

2. CHARACTERISTICS OF TIMBER SUBJECTED TO FIRE

Wood comprises a mixture of cellulose, hemicellulose and lignin, bound together in a complex network. As wood is heated above 280°C it decomposes or *pyrolyses*, and is converted to gases, tar and charcoal (1). The gases flame vigorously at temperatures above 280°C but the charcoal requires temperatures about 500°C to be consumed.

As the char builds up it tends to protect the unburnt timber from

rapid pyrolysis. The unburnt timber is an excellent thermal insulator, and as a result the timber a short distance from the char edge is unaffected by the fire; one significant consequence of this is that a timber member in a fire does not exhibit the destructive expansion behaviour of unprotected steel members.

A schematic illustration of burning wood is shown in Fig. 1. For a softwood, typical parameters of the unburnt timber are as follows (2):

density	=	500 kg/m^3
thermal conductivity	=	0.15 J/(sec.m.°C)
specific heat	=	1700 J/(kg°C)

The effect of temperature on the strength and stiffness, both during and after a fire, are shown in Figs 2 and 3.

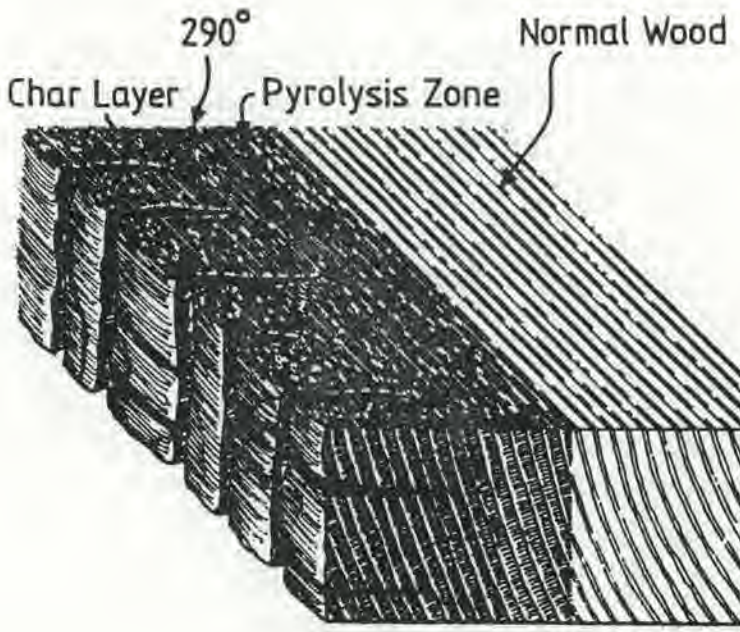

FIG. 1. Degradation zones during burning of timber

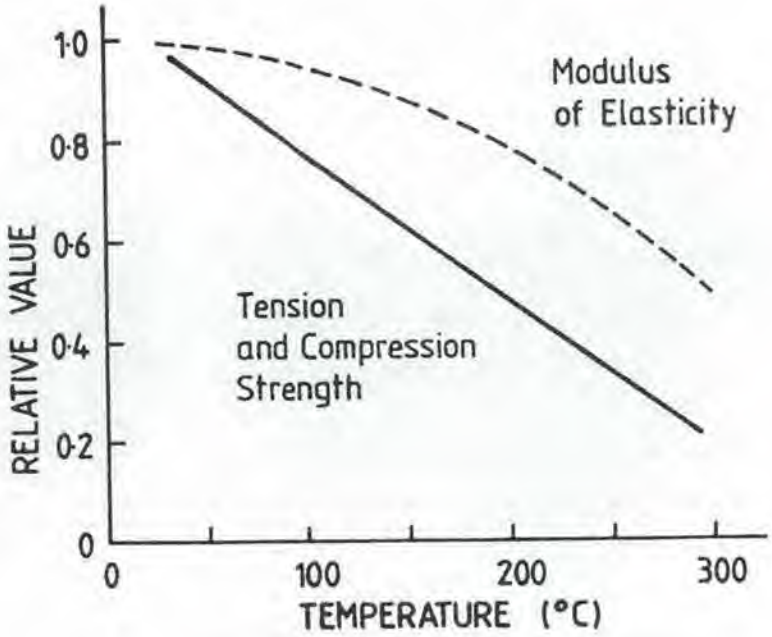

FIG. 2. Effect of elevated temperatures on the strength and stiffness of wood

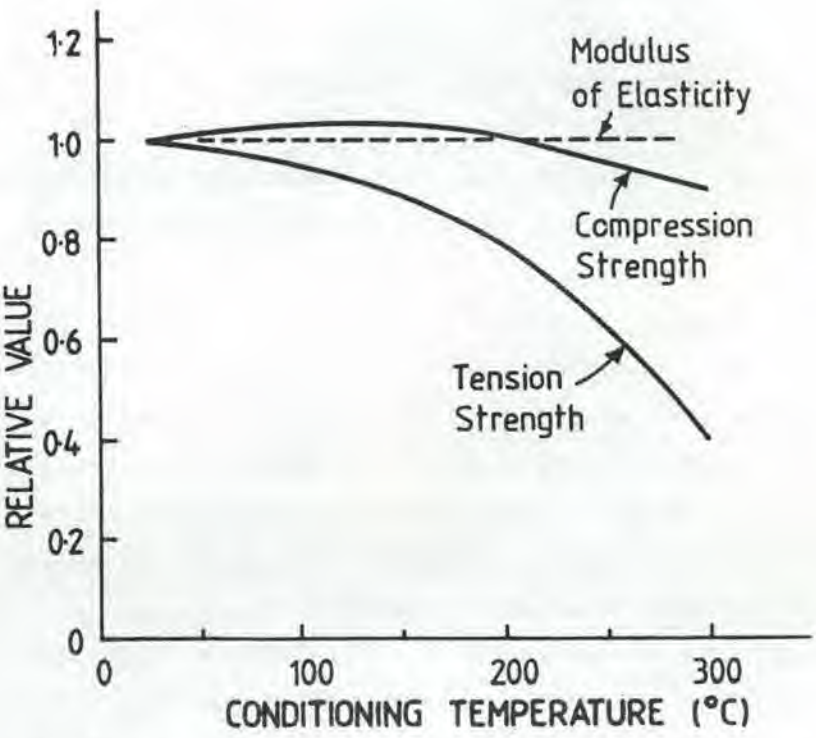

FIG. 3. Effect of heat conditioning on the post-fire strength and stiffness of wood

When dry wood is first heated it will char at a rate proportional to the incident radiation, given by (3)

$$dh/dt = 10\ R/\rho \qquad (1)$$

where

dh/dt = rate of char (mm/min)
R = radiation (kw/m^2)
ρ = wood density (kg/m^3)

Once the wood has developed a protective layer of char, the char rate will slow down considerably. In a standard furnace test as specified in AS 1530.4-1985, dry wood will char for several hours at a roughly constant rate given by

$$dh/dt = 360/\rho \qquad (2)$$

For a typical softwood of density 500 kg/m^3, this gives a charring rate of 0.7 mm/min.

For the case of wood burning in a compartment fire, charring rate can be computed from equations given by Pettersson and Jonsson (4).

3. COMBUSTIBILITY

The assessment of combustibility given in AS 1530.1-1984 is measured by placing small 45 mm diameter specimens in a calorimeter and heating them to about 800°C for 30 minutes; if flaming or a temperature rise in the calorimeter is noted, then combustion is deemed to have occurred. According to this criterion, timber, even timber treated with fire retardants, is classified as combustible.

If the purpose of the combustibility test is to reduce the fuel load in building fires, then this does not appear to be a rational basis for banning the use of timber as a structural material. For a start, it is quite an easy matter to design a timber structure that contributes less than 20 per cent of the fuel loading of a building. In addition, timber

is not the most dangerous of the fuels that are to be found in buildings. This is indicated by the comparison of burning rates of some selected materials as shown in Table 1.

TABLE 1
'Ideal' Burning Rates

Material	'Ideal burning rate' (gm/cm^2 sec) x 10^4
Ethyl alcohol	40
Polystyrene	35
Polycarbonate	25
Douglas fir	13

Note: The 'ideal' burning rate is defined as the combustion rate when energy losses from the burning surface equals the energy supplied by other bodies. Data cited is given by Tewarson and Pion (5).

Of more concern than combustibility is the phenomenon of 'after-glow', the ability of exothermic materials such as timber to continue burning after the external heat source has been removed. This can occur in timber treated with the CCA wood preservative, after only a few seconds of contact with a grassfire; in this case the risk of after-glow can be minimized by replacing CCA with the CSIRO patented 3S formulation which is based on the use of zinc and phosphorus additives. After-glow can also occur in untreated timber if it is subjected to a fierce fire for more than 30 minutes; treatment with a suitable fire retardant will remove the risk of this happening. In urban fires, the risk of after-glow is negligible, as firemen have been trained to douse burnt timber with water.

4. EARLY FIRE HAZARD

The initial stages of a fire, before flashover occurs, are usually the most dangerous with respect to human safety. This risk may be assessed by the Australian Standard AS 1530.3-1982. Some hazard values

measured in this way are shown in Tables 2-4. The range of the hazard index is 0-20 for ignition and 0-10 for the other parameters, with zero indicating a negligible hazard.

Table 2 shows that the hazard of an untreated softwood timber is no worse than that of acceptable furnishings, such as acrylic carpet, but certainly no where near as good as plasterboard; Table 3 shows that the hazard indices tend to reduce with increasing density of the timber; Table 4 shows that the early fire hazard of timber can be essentially eliminated through the use of fire retardant treatments.

TABLE 2
Hazard Indices for Some Building Materials

Material	Hazard index*			
	Ignition	Flame spread	Heat Evolved	Smoke Developed
Plasterboard	12	0	2	3
Pine	15	7	6	3
Acrylic carpet	16	8	9	6

* after Beesley *et al.* (6)

TABLE 3
Hazard Indices for Untreated Timber

Timber Density	Hazard index*			
	Ignition	Flame spread	Heat Evolved	Smoke Developed
400	14	9	9	4
900	13	5	5	2

* After Moulen and Grubits (7)

TABLE 4
Hazard Indices for Radiata Pine

Treatment	Hazard index*			
	Ignition	Flame spread	Heat Evolved	Smoke Developed
Untreated	15	7	6	3
Impregnated with fire retardant	0	0	0	2

* After Beesley *et al.* (7)

5. STRUCTURAL INTEGRITY

5.1 General

Once flashover occurs and the contents of a compartment become fully involved in a fire, it is necessary to prevent this fire from spreading to adjacent compartments. The defence mechanism against this requires not only that the integrity of the compartment walls remains intact but also that the supporting structure maintains its load carrying function during the fire.

The assessment of structural performance in a fire may be carried out according to the Australian Standard AS 1530.4-1985. This Standard specifies that a structural element (or system) be loaded to its intended design load, and then subjected to a furnace fire that is intended to simulate the conditions of a fiercely raging compartment fire. The time to collapse of the structural element (or system) is deemed to be the *fire resistance* rating of that element. Most of the proposed fire resistance design methods for timber structures are related to meeting this furnace test criterion.

5.2 Fire Resistance of Solid Timber Elements

For theoretical design procedures, the first step in evaluating the strength of solid timber elements during a fire is to compute the area of unburnt timber and the rate at which the char is progressing. For a furnace situation, this can be done through the use of equation (2).

Then the wood temperature at a distance x in from the edge of the char can be evaluated from

$$T = T_o + (T_{max} - T_o) \exp(-\alpha x) \quad (3)$$

where

$$\alpha = dh/dt.\rho.C_p/k \quad (4)$$

in which T_o = 23°C is the initial temperature of the wood, T_{max} = 290°C is the temperature at the edge of the char, dh/dt is the charring rate, ρ is the density, C_p is the specific heat and k is the thermal conductivity.

Figure 4 shows the temperature distribution computed in this way for a softwood timber subjected to a standard furnace test. From this information and that given in Figs 2 and 3, the strength distribution in timber both during and after a fire can be determined and these are shown in Figs 5 and 6.

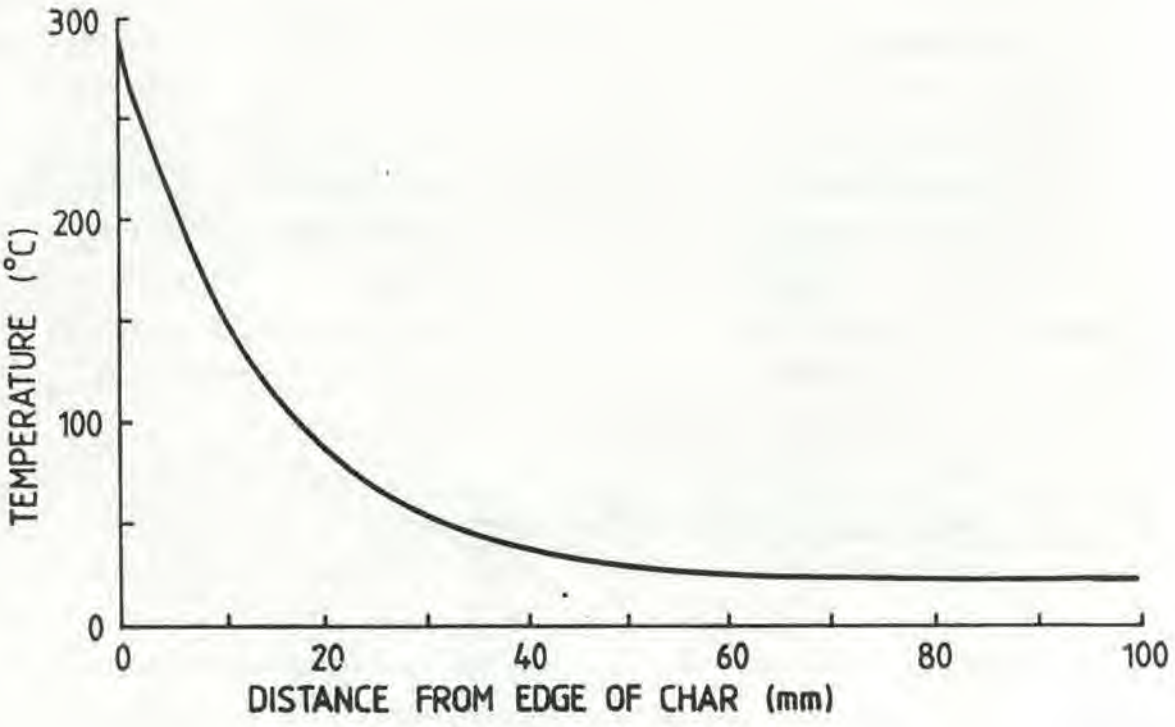

FIG. 4. Temperature distribution during a fire

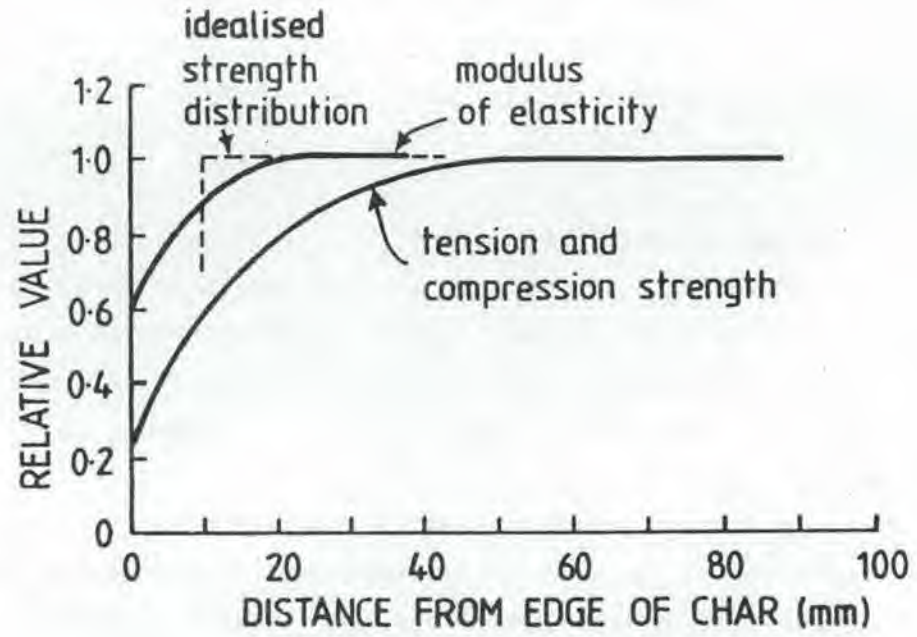

FIG. 5. Structural properties of solid timber during a fire

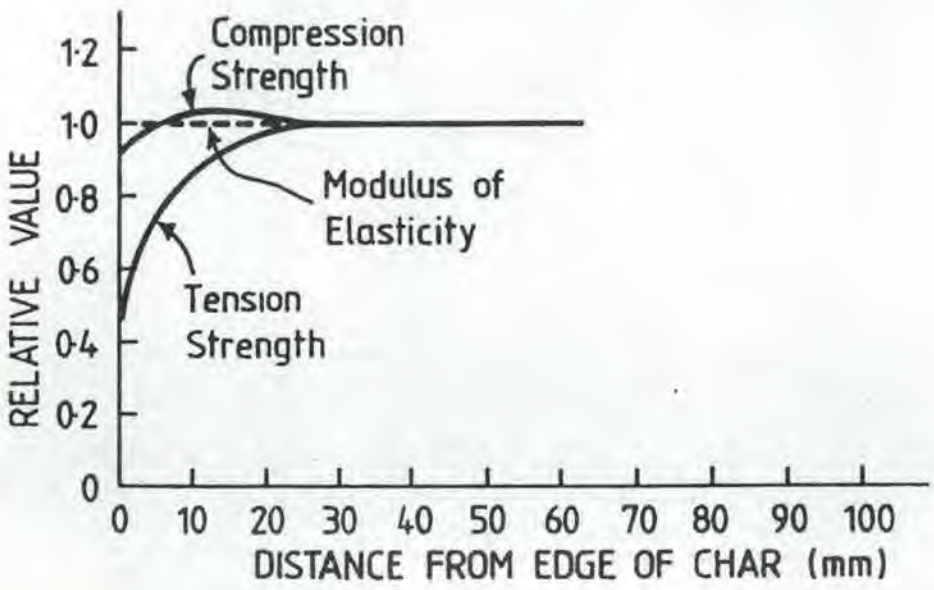

FIG. 6. Structural properties of solid timber after a fire

It is seen that during a fire one can obtain a realistic assessment of structural behaviour by neglecting a boundary of 10 mm of unburnt timber and assuming that the residue still has its full initial strength and stiffness.

5.3 Fire Resistance of Metal Connectors

Unprotected metal connector systems exhibit very poor performances in fires. The metal connectors rapidly conduct the external temperatures to the wood and when this reaches 300°C the wood loses all its local bearing strength as indicated in Fig. 2; when this happens, the connector system fails (8).

The simplest method of protecting metal connectors is by recessing them into the timber of the structural member and then covering them with an additional glued-in plug of timber. An example of this is shown in Fig. 7.

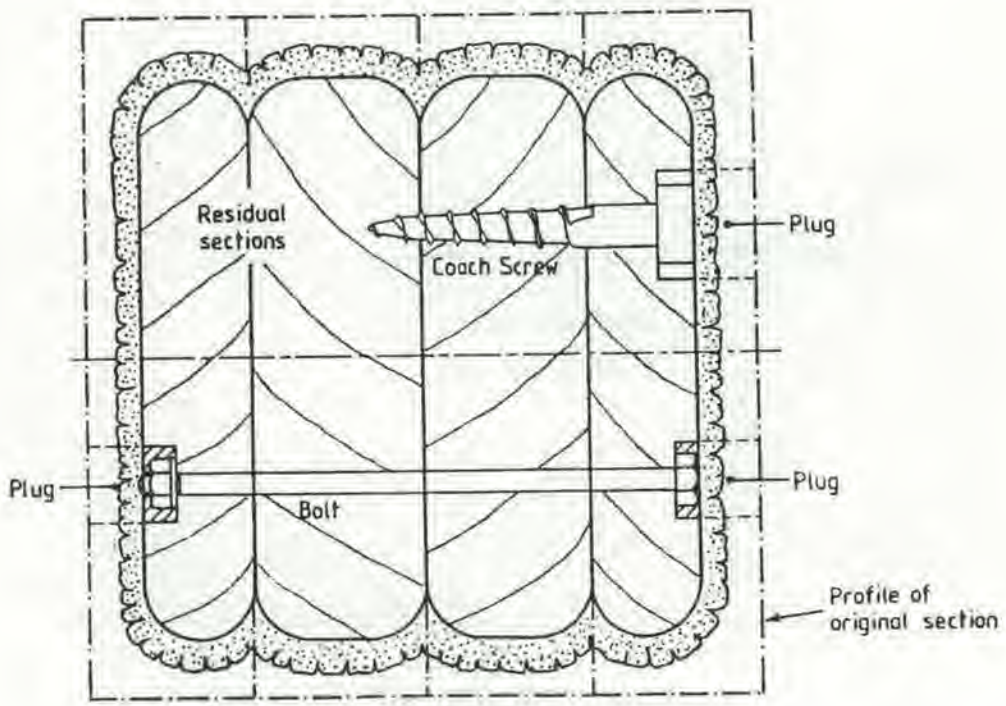

FIG. 7. Illustration of a method of protecting metal connectors

5.4 Glued Joints

Fire does not burn any faster in glued joints than it does in solid timber. However the strength of glued joints may reduce rapidly as the temperature rises; for example, urea formaldehyde glue tends to lose significant strength at 100°C.

Hence the presence of glued joints may be ignored when these are only lightly stressed and occur in bulky members such as glulam. However, in small, highly stressed situations such as occurs with finger jointed scantling, the glued joint should not be relied on to perform well unless it is first checked out by a fire performance test.

6. STANDARDS FOR FIRE RESISTANCE

There are essentially three ways in which the fire resistance rating of a timber structure may be assessed. The first is a fairly simple deemed-to-comply technique in which fire resistance ratings are given for certain types of construction. The simplest of these is to allow a 30 min. rating for heavy timber construction such as that specified in Table 5 which is based on New Zealand Standards (9). A very detailed Standard of this type is the German Standard DIN 4102.

TABLE 5
Minimum Sizes for 30 Minute Fire Resistance

Member	Minimum Size* (mm)
Beam	250 x 150
Column	200 x 200
Truss Member	200 x 200

* After Wardle (9)

The second assessment method is based on the use of a standard furnace test, and the Australian Standard AS 1530.4-1985 is a good example of this. It should be noted that the New Zealand Standard MP 9/8 has introduced a proposal wherein the structure is not required to be loaded during a furnace test; rather the failure criterion is based on

measurement of residual sections and the temperature rise in members. This is not really a satisfactory procedure since it is possible that under load a structure will deform in such a way as to effect the influence of the fire.

The third assessment method is to compute a theoretical fire resistance, in much the same way as a structural resistance is evaluated. The simplest example of this type is given in the draft Australian Standard AS 1720.4 (Document DR 83201, 'Fire Resistance of Timber Structures'). This Standard is based on the ideas outlined in Section 5 of this paper, and produces results very similar to those of the British Standard BS 5268:Part 4:Section 4.1:1978. The reference cited earlier by Pettersson and Jonsson gives a complex but realistic computational method of this type.

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Market Opportunities for Timber through Engineering

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ABSTRACT

The timber engineering sector of the Australian construction industry is characterised, not only by the multiplicity of timber species but also by a certain "laisser faire" attitude to the application and technical promotion of large wood structures.

Far from declining, the wood resources of Australia are increasing and can sustain virtually a 50 per cent increase to 7 million m^3 by the year 2000. In addition, enormous quantities of timber are coming on-stream from South America and not only other nations grouped around the Pacific rim including our neighbour, New Zealand.

There is no doubt that our scientific base in wood technology has declined in the last two decades and there are ominous signs that our industrial resilience in timber engineering is possibly being outstripped by even some Third World countries, such as Mexico, Brazil, Chile, not to mention South Africa. Thus, the underlying theme of this paper is the urgent need to recognise structural timber as one of Australia's most useful and renewable building resources.

INTRODUCTION

Timber has many advantages as a structural material:

- It is light, easy to cut, drill and nail;
- has a high resistance to shock loading and high loads of short duration;
- its thermal expansion and contraction is very small and chemical resistance excellent;
- it burns but does not readily lose its structural rigidity;
- properly treated, it requires little maintenance.

There are some disadvantages, the recognition of which helps to put wood in its proper perspective, relative to other materials:

- it is a natural product of great variability and requires to be graded;
- it is susceptible to change in moisture content which products dimensional effects, warping or undesirable deflection. Creep is comparatively large,
- dimensions of saw logs restrict sizes and length of solid timber;

- small dimensioned timber is extremely vulnerable to fire;
- timber needs to be preserved from moisture, decay and insect pests.

Structural design is concerned with much more than science and technology; it is also concerned with common sense, aptitude and a feeling for the materials to be used in construction to which scientific calculations add the finishing touches, substantiating that the project is sound and that the building satisfies all necessary service conditions.

In relation to architectural achievements overseas, we are failing to create an inspirational heritage and respect for the quality and beauty of wood in modern construction.

OPPORTUNITIES IN THE CONSTRUCTION INDUSTRY.

Overseas, architects are rediscovering timber, not only its responsive warmth, but also its lively heritage of form, ingenuity and resilience latent in this magnificent, renewable material. Man has a natural empathy with wood. There is a strong psychological appeal, unlike concrete or steel products. Wood products can be graceful, enhancing the best designs with a sense of unity and symmetry. Weight for weight, it is stronger than steel and modern timber structures can be 20 per cent cheaper than alternative forms of construction.

The per capita consumption of timber in Australia is 0.28 cubic metres per capita and contrasts with much higher figures in North America (0.38), Scandinavia (0.60) and New Zealand (0.58). The consumption of timber in Australia has remained virtually static for more than 10 years, indicating an erosion of markets in favour of other man-made building materials and products.

If market penetration were similar to New Zealand, (assuming broadly equivalent industrial demand and building regulatory practices), the consumption of structural timber in Australia could rise in approximate terms by between 0.5 and 1.0 million m^3 per year, based on methods used to predict the maximum possible potential use for sawn timber in New Zealand. The value on an Australian market, priced (on average), at, say, $700 (structural) per cubic metre

would mean an additional $350 to $700 million annually.

There is, however, a tremendous problem in the market place, not only to promote a modern image of technology and professionalism, but simply good public relations. The most powerful tool to redress this situation is the recognition of the enormity of the problem, particularly the commitments needed by all sectors of the timber industry to withstand intense competition from the concrete and steel community.

The problem, succinctly enough, is that the consumer, particularly the professional client in the market place, lacks inspiration, technical appreciation, and quality assurance, all of which disastrously undermine his confidence in the timber industry to provide quality and value for this market dollar. It is not an exaggeration to say that the decision to build a prestige or large commercial building in timber requires an act of faith, or, as the Darling Harbour Authority in Sydney recently put it, "a reliance upon an unproven technology!"

There is a crying need for laboratory facilities to reassure local professional consumers of the ability of full-sized structural timber elements to demonstrably withstand dynamic cycles of load simulating a working life of up to 50 years or more.

At the sharp end of the industry, there is a prime objective to inspire local confidence in structural timber through technical education, guidance in design and fabrication techniques and performance data obtained from tests on full scale building elements. The sophisticated consumer is entitled to the concept of proof engineering to which he has been accustomed in dealing with other building materials. The role of Quality Assurance programmes must also receive much more than mere lip service.

While there is need for market research and strengthening of the statistical base, these activities should not obscure the fundamental reasons for poor market penetration and industry performance. These reasons can be attributed thus:-

* Until recently, there has been little success in preserving or indeed influencing the timber industry's perceived share of the market place. The industry compares unfavourably with organisations in other countries, such as Canada (the Canadian Wood Council,) the U.S.A. (US Forest Products Association), and Scandinavia, (The Nordic Timber Group).

* The decline in wood technology and forest products research has been marked over the last two decades. This has severely affected the industry's capacity to appoint technical personnel of the necessary high calibre, effectiveness and motivation, who should be not only knowledgeable and experienced, but who must be able to communicate and influence the Building Professionals at the highest levels in the design and construction process.

* The technical promotion of timber components has been rather uninspired and unconvincing. Although well meaning, it has not really been effective, being largely preoccupied with traditional timber frame construction. The concept that structural timber is as different from wood as concrete is different from cement was also ill-defined.

* Quite simply, the technical dedication to develop commercial building did not exist relative to glulam or panel board applications. Management commitment was minimal and technical personnel were hesitant to enter a sophisticated area which was beyond their design capabilities.

* Within the timber industry, management tends to lack the authoritative and experienced voice of professional staff necessary to acquaint it and steer it successfully over the hurdles of sophisticated markets, design implications and vital quality assurance procedures.

* There has been little support for builders anxious to expand their operations in the timber engineering fabrication and erection field. Without market penetration, there can be no continuity of work. Without fabricators there could be no prospect for completing a project in structural timber.

One of the basic problems, apart from cost competitiveness, is the lack of completeness of information on the behaviour of timber elements. Performance reliability (proof testing) are critical issues in the acceptance of engineering products. Both depend on the variability of strength properties, quality control, workmanship and an accurate assessment of induced loading over the lifetime of the structure. Without a thorough knowledge of both the short term and long term behaviour, the crucial reliability performance of timber will remain less attractive, under limit state philosophy, than alternative designs in concrete and steel. The recent development of high performance seasoned hardwood lumber, stress related to F17 and F27, is seen to be a step of significant importance for the industry in relation to reliability, quality control and basic market resilience in the building sector.

While recognising that wood is a combustible material, its behaviour is highly predictable and it does not constitute a hazard in excess of other construction materials.

A far reaching industry commitment must inevitably extend beyond the simple needs for a TV awareness campaign, since vigorous technical, educational and research efforts are needed in all States to halt the decline in the consumption of timber in Australia. The realisation of the enormity of that commitment is the fundamental step towards a high value-added product development.

The idiosyncrasies of wood technology are not complex, the chemistry of wood adhesives, moisture content, variation of grain, and checking all respond well to modern production techniques. There is, indeed, a wealth of experience both locally and overseas, upon which the designer or product developer can draw. The resilience of wood is such that it is basically a forgiving material. The variability of timber, however, between species and within species, ensures that any disregard or lack of quality assurance procedures is commercially fatal. The design of good quality control procedures is one of the corner-stones upon which product viability or further

diversification is based. In the right hands, Proof Engineering and Quality Assurance is the tool which differentiates between rival firms or excises fly-by-night exploiters from the market place.

RESEARCH ON TIMBER CONNECTORS IN CSIRO

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Abstract

This paper refers briefly to previous CSIRO research on timber connectors and reviews activities in three current areas of work. The capacity of bolted joints loaded perpendicular to the grain, the performance of tooth plate connectors in low density and juvenile woods and the affect of climatic variables on long term creep are the projects reviewed. The reasons for undertaking the research are stated and the application of results are summarized.

INTRODUCTION

Mack's paper to the 19th Forest Products Research Conference (1) (abbreviation FPRC) (1979) reviewed a range of research undertaken in two CSIRO divisions over a period of years; it indicated that much of the work had reached a satisfactory stage of completion, although some problems were considered to require further consideration. Investigations of bolted timber and tooth plate connections required more work and a better understanding of the effects of long duration loads on fasteners was necessary. A world wide shortage of information on the strength properties of connectors in plywood was said to exist.

Since 1979 a need for further research on the performance of timber connectors was recognized and some aspects of the work undertaken at DBR were reported at the 21st FPRC (1984), (2, 3, 4). The project has continued and this paper reviews three present areas of investigation and explains the background to the work. The projects to be discussed are:

A. Study of the load capacities of bolted joints where the wood is loaded perpendicular to the grain.

B. Measurement of load capacities of tooth plate connectors in low density and juvenile softwoods.

C. Consideration of the variables affecting the long term creep of connectors subject to seasonal changes in climate.

Project A - Investigation of Load Capacities of Bolted Joints Loaded Perpendicular to the Grain

Background. Several factors have led to this work being carried out: A study by Mack (5) indicated possible inaccuracies with the loads tabulated in the Timber Engineering Code AS 1720 (6) for bolted joints loaded perpendicular to the grain. The findings were based on three member joints which were tested to the provisions of AS 1649 (7). It appeared from the results that substantial increases in code design loads could be considered. Results obtained for loading parallel to the grain appeared to be of the correct order.

Other tests which simulated loading due to wind uplift on a 'tee' joint (8), indicated that no load increase above the existing code value could be assigned to these joints.

A report by Wilkinson (9) concerned with the load capacity of three and two member bolted joints loaded parallel to the grain appears to have led to a halving of the load capacity of two member joints as specified in the 1977 and 1982 editions of the NDS Codes (10). Application of this information to the Australian Code AS 1720 results in halving the capacity of joints made with M10, M12 and M16 bolts up to member thickness to bolt diameter ratios (b/d) of 3.0 to 4.0. This is an important range in commercial use and the possible reduction of the code values for perpendicular to the grain loads, which are already of a low order, was of major concern to designers. The foregoing considerations provided the reasons for undertaking a range of experimental work, some major results of which are discussed below.

Bolt Test Program. Table 1 lists results for 3 member joints in radiata pine tested in compression and tension loading systems with a 16 mm diameter bolt (Figure 1). A range of bolt edge distances and supported spans were used. Table 2 compares the load capacity of 2 and 3 member joints tested in tension.

TABLE 1
Comparision of load characteristics of 3 member joints
Test mean values and standard deviations in brackets

Test No.	Number of samples	Method of loading	Edge distance (mm)	Beam depth (mm)	Beam span (mm)	Maximum load P kN	Proportional Limit kN	Stiffness kN/mm	First major split	Load at 3 mm slip kN	Timber density kg/m^3
1	7	Comp.	4D	100	150	22.8 (1.6)	6.1 (0.52)	8.1 (2.2)	17.8 (1.5)	12.9 (0.5)	534 (15)
2	7	Comp.	4D	100	240	20.7 (1.9)	6.1 (0.89)	11.5 (0.9)	13.9 (1.7)	13.7 (1.7)	537 (36)
3	8	Comp.	3D	80	450	11.4 (1.9)	5.1 (1.1)	6.9 (1.4)	11.4 (1.9)	11.1 (2.2)	510 (46)
4	7	Comp.	4D	100	450	15.7 (1.7)	7.0 (1.3)	7.5 (1.1)	15.7 (1.7)	13.9 (1.4)	545 (71)
5	10	Comp	6D	150	450	32.8 (3.3)	7.5 (1.4)	9.8 (1.6)	22.9 (2.6)	14.6 (1.7)	-
6	10	Comp.	8D	195	450	44.9 (10.3)	5.2 (0.9)	8.5 (1.4)	11.0 (2.8)	11.6 (1.5)	579 (40)
7	6	Tens.	4D	195	300	12.6 (1.3)	5.8 (1.2)	10.4 (2.1)	12.6 (1.3)	12.6 (1.3)	565 (49)
8	9	Tens.	3D	150	300	11.0 (1.8)	6.5 (1.3)	7.3 (1.3)	11.0 (1.8)	11.0 (1.8)	-
9	9	Comp.	4D	96	0	34.9 (1.9)	7.9 (1.1)	9.2 (1.2)	15.2 (1.4)	14.2 (0.8)	516 (17)
10	3	Comp.	8D	195	0	43.0 (8.3)	7.3 (2.4)	8.7 (1.2)	24.0 (9.6)	15.6 -	567 -
Between Tests MEANS, SD's							6.5 (1.0)	8.8 (1.5)	15.6 (4.7)	13.1 (1.6)	-

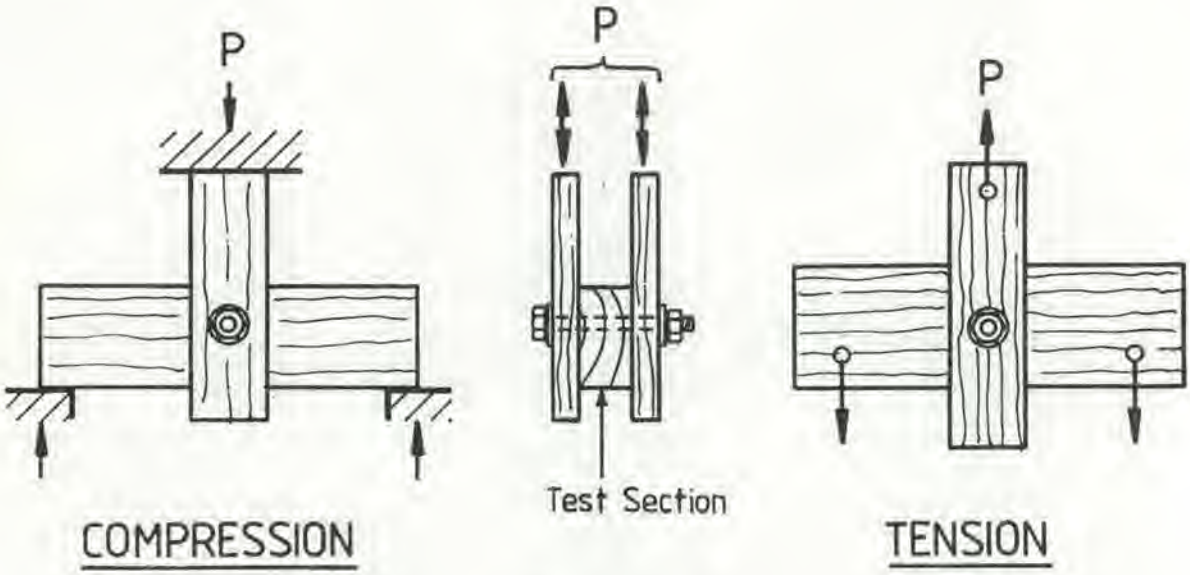

Figure 1. Tension and Compression tests for Three Member Bolted Connections

TABLE 2
Comparison of 3 and 2 member joint capacities under tension loading for three species

Test No.	Number of samples	Bolt diameter (mm)	Edge distance (mm)	Beam depth (mm)	Number of members	P Maximum load (kN)	Proportional limit load (kN)	Timber density kg/m^3
A.	radiata pine (*Pinus radiata*) 38 mm thick; seasoned							
11	10	16	48 (3D)	144	2	12.3 (1.9)	5.9 (1.4)	512 (55)
8	9	16	48 (3D)	144	3	11.0 (1.8)	6.5 (1.3)	-
12	7	16	64 (4D)	195	2	12.5 (1.9)	5.3 (1.3)	572 (52)
7	4	16	64 (4D)	195	3	12.6 (1.3)	5.8 (1.2)	565 (49)
13	6	12	48 (4D)	144	2	11.5 (1.0)	5.0 (1.4)[1]	546 (50)
14	6	12	48 (4D)	144	3	10.1 (1.2)	5.1 (0.7)	534 (42)
B.	alpine ash (*E. delegatensis*) 38 mm thick; (seasoned)							
15	5	16	64	195	2	15.6 (2.2)	7.0 (3.1)	720 (28)
16	5	16	64	195	3	16.6 (3.1)	9.6 (2.1)	720 (28)
17	6	12	48	144	2	12.5 (1.5)	2.2 (0.3)	696 (43)
18	6	12	48	144	3	12.7 (1.3)	6.7 (0.9)	677 (48)
C.	messmate (*E. obliqua*) 38 mm thick initially; (green and green to dry)							
19[1]	5	16	64	195	2	12.6 (1.3)	4.3 (0.9)	593 (72)
20[1]	5	16	64	195	3	13.6 (1.3)	9.3 (1.3)	633 (28)
21[1]	5	16	64	186	2	11.8 (2.8)	5.2 (0.9)	730 (116)
22[1]	5	16	64	186	3	13.6 (2.6)	6.0 (2.0)	803 (50)

NOTES: 1. Tests 19, 20 with green (75% moisture content) and tests 21, 22 with dry material

In Table 1 the maximum loads in Tests 1 to 6 and in 9 and 10 are dependent on the dimensions and method of support of the test specimen, although the load-deformation characteristics of all joints up to 3 mm slip are similar for each test. Test 2 conformed to the minimum requirements of AS 1649 and Mack's tests used similar dimensions but probably with a shorter span. This test and the method of analysis determines the beam strength of the test member not the joint capacity. Tests 7 and 8 were for the tension load system and the maximum joint loads corresponded to a load at which splitting occurred at the bolt-wood interface. Initial splitting in compression tests tended to occur below the maximum loads.

Table 2 indicates that the load capacity of two member and three member joints are the same for equal thickness of the main member. This is in agreement with current requirements of AS 1720, but disagrees with Wilkinson's predictions.

The results of these experiments have been discussed fully in another paper (11) and the general conclusions are:

(a) The requirements of AS 1649 for evaluating bolted (and similar joints) in loading perpendicular to the grain are unsuitable, and may overestimate the strength in situations where propagation of splitting is inhibited.

(b) There is a need to resolve the different findings that exist in relation to the measurement of the load capacity of two member joints and to develop a standard test for the measurement.

(c) The evidence of recent tests indicates that the load capacity for perpendicular to the grain loads may be increased by 1.5 for b/d ratios up to 4/1 for three member joints. This would be a useful increase for timber designers.

Project B - Load capacity of punched tooth-plate connector fasteners in juvenile and low density softwoods

Background. One of the main problems discussed at the 21st FPRC (3) was with reference to imported Spruce-Pine-Fire (SPF) for which it was shown that mature clear low-density wood with closely spaced growth rings may

have a relatively high stress grade but poor connector holding properties due to the low density. A further difficulty has been encountered where fabricators and builders, having a wide experience with a timber of a recognized stress grade and joint group (e.g. F5, JD4 for radiata pine), may associate other timber of that particular stress grade with the same joint strength group. More imports of the SPF species group through 1985 led to a need to review the data established from the earlier samples.

Inadequate connector capacity is also encountered with juvenile wood because of non-typical failure modes that can occur with tooth-plates (and other connectors) in such wood. Low connector loads with pith-included (i.e. juvenile) radiata pine, machine stress graded to F5, were noted by Taddich, Gang Nail Australia Ltd. (pers. comm. 1985) and this has been further investigated and reported by Lhuede et al. (12).

A major use of such timber (i.e. low density and juvenile softwoods) is in tooth-plate connected domestic roof trusses; while industry monitoring of product quality is highly effective the results of independent studies and assessments of tooth-plate connector performance in low density species have been sought by end users.

Work has continued on this topic for these reasons.

Spruce-Pine-Fir Characteristics. The density spread of two randomly selected packs of SPF imported from Canada in 1985 each containing about 185 sticks (90 x 35 x 4920 mm) is shown in Figure 2. they are compared with the densities of the wood of the same species group discussed at the 21st FPRC. The wood had been visually graded at the mill and one pack was marked F5 and the other was regarded as a lower 'Utility' grade. The majority of pieces were back sawn, contained pith with 10-15 rings per centimetre and both packs contained up to 10% Fir. Seventeen per cent of the F5 pack was in the JD5 density range of 380-470 kg/m^3. The mean densities of the F5 and Utility grade packs were 510 kg/m^3, s.d 59 kg/m^3 and 493 kg/m^3, s.d 55 kg/m^3 respectively. These measurements showed the marked changes that can be effected within a species group and indicated the existence of a relatively large proportion of low density material contained in an F5 grade material.

Tooth loads for 1985 Sample of SPF. Twenty-two specimens were selected

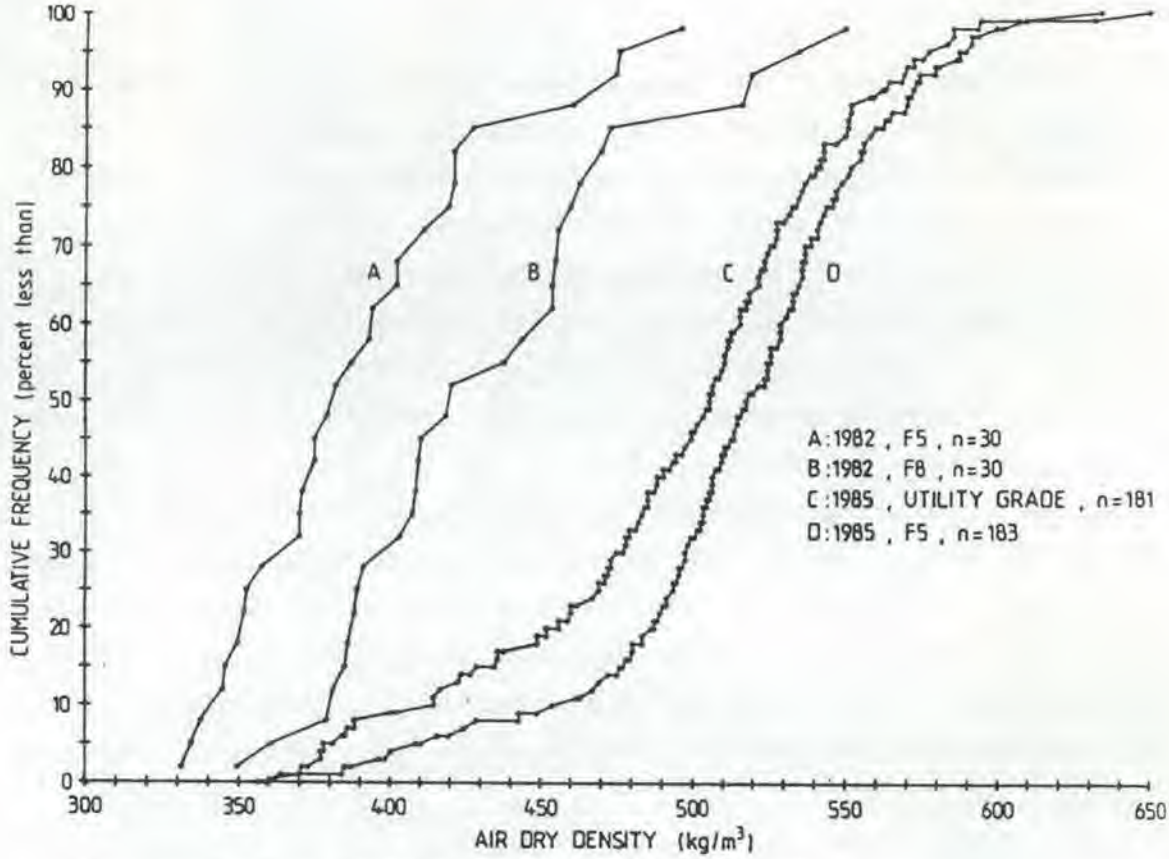

Figure 2. Density of Spruce-Pine-Fir Samples

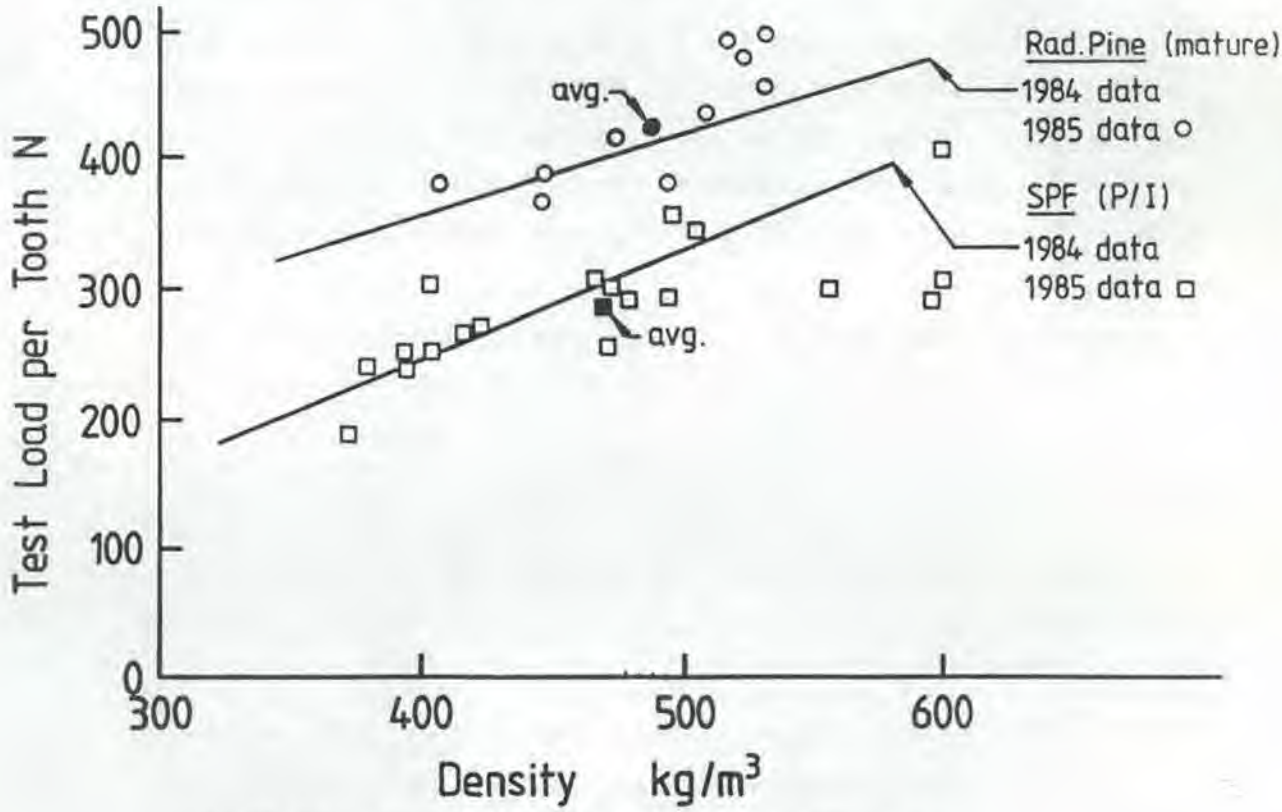

Figure 3. Load per Tooth for Spruce-Pine-Fir and Radiata Pine for Different Densities of Wood GN20 Plates

to be representative of the density range of the two packs. Connections were made with two types of 1 mm thick punched tooth-plates in current use (Gang Nail GN20 and Pryda 'Claw 3') and measurements are reported for parallel loading. A non-standard method of test was used where plates were embedded into one face of the test member and load was applied along the face of the member; the method provides comparable loads to the standard test where teeth are embedded on each side of the joint, but allows measurement of tooth loads in pith included and clear faces to be made separately (12).

Figure 3 shows the load/tooth measurements for the GN20 plates for the 22 SPF samples and a comparative test with mature(pith free) radiata pine tested in the same way. The data for the Gang Nail plates reported in the 1984 FPRC (3) is also plotted. Code basic loads derived from maximum loads are tabulated in Table 3 for the two types of plate and the manufacturers recommended basic loads for joint groups JD4, JD5 and JD6 are also listed.

Table 3 shows that for the current sample of SPF the punched tooth-plate load capacities were, at best, JD6 although the density of the sample was just outside the JD4 range of 475-595 kg/m^3. The tooth-loads are considerably lower than would be predicted from a linear average load per tooth-density relationship that is generally considered to apply to these connectors, as shown on Figure 3. Although the stress grade of Spruce-Pine-Fir can be as high as F8, the optimal utilization of this strength is made difficult by poor connection properties.

TABLE 3
Basic Loads For SPF with GN20 and Pryda 'Claw 3' Plates

Joint details wood - plate type	Wood density for sample tested (kg/m^3)	Average Maximum load per tooth N	Basic load per tooth N
SPF - GN20	470	285	75
SPF - Pryda 'Claw 3'	470	287	81
Radiata Pine - GN20	492	425	121
Manufacturers recommended loads (N/tooth)			
Joint group	JD4	JD5	JD6
GN20	125	100	–
'Claw 3'	133	113	79

Failure of juvenile Radiata-pine. Back-sawn sections of juvenile, fast-grown, radiata pine in 90 x 35 mm cross-section may include the pith and as few as 6 or 7 growth rings across the section; the bands of low density earlywood are 7-12 mm wide. Teeth engaged in these bands exhibit 10% lower load capacity than those embedded on the opposite side of the section which are engaged partly in the narrow, denser late-wood bands. In some tests failure has occurred by'ring-shear' of a section of wood under a tooth-plate along an early wood - late wood boundary. This is not the normal mode of failure where tooth-withdrawal or plate tear is expected and it represents a further limitation on the design of tooth plate connected joints in juvenile fast-grown woods.

Tests on low density woods in perpendicular to the grain loading have provided another case of a non-standard failure; depending on the span of the member being tested, failure in tension perpendicular to the grain can occur at lower loads than predicted by the load per tooth capacity of the joint.

The problem of 'non-standard failures' was also encountered with 67 mm diameter shear plates in Radiata pine (13).

The conclusions reached in this project are:

(a) There is a need to educate the users of domestic framing timbers to the differences between stress grades and joint groupings for certain local and imported species.

(b) The reasons for low tooth withdrawal loads with low density slow grown imported softwoods, particularly from the SPF group, should be determined.

(c) Designers using tooth-plate and other connectors should be aware of the possibility of non-standard failure modes of connectors at lower loads than predicted from standard tests, particularly where low density and/or juvenile woods are used.

Project C - Effect of climatic changes on creep rate of tooth-plate connectors

Background. The creep of tooth plate connected joints was measured by Leicester *et al.* (14) and increases in joint deformation were noted during the onset of warmer weather (October in Melbourne). Initial deformations of plates in current use under tensile working loads are relatively small (e.g. 0.07-0.10 mm) and they may increase by factors of

10/1 over a period of years. Such deformations are small and it is the reduction of the original short term (3-5 minute test) strength of the joint that is of concern. Literature dealing with long term creep in solid wood with changing moisture content is extensive but there is less information relating to connectors. Avaialble connector data (15, 16, 17) has been obtained in a Northern hemisphere climate and it has been difficult to extrapolate this to local conditions; a basis for comparing the affects of climatic variables (on creep) is therefore necessary.

There have been no reports of failures in service of tooth plate connected joints after long term loading but the high usage of these connectors in domestic framing justifies further work.

Current Experiments. Deformations of joints made with kiln dried radiata pine loaded in tension to either 20% or 30% of their short term failure load, and subjected to normal climatic variations have been monitored for 240 weeks. Surface moisture contents near the connectors were read with a meter and the mass of matching blocks of wood have been measured to determine average moisture contents. The joints loaded to 30% of their capacity exhibit lifting of the end of the tooth plate which may be indicative of an initial stage of failure. Deformations (after 240 weeks) relative to the initial slip (Δ/Δ_o) average 9.0 and 11.0 for the 20% and 30% loadings respectively. Moisture contents (m.c.) of the specimens vary seasonally from 10% to 14% with daily changes of 1% to 1.5%.

A laboratory controlled experiment has been conducted on a joint in dry spruce loaded to 20% of maximum load where it was cycled between 40% and 85% relative humidity (R.H.) at 20°C to an equilibrium condition at each R.H. Deformations were measured continuously to ±0.003 mm; total movements of about 0.16 mm occurred for an absorption cycle with about 95% recovery on desorption after the first two cycles. After 20 cycles a Δ/Δ_o of 2.0 resulted for Δ_o = 0.08 mm.

The long term experiment supports previous findings regarding the increase in creep (Δ/Δ_o) during the onset of warmer climatic conditions; during this period the measured average moisture content of the wood decreases from ca. 14% towards the summer value of 10%, and relaxation (of the wood) around the teeth of the connector plate takes place. As shown in Table 4, this is in accord with the generally lower e.m.c. of the wood at the test condition during spring.

Sample moisture contents change cyclically each day, and as may be deduced from the vapour pressures listed in Table 4 higher rates of moisture diffusion from the wood surface (if assumed to be at the saturation pressure Ps) to the surrounding atmosphere (P_A) may be expected in the warmer months. These daily changes, as indicated by the laboratory tests, result in a small residual deformation after each cycle.

TABLE 4
Atmopheric vapour pressures
– Summer and winter conditions (typical day)

Condition	d.b. °C	R.H. %	Wood e.m.c. %	Sat. vap. press. (kPa) P_S	Atmph. vap. press. (kPa) P_A	Diffusion rate $\alpha(P_S-P_A)$
Spring, mid-afternoon	25	60	11	3.15	1.90	1.25
early morning	15	90	20	1.76	1.59	0.17
Winter, mid-afternoon	11	80	16	1.22	0.98	0.24
early morning	4	95	22	0.78	0.74	0.04

The behaviour is very similar to that observed when a similar joint has been loaded in tension and cycled over a small range (8%) of the constant stress at fixed R.H.

The project has identified some variables which determine the increased rates of creep that are observed with tooth plate connectors during the spring months, and it may be possible to simulate this behaviour in a test machine at constant humidity by varying the applied load.

SUMMARY

Recent and current work on timber connectors has been directed towards two requirements; first, DBR has traditionally taken a lead in the formulation of timber design and testing codes; the work on bolted connections and to an extent, the effects of climatic variables on the long term load capacity of fasteners, are directed towards code modification. A better understanding of the latter topic is also necessary to permit extrapolation of overseas results to local

conditions. The direct advantages may be limited, but all major timber structural design is reliant on soundly based code data and the benefits are in the form of more efficient and safer structures.

Secondly, studies related to the connection properties of timbers used in domestic framing have high economic significance as even minor failures involve large quantities of wood and remedial actions may involve considerable consumer expense nationally; identification of problems with SPF and with fast grown softwoods is important because of the wide use of these woods. Any potential cause for failure of tooth plate connected trusses within a life span of 50 years justifies further work on these woods.

ACKNOWLEDGMENT

The author acknowledges the extensive assistance provided by Mr P.J. Crawford and Mr S. Towstoless.

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Annual East. market for roof trusses = $70 M
& East coast timber market = $500 M (mostly housing)
of sleepers $12 M !
palings $9 M !

DESIGN FOR HIGH-WIND AREAS

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ABSTRACT

Damage caused by storms and cyclones in Australia over the last 15 years have generated keen interest in domestic engineering. Design rules, test procedures and specifications that have been developed and instigated in Queensland are more than adequate to resist the wind forces currently specified by AS 1170 - Part 2. These publications need urgent revision to cater for current building techniques and to permit analytical design procedures.

INTRODUCTION

The devastating damage caused by Cyclone Althea in 1971, the Brisbane Wind Storm in 1973 and Cyclone Tracey in 1974, created an acute awareness in building regulatory authorities and designers for accurate structural design input into domestic construction. Unfortunately, this resulted in an "overkill" situation in the mid-1970's with design documents and criteria generated that did not or could not fully recognize the structural behavior of small scale "box like" buildings.

The restrictive design codes that resulted from this, provided the impetus for industry to initiate extensive research and testing programmes aimed at providing realistic design data. The programmes concentrated on full scale component testing and have subsequently led to the testing of whole houses. Major areas of interest are being directed to fixing of roofing materials, tie-down connections, wall bracing and horizontal diaphragm action.

A whole suite of industry and regulatory design documents have now been developed for timber framed construction in high wind areas. The first generation of these was published by TRADAC in 1979, and catered for design wind speeds at 33 m/s and 42 m/s. These have now been extended to wind speeds up to 65 m/s, covering Terrain Category 1 Cyclonic Areas.

The current details contained in these documents are compiled from Australian Standard Code requirements, test data and "seat of the pants" intuition.

There still exists enormous scope for further research and subsequent refinement of building design requirements, particularly in the areas of bracing and diaphragms, tie-down and composite action.

This paper provides a general overview of some of the major aspects, problems and solutions that have been addressed in the development of timber framed domestic construction design, in high wind areas, during the last decade.

DESIGN CRITERIA AND TESTING

In general, the design criteria and testing procedures adopted for domestic structures in Queensland are based on publications from the Experimental Building Station (1) and the Cyclone Testing Station (2). These documents, through a rational interpretation of the Wind Code (3), define loads, pressure co-efficients, serviceability criteria and testing procedures appropriate for component or product evaluation. Although limited in scope, they have also been widely used as a basis of criteria for analytical design purposes.

With revisions to the Wind Code and their wide use as design documents, these publications are in urgent need of revision. Their scope should be broadened to permit their application to design, with specific attention being paid to maximum and minimum internal and external pressure co-efficients and serviceability limits.

Table 1 provides a summary of the wind criteria generally applied in Queensland.

As can be seen from Table 1, "worst combination" pressure co-efficients are used for strength calculations in cyclonic areas. For well over a decade, however, one major truss plate manufacturer has used a lesser internal pressure co-efficient (Cp_i + 0.4) with no apparent major failures resulting. Also, truss plate manufacturers do not apply the local pressure factors to the underside of eaves. This is at variation to the Timber Framing Code and again, no eaves failures, due to cyclonic winds are known of.

Table 1 also highlights the philosophy of accepting less stringent serviceability (deflection) criteria in cyclonic areas than in non-cyclonic ones.

This relaxation provides a trade-off between affordable housing and minor damage that may be caused once in 50 years. This criteria is considered quite acceptable as routine house maintenance (painting, patching plaster etc) occurs at more frequent intervals. A similar philosophy may also be applicable to non-cyclonic design, although it is currently not applied.

TABLE 1

Wind Loading Criteria Generally Adopted in Queensland

	Cyclonic		Non - Cyclonic	
	Strength	Deflection	Strength	Deflection
Return Period	50 yrs	25 yrs	50 yrs	50 yrs
Regional Velocity	55 m/s	50 m/s	50 m/s	50 m/s
Cyclonic Factor	1.5	-	-	-
Internal Pressure Co-efficients:	+0.8,-0.6	+0.2,-0.3	+0.3,-0.3	+0.3,-0.3
External Pressure Co-efficients:				
Wall - Framing	+0.8,-0.6	+0.8,-0.6	+0.8,-0.6	+0.8,-0.6
- Racking (pitches up to 25°)				
- highset	+0.8,-0.3	-	+0.8,-0.3	-
- lowset	+0.6,-0.4	-	+0.6,-0.3	-
Roofs- Framing	-0.9	-0.9	-0.9	-0.9
Local Pressure Factors:				
- roof battens	1.5		1.5	
- under eaves	1.5		1.5	

The accuracy of the Wind Code is also questioned with respect to the pressures and co-efficients contained in it relevant to low rise structures. It is believed that the majority of the data contained in the Code are based on wind tunnel modelling of Terrain Category 2 conditions. This is then correlated back to other terrain categories. As most domestic construction occurs in Terrain Category 3, it seems more appropriate that wind tunnel tests data should be developed using Category 3 conditions as the base.

With respect to product testing (walls, roofs, cladding, etc), both EBS Technical Record 440 and Cyclone Testing Station Technical Report No. 5, set out cyclic loading regimes aimed at minimising fatigue damage known to occur as the result of long duration dynamic loading during cyclones.

The regimes specify approximately 1,000 load cycles for walls and 10,000 load cycles for roof and wall cladding and roof structures. The 10,000 cycles required for uplift of whole roof structures is considered extremely excessive, particularly if this regime is meant to simulate the global uplift forces occurring on a house during a cyclone.

Although limited in scope, both EBS 440 and TR5 have provided a sound basis for product, component and whole house testing. In particular, current results being obtained from full scale house evaluations are providing far more realistic design data than is able to be achieved from small scale tests or design.

TIMBER AND PLYWOOD

The design of timber components for high wind domestic construction relies predominately on the procedures outlined in the Timber Engineering Code (4). Using this code as a design base, it is very difficult to justify the traditional timber sizes used that are found to perform satisfactorily in the cyclonic region. All possible "positive" modification factors need to be applied, and indeed some modification factors that reduce basic working stresses are usually neglected in design. These include K_{12} for lateral stability and K_5 and K_6 for moisture content and temperature.

The procedure adopted in Queensland for determining house framing member sizes for high wind areas is, firstly, to determine an appropriate size using the Timber Framing Code (5), (this size will then satisfy the normal dead and live load strength and serviceability requirements) and secondly, to check this size to ensure it is capable of sustaining the increased wind loads for the higher design wind speed under consideration.

The wind load check is performed using the appropriate criteria given in Table 1.

As the Timber Engineering Code, in its current form, does not offer great scope to achieve significant economies in design, considerable testing has also been performed on the structural timber components. The majority of this work has concentrated on plywood shear wall development. In this regard, publications such as the Structural Plywood Wall Bracing Design Manual (6) have been developed which provide data to enable shear walls with racking strengths of up to 8 kN/m to be used in domestic construction.

Very little composite action is assumed to occur between timber frames and the sheet materials that are fixed to them. Full scale testing does, however, indicate a degree of composite action that can be utilized with timber design.

A testing programme conducted by TRADAC in 1981 (7) provided data that showed increases in the lateral strength and stiffness of walls of up to 25% and 50% respectively, could be achieved by nailing structural ply bracing to the studs and plates at 150 mm crs. This data has been included in the TRADAC design manuals.

Further research should be conducted to determine similar effects for other sheet materials, particularly where they are fixed with elastomeric adhesives and mechanical fasteners, as these should be capable of sustaining short duration wind loads.

Some degree of deep beam action must also occur in lined or clad timber stud walls. This action has been studied to a small extent with the shear wall testing programmes. Little data, however, has been quantified and,

therefore, tie-down spacings and wall strengths under uplift force are chosen arbitrarily or by trial and error.

Considerable gains could also be achieved in domestic high wind design if stresses for timber were based on appropriate strengths of wall and roof systems rather than the strengths of their individual components.

To illustrate this, the maximum working stress in bending, under wind load, permitted by AS 1720 is compared in Table 2, to typical modulus of rupture values obtained from full scale tests of sections of walls under lateral load (7).

TABLE 2

Comparison of Short Duration Design Bending Stresses with Modulus of Rupture obtained from Tests

Timber	Stress Grade	No. Frames	Bending Stress (a) Permitted by AS 1720 (MPa)	Modulus of Rupture (MPa) from Test	
				Minimum	Average
Cypress	F5 (Proof Graded)	12	13.3	22.4	34.1
Radiata	F5 (M.S.G)	12	12.13	16.6	30.5
Hardwood	F22 (Visually Graded)	12	53.4	88.0	105.8

Note: a) The bending stress permitted by AS 1720 takes into account the following modification factors where appropriate, K1 = 1.75, K4 = 1.10, K8 = 1.26.

It can be seen from this table, that the actual strength of the walls is at least 37% higher than that permitted by the Timber Engineering Code.

FASTENERS

The greatest challenge faced in design for high wind areas is connecting various timber components together to form a vertical chain from roof to foundations. Current data contained in AS 1720 provides a limited range of information relevant to domestic construction.

The majority of connections in current use have evolved from building practices developed on site, these connections include brackets, bent straps, screws and nails in withdrawal and bent rod.

In this regard, design limitations in AS 1720 have been found in the following areas:-

i) Short duration withdrawal loads obtained from tests, for screws and nails differ widely from those permitted by AS 1720. Refer to Table 3 for comparisons.

ii) Allowable bolt loads for tension perpendicular to grain are not provided in AS 1720.

iii) Bolt loads in AS 1720 are often limited by slip rather than strength. This limitation is not realistic with respect to domestic construction.

iv) Timber sizes in domestic construction are small, therefore, end and edge distances are often less than required for bolts, screws, etc.

v) The strength of bolts (steel strength) is far greater than currently permitted by AS 1250 (personnel communication - Dr. L. Pham).

vi) The allowable fastener loads in AS 1720 that are derived from AS 1649, do not consider cyclic loading or the potential of fatigue failure.

TABLE 3

Comparison of Withdrawal Strength (kN) of Screws

Joint Group	Current AS 1720[a]	Proposed AS 1720[b]	TRADAC Manuals[c]
J2	3.0	2.0	2.7
J3	2.1	1.5	1.9
J4	1.3	1.1	1.5
JD4	1.9	1.7	1.9
JD5	-	1.3	1.4

Notes:- a. Includes duration of Load Factor of 2.0.
b. No duration of Load Factor permitted.
c. Based on Test Data of Type 17 No. 14 Screws.

In addition to the above, shrinkage is also of concern, particularly where cyclone rods are used for tie-down.

As a result of the above considerations, extensive testing programmes have provided a great deal of the usable information that is contained in current Queensland building specifications.

CURRENT SOLUTIONS

With the support of Government, Research Authorities and other Industry bodies, the Timber Industry in Queensland have developed a comprehensive suite of framing manuals (8) that provide force tables, bracing, tie-down and timber size details for design wind velocities up to 65 m/s. These documents are tailored to the needs of domestic building designers, but are also widely used by consulting engineers, architects and local authorities.

The details contained in the manuals are based on a mix of engineering design (using current codes), test results and traditional practices. Appendix 1 provides examples of this information.

Where possible, ultimate strength has been the primary consideration in developing the details contained in the manuals.

Serviceability, deflection and joint deformations are of secondary consideration.

Surveys conducted in Queensland after the Brisbane January,'85 Wind Storm and Cyclone Winifred (9 & 10) have shown that the current building standards imposed by Appendix 4 to the Queensland Building Act and the TRADAC Framing Manuals result in domestic structures that are structurally adequate with respect to the design wind speeds currently specified in AS 1170 - SAA Wind Loading Code.

Indications do, in fact, point towards a possible relaxation of some of the structural details provided by the imposed standards, particularly in the area of bracing.

CONCLUSION

1. Current publications providing recommendations and guidelines for testing products and components for use in high wind areas are in need of revision and require broadening of scope to provide analytical design guidelines.
2. AS 1720 does not lend itself to the design of domestic timber structures in high wind areas, particularly with respect to connectors.
3. Product testing provides more economical structural solutions for house design than do Code requirements.
4. The current building standards imposed by legislation in Queensland are more than adequate with respect to the design wind speeds applicable in the State.

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APPENDIX 1

(Extracts from Queensland Timber Framing Manual W42)

8.8 UPLIFT FORCES ON RAFTERS/TRUSSES

The uplift forces on rafters or trusses shall be determined from Table 8.8 and tie-down details to resist the uplift from Figures 8.8(A), 8.8(B), 8.8(C), as appropriate.

TABLE 8.8

RAFTERS/TRUSSES TO WALL FRAME, FLOOR FRAME OR SLAB WALL FRAME TO FLOOR FRAME OR SLAB			
Dimension 'A' (mm)	'Fixing Spacing' (mm) i.e. rafters/trusses/ studs or bottom plate fixing spacing etc.	Uplift Force (kN)	
		Tile Roof	Sheet Roof
1800	450	0.7	1.1
	600	0.9	1.4
	900	1.3	2.1
	1200	1.7	2.8
	1800	2.6	4.2
2500	450	0.9	1.5
	600	1.2	2.0
	900	1.8	2.9
	1200	2.4	3.9
	1800	3.6	5.8
3600	450	1.3	2.1
	600	1.7	2.8
	900	2.6	4.2
	1200	3.5	5.6
	1800	5.2	8.4
4500	450	1.6	2.6
	600	2.2	3.5
	900	3.2	5.3
	1200	4.3	7.0
	1800	6.4	10.6
5200	450	1.9	3.0
	600	2.5	4.1
	900	3.7	6.1
	1200	5.0	8.1
	1800	7.4	12.2
6700	450	2.4	3.9
	600	3.2	5.2
	900	4.8	7.8
	1200	6.4	10.5
	1800	9.6	15.6

Note:— Top plates required to resist uplift (refer Section 10 Tables 18 & 19) shall be tied down to studs, lintels, bottom plates or floor at a maximum of 1800 mm crs for truss spans up to 9000 mm and 1200 mm crs for truss spans 9001 mm to 12000 mm.

8.8.1 Underbattens

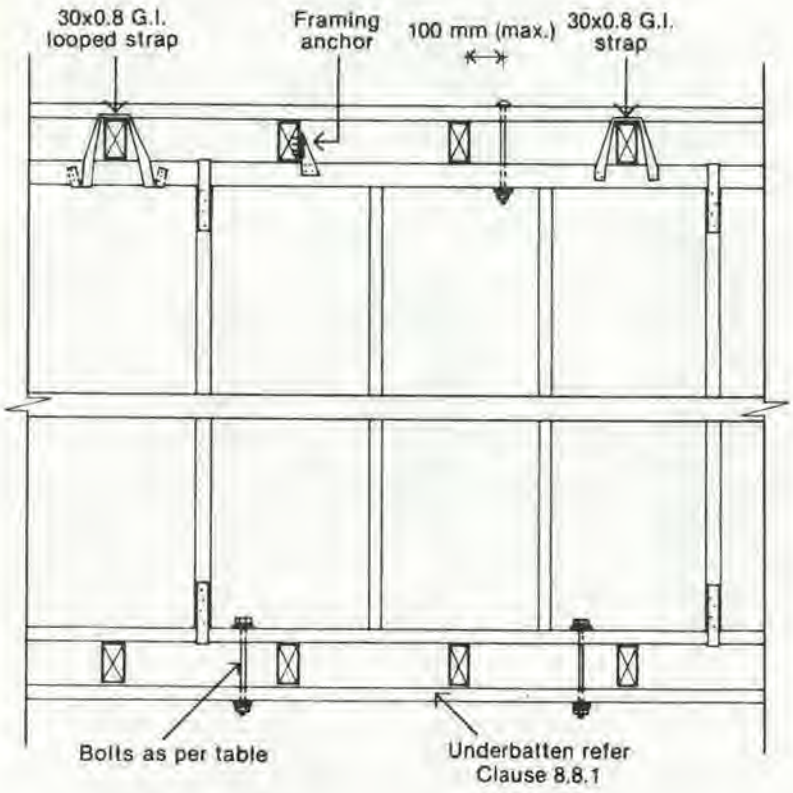
Where underbattens are required under floor joists to resist uplift loads, the underbatten size shall be 50x75 for stress grades F11 or better and 75x75 (70x70) for stress grades less than F11.

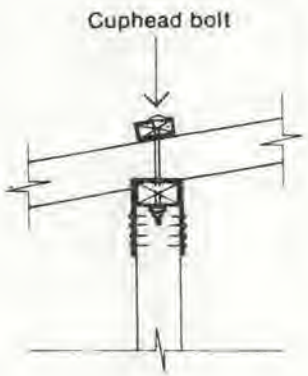
FIGURE 8.8(B)

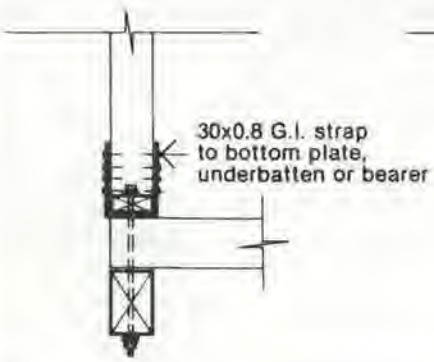
TIE-DOWN: RAFTER OR TRUSSES TO WALL FRAME/FLOOR FRAME/SLAB

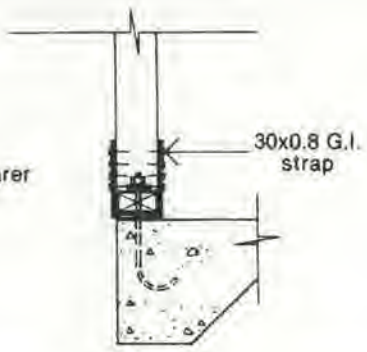
	Design Strength (kN)					
	Unseasoned Timber			Seasoned Timber		
	J2	J3	J4	JD4	JD5	JD6
30x0.8 G.I. Strap 3/2.8 ⌀ nails each end	4.0	2.8	2.0	3.0	2.5	1.9
30x0.8 G.I. Strap 4/2.8 ⌀ nails each end	5.1	3.6	2.6	4.0	3.3	2.5
1 Framing Anchor 4/2.8 ⌀ nails each end	3.0	2.2	1.5	2.2	1.8	1.3
2 Framing Anchors 4/2.8 ⌀ nails each end	5.1	3.6	2.6	4.5	3.3	2.5
*M10 Cuphead bolt	8.4	6.7	3.6	6.7	4.3	2.8
*M10 bolt	13	12	6.0	11	7.0	4.6
*M12 bolt	20	20	10	19	12	8.0
30x0.8 G.I. Looped Strap - nails required each end are: 3/2.8 ⌀ for J2, 4/2.8 ⌀ for J3 & JD4, 5/2.8 ⌀ for J4, JD5 & JD6	7.2	7.2	7.2	7.2	7.2	7.2

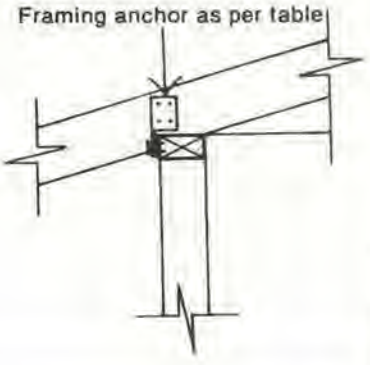
* **Note:** Metal straps and anchors may limit tie-down strength.











8.11 UPLIFT FORCES ON ROOF BATTENS

The uplift forces on roof battens shall be determined from Table 8.11. For typical batten to rafter/truss tie-down details and design strengths refer to Figure 8.11.

TABLE 8.11

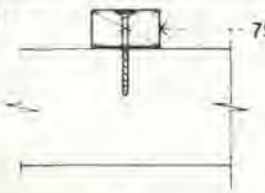
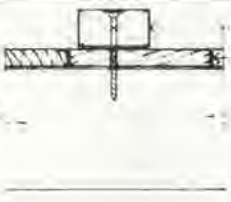
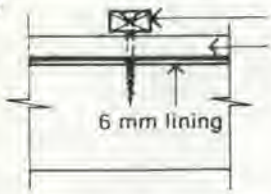
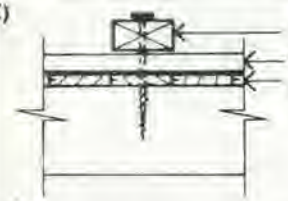
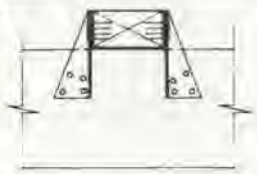
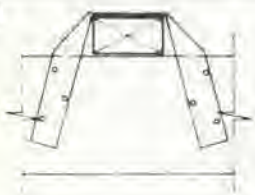
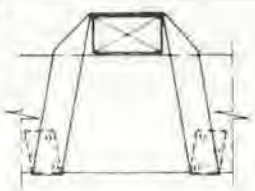
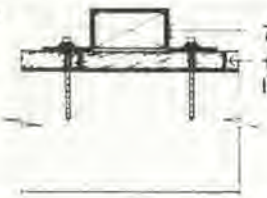
BATTENS TO RAFTERS OR TRUSSES			
Rafter or Truss Spacing (mm)	Batten Spacing (mm)	Roof Type	Uplift Force (kN)
600	330	Tile	0.41
	370	Sheet	0.58
	450	Sheet	0.71
	600	Sheet	0.94
	750	Sheet	1.2
	900	Sheet	1.4
	1200	Sheet	1.9
900	330	Tile	0.62
	370	Sheet	0.87
	450	Sheet	1.1
	600	Sheet	1.4
	750	Sheet	1.8
	900	Sheet	2.1
	1200	Sheet	2.8
1200	330	Tile	0.83
	370	Sheet	1.2
	450	Sheet	1.4
	600	Sheet	1.9
	750	Sheet	2.4
	900	Sheet	2.8
	1200	Sheet	3.8

Notes: i) Tile roofs shall mean concrete or terracotta tiles. Sheet roof shall mean metal or other "lightweight" tiles or other sheet materials.

ii) The uplift forces in Table 8.11 assume maximum internal pressure. Where ceiling lining material is structurally sufficient to resist the maximum internal pressure and the ceiling cavity is not vented to internal room pressure, then the batten to rafter or truss connection may be designed for partial internal pressure by multiplying the respective uplift forces above by 0.8.

FIGURE 8.11 continued

FIXING OR ROOF BATTENS TO RAFTERS OR TRUSSES

			Design Strength (kN)					
			Unseasoned Timber			Seasoned Timber		
			J2	J3	J4	JD4	JD5	JD6
H)	 75 x 38 batten	1/90 mm No. 14 Type 17 screw (50 mm penetration into receiving member)	3.5	2.5	2.0	2.5	1.8	1.4
I)	 75 x 38 batten 19 mm lining	1/90 mm No. 14 Type 17 screw (33 mm penetration into receiving member)	2.3	1.6	1.3	1.6	1.2	1.0
		1/100 mm No. 14 Type 17 screw (43 mm penetration into receiving member)	3.1	2.2	1.7	2.2	1.6	1.2
J)	 50 x 25 batten 50 x 25 counter batten 6 mm lining	1/100 mm No. 14 Type 17 screw (43 mm penetration into receiving member)	3.1	2.2	1.7	2.2	1.6	1.2
K)	 75 x 38 or 50 x 38 batten 50 x 25 counter batten 19 mm lining	1/150 x 5.6 Ø helical threaded nail	2.4	2.1	1.7	2.1	1.5	1.1
L)		1 framing anchor (4/2.8 Ø nails each leg — to be placed on alternative sides of batten)	3.0	2.2	1.5	2.2	1.8	1.3
		2 framing anchors (4/2.8 Ø nails each leg)	5.1	3.6	2.6	4.0	3.3	2.5
M)	 30 x 0.8 G.I. strap with 2.8 Ø nails each end of strap as per table	No. of nails each end of strap 3	4.0	2.8	2.0	3.0	2.5	1.9
		4	5.1	3.6	2.6	4.0	3.3	2.5
N)		30 x 0.8 Ø G.I. looped strap (3/2.8 Ø nails each end for J2 timber) (4/2.8 Ø nails each end for J3 & JD4 timber) (5/2.8 Ø nails each end for J4, JD5 & JD6 timber)	7.2	7.2	7.2	7.2	7.2	7.2
O)	 75 x 38 batten 19 mm lining	30 x 1.8 G.I. strap 1/75 mm No. 14 Type 17 screw at each end	7.0	5.0	3.6	5.0	3.6	1.9

THE STRUCTURAL RESPONSE OF A TONGAN HURRICANE HOUSE TO SIMULATED CYCLONE LOADING

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ABSTRACT

The hurricane house has been loaded simulating the pressures of cyclone winds. Its elastic response has been measured, and an analysis made to determine load sharing between lateral walls, together with the effect of a roof diaphragm. The cyclic loading regime pinpointed a weakness in construction in respect of light gauge metal hold-down straps. The house was modified and successfully withstood the full complement of load cycles, despite a number of local failures and some resultant excessive deflections.

1. INTRODUCTION

A severe housing shortage was one of the main consequences of cyclone Isaac, after it devasted the Pacific island kingdom of Tonga in 1982 (1). Two thousand families were left homeless. The Tongan Ministry of Works embarked on a reconstruction programme and designed a cyclone resistant house of timber framed panel components. The panels were constructed at Nuku'alofa, the capital and transported either by land or sea to the villages. One set of components was shipped to the Cyclone Testing Station where facilities have been developed to simulate cyclone wind forces on houses, and measure their response and strength.

2. THE TONGAN HURRICAN HOUSE

The structural design of the components was undertaken by Ministry of Works (MOW) engineers in consultation with the Building Research Establishment, U.K. (BRE) who had been involved in a similar exercise at St. Vincent in the Caribbean (2). The results of the combined MOW, BRE design became known as the 'Hurricane House'.

Simplicity was the basic concept of the reconstruction programme. The decision was made to have only one floor plan, Fig. 1, with the possibility of later extension by the owner. The plan is based on modular wall construction 2.4 m long, thus the standard house is three panels long and two panels wide (7.2 m x 4.8 m).

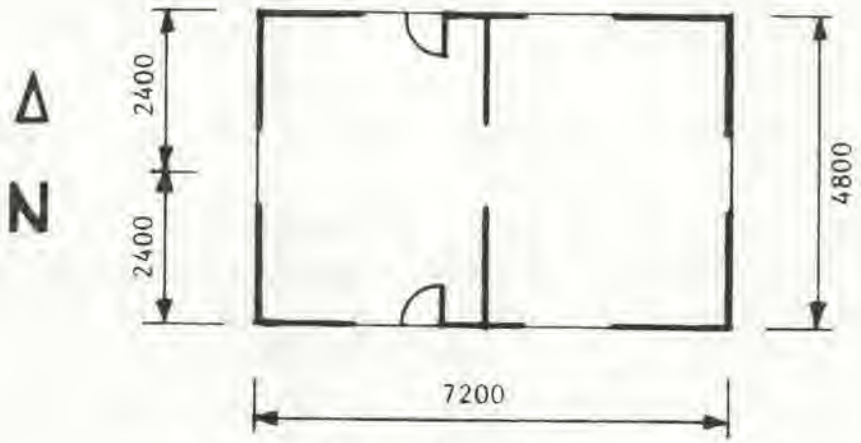

Figure 1 Floor plan of hurricane house

BRE co-operated with MOW to organize a sample set of components to be sent to the Cyclone Testing Station for erection and test. By doing this, the strength of that prototype house under simulated cyclone wind conditions could be determined. Further if there were an unforseen weaknesses in the design they could be pinpointed during the test programme. This would allow modifications to be made to existing houses if necessary, and thus they could be made safer prior to the next cyclone.

To ensure that the components were correctly assembled in Australia, the Tongan Assistant Secretary of Works supervised and participated in the construction of the test house. Thus with Tongan components and construction techniques the house represented as closely as possible a typical hurricane house. Only the foundation conditions were different.

Structural details of the test house nominally were as follows:

200 mm dia. pile stumps on 1200 mm grid
100 x 75 mm bearers at 1200 mm spacing
100 x 50 mm joists at 600 mm spacing
100 x 50 mm wall studs at 600 mm spacing
100 x 50 mm top and bottom plates
4.8 m span roof trusses at 1200 mm spacing
75 x 50 mm battens at approximately 600 mm spacing

The house was clad externally with 8 mm thick plywood and had a corrugated galvanized steel roof. The timber was hem-fir from USA.

The internal partition wall was basically non-structural. The timber framing of that wall was clad on one face with 4.5 mm hardboard fastened with light gauge brads at about 150 mm spacing. There was no other internal lining or ceiling.

3. WIND LOADINGS AND SIMULATION

3.1 Design Wind Loads

Structural engineering calculations for the design of the test house were provided for the Station by the Tongan MOW. They were based on the New Zealand wind loading code (3) and timber code (4). The basic gust wind speed was taken as 66 metres per second which after various modifications yielded a design wind speed of 62 m/s and a quasi static design pressure of 2.36 kPa. Net uplift design pressure on the roof structure was calculated as 2.6 kPa and the wall bracing was designed for 3.5 kPa. A subsequent check of the calculations by the Cyclone Testing Station revealed that the light gauge metal strap securing the trusses would be overstressed by about 60% at design load, but that stress would still be only about 50% of the predicted static failing load.

3.2 Simulated Loading and Measurement

After having determined design loads, forces were applied to the hurricane house in such a manner as to produce the same structural effect as those loads. The mechanics of the force application are illustrated in Fig. 2.

Racking forces were applied to the top of the structure by a hydraulic ram (a) which applied a tension force to a cable. This cable passed over a pulley (b) and through the house to a load spreader (c). Three such loading frames and spreaders distributed lateral loads over the length of the top plate of the house, approximating the uniformly distributed load applied to the walls in high winds.

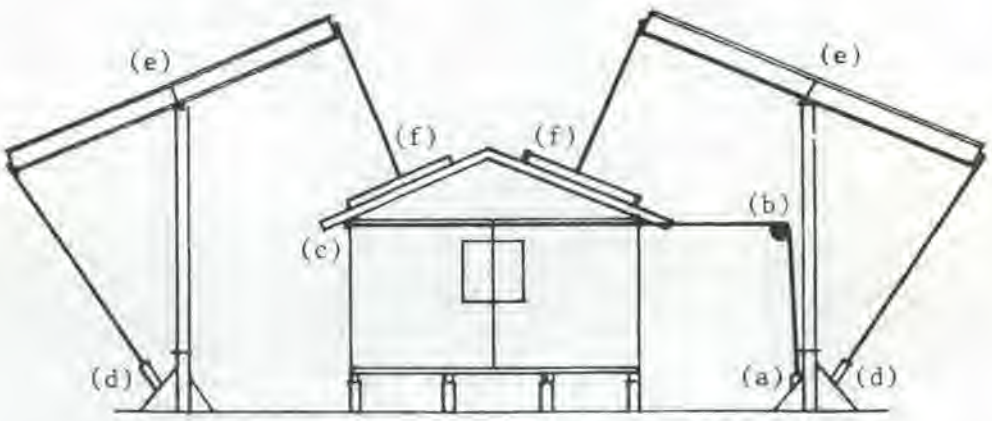

Figure 2 Configuration of loading system

Uplift forces were applied using the hydraulic ram (d) which pulled downwards on one end of a large "see-saw" beam (e). The other end lifted a load spreader (f) which distributed the uplift loads to load spreaders adjacent to the roof battens.

The forces were monitored using strain gauge load cells, and deflections were measured using a computer based instrumentation system (5). Over fifty specially constructed displacement transducers were placed on the house, and they electronically transmitted measurements to a portable computer. The data acquisition system took less than 5 seconds to record readings from 52 transducers, so that creep during the measurement period was minimised. The loads and deflection curves could be viewed as the test was being performed. These curves verified that the house was behaving in a linear fashion during elastic tests and were used to determine modes of failure during the destructive tests.

3.3 Test Programme

There are two separate areas of investigation in the house testing research programme. The first involves stiffness tests on elements of the building during its construction; the second is the determination of strength of the building as an entity and of its components.

3.3.1 Stiffness tests

This test programme necessitates construction of the building in an unusual sequence, whereby the walls are erected and lined prior to the installation of the roofing. By building in this manner, racking tests can be conducted on individual walls to determine their stiffness. Addition of the roofing material may constitute a structural diaphragm, capable of distributing the applied racking force to nearby walls. Roof sheeting can act as an efficient diaphragm, depending upon its fastenings (6). Internal lining materials can also act as structural diaphragms, but this house had no such linings or ceiling.

3.3.2 Strength tests

When testing a house designed to resist tropical cyclones, it is essential to simulate the continual buffetting forces that the house would receive from wind gusts. The sequence and magnitude of application of the forces were in accordance with an industry accepted standard (7). The programme required 10200 cycles of uplift load to be applied to roofing, and 1020 cycles of lateral load to be applied to walls.

For roofs the following sequence is adopted:

8000 cycles	0 - 5/8 design load - 0
2000 cycles	0 - 3/4 design load - 0
200 cycles	0 - design load - 0

For walls one tenth of the number of cycles to each load level is applied.

Racking and uplift forces were applied to the house simultaneously. During the cyclic loading programme this was accomplished by applying nine cycles of uplift only followed by a cycle of combined uplift and racking.

At the completion of the cycling sequence the house was loaded incrementally in both uplift and racking, maintaining the correct ratio of forces, until failure occurred. This was taken as the strength of the hurricane house.

4. RESPONSE OF THE HURRICANE HOUSE

4.1 Elastic Loading

Racking tests were conducted on each transverse wall of the house, with the roof structure in place, but no roof sheeting. The measured racking stiffness of the three transverse walls of the Tongan house was a follows:

West wall	2.02 kN/mm
Internal wall	1.35 kN/mm
East wall	2.03 kN/mm

The end walls show remarkable agreement and the internal wall, which was not designed as a bracing wall, demonstrated that it had the capacity to act as one.

Although the racking force was applied directly to the top of each transverse wall in turn, there was some lateral distribution of that force by the side walls of the house. Table 1 lists the percentage of load carried by each wall. Although the end walls had indentical stiffnesses, they attracted different percentages of the applied load. This is a reflection of the discontinuity provided by the doorways in the external walls (see Fig. 1). It was more difficult for forces to be transferred between the west wall and the internal wall than between the internal and the east wall.

TABLE 1

Racking force distribution in hurricane house without roofing

Racking load applied at top of	Percentage of applied load carried by		
	West wall	Internal wall	East wall
West wall	83	17	0
Internal wall	9	78	13
East wall	2	30	68

After the corrugated steel roofing was installed the racking test on each wall was repeated. The results of the force distribution analysis are listed in Table 2.

The diaphragm effect of the roof sheeting was most pronounced when the west wall was loaded. It negated the effect of the discontinuity, and made the response almost the same as for the case of the loaded east wall. The roofing diaphragm also affected the force distribution for the internal wall, but the effect of the doorways was still evident.

The response of the east wall is interesting in that it shows little effect of the roofing diaphragm. This suggests that, in the elastic range of the house response, the looped strap connecting roof trusses to walls allowed some lateral movement of the walls before the roof diaphragm could act, virtually nullifying the effect of the diagphragm.

TABLE 2

Racking force distribution in hurricane house with roofing

Racking load applied at top of	Percentage of applied load carried by		
	West wall	Internal wall	East wall
West wall	64	32	4
Internal wall	15	52	33
East wall	4	34	62

4.2 Cyclic Loading

4.2.1 Original house

Complete details of the Tongan hurricane house under simulated cyclic loading have been published by Boughton and Reardon (8). A summary is given below.

During application of the proposed 8000 cycles of 5/8 design uplift load, a twisted metal strap securing a truss failed. The strap had been installed in such a way as to attract a disproportionate amount of tensile force to its outer edge. Figure 3 shows the installed strap. A crack started at the edge and propogated until the strap failed in tension, after 2500 cycles of uplift load (hence 250 cycles of lateral load). At about 4000 uplift cycles straps securing three other trusses failed, allowing significant lateral movement of the top of the 'windward' wall.

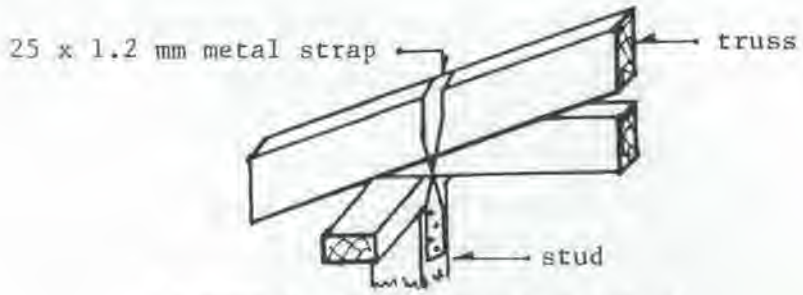

Figure 3 Truss hold-down detail

The test was stopped and the situation assessed.

It was acknowledged that the straps were overstressed by about 57% in uplift. Further, the lateral racking force on the walls caused the trusses to apply an extra force to the straps by means of a wedging action. This may have increased the uplift force to approximately 2.2 times design, and the cycling force to 1.4 times design. But this force is still only about 50% of the anticipated failing load of the strap.

It must be concluded therefore that the strength of the straps had been significantly reduced with application of the loading cycles.

4.3 Modified House

The house was repaired by installing overbattens on top of the trusses and bolting them to the top plate of each wall. Figure 4 demonstrates the principle. This sytem was chosen so that it could easily be implemented on existing houses in Tonga, if necessary.

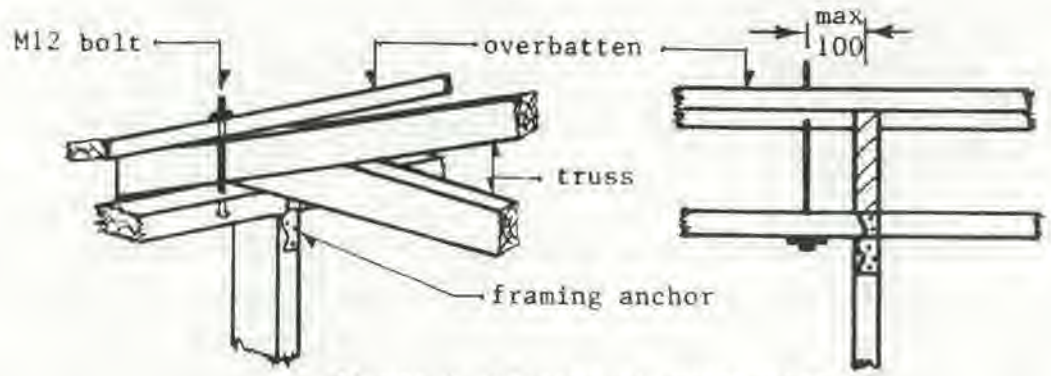

Figure 4 Bolting of overbatten

In order to fully load the new hold-down system it was decided to apply the total 8000 cycles of 5/8 design uplift load to the modified house. However as no modifications were made to the bracing strength of the house only 400 cycles of 5/8 design lateral load were applied, that is, the complement of the original number.

Only minor failures of the internal wall occurred during application of the 8000 uplift cycles. The deflections, however, were quite significant with 20 mm vertical moment at the eaves and 35 mm lateral movement at the top of the windward wall.

Commencement of the 2000 cycles of 3/4 design uplift load, and the corresponding lateral load, caused a significant increase in total movement of the house. The eaves lifted 35 mm and the top of the wall moved 60 mm laterally. These deflections were due in part to the concrete footings lifting by about 15 mm on the windward side of the building.

Significant structural damage occurred during this loading sequence. Nails pulled out of batten straps, teeth broke off the truss plates and the hardboard was being sprung off the internal wall.

Despite its overall deterioration the house managed to resist that full complement of load cycles.

After 50 cycles of design uplift load (5 of design lateral) the internal wall was virtually destroyed, but the house was still resisting the applied loads. The apex joint of two trusses had completely failed, but truss action continued as the ridge capping started to act as link between the two top chords, despite a relative movement of about 30 mm between chords, Fig. 5. This situation prevailed for the rest of the loading sequence, but it resulted in large deflections, beyond the capcity of the measuring equipment.

Subsequent analysis of the forces at the ridge of the truss indicated that the ridge capping had the capacity to resist even higher loads if it acted similar to steel roofing (6).

With the completion of the cycles to design load the full cyclic loading sequency was achieved. The modified hurricane house had been able to resist simulated cyclone wind conditions commensurate with a design wind velocity of 62 m/s. The house had deflected significantly but it had not totally failed.

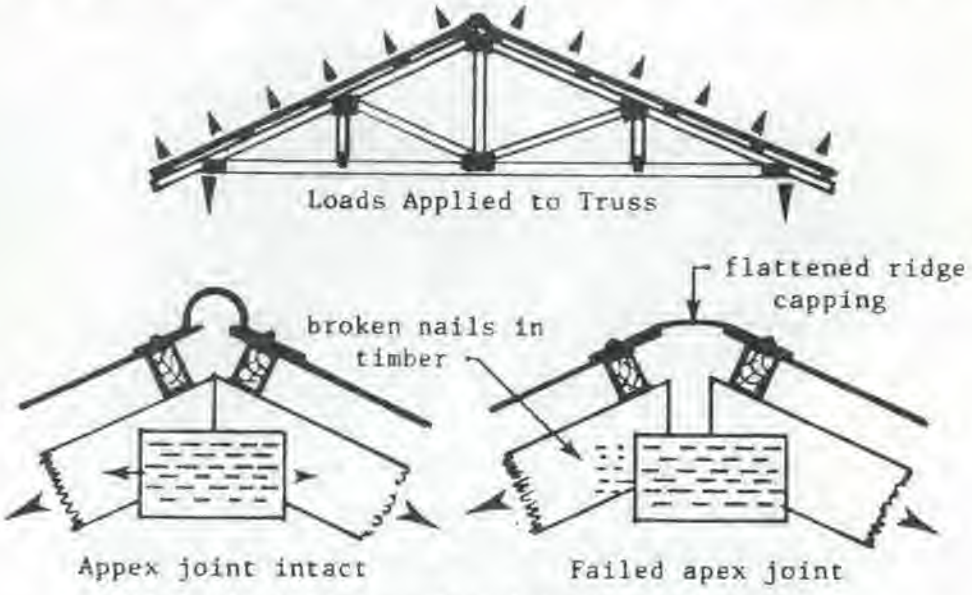

Figure 5 Load transfer through ridge capping

After the cyclic loading sequence the house was loaded incrementally in uplift and racking until failure occurred. This happened at 1.3 times design load when the top chord of one of the trusses broke at a position near the heel. The very clean break indicated that the failure mode was caused by a combination of shear and tension forces.

The consequences of this 30% reserve of strength should be considered in the light of the Tongan economy.

5. CONCLUSIONS

All transverse walls acted as bracing walls. The roof diaphragm had a greater effect on the western end of the house than on the eastern end, during the elastic response tests. Almost 40% of racking forces applied to a wall can be transferred laterally by the roof diaphragm.

The vulnerability of a traditional method of joining structural components has been highlighted, insomuch as the strength of the light gauge metal straps was significantly affected by the load cycling.

The modified hurricane house resisted the simulated cyclone wind forces based on a design velocity of 62 m/s. Although some joints broke and the house deflected significantly, the structural redundancies allowed it to maintain its integrety.

The authors are of the opinion that the structural principals used in the modified hurricane house could be used as a model for the design of cyclone resistant housing in other countries in the Pacific area. The architecture may need to be changed but the basic concepts could be maintained, especially as they have now been tested by a simulated cyclone. However, traditional jointing materials such as light gauge steel or wire may have to be replaced by bolts and other elements less prone to degredation under cyclic loading.

6. ACKNOWLEDGEMENTS

The authors gratefully acknowledge the contribution to this project made by:

The Tongan Government for providing the house,
The New Zealand government for funding Mr. 'Aho's visit,
The British Government for funding the cost of transportation,
The Australian Government for funding part of the test programme,
Dr. Keith Eaton (BRE) who informed the Tongan Government of the Station's facilities,
Mr. Pilimi 'Aho who supervised construction of the house,
The British High Commission (Tonga) who liaised with all parties.

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CONTINUOUS PRODUCTION AND TECHNOLOGICAL TRENDS IN TIMBER CONVERSION

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ABSTRACT

Economic, environmental and resource considerations are forcing the Australian timber conversion industry to become more productive and efficient in relation to usage of labour and materials. The realization of these objectives is closely influenced by the attitude of management to the adoption of appropriate existing technology to handle the changing nature of the resource and to maximize profitability.

The basic elements needed for optimal performance by a timber processing complex include: effective utilization of raw materials; the right combination of vertically and horizontally integrated operations for processing these materials, particularly to high value-added products; appropriate machinery and operator training to convert these materials efficiently and to achieve high productivity levels; and the planned incorporation of flexibility at each stage of processing to enable a realistic range of profitable products to be manufactured at short notice to meet market demands.

This paper considers a range of primary and secondary processing technologies that are appropriate for converting the changing hardwood resource and others that have been introduced by progressive softwood producers to increase the degree of automation employed.

The increasing trend to the use of computers in all phases of timber conversion operations is helping to increase recovery of sawn timber, decrease labour costs and improve conditions for operators by eliminating some tasks low in job satisfaction, by drastically reducing their numbers in high risk areas on the mill floor and by minimizing the mental stress induced by a high rate of decision making. While completely automated sawing of softwood timber is already a practical reality, this is unlikely to occur in the foreseeable future with Australian hardwoods because of the need to grade saw to eliminate unacceptable natural defect occuring in most logs now being processed.

The adoption by sawmillers of relatively simple technologies, such as the upgrading of defective and otherwise unusable timber by finger jointing or the development of rationalized grading rules to ensure a realistic correspondence between timber quality and end-use requirements, has the potential to provide effective cost benefits. Likewise, a realization of both the need and means for drying timber as rapidly as possible to optimize drying costs and minimize drying degrade should be recognized by the timber industry.

SEASONING RESEARCH IN W.A.

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ABSTRACT

Timber seasoning research in Western Australia is reviewed. The work is centred on seasoning jarrah from mature and regrowth trees and on those problems of pine seasoning most encountered in that State.

Trends in the status of seasoned timber production and housing approvals are used to demonstrate low cost effectiveness of seasoning in the industry.

Apart from the ATRI funded fundamental project on mechanical creep, all the research is of an applied nature. Industry activity is directed to improving cost effectiveness of commercial operations, while the State's Wood Utilisation Research Centre develops seasoning techniques for immature jarrah and pine timbers.

INTRODUCTION

The trend for increased use of seasoned dressed pine for house framing apparent in eastern states in recent years has been less evident in Western Australia. A shortage of locally produced mature pine and a consumer preference for cavity brick rather than timber framed construction, have contributed. Nevertheless, a steady decline in the availability of mature hardwoods together with the increasing use of pine has led to renewed efforts for improved seasoning techniques.

The thrust in Western Australia for improved seasoning has been in three areas:

* mature jarrah (Eucalyptus marginata)
* regrowth jarrah (Eucalpytus marginata)
* locally grown pine (Pinus radiata and P. pinaster)

and I propose to discuss the direction and progress of each.

Before doing so, I wish to illustrate the status of timber seasoning in Western Australia by referring to some statistical trends.

In looking for a trend in hardwood seasoning, I summarised figures from monthly returns submitted by all hardwood sawmillers to the Department of Conservation and Land Management (formerly Forests Department), over a period of thirteen years (Figure 1). The amount of hardwood timber set aside for seasoning, expressed as a percentage of the total production is graphed against time. There is a gradual increase but no apparent cause for the marked fluctuations.

When the Australian Bureau of Statistics' figures for housing permits issued in W.A. are graphed against the same time period (Figure 2), it becomes clear that increased seasoning is dependent on downturns in the housing market, when the demand for green timber decreases. As the market demand swings towards seasoned timber, industry apparently perceives a need to improve its cost effectiveness in this area or face reduced returns on invested capital.

For the first time in the history of the Western Australian timber industry, a company with no sawmilling capacity at all has invested significant capital in establishing modern timber seasoning facilities. Timber seasoning and dressing are the company's only activities, which I believe highlights the need for improved technology in the rest of the industry. Another example is the installation of a dehumidifying kiln by a furniture manufacturer because of his need for timber to be seasoned to a lower moisture content.

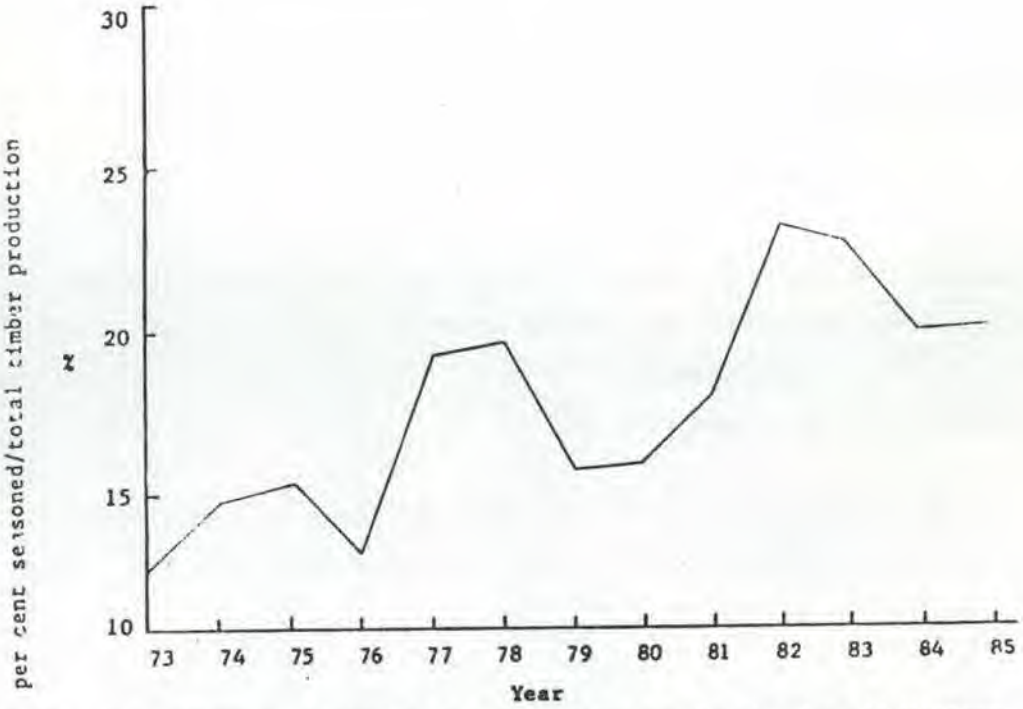

FIG. 1. Percentage of seasoned to total timber production by all Western Australian general purpose hardwood sawmills, plotted against year.

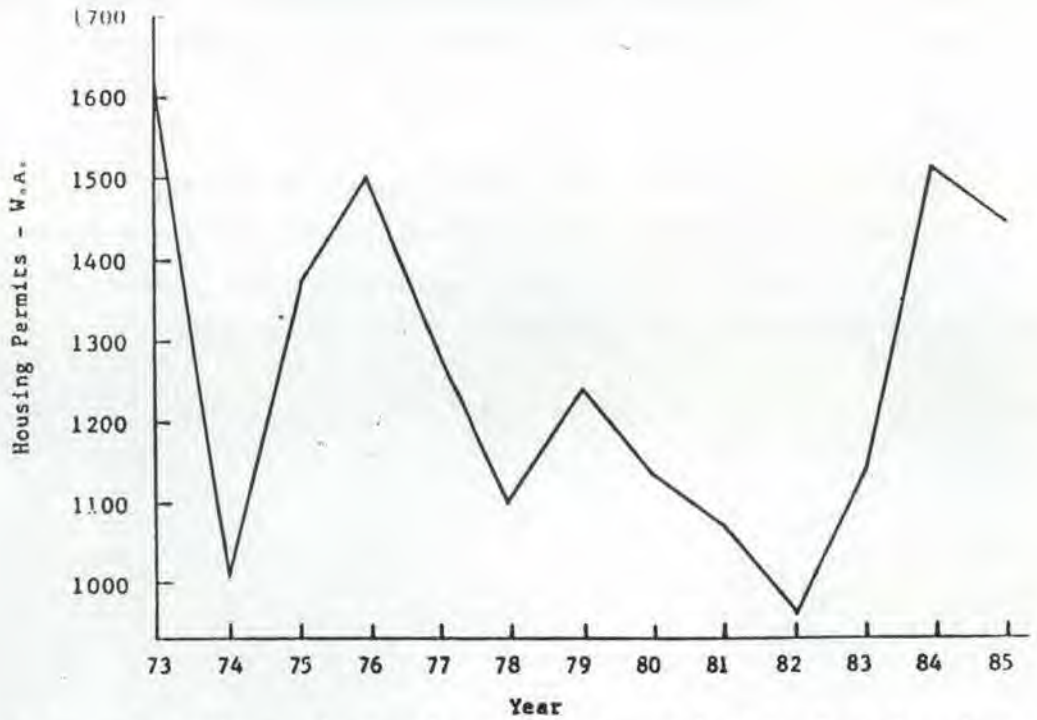

FIG. 2. A.B.S. figures for housing permits issued in W.A. plotted against year.

MATURE JARRAH SEASONING

CREEP

Whittakers Ltd with the support of ATRI are conducting fundamental research into the properties and extent of mechanical creep as a factor in seasoning shrinkage. Measurements are being made of creep in jarrah at a range of fixed wood moisture contents.

The aim of this project is to provide input data to Prof. Oliver's seasoning model and so develop improved seasoning schedules for use by industry.

INITIAL SEASONING CONTROL

Whittakers Ltd are also conducting applied research into controlled environment conditions for sorting and stripping off the saw, because both research and experience have shown that the first few hours after sawing are critical if seasoning checks are to be avoided.

PREDRYING

Whittakers Ltd are developing predrying techniques for jarrah. This applied research is largely directed towards improved cost-effective facilities.

Great Southern Hardwoods Pty Ltd are developing a pre-drier with variable air speed and precise control of temperature and humidity based on model schedules purchased from overseas. Samples of local timbers seasoned overseas have confirmed the suitability of the model schedules.

PLASTIC WRAPPING

Control of surface splitting in 38mm and thicker jarrah is the subject of Bunning Bros applied research with PVC film coatings glued on with PVA. The initial work has commenced with 75mm and 100mm squares and is directed towards optimum cost benefit systems and the development of wrapping equipment.

HIGH TEMPERATURE SCHEDULES

With the State's only hardwood commercial high temperature kiln, Great Southern Hardwoods are developing improved schedules for H.T. seasoning from fibre saturation point to equilibrium moisture content. The Company has not released any details of its schedules which are based on model programs purchased from overseas, but the results so far are very promising. Its kiln has sophisticated steam control which is an important factor for the schedules being developed.

REGROWTH JARRAH SEASONING

This research is being conducted by the CALM Wood Utilisation Research Centre at Harvey (2) and is funded by a Public Interest Project through the Commonwealth Industrial Research and Development Board. Although the work is directed towards timber from regrowth trees, timber from mature trees will be used as controls.

PROGRESSIVE TUNNEL KILNS

Two experimental kilns are used to develop low energy schedules for seasoning from green to fibre saturation point. They are presently being refurbished to provide improved humidity control and converted from manual to computer operation and data logging.

With the easing of the energy crisis and steep increases in interest rates, there is less pressure to develop low energy long duration schedules. As these economic factors are likely to change with time, the research will proceed as an investment for the future.

EXPERIMENTAL BATCH KILN

Particular emphasis has been placed on producing timber for high value furniture. This market requires uniform final moisture contents of 6%-8% for added stability.

An experimental kiln is under construction which will cater for low moisture contents and the parameters of mathematical models being developed in other states and overseas. It will provide for cyclic steaming and for variable drying schedules up to 70°C and 95% relative humidity.

An added feature is an adjacent climate controlled evaluation room with space and adequate lighting to allow for frequent assessment of all the boards in the experimental batch throughout the seasoning schedule. This 100% sampling will greatly improve the statistical reliability of results.

In addition to testing schedules for conventionally dimensioned timber a project involving SDR (saw dry rip) will be evaluated. Preliminary results from seasoning regrowth jarrah from green to fibre saturation point in the tunnel kilns followed by high temperature seasoning, have shown shrinkage values in excess of those obtained for mature jarrah using air drying and conventional kilns. How much of this is due to wood properties and how much to seasoning technique is to be determined. It is thought the SDR method will eliminate some of the problems associated with excessive shrinkage. Parallel trials are being conducted at Great Southern Timber's facilities.

Another project will involve the seasoning of predressed boards. A preliminary trial with 25mm jarrah indicates a marked reduction in surface splitting of green dressed jarrah compared to circular or band sawn boards.

HIGH TEMPERATURE SEASONING

The Wood Utilisation Research Centre has had a laboratory high temperature kiln for the past two years. Timber taken below fibre saturation point in the tunnel kilns has been successfully seasoned to final moisture contents below 10%. The kiln will shortly be fitted with improved steam capacity, and controls will be connected to the Centre's computer facilities.

PINE SEASONING

Several problems facing Western Australian softwood producers are more significant than those affecting their eastern counterparts:

* a small proportion of mature plantations at present
* a thrust towards agroforestry
* a tendency for plantations in many areas to be drought stressed
* a high percentage of P. pinaster
* the small size of most producer firms

The work of CSIRO and RPRI have been applied successfully to locally grown pine, and Australian and industry standards achieved. However, when market pressures increase, the acceptability of the local product declines in favour of the imported product.

Seasoning research is concentrating on the following problems faced locally.

DEHUMIDIFYING

Because of the low capital cost of dehumidifying kilns, the Department of Conservation and Land Management and the Radiata Pine Research Institute conducted a project on the dehumidification of heart-in (i.e. juvenile) P. radiata.

The results (1) showed that dehumidifying is less effective in stabilising juvenile wood than is the industry code of high temperature seasoning, and concluded that it is not a recommended alternative.

PROPERTIES OF FAST GROWN PINE

The Department of Conservation and Land Management is presently comparing the economic viability of fast grown P. radiata from agroforestry and heavily thinned plantations with conventional forest grown timber. A market oriented cost/benefit model will be prepared for advice to potential plantation investors.

EFFECT OF MOISTURE CONTENTS ON PROCESSING TECHNIQUES

The prevalence of low timber moisture contents in drought stressed plantation trees particularly during the hot dry summers of Western Australia have prompted a study of the processing problems involved. This project will aim to quantify the critical parameters of moisture content at all stages from tree felling to seasoning and to provide advice to logging contractors and sawmillers.

P. pinaster is more difficult to season than P. radiata and past research (unpublished) has shown that timber sawn from the former species logged at the end of summer had greater distortion than timber from that logged at the end of winter.

PLASTICISING WITHOUT STEAMING

Wesfi Pine in association with the RPRI propose to test the efficiency of replacing the requirement for presteaming of heart-in P. radiata with a rapid heating cycle in the kiln chamber.

The small dimensions of logs milled in WA result in high proportions of juvenile core material. If presteaming was not required, this would mean significant cost benefits to local producers.

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SAWING SMALL-DIAMETER EUCALYPTS IN AUSTRALIA

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ABSTRACT

The need to develop improved sawing systems to handle small-diameter eucalypts has become of prime importance to the Australian hardwood sawmilling industry. Fast, light carriage systems, log edgers and a greater emphasis on operator training are helping to overcome some of the productivity problems in handling small logs. However, the sawmilling industry will need to go one step further, put aside traditional grade-sawing practices, to look at using programmed sawing strategies and product rationalization if it is going to succeed in utilizing logs at the bottom end of the distribution of available log diameters.

INTRODUCTION

Hardwood sawmillers throughout Australia are facing a period of uncertainty due to the rapid diminution of their traditional high-quality sawlog resource, with survival of the industry in the long-term being dependent on the ability to utilize alternate smaller diameter and poorer quality eucalypts. This industry has shown a high degree of versatility in handling a very diverse range of sawlog qualities. Historically, sawing practices have developed around the judgmental skills of the saw operator (sawyer). It has to be kept in perspective that many of the labour intensive techniques employed by the industry have been brought about by the unique nature of the resource, combined with a demand for high-quality sawn products and there is no indication that it is any less efficient than similar hardwood operations in the northern hemisphere (1,2). However, the transition to smaller logs does require greater emphasis on certain skills, particularly for handling distortion during sawing and face-cutting.

RESOURCE CHARACTERISTICS

Large areas of young fast-grown eucalypt regrowth forests exist in Australia, often close to major population centres (Huon and Florentine

valleys in Tasmania, central highlands in Victoria, north coast of NSW and the coastal foothills of south-west Western Australia). Such forests have resulted from past forest operations or wild-fires. These are to the greatest extent even-aged forests and in time have the potential to yield high-quality (and high-value) sawn products.

The regrowth forests of the fast-grown high-quality mountain and foothill species will give rise to a completely different set of operational and marketing problems associated with the utilization of the smaller diameter younger forests (3). Because of the smaller diameters, there is a reduced potential for both quarter-sawn and larger dimensioned products (4), while such characteristics as log sweep and a large knotty core can severely limit the recovery of longer length clear products (5). The knotty core which is difficult to ascertain from external indicators can result in many sawn products being produced with knots unacceptable in either number or size for many products, resulting in a higher proportion of short length sawn products being produced. Waugh (3) reported that knots are the most serious product down-grading defect in fast-grown young ash-eucalypt species. Knots were shown to be an even greater problem in products sawn from plantation-grown young *Eucalyptus nitens* (6) (Figure 1). It would appear that the incidence of knots is no worse, in fact, in most cases, not as prevalent as exotic species grown under plantation conditions, but rather that the expectations of the industry and the consumer are much higher. This is expressed quite clearly in the relevant Australian Standards determining visual grades and end-uses for the different species.

The proportion of pulpwood from the mature mountain forests to the overall merchantable volume of a tree is relatively low, as there is often only a short distance between the current upper merchantable limit for sawlogs and where the tree develops an open crown. It is a different situation with the regrowth forests, where the tree is still actively growing, and upper merchantable limits are defined by log diameter and the appearance of knots. In this case, upper limits are more subjective and changes in conversion practices, product values and marketing practices can substantially alter this upper limit of merchantability. Other differences also exist. Strength properties, (particularly stiffness) of the young fast-grown regrowth resource are often considerably reduced compared to that of mature trees of the same

species (7,8). This factor, combined with higher shrinkages, makes the drying of such wood more critical, in order to improve both strength characteristics and in-use dimensional stability.

THE DEVELOPMENT OF SAWING EQUIPMENT AND PRACTICES FOR SMALL EUCALYPTS

The indigenous sawmilling industry of the early part of this century was itself an interesting study of innovation, relying on local skills to build and maintain sawmills and novel means of powering the sawmill, of waste disposal and using gravity for the movement of material through the sawmill. Many of our current practices and fundamentals in equipment design can be traced back to this era, and the remnants can still be seen in the many small sawmills throughout Australia, where through-put levels could not justify the high capitalization of modern technology.

Perhaps the one feature which so much distinguishes the sawing of small eucalypt sawlogs from the alternate exotic conifer and large eucalypt resources is the high growth stresses (or rather the high growth stress gradient) found within these logs (1,9,10). This high stress gradient contributes greatly toward the problems of end-splitting of logs if they are in any way mishandled and also toward the distortion problems found during the sawing of such logs (11).

Where sawmillers are required to stock-pile logs in dumps, there is a danger of drying degrade occurring, particularly with smaller logs, which have a greater surface to volume ratio, often lower density wood and a higher proportion of sapwood. Drying degrade takes two forms: firstly, the obvious surface checking, which can extend well into a log, and secondly, drying stresses, which are additive to growth stresses and result in even greater distortion during sawing than encountered with fresh green logs. One solution, the use of water sprays on log dumps, is effective in controlling surface checking. This practice has been found to produce a beneficial side-effect, significantly reducing growth stress levels when the logs are allowed to undergo a period of stress relaxation. Work carried out at CSIRO (12), has shown that over a six month period, overall stress levels can be reduced by as much as 20 per cent; but, what is more important, is that most of this reduction takes place in the most highly stressed logs in which over that period the

stress intensity can be reduced to half of their previous levels. Therefore, as well as stresses being reduced, the logs end up much more uniform in their distortion characteristics.

One common problem experienced in most medium- to large-sized hardwood sawmills handling small eucalypt sawlogs, is the large number of logs which have to be handled. Most hardwood sawmillers have a remote log preparation location and feed sawlogs directly onto the log deck using a log fork-lift (or even two fork-lifts). The exotic softwood industry, even though often of a larger scale, make wide use of log merchandising systems for preparing mill log lengths, debarking and then using a conveying system to feed logs into the sawmill. This practice has been applied on a much smaller scale in many of the Cypress Pine sawmills in central Queensland, to a scale which could be readily adapted to most hardwood sawmills. It has the advantage of effectively halving the use of a fork-lift on the sawmill infeed side, placing the operator in more favorable working conditions and removing him from the danger of portable chainsaws.

Log headsaw systems

While there has been an evolution of practices, equipment development has been influenced by Northern Hemisphere technology, imported to handle the exotic conifer resource. This is particularly evident in the design of modern high-speed conventional sizing pony carriage and log-edger systems used to break-down small eucalypt logs. As log diameters became smaller, it was necessary to use faster and, at the same time, possible to use lighter log carriages as a means of maintaining through-put levels. Some minor differences compared to carriage systems in exotic conifer sawmills can be noted, such as the greater use of auxiliary storage decks, more robust log-turning equipment and the use of a greater number of sizing heads, particularly for longer-length carriages. This latter difference is necessary to offer more restraint to minimize distortion during sawing.

Any distortion in a log or flitch during sawing on a conventional sizing carriage will result in sawing inaccuracy in subsequent cuts unless;

(i) the log or flitch is turned and a new reference cut is made, or

(ii) a straightening cut (which effectively is a new reference cut) is put into the log.

Sawing inaccuracy due to growth-stress induced distortion will normally appear as over-sizing at mid-length of the sawn material. No matter how good the sawing tolerances are on a conventional sizing carriage, the sawing of dimensioned material, particularly from logs less than 350 mm diameter should be avoided, particularly when exacting sizing tolerances for product drying are required. Smaller logs should be broken-down to non-dimensioned flitches whereas for logs of between 350 and 450 mm diameter, sizing accuracy must be closely monitored and sawyers be prepared to use straightening cuts frequently.

One uniquely Australian designed log carriage system which has been found very successful in combatting many of the distortion problems associated with sawing small eucalypts is the "Line Bar Carriage". It was originally designed to act as a heavy-duty resaw in sawmills handling large logs, with the line-bar serving the purpose of readily re-referencing sawn faces for further sizing. The line-bar carriage is a sawing unit well suited to handling small 'springy' logs by the sawyer being able to move the rear heads of the carriage during sawing to keep a sawn face against the nose of the line-bar. This technique ensures accurate sizing, even when a sawn reference cut is distorted, as it is the gap between the saw and the line-bar which controls product sizing, rather than the movement of the carriage heads. While this technique may be easy to grasp in concept, it is difficult to execute in practice. The heads of the carriage are either locked into place once the head location is determined for face-cutting, or allowed to "float" and then used to push the log (or flitch) up to the line-bar. By ensuring wood is against the "nose" of the line-bar, accurate sizing can be achieved even when reference saw-cuts have been badly distorted by growth stresses. However, the additional distortion associated with each saw pass is cumulative, with the overall distortion becoming greater with each cut, until it is finally necessary to either make a straightening cut or preferably turn the log or flitch. It is not possible to achieve the feed speeds possible on conventional carriages and a much higher degree of operator skill is required to effectively operate this type of unit.

Some interesting practices can be observed amongst sawmillers using line-bar carriages. One sawmiller uses a strategy for quarter-sawing which could only be applied using this type of carriage for logs of over 400 mm diameter (Figure 2). A first opening cut is put into the log which is turned with the face down. The next cut is placed through the heart of the log, for about eighty per cent of its length, and the carriage then reversed, leaving a log with two halves opened out. This technique relieves the stresses in the horizontal plane. The next cut is a face-cut. For the following cut, the log is pushed lightly against the line bar and a cut made for the desired width of the quarter-sawn products. Due to the stress relief cut, both faces of this flitch will be straight and the flitch accurately dimensioned. The next cut into the log is to remove a slab to final product thickness, until the centre stress relief cut is reached, this piece is then removed, another slab possibly taken (depending on log size) and the remaining piece either turned for quarter-sawing on the carriage or directed to a resaw, depending on the status of the log decks.

More common practices for handling small logs (less than 400 mm diameter), generally aim at maximizing back-sawn products and controlling sawing accuracy by using the above techniques whereby residual distortion will appear as bow, which is of little consequence in most sawn products. Distortion during sawing can be handled; in fact, a knowledge of distortion behavior can be used to produce straight flitches from distorted logs. For example, using a back-sawing strategy on small-diameter sawlogs (Figure 2), by balancing cuts either side of the heart, to produce a flitch, it is possible to "pull back" a badly distorted sawn surface to close to being straight and obtain a flitch which is both accurately sawn and straight. If a straightening cut had been made prior to sizing the flitch, the flitch would have been badly distorted away from the last cut and final products cut from the flitch would have all had spring sawn into them.

Log edger systems have also come a long way from having two fixed saws and a continuous chain-feed for logs. Developments have included the beam-edger and different forms of overhead carriage systems, incorporating a greater degree of control over restraining and orientating the log. However, one common problem encountered with the

use of the log-edger remains, is that while distortion and sawing accuracy problems are controlled across the log, distortion problems in the vertical plane (parallel with the saw cuts) are increased. The stress profile across the centre cant is greater than it was across the same location when the log was in the round. This is because in the intact log, wood under the bark is in tension, but under an even higher level of compression at the core. Most of this core wood remains in the centre cant and in coming to a new stress equilibrium condition, imposes further tensile stresses on the outer wood, thus increasing the stress differential. These high residual stresses impose further problems during resawing as pieces distort. Most edger systems in Australia use circular saws, which have quite a well-defined upper limit of log diameter which can be handled, unlike carriage systems, where log weight and diameter to a certain extent interact. Due to the large variation in log diameters handled at most sawmills, an edger system becomes impracticable as a primary log breaking-down unit for handling larger logs. Most units are installed as secondary headsaws.

While early edger systems (chain-feed and beam-edgers) did not allow successive sawing passes (slabbing-off), end-dogging on later beam-edgers and the better restraint of overhead carriages do allow slabs to be sawn. One overhead carriage system manufactured in Australia, enables the saws to be set independently. One saw only needs to be set to halve a centre cant or to enable a centre cant to be offset, thus introducing the possibility of introducing optimizing sawing strategies similar to the American Best-Opening-Face Program (13).

One very interesting development to the log edger system is the use of scribing saws (Figure 3). These are small-diameter, but heavy gauged circular saws, set at right-angles to the main saws, as a gang, and mounted in front of the main saw, where they cut to a depth equivalent to the saw line of the main saws. Depth of cut is generally limited to less than 70 mm. The units have the advantage of being able to produce accurately dimensioned sawn products, rather than slabs with each pass of the log through the edger, and instead of producing round- backs with the first pass, a flitch, dimensioned on three faces is produced. This means that the "round back" can be processed on the resaw using two or three less cuts.

One major problem encountered in producing sized products from small logs using scribing saws is the considerable distortion in products sawn from what would normally have been sized slabs. There are two ways of reducing this problem, one is to cut logs to short lengths, the other is to halve logs first on a carriage system. Both solutions do have limited success. Short lengths increase the number of logs which it is necessary to handle and limits the range of products which can be marketed, while halving logs can obviously only be done on the larger logs (approaching 400 mm diameter).

The use of scribing saws does appear to have several advantages, particularly if improved sawing strategies can be developed and the problem of segregating the off-cuts and dimensioned products solved. To gain the full benefit of such equipment, sawmillers will need to get away from "grade-sawing" concepts and start thinking in terms of programmed sawing strategies, using "optimizing" techniques and rationalizing the range of product dimensions sawn with such a unit. In terms of productivity, this unit could do for the small hardwood sawlog what the multi-saw edger can achieve with both exotic conifers and larger hardwood logs, as it can place up to eight cuts in a log with each pass through the saw and eliminate a lot of subsequent face-cutting during resawing. Particular products such as tiling battens, which are required in long lengths, need to be accurately sawn, but where distortion (which can be straightened out) is not so critical, their production could be well suited to this process. Also, the edging of slabs prior to drying (to improve stacking efficiency and recover green chips) could also be carried out as a single operation on this unit.

Resawing systems

Most resawing equipment and practices used in Australia for the grade-sawing of small eucalypts owe their origins to the four-man breast-bench, which with the double-sided "Trewallah" gauging system, made it better suited for grade-sawing than many of the modern derivatives (14). The four-man breast-bench crew consists of: a sawyer, responsible for the alignment and feeding the wood through the saw; the lever-man, controlling the feed rollers and the manual sizing gauge and assists in loading flitches; and two "puller-outers", located at the resaw outfeed and responsible for returning flitches and disposing of

residue and sawn products. The first step towards improving labour efficiency was to automate the resaw outfeed, using kickers and a flitch return belt, all controlled by the lever-man, thus increasing his work-load. At the same time, the incorporation of hob-feeds, a larger fence for sizing and hydraulic sizing system, assists his performance, while the task of the sawyer remains basically unchanged.

One interesting practice using this type of resaw in the Cypress Pine industry is to face-cut following the sweep of a log. This is rather an unique practice and requires a high level of judgmental skill from the sawyer, who is required to control a face-cut by side-ways movement as he feeds a piece through the saw. Without the application of this practice, it would be almost impossible to obtain the long lengths needed from logs with bad sweep. It is quite common to see a sawlog 4.8 metres in length, 250 mm in diameter with 250 mm of sweep being sawn and full-length products being obtained. It would be interesting to see how far this practice could be adopted on similar equipment for sawing small eucalypts. While this practice appeared to have been universally adopted in this industry, there was no indication of it being applied in the local hardwood industry and it would be certainly worth-while evaluating its potential as a universal practice for sawing small eucalypts.

Another form of two-man resaw has the sawyer located at the sawing console and the other operator controlling the output side of the resaw. The sawyer is assisted in his task by moving cross-chains and a line-bar and hob-feed. When sawing large high-quality logs, these units can have a much higher output and are less physically demanding to operate, but are not as successful where a lot of face-cutting is required because of the difficulty in correctly orienting the wood on the infeed side of the resaw. Distortion due to the release of growth stresses in small logs necessitates a high degree of face-cutting. This problem mainly appears to rise due to difficulties in correctly aligning pieces when the fence cannot be used to reference a saw cut, but can be overcome to some extent by the use of a "shadow line" or low-powered laser providing a visual reference line.

Mainly based on this above unit, a number of manufacturers have developed one-man resaws. The most notable being the unit manufactured by Grey Engineering. These units can be found in many sawmills in

eastern Australia. Like the above two-man unit, they perform very well, with a well-trained operator, sawing dimensioned flitches prepared from large logs, where growth stresses are not a real problem. However, likewise they run into problems when handling small logs. The degree of the problem to a certain extent depends on how the log is broken-down. Log edger headsaw systems and in particular, one-man resaws do not often marry together very well for the cutting of small fast-grown eucalypts. This is due to the higher degree of face-cutting necessary to handle the high growth stress gradients when compared with sawing larger logs or using carriage log breaking-down systems which can more effectively reduce residual stresses in flitches. An additional problem is that an edger system produces two "round-backs" from each log rather than one, both requiring a high degree of sawing.

Multi-saw edger systems have not proven to be very successful in handling green slabs from small logs, due to high residual stresses across the slab, resulting in a high degree of distortion in sawn products. However, they may have some application if wide slabs are dried before resawing. The resawing of a wide slab (broken-down to final thickness) from a small-diameter eucalypt sawlog probably represents the greatest challenge to a resaw operator; and the situation becomes worse, the closer the slab approaches the centre of a log. The slab can be expected to contain a rather complex distribution of residual growth stresses, which can still result in considerable further distortion during resawing. Often, these stresses are sufficient to cause the slab to split open, which at least alleviates the stresses and then allows accurate resawing. What is worse, the residual stresses will cause spring in products, often sufficient to render a sawn product useless, if they are not removed. What the sawyer must do is make an initial stress relieving cut, in the vicinity of the centre of the slab, but so located as to not restrict the size of sawn products. The location of the cut must be made considering the expected amount of spring and required product dimensions. Further cutting is then from the bark, toward the heart of the log, so any waste is worked back to where the first cut (now curved due to distortion) was made. The high degree of face-cutting required when resawing and the precision in locating those cuts, makes the combination of log edgers and one-man resaws rather impracticable for handling small logs. Normal carriage systems, in particular, line-bar carriages, can present flitches and slabs to a

resaw which do not contain the same high residual stresses and a one-man resaw can be used in such situations with more success.

Product handling systems

This is certainly an area that has room for improvement. Many sawmillers have invested millions of dollars in the actual sawmill, and almost nothing on product handling, employing more staff to sort and grade products than to saw them. Admittedly, there is often the need to sort out individual orders at the sawmill outfeed, but still a great deal could be done to improve information flow and materials handling at the outfeed end of a sawmill. Small sawmills often have fairly simple systems and can get away with one person preparing orders and sorting products, but most large sawmills are no more labour-efficient.

In sawmills cutting high-quality products, if wood is allowed to accumulate on an exposed green-chain or circular table for any period of time, severe collapse and associated surface checking can occur. Sawmillers in Western Australia have overcome the problem by 'air conditioning' the output line from sawmills. Green chains are a little better than circular tables in ensuring sawn products are kept moving, in fact they can work well under certain situations. Probably the most outstanding example is at Wilco's Cooroy sawmill in Queensland. The single docking/tallying station handling and documenting the total sawmill production is interesting in that a computer is used for tallying and telemetric communication is used between the two operators to determine product dimensions and order or stock designation. The green-chain operation is brilliant in design, although it is still fairly labour intensive. Product placement is determined at the docking/tallying station, the green chain consisting of two chains, running in opposite directions so missed product can be returned to the start. Stock can be pulled out and returned to make up orders from storage areas in the "island" between the two chains, and orders and drying stocks accumulated around the outside, with shorter items recovered for pallet timbers.

CONCLUSIONS

A number of different sawing systems have been developed in Australia to saw small-diameter eucalypts. Fast, light pony carriages using either conventional sizing on heads or line-bar sizing handling logs through circular saws are the most acceptable form of log breaking-down units, with the line-bar sizing having certain advantages in handling growth-stress induced distortion during sawing. Log edger systems are used as secondary headsaws and when coupled with scribing saws have the potential for greatly improving productivity when sawing logs less than 350 mm in diameter. However, this improved productivity will only be realized if sawmillers can break free of traditional grade-sawing practices for handling these small logs and look towards the higher degree of automated control afforded by using programmed sawing strategies such as those used in the Australian exotic softwoods industry. To follow this path would require the rationalization of product sizes from small logs and the development of further processing facilities to upgrade the high proportion of short lengths and defective pieces inevitably obtained from sawing small-diameter eucalypts.

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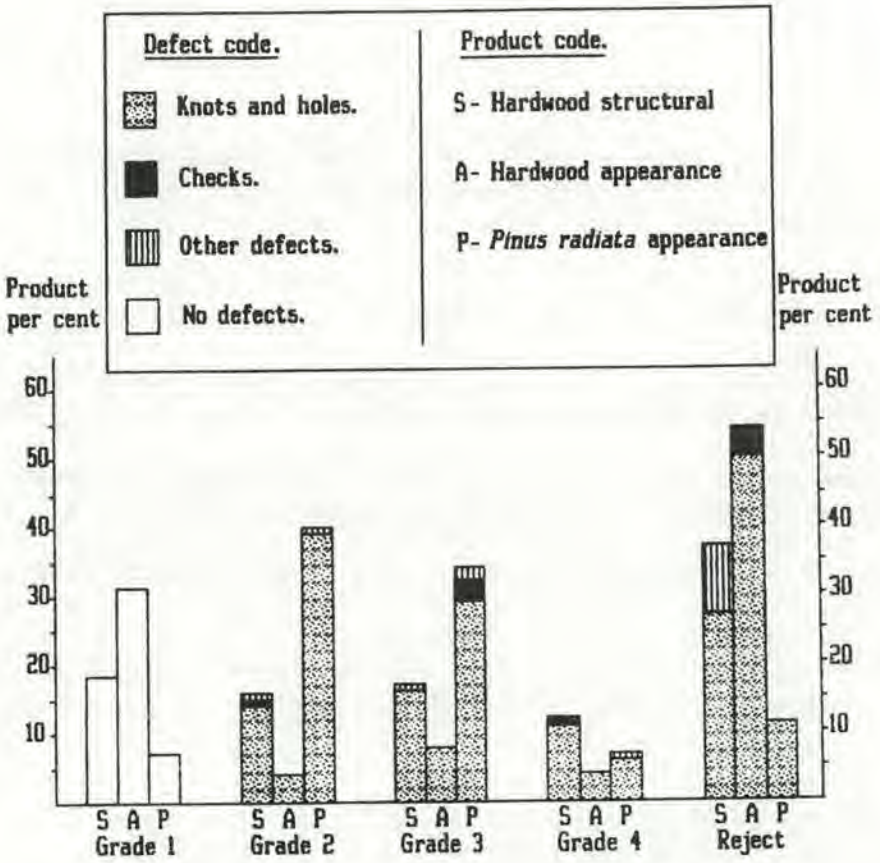
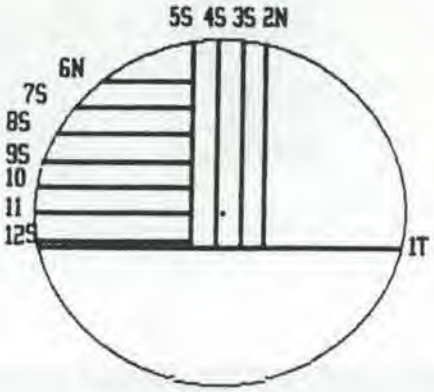


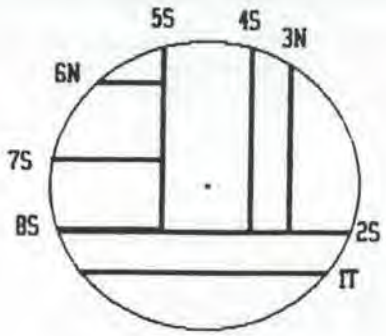
Figure 1. Grade and defect categories for 20-year-old plantation-grown *E. nitens* (Shining gum).
(from McKimm et al. 1986)



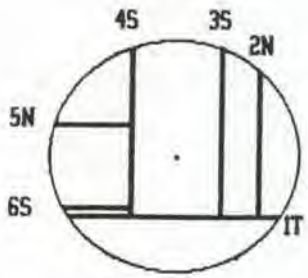
Legend

N - non taper cut
T - taper cut.
S - sizing cut
1,2,3 etc - cut sequence number

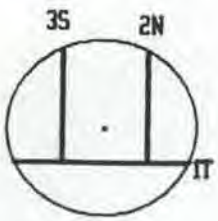
48 cm diameter
quarter-sawing strategy
dimensioned slabs and
non-dimensioned flitches.



40 cm diameter.
dimensioned slabs and
flitches.
back-sawing strategy.



32 cm diameter.
dimensioned slab and flitches.
back-sawing strategy



24 cm diameter.
dimensioned flitch.
back-sawing strategy.

Figure 2: Sawing strategies with line-bar carriage.

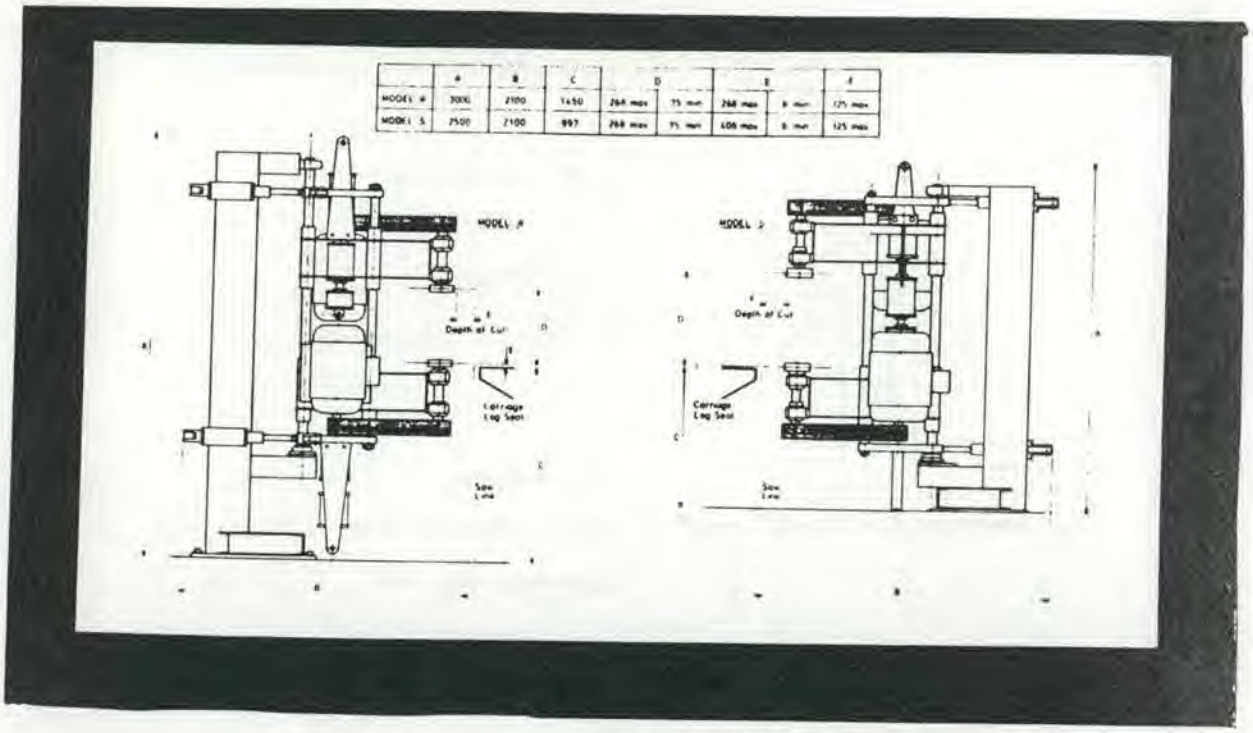


Figure 3:

SPECIFICATIONS — McKee Horizontal Scribing Saws

	MODEL A	MODEL S
● Number of saws	2 TCT	2 TCT
● Maximum depth of cut	125 mm	125 mm
● Setting mechanism between saws	Air	Air
● Size setting limits between saws (standard)	75 mm-250 mm	75 mm-250 mm
● Total movement both saw assemblies (log seat to bottom saw)	0 mm-250 mm	0 mm-400 mm
● Setting mechanism for moving both saws	Air	2 hp jack
● Motor horsepower each spindle	50 (Total 100)	50 (Total 100)
● Approximate floor area required	1600 mm x	2000 mm
● Foundation type	Pit	Floor
● Packed dimensions	1.6 x 2 x 3.1	1.6 x 2 x 2.5
● Packed weight	4 tonnes	3.5 tonnes

A MODEL TO CORRELATE MEASUREMENTS DIRECTED TOWARDS REDUCING DRYING DEGRADE IN SAWN EUCALYPT TIMBER

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ABSTRACT

A model has been developed to give realistic values for stresses and the various components of strain that are obtained during drying. The basic assumption is that the net shrinkage strain has four separable and separately measurable but linearly additive components as described in the paper. Timber is treated as homogeneous and orthotropic as a first approximation. Its first aim was to correlate measurements. It has also turned out to be a valuable educational tool for both researchers new to the field and operators in saw mills. The simplest version has been rigorously tested and accepted as realistic by experienced kiln supervisors. This is the one-dimensional model described in the paper and restricted to constant air conditions during drying.

INTRODUCTION

The internal structure of timber is so complicated and the variation of numerical values of its mechanical properties so large (even within the same tree) that drastic simplifications are required to produce a model with any practical value. The aim for the model was that it produce useful numerical values for stresses and the various components of strain on small readily available computers (PC^S) in a thousandth part of the time required for a physical test.

The first simplification is that the material is homogeneous as a first approximation. It is envisaged that the effect of local variations due to grain etc. would be calculated as "secondary" effects superimposed on the stress field calculated for the homogeneous material but this has not yet been tried.

The second simplification is that the material is orthotropic i.e. having different properties in each of the three principal directions. It is also taken that the ratios of values in the radial and tangential directions to that in the axial direction remain constant. There is a considerable body of evidence in many CSIRO publications to suggest that this is a useful

approximation in many situations, but it has been used in the model under conditions where it has not yet been justified. In this, as in several other aspects, the model must be regarded as being in a primitive stage of development. Nevertheless, numerical values produced by it appear credible so far.

The basic principles of the model remain unchanged from those presented to Twenty First Forest Products Research Conference (1). It is taken that, in each time step (generally one hour), the increment in the net strain (overall shrinkage) has four separate and separably measurable but linearly additive components. In general these strain components are taken to be functions of stress, moisture concentration, temperature and time.

A preliminary analysis by Schaffner (2) showed that published models based on linear elastic or visco-elastic behaviour produced unrealistic values for stresses and net shrinkage. It then became apparent that a realistic model needed many of the non-linear aspects of behaviour that are obtained under the extreme conditions that are required to be reached under the economic constraints of commercial seasoning.

The addition of non-linear effects usually increases computing cost so the number of these was kept as low as thought to be practical. At this stage of the development of the model there has not arisen the need to add more than are being used nor does it seem desirable to reduce the number. However, it is recognised that the model is in a rather primitive state and future developments may well lead to appreciable modification.

The ultimate aim is automatic kiln control but there is still much to be learned about which properties to monitor.

MOISTURE DISTRIBUTION

The classical simple model of the distribution of moisture in wood is based on the concepts of "bound" water and "free" water with a sharp demarcacation between them at the "fibre saturation point" (FSP). The many levels of bonding that occur between adjacent water molecules and between them and the various constituents of dry wood renders this a rather gross oversimplification but it remains a useful starting point for more detailed discussion.

The simple model implies that the surface moisture concentration of a drying board remains in equilibrium with air saturated with water vapour so long as that

surface moisture concentration remains above FSP. However, it appears that other factors must be involved. It has not yet been possible to reconcile values of surface moisture concentration (as inferred from measurements of the average moisture concentrations of slices obtained during drying tests) with any of the accepted models of drying by convection. It now seems likely that this difficulty is associated with the problem of defining the position of an equivalent plane to replace the very rough surface of a sawn board.

The current version of the model presented here uses the purely empirical rule for surface moisture concentration c_s proposed by Schaffner (2), namely

$$c_o - c_s = (c_o - c_e)(1 - \exp(-t^{0.286}/A_1)) \qquad (1)$$

It turns out to be convenient to use a moisture concentration deficiency $c_o - c_s$ rather than the actual value c_s . Equation (1) was derived from tests at 25°C, 50% R.H. and an air velocity of about 2 ms^{-1} over the surface of the boards so its application should be restricted to those conditions.

The diffusion equation most commonly used to estimate the internal distribution of moisture concentration is Fick's Law i.e.

$$\partial c/\partial t = D\, \partial^2 c/\partial y^2 \qquad (2).$$

Although there are many apparently sound theoretical arguments against the validity of this equation under these conditions, the experience hitherto has been that useful agreement between predicted moisture concentrations and those inferred from measurements on slices has been obtained by using a value of D depending only on the direction of moisture movement i.e. radial or tangential.

There seems to be no realistic alternative to using,as a starting condition, a uniform moisture concentration, however far this differs from the actual situation.

(a) SOLUTION OF THE DIFFUSION EQUATION

Two different forms of solution of equation (2) are used, the first to give starting values for at least two internal points and the second for later times.

Values for moisture deficiency on the surface are obtained for the first few hours from equation (1) then we use the classical solution (3) for a semi-infinite body with initial values zero and surface values varying as a known function of time. This yields

$$c(t) = y/\sqrt{(4\pi D)} \int_0^t c_s \exp(-y^2/(4D(t-\tau)))/(t-\tau)^{3/2}\, d\tau \qquad (3)$$

The integration is carried out numerically. Time steps $d\tau$ of 0.1 hour have generally been found small enough for Australian eucalypts with steps dy between 1 and 2mm. Usually the application of equation (3) is limited to three hours but longer times are occasionally required to ensure large enough values at the second internal point to allow reasonable numerical accuracy in the application of the second form of solution.

At later times values of moisture concentration deficiency at internal points are obtained from the initial value solution of Laplace (3). This states that, for an infinite body, the value c(y, t) for point y at time t is obtained from the initial values c'(y',0) at all points y' at zero time by

$$c(y,t) = 1/\sqrt{(4\pi Dt)} \int_{-\infty}^{\infty} c'\exp(-(y-y')^2/4Dt)dy' \qquad (4).$$

Values of dy' in the range 1-2mm with t equal to one hour appear to give satisfactory solutions for Tasmanian eucalypts.

At the time of writing, applications of equation (4) have been by fitting parabolas to logarithms of moisture concentration deficiencies at internal mesh points. This is equivalent to fitting error functions to actual deficiencies and avoids the large overshoots associated with the more common practice of fitting parabolas to deficiencies.

The term linear in (y-y') is expanded as the well known series for the exponential and then the integral is evaluated analytically term by term. The resulting series converges rapidly whilst drying is continuous but the method is inappropriate to steaming conditions for which a satisfactory solution has not yet been obtained.

During the early stages of drying the parabola is extrapolated past the last point for which usefully high values (currently taking as 0.001) of deficiency are obtained until the next innermost point has reached this same high value and is included in the process of fitting parabolas to logarithms of deficiency. This process seems to avoid the round-off errors otherwise associated with blind extrapolation.

DETAIL OF MODEL

The detail of the model remains substantially as presented previously (1) and

so is only briefly outlined here.

The basic assumption is that the net shrinkage strain is the sum of four separate and separably measurable but linearly additive components which are

(i) e_i = instantaneous strain as related to stress and measured by the usual quick loading test,

(ii) e_u = unconfined shrinkage strain (including collapse shrinkage) as measured by the usual test on thin specimens to obtain "normal" shrinkage added to an estimate of collapse shrinkage,

(iii) e_m = mechano-sorptive strain resulting from the interaction of stress with moisture movement and

(iv) e_c = mechanical creep strain.

The non-linearities that arise from these components necessitate numerical integration and so it is increments of them which are used to yield the equation

$$\delta e_n = \delta e_i + \delta e_u + \delta e_m + \delta e_c \qquad (5)$$

The application of the model in current use is essentially one-dimensional. It is thus restricted to the middle parts of wide planks of purely backsawn or purely quarter sawn material far from the centre of the tree so that moisture movement is in only one direction. It is further restricted to drying at constant air velocity, humidity and temperature although different values of these conditions are requested as part of the input of data. (It turns out that these latter restrictions are not so significant as might appear for its current applications because these depend on the visual observation of surface checks which usually appear in a few hours after the board leaves the saw).

Steaming processes are excluded at present, although it is hoped in a later development to use the model to resolve the conflict of evidence about the advantages of steaming.

(i) INSTANTANEOUS STRAIN (e_i)

This consists of a linear part up to a proportional limit followed by a non-linear part leading to failure.

(ii) LINEAR PART

The results obtained by Ellwood (4) on American beech have been used to provide

general rules because these provide the widest range of test conditions available to the author.

The measured values of Young's Modulus are described by a straight line for each temperature, meeting the value for green timber at that temperature at a moisture content of twenty percent. The values for green timber are also taken to vary linearly with temperature to reach zero at 100°C. The ratio of the Modulus for green timber to that for the bone dry material is also taken to vary linearly with temperature following a mean line through Ellwood's measurements (4) according to the equation

$$E_g/E_o = 0.475 - 0.0038T \qquad (6)$$

It is taken that there is a known ratio (currently 0.1) between the Modulus in the radial direction and that in the longitudinal direction and another for the tangential direction (currently 0.05). A single value for the Modulus of the green material in the longitudinal direction and the temperature at which it was measured thus define all of the slopes in the linear range of the curves of stress against instantaneous strain.

Computational difficulties which often arise when dealing with data described by two intersecting straight lines have been avoided by replacing them with an hyperbola having the straight lines as asymptotes. The equation for E, the local value of the modulus is then

$$(E - E_g)(E - E_o + C_m .m) = k \qquad (7)$$

in which the value for C_m is obtained from the condition that the asymptotes intersect at $m = 0.2$.

The limit to the linear range is taken to be a fixed value (currently 0.005) for the strain at the proportional limit, the same for both tension and compression as well as in both radial and tangential directions.

Equations (6) and (7) and the accompanying discussion describe a set of model rules which may be altered as soon as better data become available without, in any way, affecting the basic assumption of the model as expressed by equation (5).

(b) NON-LINEAR RANGE

The non-linear part of the curve of stress against instantaneous strain has been taken as an exponential curve tangent to the linear part at the proportional limit and asymptotic to the ultimate stress as an upper limit.

The argument for this shape is that the model material is taken to be continuous in order to keep the amount of computation within due bounds. The real material exhibits local failures under drying conditions and these local failures relieve the stresses there so that the average values never reach the ultimate which causes failure. In a direct loading test such local failures often lead quickly to a complete collapse of the specimen but there are exceptions. A good universal failure criterion for timber is not yet available.

It is taken in the application of the model that the ultimate stress at failure is a fixed fraction (currently 0.01) of the Modulus for the linear part at the local conditions of moisture content and temperature. This rule allows an effect of each of these variables to be included in the ultimate stress.

These arguments have led to the removal of ultimate stress as a criterion of failure so the current application of the model uses a limiting value of the instantaneous strain, e_i (currently taken as 0.02) to replace it. The only tests of this as a criterion have been the records of the appearance of excessive surface checking by experienced seasoning supervisors. Its present status is that it does not seem to be too bad a guess but gives a useful measure for drying at atmospheric temperatures.

(c) UNLOADING AND SET

As drying proceeds all points in a board eventually unload. This unloading is taken to be along a straight line having the same slope as that given by equation (7) for the particular moisture content and temperature. When unloading is detected, the current version of the model takes it that it began at the beginning of the time step at a slope determined by the moisture content and temperature prevailing at that time. The actual unloading path during the time step is taken to be at the average of the two slopes.

More detailed computation to estimate a better measure of the time of onset of unloading is thought to be not warranted by our present understanding of the

material.

At present, set is defined as the strain at which this unloading process crosses the axis of zero stress and subsequent reloading curves are taken to pass through that point.

Points where the stress has not exceeded the proportional limit are taken to have no set.

It seems likely that there should be an interaction between creep and set and that this is an aspect of the problem where the assumption of equation (5) that strain components are separately measurable is no longer valid. This question awaits further clarification of the detailed mechanisms of the various strain components.

(ii) UNCONFINED SHRINKAGE (e_u)

The unconfined shrinkage strain is taken to arise from two separate mechanisms. "Normal" shrinkage is largely attributable to decrease in fibre wall thickness whilst the fibres retain their shape whereas "collapse" shrinkage is associated with change of shape of fibres as they collapse.

(a) NORMAL SHRINKAGE

The classical simple model based on the concepts of "free" water and "bound" water again gives a valuable starting point. On this basis there would be no shrinkage caused by removal of free water. Below FSP this simple model has it that shrinkage results from the removal of bound water resulting in a volumetric shrinkage strain rate nearly equal to the rate of volume of water removed.

Measured shrinkage curves usually show some small shrinkage at FSP, presumably due to some movement of bound water at higher moisture contents or to some collapse.

Once again, an hyperbola is used to replace the two straight lines of the simple model. At the time of writing, this hyperbola is defined by three points on a measured shrinkage curve. The longitudinal shrinkage is taken as negligible and the rate in the tangential direction taken to be twice that in the radial direction so that the "normal" component of shrinkage in the tangential direction is taken to be two-thirds of the volumetric shrinkage strain.

Below about ten per cent moisture content, curves of measured values of shrinkage

against moisture content become steeper. This is usually attributed to the removal of more tightly bound water which has an effectively higher density. This region is ignored in current applications of the model as being outside the range of interest.

Currently, the normal shrinkage curve is taken to be independent of temperature even though various reports on tests on North American timbers show FSP decreasing as temperature increases, and the simple model has normal shrinkage starting at FSP.

(b) COLLAPSE SHRINKAGE

The traditional view is that collapse is the result of internal tension in the water inside fibres whose internal diameter is less than that of the smallest bubble that can grow against surface tension forces. The resulting compression in the fibre walls causes them to collapse. In this view, the whole of collapse is completed by the time that the moisture content has been reduced to FSP. There is much indirect evidence to support this view.

Details of the progress of collapse do not seem to be available so the rate of collapse shrinkage has been defined by some almost arbitrarily chosen model rules.

It is taken that the large vessels and rays are almost empty of free water at the start of drying so that the volumetric rate of collapse shrinkage cannot exceed that allowed by removal of water. The ratio of shrinkage in the tangential direction to that in the radial direction is taken to be 2:1 as in normal shrinkage.

The limit to collapse shrinkage is further modified by specifying a fraction relating the cross-sectional area of fibres undergoing collapse to the total area. It is also specified that this fraction increase linearly with temperature on the grounds that the Young's Modulus of the bulk material in the green state was shown by Ellwood (4) to decrease as temperature increases.

The form of the curve describing the variation of collapse shrinkage with changing moisture content at a given temperature has been taken as another hyperbola. This is defined as passing through zero at the initial moisture content having an upper asymptote at the greatest slope allowed by movement of

water and tangent to the translated image of the normal shrinkage curve at an arbitrarily chosen moisture content at the specified amount of total collapse strain.

There is, as yet, no allowance for the effect of reconditioning.

The simple version of the model in current circulation (7) has no allowance for collapse.

(iii) MECHANO-SORPTIVE EFFECT (e_m)

The rule for mechano-sorptive effect follows the information reported by Armstrong and Kingston (5) and remains the same as that reported to the Twenty First Conference (1). There does not seem to be yet available any information regarding the ratio of this effect across the grain (as occurs in drying) to that along the grain in was the case in the CSIRO tests (5) for eucalypt timbers.

Briefly, the mechano-sorptive effect in beams is seen as a greatly increased deflection under load as they dry out. It appears that when the strain associated with moisture movement is in the same direction as the applied stress there is this additional component of strain related directly to the applied stress and the water movement. Most of this additional strain is recovered when the moisture movement is reversed.

The CSIRO test results (5) have been interpreted in the model by the equation

$$\Delta e_m = u.\ \Delta m.\ s/E_g \qquad (8)$$

which purports to relate the increment of this component of strain to the change in moisture content during a time interval and the average stress over that step in time.

At the time of writing there is no other allowance for variation of mechano-sorptive effect with temperature besides that used to estimate the Young's Modulus of the green material (E_g).

(iv) MECHANICAL CREEP STRAIN (e_c)

Data for the mechanical creep strain have been taken from results of CSIRO tests reported by Kingston and Clarke (6). The numerical values used in the model are for the species E. regnans grown in Victoria because these covered the widest available

range of conditions.

Following the suggestion of Kingston and Clarke (6) the model represents creep by a spring-dashpot model but requires that the ratio of secondary spring stiffness (i.e. the one in the spring-dashpot unit) to the primary spring stiffness (i.e. the Young's Modulus of equation (7)) should vary with stress ratio as well as temperature.

The reference stress has been shifted to the ultimate stress of green material from that at 11% m.c., which was used by Kingston and Clarke, by taking the latter to be twice the former.

The equation for the straight lines are then

$$R = E_2/E = R_o - R_s \, .s/U \qquad (9)$$

In later applications of the model the intersections of the straight lines with the axis of zero deflection ratio has been taken as fixed by the equation

$$s/U = 1.59 + 0.015T - 0.0003T^2 \qquad (10)$$

in the belief that these intersection points will remain substantially unaltered as the creep rate changes between species. The equation fitted to the intersection of these straight lines with the ordinate from the date of reference (6) is

$$R_o = 105.6 - 3.46T + 0.0319T^2 \qquad (11).$$

For species with higher creep it should be sufficient to decrease the parameters of equation (11) in proportion.

As elsewhere in this discussion, computational problems associated with data described by two straight lines have been avoided by using hyperbolas, the lower asymptote being taken in later applications as at $R = 0.04\ R_o$ so that some dependence on temperature is retained at the higher values of stress ratio.

It has been taken that the curves of creep ratio against time as published (6) can be replaced by one curve when all values are divided by the final value (A) to which they are asymptotic, whence a little manipulation yields

$$de/dt = k(A - e) \qquad (12)$$

in which

$$e = e_c / e_i \qquad (13)$$

There is much evidence to indicate that equation (12), as it stands, is a poor fit to measurements for stress ratios greater than about s/U = 1 but this author has not yet found enough consistent data from measurements of creep under stress across the grain for any particular species to fix on a rule for this situation.

It also appears, from the anatomy of the material, that creep in shear when the maximum shear stress is in the tangential direction requires modification to the rules.

APPLICATION OF THE MODEL

Computer programs that have been released (7) are restricted to one-dimensional behaviour under constant drying conditions in a narrow range of air velocities, temperatures and relative humidities. There is no allowance for collapse and no attempt to model effects of presteaming or reconditioning after collapse.

One-dimensional behaviour is appropriate to the middle parts of wide boards which have been purely backsawn or pure quarter sawn and far from the centre of the tree. This restriction ensures that the net shrinkage, e_n , be the same at all points across the board. This condition together with the additional one that there be no net force in the lateral direction have been used to set up equations relating e_n to local stresses in a manner described in reference (1). Iterative solution of these equations is used to give values for e_i at all points across a board and hence an indication of the appearance of surface checks, currently taken as defined by $e_i = 0.02$.

CONCLUSION

A model of a drying board has been developed from CSIRO test results. It gives realistic numerical values of stresses and various components of strain and has been confirmed by field observations of the first appearance of surface checks.

Staff of the Tasmanian Timber Promotion Board have translated the original BASIC program into Pascal language and added graphical presentation of the most important aspects of behaviour as well as an allowance for air velocity and relative humidity (7). This is simple enough to run on most modern "Personal

Computers" and usually simulates an hour of drying time in about a second.

The graphical output has proved a very valuable training aid. It allows experienced supervisors to consolidate their experience and refresh their memories more quickly than consulting their written records. It helps them train their subordinates and lets them present memories of past failures without personal embarrassment. It also assists them in explaining the reasoning behind their practices to management. In some cases it has started even experienced people thinking along new lines as to how they might economically improve the output of select grade material and hence the profitability of the industry.

Researchers have used the more detailed results from the computer program to correlate their own measurements with the results of others. The patterns that follow from the CSIRO tests are expected to be the same for many species, even when absolute values change, so the amount of testing required for a new species is in most cases considerably reduced. Newcomers to the field can examine details and learn in a few months as much as would require many years of physical testing and reading.

Up to the time of writing, the numerical output from the computer program (7) has proved so nearly credible that it has been necessary to continually remind users that it is only a model and that there are many limitations to its application.

NOTATION

A	limiting value of creep ratio	c	moisture concentration
A_1	parameter in equation (1)	c_o	starting value of c
D	diffusion coefficient	c_s	surface value of c
E	local value of stiffness	c_e	equilibrium value of c
E_2	stiffness for creep	c_m	variation of Eg with m
E_o	stiffness at zero moisture	e	creep ratio e_c/e_i
E_g	stiffness of green timber	e_n	net strain
R	ratio E_2/E	e_i	instantaneous strain
R_o	value of R for dry wood	e_u	unconfined shrinkage
R_s	variation of R with stress	e_m	mechano-sorptive effect
T	temperature °C	e_c	creep strain
U	ultimate stress of green wood	k	parameter for creep

k_t	constant in equation (7)	t	time
m	moisture concentration	u	mechano-sorptive multiplier
s	stress	y	distance into board

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COPING WITH WOOD FROM YOUNG FAST-GROWN EUCALYPTS

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ABSTRACT

Statistics are provided to support the view that future hardwood supplies will be derived from regrowth forests of relatively young age.

Seed provenance, sawing procedures, together with drying and grading of sawn timber are identified as important in the production of timber products from young, fast-grown eucalypts.

INTRODUCTION

The public forest estate dominates the supply of hardwood, environmental services and other forest produce in Victoria. Data provided in the recently published Timber Industry Strategy (1) shows that about 8.1 million hectares of Victoria's land area of 22.7 million hectares carries forest, dense woodland and shrubland. This represents 36% of the total area of the State. Approximately 4.7 million hectares (58%) of this is public forest in which 1.3 million hectares of hardwood forest is available and suitable for sawlog production, representing 5.7% of the area of Victoria. Approximately 500,000 hectares (39%) of this land carries mature and advanced regrowth and the remaining 800,000 hectares is either understocked, carrying

unmerchantable stems and inadequate regeneration, or carrying regrowth less than 35 years old.

These facts support the contention that a large part of the hardwood resource will, in the future, be derived from regrowth forests of relatively young age. Additionally, it is apparent that we are confronted with a shrinking hardwood forest land-base and more intensive forest management practices will be required if productivity is to be maintained. These intensive management practices will result in sawlogs being produced on shorter rotations than previously and substantial proportions of the growing stock will be removed as thinnings from which a diversity of products may be produced.

Since 1980, the Department of Conservation, Forests and Lands (formerly Forests Commission) has been, with limited resources and the co-operation of the CSIRO Divisions of Chemical and Wood Technology and Building Research, addressing the problems associated with the utilization and conversion of wood from young fast-grown ash-type eucalypts.

For 10 year-old trees of plantation grown Eucalyptus nitens (shining gum) it was found that provenance influences growth stresses, and a number of strength properties such as moduli of elasticity and rupture, crushing strength parallel to the grain and hardness in either green or dried wood. Compression strength perpendicular to the grain was influenced by provenance in both green and dried wood (3).

Additionally, it was found that the inner-wood (near the pith), generally had lower strength properties than the outer-wood (3).

In a study on the utilization of 20 year-old plantation-grown dominant E.nitens trees, for the production of structural and appearance products four drying techniques (pre-drying and conventional kiln drying, air drying and conventional kiln drying, air drying and high temperature kiln drying, and progressive kiln drying) were applied to 25mm and 50mm thick back and quarter-sawn boards. After drying the boards to a moisture content of 12%, they were machined and assessed for degrade.

The results showed that product grain-orientation had a real effect on checking. On quartersawn products face checking was significantly less than on backsawn products though the reverse was true for internal checking. The latter result is considered relatively unimportant for structural products because internal checking has almost no effect on strength or stiffness. However, for appearance products, the extent of internal checking is clearly important because cross-cutting or turning can expose these checks, and if excessive, the product may be rendered unacceptable.

All drying methods were associated with similar amounts of face checking. Pre-drying, followed by conventional kiln drying, resulted in significantly more internal checking than any of the other drying treatments, whereas air drying, followed by high temperature kiln drying, resulted in minimal internal checking.

The results in Figure 1 summarize the data and show quite clearly that knots were the largest downgrading defect for both structural and appearance grade sawn products. Knots accounted for 65 and 84% of the grade-limiting defects of structural and appearance products respectively. Other defects such as checks, pith, wane and holes, though present, had only a minor effect on

product grade outputs. The 37% rejection rate for structural sawn products (Fig. 1) borders on the limits of acceptability in a commercial environment, but the real possibility of converting rejected pieces into useable products through secondary processing, should make the utilisation of this resource a viable prospect. However, the 54% reject rate for appearance products, and the presently poor market demand for products below the standard of the two highest grades, indicates that this resource is presently unsuitable for hardwood appearance products.

The market expects and demands clear wood from our hardwood resource, as such wood is not readily available from plantation-grown conifers. The current grading rules for appearance grade hardwoods and softwood sawn products reflect this rationale, despite the fact that the occurrance of knots in plantation-grown E.nitens is similar to that from Pinus radiata. If however, the appropriate P.radiata appearance grading rule is used, a very different picture emerges. Because grades 1 and 2 of that species are roughly equivalent to hardwood grade 1 and account for almost 50% of total products as opposed to 30%, the rejection rate drops from 54% to 11%. Therefore, judged by P.radiata standards, the appearance products obtainable from 20-year-old E.nitens are a high quality resource, though not by hardwood standards.

Regression analysis showed that the degree of checking on the end of a structural products is not indicative of the extent of internal checking ($r = -0.012$, $n = 125$), and that there is no significant correlation between internal and face checking for individual products

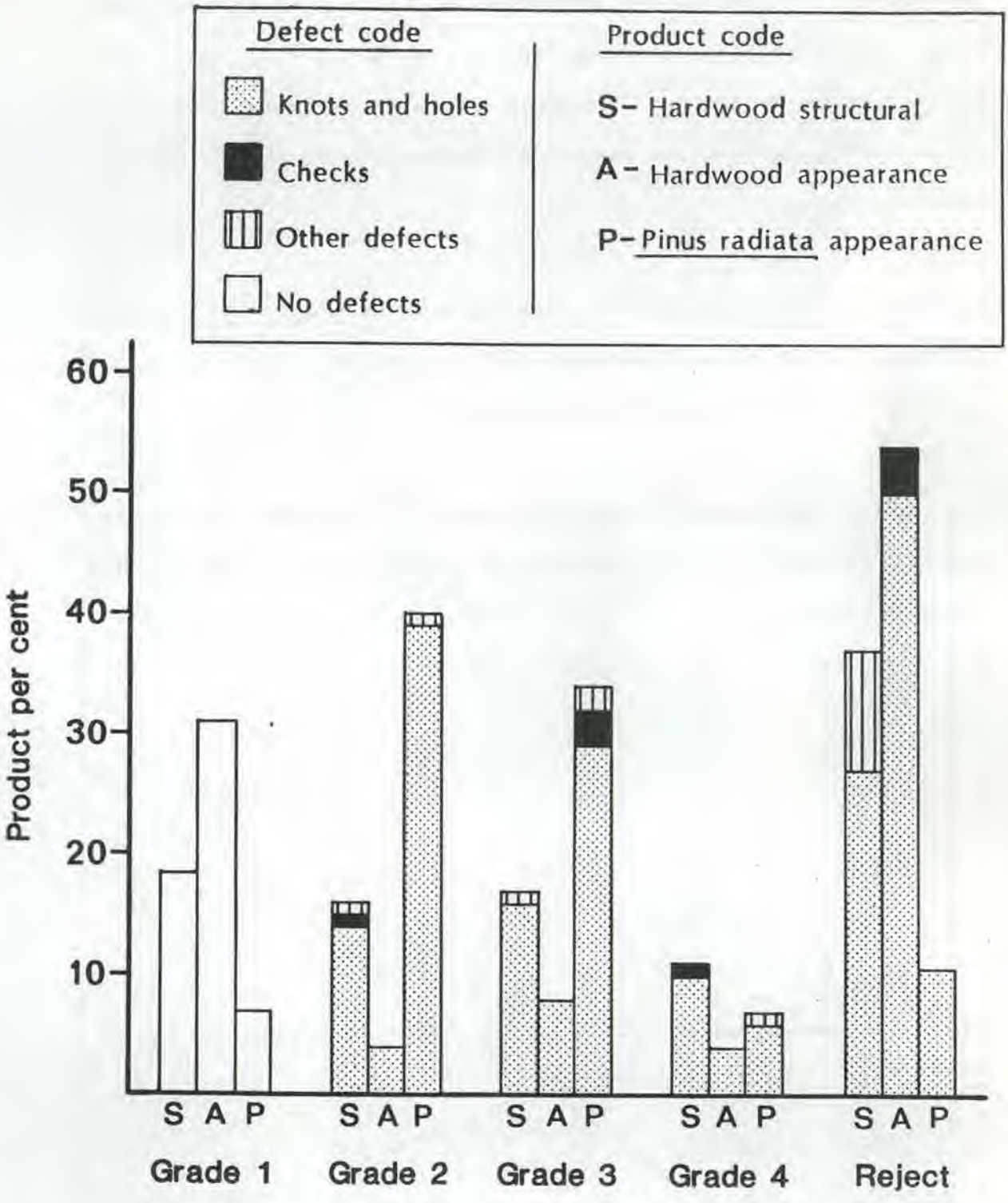

Figure 1. Grade and defect categories for 20-year-old plantation-grown E. nitens (Shining gum).

(r = -0.049, n =125), though when examining for difference between trees, a significant relationship (r = -0.716, n = 8), was found between internal and face checking. This showed that there is a marked difference in the amount of checking which occurs between individual trees.

The degrade in sawn timber from fire damaged E.regnans trees was measured for two drying treatments, conventional and high temperature kiln drying, following the "Ash Wednesday" fires in 1983.

The results showed that the moisture content of the boards before the reconditioning treatment affected the degree of face and internal checking in irrespective of their growth ring orientation (Fig. 2).

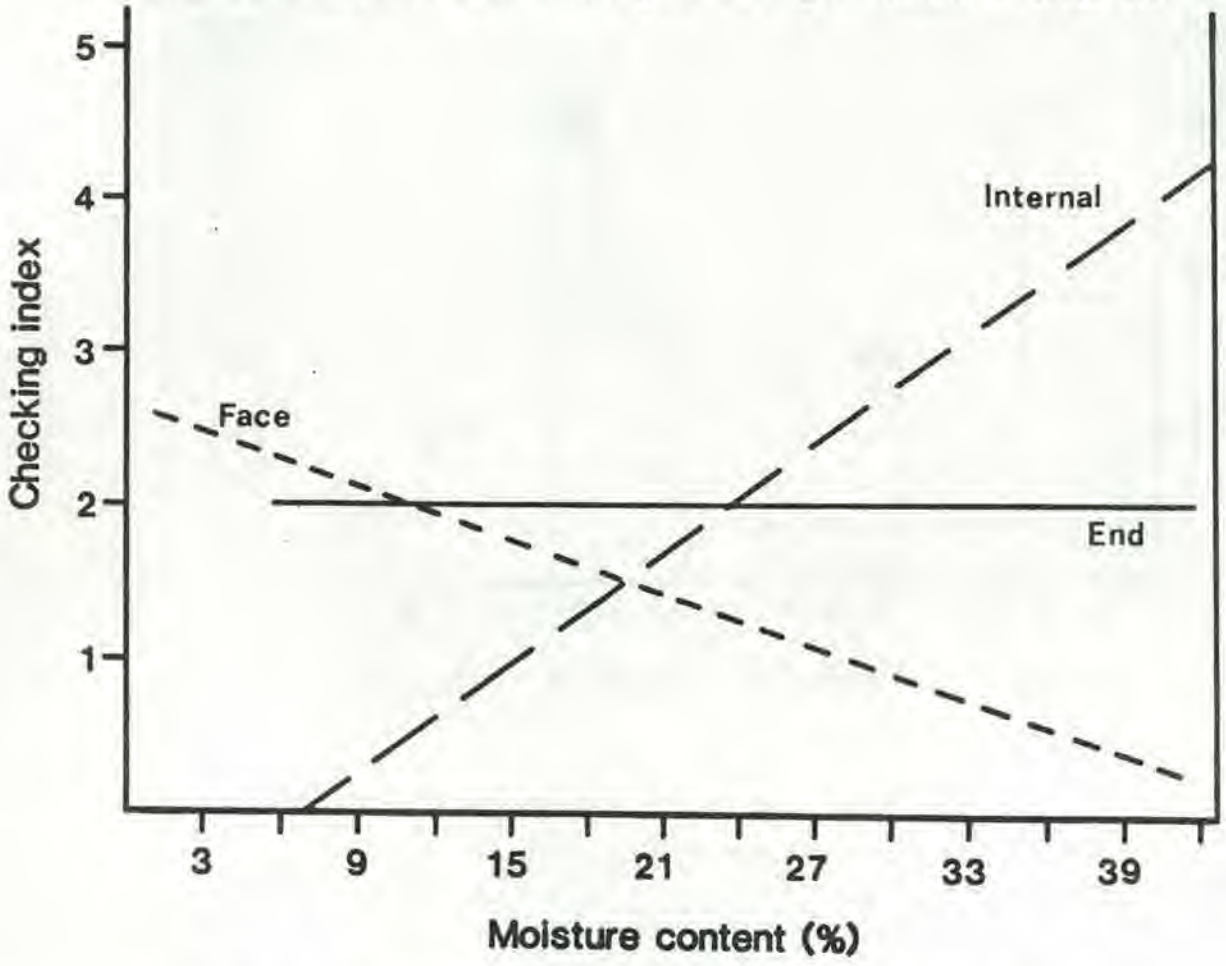

Figure 2. Checking categories and moisture content before reconditioning in boards from regrowth E. regnans.

High temperature kiln drying resulted in significantly more face and internal checking irrespective of whether the boards were back or quartersawn.

Results from this study also showed that after drying and machining to size, 95% of both board sizes (100 x 50 mm and 100 x 38 mm) complied with standards for structural timber and 77% complied with standards for appearance grade timber. These results indicate that a high proportion of this particular resource, presently being sold as scantling, will produce a much higher quality product.

The problems regarding the utilization of young fast-grown eucalypts involve interaction between genetics, silviculture and conversion techniques. To maximize the value of this new type of resource these problems must be tackled in a systematic manner.

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QUALITY CONTROL AND THE USE OF ELECTRONICS IN THE FOREST PRODUCTS INDUSTRIES (SAWN TIMBER)

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We have, in the world, a huge amount of poverty combined with an equally large surplus of labour. What we lack is the talent and the will to get this labour working.

The average age of our workforce is increasing and so we can expect, in the short term, an even smaller percentage of our population will be called upon to support the remainder. For this reason and because labour must be kept out of dangerous enviroments it is essential that labour saving machinery be introduced wherever possible.

A glance at our balance of payments or the dwindling world resources makes clear the need for conserving our raw material.

For these reasons the aim in modern machine design must be to turn out high speed accurate machines that will make the best possible use of our labour and raw materials. End users of our timber must get a product that is reliable, consistant and asthetically pleasing. Those that design structures must be able to rely on accurate dimensions and strengths. Over design and large factors of safety can no longer be tolerated.

Bearing these facts in mind we will now consider the effects on the timber milling industry of modern electronics and computers together with the design of modern processing machinery.

The timber industry was quick to see the advantages of automatic systems and to follow this by making use of electronics and computers. Although there is still some way to go in the introduction of these systems the timber industry would even now be a leader in control by electronics.

Analogue position devices were probably the first we saw of electronics inside the mill. They were a big improvement on the earlier electro mechanical systems but these in turn have been replaced by digital systems generally making use of high speed accurate proportional hydraulics.

These digital systems are at least as accurate as are the analogue systems and from a users point of view are much more flexible, more environmentally stable and more simple to maintain.

Most digital systems are now processor based making it possible, with proper design, for information to be passed between machine centres or to a periferal computer.

Machine design has also gone through a revolution. High speed accurate machines can only function if inertia is kept to a minimum. Heavy machines might last forever but they will be expensive, slow, perhaps dangerous and accuracy will suffer.

The bandmill is a typical example where modern machines use thin, high strain blades yet inertia of the strain mechanism is so low that a piece of 100 x 50 can pass between blade and wheel without damage to the blade. Please remember that not only are the blades of these high strain bands thinner than those on the old machines but they are more stable improving surface finish and accuracy thus reducing machining loss.

Modern mills are designed with small factors of safety and are adjusted to keep materials moving. Acceleration forces associated with stopping and starting are eliminated wherever possible.

Modern milling techniques make ever increasing use of non contact automatic devices.

Electronics detect and report position dimension, shape and direction of moving logs or boards without even touching. We also have non contact high speed measuring of moisture content, strength and visual defects. While non contact circular saw guides hold blades upright and free them from vibration.

These non contact systems operate with little or no wear and in probably all cases do a better job than did the older system. As an example the non contact stress grader checks strength and faults throughout the full length of each board and actually marks the stronger side.

When breaking down, residual stress in a log must be considered together with cutting techniques that will maximise recovery. Computer models are in continual use in the timber industry where studies are being made of patterns to enhance recovery and quality and of course it would probably be impossible to make use of this information without high speed scanners and digital setworks.

Where are we now.

1. Trees are felled and limbed without chip loss or damage.
2. Logs are scanned, automatically sorted, and reports are prepared that:-
   a. Keep foresters informed.
   b. pay all contractors.
   c. buy the logs.
   d. advise log volumes into the mill that will permit the production of recovery figures.
3. Logs are passed to the mill where equipment is automatically set up to cut the best pattern and throughput reports are produced.
4. Sawn timber is next passed through a sorter that measures accurately, sorts and then stacks. Reports of mill output, cutting inaccuracies and the like are prepared at this stage.
5. Drying is the next stage where big savings are made and losses reduced by controlling accurately the drying cycle, airflows and the like.
6. In the planer mill the board is planed then passes through a stress grader that marks and sorts according to strength and/or visual defects. It is then again stacked and wrapped ready for the customer.

Where to next:-

The next step is to tie all machines together by computer permitting the production of complete management reports which will identify wastage throughout the milling complex. This will be followed colsely by the widespread use of the quality control equipment we have mentioned earlier.

What purpose is served by accurate finish if the end user is goint to build in large factors of safety purly to ensure that his structure is not destroyed by the weakest link?

Laminated sections are going to play a major role in structures and for these to be economical and practical it will be necessary to closely control moisture content and distribution and to keep a close check on the strength, not only of a finished section but on all its component parts. Outside members of a beam in bending will be strong with strength reducing as the centre is approached.

Visual grading will also become more important as timber takes its place in high quality buildings.

Timber buildings are well accepted throughout the world. Overseas, structural members of widespan buildings are often wood. This type of construction has a price advantage, an asthetic advantage is fire resistant and, of course, takes advantage of a renewable asset. In Australia timber is seldom used except for framing and decorative purposes and other materials are tending to take over even in those areas. We have a long way to go.

LAMINATED VENEER LUMBER

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ABSTRACT

It is possible by laminating structural grade veneers unidirectionally with a rigid permanent adhesive to produce a structural reconstituted wood based product, Laminated Veneer Lumber (LVL) which possesses superior basic working stresses and elastic moduli and improved reliability compared to sawn sections of structural timber from the same resource. The improved working stresses and structural reliability are due to randomising defects throughout the assembly so the effect of defects is minimised. LVL products have the advantage of being available in long lengths due to the continuous processing techniques now adopted and large section size.

INTRODUCTION

The craft of veneer laminating is as old as the craft of veneer cutting itself and dates back to the reign of the Pharaohs. Over the years a wide range of laminated wood veneer products have been produced to meet specific aesthetic and physical requirements ranging from highly decorative inlaid veneering, sporting goods such as golf club heads, tennis racquets and hockey sticks, air craft propellers and moulded furniture components.

A great deal of literature is available concerning materials produced by laminating veneer. Possibly the most significant work in regard to the modern direction and objectives of veneer laminating resulted from Luxford[1] in 1944 concerning the glue laminating of 3.63mm rotary peeled Sitka spruce veneer for aircraft components. This work showed that clear laminated and clear solid wood material possessed equal properties.

During the last decade significant developments have been made in machinery and processing techniques for the continuous manufacture of structurally reliable and cost competitive laminated veneer products. The major developments have taken place in Finland, USA and Canada.

Younquist[2] in 1985 suggested the incentives for these developments were:

"(1) Overcoming the problem created by the diminishing supply of large logs suitable for lumber of large dimensions.
and
(2) Optimising the economic picture by using an increasing percentage of the forest biomass previously considered forest residue."

The objectives of this paper are to investigate the basis for the development of structural laminated veneer lumber products and manufacturing processes overseas, primarily in Finland, USA and Canada and assess their applicability to the development of a laminated veneer lumber industry in Australia. The paper will cover developments overseas and in Australia; the development of standardised, reliable properties; a comparison of working stresses and elastic moduli of LVL with solid in grade timber from the same raw material and potential markets for LVL in Australia and overseas. A theme throughout the paper is the perceived necessity for structural LVL products to be manufactured and marketed, on a firm technical basis, as a reliable, standardised, quality controlled, engineered, reconstituted wood based material.

DEVELOPMENTS OVERSEAS

This paper is restricted to developments specific to the manufacture of LVL products using equipment and/or processes other than those used in the manufacture of standard (2400mm x 1200mm) plywood panels. It is however well documented in literature[3] that LVL can be manufactured in plywood presses and used in short lengths or end jointed in a separate operation into longer lengths by scarf or finger jointing or toothed plate metal connectors.

General Description

Laminated veneer lumber can be defined as an assembly of veneers laminated with adhesive in such a way that the grain direction of all veneers is in the same direction which is parallel to the principal dimension of the LVL piece. Modern structural LVL is manufactured from softwood veneer, usually from a plantation grown resource, of the quality and species traditionally used for the manufacture of softwood structural plywood i.e. C or D grade veneer as defined in Australian Standard AS 2269 - 1979 Structural Plywood[4] Two common veneer thicknesses used are 2.5mm and 3.2mm.

In all commercially produced structural LVL in Finland, Canada and the USA the adhesive used for bonding is a phenol formaldehyde which would meet the requirements of Australian Standard AS 2754 - 1985 Adhesives for Timber and Timber Products, Part 1, Adhesives for Plywood Manufacture[5]. End joints in veneers may be scarfed, butted or overlapped. Other physical characteristics depend on the type of manufacturing process used for the LVL manufacture. The three LVL types which will be broadly outlined in this paper are:

1. Finnish LVL, as developed by Metsaliiton Teollisuus Oy and Raute Oy.
2. MicroLam(R) as developed by the Trus-Joist Corporation of the USA.
3. Parallam(R) as developed by MacMillan Bloedel Ltd of Canada.

The processing technology for the abovementioned products is protected by patent and copyright and very little information is therefore available for publication. This paper therefore refers very briefly to processing and concentrates more on the physical characteristics specific to each product.

Finnish Developments - Kertopuu(R)

Finnish LVL, manufactured by Metsaliiton Teollisuus Oy using Raute Oy machinery, utilises 3mm veneer of either Scotch pine (P. sylvestris) or Norway spruce (Picea abies). In the more modern processing lines each veneer in the assembly is end scarf jointed prior to fabrication into LVL in a semi continuous pressing operation. Veneers are arranged through the assembly with the higher veneer quality towards the outside.

The process has the following steps:

(i) Grade the veneers into outer and inner quality.

(ii) End scarf joint all veneers.

(iii) Spread the veneers with a phenol formaldehyde adhesive.

(iv) Prepress the parallel laminated assembly in a cold press (prepress) to achieve glue transfer and grip. The prepress moves along the pack of spread veneers to allow for continuous processing.

(v) Hot press the final assembly. Hot press pressure and temperature are higher than for normal plywood manufacture.

(vi) Cross cut the continuous panel to desired length and rip to width using an adjustable gang rip saw.

It should be noted that in the original machinery used in Finland for LVL manufacture, outer veneers only were scarfed. All inner veneers were butt jointed.

The Raute Oy machinery usually has a single opening (daylight), however some of the more modern machines are multi daylight, producing LVL nominally 1200 to 1800mm wide in thicknesses ranging from 27mm to 75mm on a continuous basis. Hot presses of 17m length are common. The final length of the LVL is governed by handling not manufacturing restrictions. The maximum standard beam length is usually 18m. The largest beams, up to 23m long, need to be supplied by special transport.

Kertopuu(R) manufactured using the Finnish machinery and processes described above has the following dimensional tolerances at the time of manufacture (6):

Length	- 6m	-	±3mm
	6m-12m	-	±8mm
Depth to 400mm		-	±1mm
Thickness		-	±2mm
Finish		-	Unsanded faces and sawn edges.

Typical beam depths described in Metsaliito's technical literature(7) are 200, 225, 260, 300, 360, 400, 450, 500 and 600mm.

USA Developments - MicroLam(R)

The Trus-Joist Corporation's MicroLam(R) is a laminated veneer lumber product which utilises 2.5mm or 3.2mm Douglas fir (Pseudotsuga menziesii) veneers throughout the parallel laminated construction. The veneers are ultrasonically stress graded prior to fabrication and are arranged through the assembly to give the end product desired, pre-determined properties. The laminating is carried out continuously, in a segmented platten hot press approximately 600mm wide.

The basic process steps are:

1. Ultrasonically stress grade the 2.5mm to 3.2mm Douglas fir veneer into a number of pre-determined strength grades.
2. Spread the graded veneers and assembly them in a pre-determined sequence. The adhesive used is phenol-formaldehyde.
3. Press the assembly through the continuous segmented platern hot press. End joints are crushed lap joints. Hot press temperatures and pressure are above normal plywood manufacturing conditions.
4. Cross cut the continuous panel to length and rip to width.

The machinery used is single daylight, continuously producing MicroLam(R) approximately 600mm wide in thicknesses 19mm to 63mm and lengths up to 25m. Again because of the continuous nature of the process the maximum length constraint is transport. In the MicroLam(R) process, pressure is used to densify veneers and improve structural characteristics. It is also reported(8) that MicroLam(R) has a coefficient of variation(CV) of 12 percent compared to 25 to 35 percent for sawn Douglas fir. The low coefficient of variation is characteristic of all LVL products as 'Woods natural defects, such as slope of grain, knots and splits are controlled, or dispersed and reinforced by the grading and manufacturing processes. The result is a structural lumber in a wide range of sizes with uniformity and predictable performance." (9)

MicroLam(R) may be ordered in any depth up to 600mm to suit specific application requirements.

Canadian Developments - Parallam(R)

MacMillan Bloedel's Parallam(R) is a parallel stranded lumber product using pieces of veneer approximately 2400mm long, 12mm wide and 3mm thick. The process has been patented and details of the manufacturing techniques are not available. In general terms, from published literature(10) the strips of veneer are coated with phenolic adhesive and pressed into continuous billets with a cross section approximately 450mm x 150mm and length 18.5m and longer. The billets are resawn into the desired sections. The Parallam(R) process is quite different to the Kertopuu(R) and MicroLam(R) processes. The end product is also quite different in appearance. The structural properties of Parallam(R) however compare with other LVL products due to the randomisation of defects which occur during the manufacturing process.

The basic process steps are:

1. Cut the dry veneer into strands approximately 2400mm x 12mm x 3mm.
2. Grade the veneer strands. Defects in strands greatly affect the final structural properties. Although the process was seen initially as a recovery operation, it was established that control of strand quality was significant in controlling end product performance(11).
3. Coat the veneer strips with phenol formaldehyde adhesive.
4. Hot press the veneer into continuous billets approximately 450mm x 150mm.

5. Saw the billet into the desired sections.

Parallam(R) is available in any section size from 50mm x 50mm to 350mm x 175mm with larger sizes available on custom order.

Comparison of Properties

Table 1 compares the allowable design stresses for Kertopuu(R), MicroLam(R) and Parallam(R) based on a 10 year duration load factor and 5 percentile exclusion limit, with two grades of Douglas fir lumber. Select Structural is the highest grade Douglas fir lumber used for both structural beams and joists, and as an appearance grade. It would be roughly equivalent to a Structural 1, i.e. a 75 percent grade factor[12] material, in AS 1720 - 1975 Timber Engineering Code[13]. Grade 2 Douglas fir would be roughly equivalent to Structural 3 i.e. a 45 percent grade factor material detailed in AS 1720.

DEVELOPMENTS IN AUSTRALIA

The Australian plywood manufacturing industry became seriously interested in the production of LVL in the late 1970's. LVL is a complimentary product to plywood with regard to manufacture as two processes, veneer peeling and drying, which require high capital investment and skill factor, are common. Many plywood operations have excessive peeling capacity. Additionally the science of gluing veneers with phenol formaldehyde is well understood by all Australian plywood manufacturers. Thus plywood and LVL manufacturing technology is similar.

A number of individual companies carried out economic feasibility studies in the early 1980's. Raw material, P. radiata, was shipped to Finland and the USA for manufacture into LVL using the Kertopuu(R) and MicroLam(R) processes.

Additionally LVL was manufactured in short lengths in traditional 2400mm x 1200mm plywood presses utilising 2.5mm to 3.2mm P. radiata veneer and modified phenolic adhesives.

Locally and overseas manufactured LVL was mechanically tested to establish basic working stresses and elastic moduli on edge (beam) and on the flat (plank). The economic viability of marketing LVL in Australia based on locally produced P. radiata LVL or imported LVL was investigated based both on the structural performance versus cost ratio established via the test program when compared to sawn timber, glue laminated beam, structural timber fabricated components and metal products, and the physical advantages of large section size and long length availability. The structural reliability of LVL resulting from its comparatively low coefficient of variation(CV) was also a consideration for engineered structures.

TABLE 1. ALLOWABLE DESIGN STRESSES FOR OVERSEAS LVL COMPARED WITH DOUGLAS FIR LUMBER (MPa)

Property	PRODUCT							
	MicroLam(R) (Plank)[8]	MicroLam(R) LVL (45 to 65mm)			Parallam(R)[10]	Master Plank (R)[14] or Kertopuu	Douglas Fir Lumber[15,16]	
		2.2E	2E	1.8E			Select Structural	Grade 2
Modulus of Elasticity (E) Beam		15160	13780	12400	13780	13780	12400	11200
Modulus of Elasticity (E) Plank	14800					14470	12400	11200
Bending Strength (Fb) Beam		18.25	16.53	13.43	19.29	19.29	12.80	8.90
Bending Strength (Fb) Plank	19.98					18.60	12.80	8.90
Tension Strength (Ft)		12.06	10.67	9.65	15.61	17.91	6.90	4.50
Compression Strength (Fc), parallel to grain		16.53	15.58	14.12	19.20	16.53	9.70	7.30
Shear parallel to wide face of strand					1.70			
Shear perpendicular to wide face of strand					1.10			
Shear (Fs) parallel to glueline	1.00	1.10	1.10	1.10		1.03		
Shear (Fs)Perpendicular to glueline		1.96	1.96	1.96		1.72		
Beam Shear (Fs)							0.62	0.62

Note: The allowable design stresses detailed in Table 1 are based on the test methods and exclusion limits adopted in North America[15] for the application of design stresses to in grade lumber. The values are based on a 10 year duration of load factor (DOL) with reduction factors applied to the five percentile exclusion limits. The values are intended for comparative purposes and would need modification to be considered as basic working stresses as defined in AS 1720 - 1975 SAA Timber Engineering Code.

The first commercial continuous LVL processing line was purchased by International Panel and Lumber (Aust) Pty Ltd in 1985 and commissioned in 1986. The line is an original Finnish LVL system developed by Metsaliiton Teollsuiuus Oy and Raute Oy to produce Kertopuu(R). The product produced by IPL (Aust) Pty Ltd is called Hyspan LVL(R).

A significant degree of interest still exists, and development studies are still progressing by a number of Australian and New Zealand plywood and timber producers. At the time of preparing this paper, however, Hyspan LVL(R) is the single commercially available LVL manufactured in Australia. This section of the paper will therefore concentrate on Hyspan LVL(R).

Description of Australian Hyspan LVL(R)

Hyspan LVL(R), manufactured in Australia, is constructed from 3.2mm (nominal) thick P. radiata veneers of a minimum Quality D as specified in Australian Standard AS 2269 Structural Plywood. Joints in the face veneers are scarfed whereas other end joints between internal veneers are simply butted. The bond between plies is phenol formaldehyde capable of meeting the requirements of AS 2754 and AS 2098.2 - 1977 Methods of Test for Veneer and Plywood - Bond Quality Chisel Test(17). The processing is as previously described for Finnish manufactured Kertopuu(R). The manufacturing line is single daylight, and produces continuous LVL 1200mm wide. Final density of Hyspan LVL(R) is approximately 600Kg/m3.

Dimensional tolerances are as follows:

Length	to	6m	-	-0 + 6mm
6m	to	12m	-	-0 + 12mm
Depth	to	400mm	-	-0 + 5mm
Thickness			-	-0 + 3mm.

The finish is unsanded faces and sawn edges. Standard depths detailed in Hyspan LVL literature(6) are 150, 200, 240, 300 and 400mm. Standard thicknesses are 36, 45 and 63mm. Depths above 400mm are available for engineered applications such as members in industrial and commercial buildings.

Comparison of Properties

Table 2 compares the basic working stresses of Hyspan LVL(R) manufactured in Australia from P. radiata with Kertopuu(R) manufactured in Finland from Norway spruce and two structural grades of Pinus radiata sawn timber, F8 and F5. The basic working stresses were determined in accordance with Draft Australian Standard for Evaluation of Timber DR 83205 - July, 1986(18) which is based on a 50 year duration of load factor (i.e. K1 = 1.75 Table 2.4.1.1. of AS 1720) and the five percentile lower exclusion limit for material tested in grade.

TABLE 2. BASIC WORKING STRESSES FOR AUSTRALIAN LVL COMPARED WITH OVERSEAS LVL AND PINUS RADIATA SAWN TIMBER (MPa)

Property	PRODUCT			
	Hyspan LVL [19] Australian (P. radiata)	Hyspan LVL [20] Finnish (Picea abies)	F8 [13] Structural 3 (P. radiata)	F5 [13] Structural 5 (P. radiata)
Modulus of Elasticity (E) Beam	13,200	13,500	9.100	6,900
Modulus of Elasticity (E) Plank	13,300	12,800	9,100	6,900
Bending Strength (Fb) Beam	16.4	18.6	8.6	5.5
Bending Strength (Fb) Plank	16.2	16.0	8.6	5.5
Tension Strength (Ft)	10.5 (butt joints)	14.1 (scarf joints)	5.2	3.3
Compression Strength Parallel (Fc)	10.2*	13.4	6.6	4.1
Shear Parallel to Gluelines (Fs)	1.25*	0.98		
Shear Perpendicular to Gluelines (Fs)	1.82	1.86		
Beam Shear (Fs)			0.85	0.60

*Values extracted for F14 material from AS 1720.

NOTE: The basic working stresses given in Table 2 are based on test methods and exclusion limited adopted in Australia for the application of basic stresses to in grade timber[18]. The values are based on a 50 year duration of load and the five percentile lower exclusion limit. The values compare directly with the basic working stresses detailed for the range of stress grades in AS 1720. F8 and F5 stress grades of P. radiata were considered appropriate for comparison as they are the most common grades of structural radiata pine.

DEVELOPMENT OF STANDARDISED PROPERTIES

The assurance of reliable physical and mechanical properties is paramount to the marketing of LVL as a standardised, engineered structural timber product. A programme needed to be developed to provide such assurance. The two characteristics most important to LVL's penetration into the market as an engineered product were considered structural properties and durability. It is believed the following programme provides a firm technical basis for the assurance of these properties.

(1) Define the variables which affect the physical and mechanical properties deemed to be critical i.e. basic working stresses, elastic moduli and bond durability.

Through studying the literature from overseas already cited, as well as a draft performance standard for LVL prepared by the American Plywood Association[21], together with a knowledge of the factors affecting the performance of structural plywood, which is a similar product, and through discussions with CSIRO staff, the following variables were defined as those affecting mechanical properties and durability.

(a) Species
(b) Density
(c) Veneer quality
(d) Joints in veneers
(e) Manufacturing process
(f) Tolerances
(g) Laminate thickness
(h) Bond type
(i) Bond quality
(j) Arrangement of veneers.

(2) Prepare a manufacturing specification which sets limits on the variables defined as affecting critical properties.

The manufacturing specification is specific to a particular LVL product. The specification sets limits on the variables which affect the performance characteristics.

Species: The species used for the manufacture of specific LVL is defined together with the absolute minimum density of dried veneer deemed acceptable.

Veneer Quality: Veneer quality aspects which affect mechanical performance such as peeler check depth, knots, splits, holes, patches, sloping grain and aggregate dimension of defects across the grain are limited to a quality deemed acceptable and practical.

	Veneer roughness, which affects bond quality is also limited. In Australian LVL veneer quality limits will be close to 'Veneer Quality D' as specified in As 2269 Structural Plywood.
Joints in Veneer:	Tolerances on veneer edge joints are specified. The type of end joint used in the specific LVL product is specified. In the case of scarf jointed veneers the slope of scarf and type of glue bond is specified. In butted end joints, limits on gaps and overlaps are spedified.
Manufacturing Process:	A description of the manufacturing process covering glue spread, open assembly times, prepressing and hot pressing conditions together with the processing technique e.g. MicroLam(R), or Kertopuu(R) process, is included in the specification.
Tolerances:	Tolerances on finished dimensions are specified.
Laminate Thickness:	The thickness of veneers used for the specific LVL product is specified.
Bond Type:	The type of adhesive and bond type is specified. In Australian LVL as in Canada, USA and Finland, this will be phenol formaldehyde adhesive which meets the Type A bond requirements of AS 2754.1.
Bond Quality:	The average and minimum bond quality values as detailed in AS 2098.2 Methods of Test for Veneer and Plywood - Bond Quality, are specified.
Arrangement of Veneers:	Where a mixture of veneer qualities are used the position within the assembly will be specified. Where a mixture of joint types are used, the position within the assembly must also be specified. Other assembly considerations such as the relative positioning of veneer tight and loose loose sides and the minimum spacing of butt joints in adjacent laminates are also specified.

(3) Develop a process quality control programme to ensure the minimum requirements specified in the manufacturing specification can be strictly adhered to.

(4) Manufacture LVL utilising the process quality control to ensure the product meets the requirements of the manufacturing Standard.

(5) Take a random sample of the LVL manufactured and quality controlled to the manufacturing specification and test the material for mechanical properties.

Sample: A random sample of 100 pieces is considered sufficient to establish Modulus of Elasticity (E), bending strength (Fb), tension strength (Ft), compression strength (Fc) and shear strength parallel and perpendicular to the laminations (Fs).

Test Method: Test methods used are the same as those used to establish basic working stresses for in grade timber. As well as in grade testing of large specimens, small specimens are used for compression strength perpendicular to the grain and to establish block shear or joints shear properties[22]. Nail lateral load and withdrawal tests are carried out in accordance with Australian Standard AS 1649 - 1974[23].

Derivation of Working Stresses and Elastic Moduli:

Based on the in grade test results of LVL manufactured to the specific manufacturing standards, basic working stress and elastic moduli are derived in accordance with Draft Australian Standard DR 83205 - 1986[18].

(6) Test bond quality using standard test proceedures for plywood.

(7) Derive a sampling and testing program for quality assurance.

(8) Develop an industry and national performance standard for LVL.

RELIABILITY OF LVL

Distribution of Defects

The process by which LVL is manufactured i.e. parallel laminating a large number of thin laminates, always more than 10 and as high as 25, using a rigid permanent adhesive, ensures that defects such as holes, knots, splits and slope of grain, which affect structural reliability, are distributed throughout the material. The distribution of defects enhances the structural reliability by reducing dramatically the chances of a single large defect such as a knot or hole, governing the mechanical properties of the piece. An example is that a large knot on the edge of a sawn timber member will be critical in bending and tension strength.

Glue laminated beams have improved reliability over sawn timber by distributing defects to a more limited extent because of the smaller number of laminates. The reliability in glue laminated beams is reduced relative to LVL because the continuity in extreme fibres relies upon the satisfactory finger jointing of the outer laminates.

Three critical structural properties for structural timber members are Modulus of Elasticity and bending and tensile strengths. The structural reliability of LVL compared with clear wood and in grade timber, based on coefficients of variation is shown in Table 3.

TABLE 3: RELIABILITY OF LVL

Property	COEFFICIENT OF VARIATION (%)			
	Sawn Timber (24)*		Clear Wood (24)	LVL (10,19)
	Structural Clear	No 2 Grade		
Modulus of Elasticity (E)	25	19	25	8-9
Bending Strength	20	32	15	12-14
Tensile Strength	35	44	30	12-14

Note:* Properties of 100mm x 50mm dry southern pine (After Doyle and Markwardt 1966/1967).

It can be seen from Table 3 that the structural reliability of LVL is superior to sawn ingrade timber and clear wood, based on coefficients of variation. It is believed that this improvement in reliability is due to the randomisation of defects. Improved structural performance in LVL compared to sawn lumber of similar species is shown in Tables 1 and 2.

Modification Factors

In LVL manufacture, the longitudinal wood structure is kept intact. Laminates are bonded with a rigid thermosetting phenolic adhesive in a similar manner to plywood or laminated beam. The duration of load factors for strength and stiffness specified in AS 1720 Timber Engineering Code Tables 2.4.1.1 and 2.4.1.2 for solid timber glue laminated beam and plywood are equally applicable to LVL. Other modification factors detailed in AS 1720 for solid timber are also applicable to LVL. Thus the basic working stresses published for LVL can be readily converted to design stresses by applying the appropriate modification factors from the Code.

Glueline Durability

All structural LVL products manufactured overseas discussed in this paper, are laminated using phenol formaldehyde theremosetting adhesives. In Australian manufactured LVL the gluelines are also phenolic which must meet the minimum requirements of AS 2754.1.

The manufacturing specification prescribes that the bond quality in all gluelines must average Quality 5, with a minimum in any single glueline of Quality 2, after Type A bond testing in accordance with AS 2098 Methods of Test for Veneer and Plywood. The Type A bond test is a 72 hour boil in

water or 6 hours at 200 kPa steam pressure followed by a cold water quench. Phenol formaldehyde bonds which meet the type A bond test requirements detailed above have proven long term durability[25]. Type A bond requirements for LVL are equivalent to marine plywood in AS 2272[26] and structural plywood in AS 2269.

All of the species from which LVL is manufactured, including P. radiata in Australia, are considered non-durable in applications involving long term exposure to weather. Applications should be limited therefore not to include long term exposure or if exposure is unavoidable the LVL must be made durable by preservative treatment. It is believed that the current research programme studying the suitability of benzalkonium chloride/permethrin preservatives applied to softwood structural plywood may be applicable to LVL products.

MARKETS

The area of market potential for LVL products in Europe and North America generally are perceived to be applications which require reliable structural properties and availability of long length and large section size. Table 2 clearly shows the increases in basic working stresses and elastic moduli for a range of LVL products compared with high and medium grades of sawn timber. The higher price of LVL per cubic metre is offset by the ability to use a smaller section size to perform an equivalent structural task. Yonquist[2] predicts that the market potential for LVL products will improve as wood quality in North America deteriorates leading to reductions in basic working stresses and difficulty in obtaining long lengths and large section sizes. The large improvement in tensile working stresses is certainly being utilised by the Trus-Joist Corporation where MicroLam(R) is utilised as the flanges of plywood webbed I beams. Additionally Gang-Nail Systems Inc., Wilmington NC, USA have purchased a large Raute Oy LVL line. The LVL produced in this plant will be utilised for tension chords in trusses, flanges in plywood webbed I beams and as joist material.

In North America LVL products have had excellent penetration and acceptance in both the residential and commercial construction sections in a relatively short period of time. Fabricated members such as Truss-Joist Corporations TJI beam which comprises MicroLam(R) LVL flanges and plywood webs are widely used as sub bloor and roof beams[27,28]. It was suggested to the writer during a study tour of the USA and Canada in 1985 that this type of structural timber fabricated component had, at the time, the best growth rate of any timber product, in spite of a price disadvantage. The product was marketed on structural reliability, length and section availability, ease of handling and installation and stability. LVL is being widely used in solid sections as headers (lintel beams) and other residential roof beams[29].

A list of markets in North America for LVL, established on the basis of performance/cost and size and length availability by Younquist[2] is as follows: Headers, horizontal truss chords, manufactured housing, mobile home truss chords, truck decking, container decking, scaffold planking, electrical distribution cross arms, ridge beams, tension laminates for glue lam beams, ladder rails, purlins and girts in industrial buildings, joists and garage door headers. The market potential for LVL products in Australia is based on the same premise as described by Youngquist for the North American markets. Tables 2 and 3 clearly show the improved structural properties and reliability of Australian manufactured LVL compared with solid section timber of high and medium grade. This availability of a reliable engineered product with large section size and long length must be the marketing basis for LVL in Australia.

It is not envisaged that LVL will compete with small section framing sized timbers in either residential or industrial buildings in Australia. The ecomomics of LVL however compare favourably with glue laminated beam. In their technical bulletin for Hyspan LVL[6] IPL (Aust) Pty Ltd have provided span tables for ridge beams, under purlins, hanging beams, strutting beams, combined strutting and hanging beams, lintels, bressummers, floor joists and bearers in sections ranging from 150mm x 36mm to 400mm x 63mm. Additionally with the improved tension properties detailed in Table 2, Australian LVL also has the same potential as its overseas counterparts for use as flanges in plywood webbed beams for residential and industrial applications and truss chord members. Plywood webbed box and channel section beams and box section portal frames are making inroads to the industrial building markets utilising solid timber flanges. LVL has the potential to replace the solid timber flanges on the basis of performance, reliability, cost and size and length availability. Finally, it is believed that for all of the reasons already given LVL will compete favourably as a scaffold plank, and solid section beams and columns in industrial buildings.

CONCLUSION

This paper has given an overview of the types of LVL products produced overseas and in Australia. It has been shown that LVL has improved basic working stresses and elastic moduli over high grade timber of the same species. The greatest improvement is in tensile strength, which can be used to advantage in flange members in fabricated beams and truss chords.

The improved reliability of LVL over sawn timber was also established by comparing coefficients of variation. It is concluded that this property can be used to market LVL to designers as a reliable product with a coefficient of variation approaching steel rather than traditional sawn timber. It is believed consideration should be given to applying a five

percentile value to modulus of elasticity in industrial building design where there is minimum load sharing instead of the current average values given in the Code which are considered suitable for domestic type framed structures where there is a high degree of load sharing.

It is concluded that the improved basic stresses and coefficients of variation are due to the randomisation of defects which occurs in LVL manufacture.

It is also concluded that the improved properties and reliability of LVL compared to timber sections and the price of LVL relative to glue laminated beam together with the availability of large section size and long length give LVL a performance/cost advantage in the residential and industrial applications discussed in the paper.

Finally, the designer and fabricator will need to be educated to consider deep narrow sections rather than traditional timber and laminated beam depth to breadth ratios. Consideration for lateral restraint will therefore become more important.

As the timber resource in Australia follows the overseas trends regarding wood quality, section size and length availability, LVL products will inevitably become more economically viable for a wider range of applications. The ability to preservative treat the plywood will also increase its market potential.

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PERFORMANCE TESTING OF STRUCTURAL COMPOSITE PRODUCTS

By M. R. O'Halloran (1)

INTRODUCTION

The objective of this paper is to review the status of structural composite products and to identify, in a general way, the technical state of the art in the U.S.A.

The structural wood panel products industry's primary market is the light-frame construction industry. For the past three decades it has supplied panel products to suppliers and contractors for on-site assembly of residential and commercial structures. The wood panels are long lived, durable goods which are commodities manufactured and distributed in standard sizes and grades.

Following World War II, plywood began to be utilized in light-frame construction in ever-increasing volume. Much of this increased use can be attributed to research and promotion by the American Plywood Association (then Douglas Fir Plywood Association) as well as the technical work of the Forest Products Laboratory and several universities providing proper engineering information to users and regulators alike. Because of sound research information, and the flexibility of panels in construction use, plywood displaced lumber as the dominant sheathing material for floor, wall and roof construction.

In recent years (mid 1970s), new generations of structural panels began to emerge. To better understand the nature of this evolutionary change, a look at the products, standards and their technology seems to be in order.

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THE PRODUCTS

Structural panel products include plywood, oriented strand board, waferboard, COMPLY*, and structural particleboard. Structural composite lumber includes laminated veneer lumber (LVL), and parallel strand lumber (PSL). Each product is discussed briefly, reviewing the raw material resource and basic product structure.

COMPLY Panels and Lumber

Since 1976 several manufacturers have produced COMPLY, which features face veneers bonded to a structural wood core. The panel product looks much like plywood because the veneer used for the face and back is identical to that used in standard plywood production. While plywood utilizes veneer in its interior laminations, COMPLY utilizes structural composite boards-made from strands, flakes or wafers. Cross alignment of the particle core considerably enhances overall panel dimensional stability and improves cross-panel strength and stiffness.

The panel manufacturing procedures used are either a one- or two-step process. In a two-step manufacturing process the core is made separately and transferred to a conventional plywood plant for processing to the finished composite product. In a one-step process where the wood particles composing the core are laid directly on the veneer sheets, the top sheets are then placed and the entire panel pressed in a single-step operation.

Composite studs and joists have been prepared utilizing structural particleboard cores and veneers to produce lumber substitutes (19, 35, 41). Again, the basic components are derived from structural panel plants, and have the advantages of consistent strength and stiffness in unlimited lengths. Size limitations (cross section) appear to be consistent with ordinary commodity lumber.

At one time five composite panel plants were in production. As of the first quarter 1986 only one plant is operating. One

*Comply is a registered mark of the American Plywood Association

further announcement has been made for construction of a plant to produce COMPLY lumber.

Laminated Veneer Lumber

Since the late 1950s a variety of researchers have reported on various "super strength" beams manufactured from rotary peeled veneer. The products have come to be known as parallel laminated veneer (PLV) or laminated veneer lumber (LVL) (10, 33, 34, 36, 37). Generally, the products are manufactured from continuously laminating rotary peeled veneer into panels or billets in which all the veneer sheets are oriented in the same direction. The economics of these structural products is exemplified by the significant manufacturing facilities operated by the Trus Joist Corporation of Boise, Idaho (36).

Primary advantages of LVL are the dispersement of defects by utilizing veneer, and the attainment of very high stresses consistent with the highest grades of solid sawn lumber.

As of the first quarter of 1986, two companies were in production and two additional companies have announced plans to construct a plant.

Oriented Strand Board

Oriented strand board is a panel product composed of three to five layers of strands or rectangular shaped flakes. The flakes are typically three to five times longer than they are wide. Strands are produced (by a variety of flaking machines) from round wood, which are logs transferred directly from the forest (18, 24, 27, 49).

The product gets its name from the fact that the strands are oriented, that is strands within a layer are aligned in the same general direction. Each layer is oriented perpendicular to the next, much as the veneers in plywood are perpendicular to one another in alternating layers. Strand alignment on the faces is typically parallel to the long or 8-foot direction, with cross-alignment of one or more layers in the interior of the product.

Orientation is perceived to provide considerable product flexibility in that it may be designed with stiffness and strength characteristics in particular panel directions.

Oriented strand board is typically manufactured with liquid phenolic resin and wax applied just prior to pressing. The use of liquid phenolic resin typically results in slightly darker appearance to the board. The strand or rectangular wafer geometry provides a somewhat different surface appearance than other flakeboard products.

As of the first quarter 1986, there are eight oriented strand board plants in production with several others announced.

Particleboard

Particleboards typically differ from other structural products such as waferboard or oriented strand board in that the raw material source is typically the residue of other solid wood processing operations. Consequently, the particles from which the board is manufactured tend to be very small and have short particles. Certain of these products can be used structurally in light frame construction. Such products typically will gain their additional strength and stiffness from either higher resin content and/or additional product thickness along with increased density (2, 13). Because of the resulting cost differential the percentage of product manufactured under these constraints is very small. One plant was currently producing such a product in the first quarter of 1986 (42).

Parallel Strand Lumber

Another more recent proposal has been to produce structural lumber substitutes using parallel strand lumber (PSL). Such schemes would develop cross sections in a continuous process using strands developed either from veneer or other processes utilizing round wood as the basic raw material source. Again, the perceived advantages are unlimited sizes and lengths, consistent properties and very high mechanical properties.

As of the first quarter of 1986, one plant is in production.

Plywood

The first production runs of softwood plywood took place in the U.S. West Coast in the early 1900s. Production capacity continued to build on the West Coast until the early 1960s when southern pine plywood was introduced. Currently nearly half the construction plywood industry (capacity basis) exists in the southeastern United States with the remaining plants in the Inland Empire and West Coast of the United States (7, 18).

Plywood is produced from veneers which are laid up in alternate layers, each layer being perpendicular to the other. By altering veneer thickness, ply orientation and species, plywood has demonstrated considerable versatility in being useful for a wide variety of industrial and residential construction market areas. Continuing research over the past twenty years has enabled plywood to enter many diversified markets, primarily due to a sound data base. Currently, approximately 56 percent of plywood's markets are tied directly to new residential construction or construction activities associated with repair and remodeling (7). The remaining material finds its way into a variety of end uses such as products made for sale; materials handling; plant repair and maintenance; and the transportation market. Additional uses include concrete forming, farm buildings and a wide variety of miscellaneous applications. As of the first quarter 1986 approximately 170 individual plywood mills were producing. Their total in-plant capacity exceeds 22 billion square feet on a 3/8" basis.

Waferboard

Waferboard is a structural panel first produced in Canada in 1966. Since then it has spread to several Canadian and U.S. manufacturing locations. Plant locations, as for OSB, are taking advantage of low raw material costs in central and eastern Canada, and central and upper midwestern U.S.

Waferboard is generally manufactured from low density hardwoods (most predominantly aspen), although other manufacturers are considering the utilization of spruce, southern pine and western softwoods.

The product is composed of a rather large squarish (2" x 2" to 3-1/2" x 3-1/2") wafers. These wafers are flaked from roundwood and are generally bonded together with a powdered phenolic resin (24, 42).

Waferboards are typically produced in three random layers. The largest flakes possessing the best mechanical properties, are laid on the faces of the panel, and the fines and other smaller flakes being utilized as core material. More recently, most manufacturers have begun orientation of the panel faces using more rectangular wafers -- thus approaching the OSB concept.

As of first quarter 1986, twelve waferboard (and oriented waferboard) plants existed in the Continental United States. There are eleven similar plants in the Canadian provinces.

THE STANDARDS

Product Standards

National consensus or product standards are most frequently promulgated through organizations such as the American National Standards Institute (ANSI), or the U.S. Department of Commerce. Wood based panel standards include PS 1-83 for Construction and Industrial Plywood, or ANSI A208.1 (2) for Mat-Formed Wood Particleboard.

Review of the product or commodity standards reveal that they are essentially manufacturing prescriptions for minimum product. Requirements are centered around the specific manufacturing process, and typically do not address the question of product application nor how well the product is suited for any particular application.

Performance Standards

A performance standard, such as that promulgated by the American Plywood Association for APA Rated Sheathing and APA Rated Sturd-I-Floor (4), reverses the standards process by defining the end use of the product and does not prescribe how the product will be made. The objective of a performance standard is to assure for a particular end use that the product

will satisfy the requirements of the application for which it is intended. To do this the performance standard must define performance criteria and test methods. Performance standards are limited in application to the intended end use.

In the case of the two standards currently promulgated by APA, that for single layer floors (APA Rated Sturd-I-Floor) and that for sheathing (APA Rated Sheathing), the intended end use is light-frame wood construction as practiced in the United States. As the names imply, panels are intended for combination subfloor-underlayment and sheathing intended for roofs, walls and subfloors. The products are span rated for their particular end use. The standards cover supports spaced 16 to 48 inches o.c. (400 to 1220mm) for floor and roofs. Provisions are also made for wall bracing when the studs (vertical framing elements) are spaced 16 or 24 inches o.c. (400 or 600mm).

The system results in a simple span index, which rates the panel for a single floor use, or a sheathing application where the index indicates its possible use at a maximum rafter or floor joist spacing.

The performance concept is being applied to structural composite lumber (LVL and PSL) but in this case for mechanical performance. A document under development by the APA will rate the product by testing and follow up verification, as with panels. Other standards activity includes a subcommittee of ASTM D07 and an AITC Standard (3). The APA approach will follow the basic elements outlined here, except the measurement of performance will be directed toward engineering properties rather than tests oriented toward a very specific application.

Requirements. Panel performance is evaluated through testing under a qualification procedure for three basic areas of investigation: structural adequacy, dimensional stability, and bond performance.

Testing for structural adequacy includes:

1. Verification of the ability to sustain concentrated loads, both static and following impact at the rated span.

2. Uniform loads testing demonstrates the ability of the product to sustain wind or snow loads at the rated span.

3. Fastener holding ability is tested to assure the panel has the ability to hold covering materials in place and to develop lateral load capacity in mechanically fastened connections to lumber or other framing.

4. Wall sheathing panels must demonstrate shear resistance for wall bracing at the rated stud spacing.

Physical properties include measure of the expansion of the panels when exposed to moisture conditions. A performance test was developed which measures linear expansion when wetting on one side for a period of 14 days. This test approximates severe exposure conditions as might occur during construction and serves as a relative measure of linear expansion conditions that might be expected in service.

Finally, the bond durability of the panel must be demonstrated for site-built construction, since panels will be called upon to resist wetting and drying and still be able to perform following exposure in these conditions (43). Research indicates that large-scale specimens exposed to hot water soaking and oven-drying and then subjected to the same structural performance criteria is adequate evidence of the ability of the product to remain intact during exposure to weathering. These tests are equivalent to several years permanent exposure to the weather.

Qualification. Certification of performance is a straightforward procedure under a performance-based system. To begin, a sampling of the candidate product is tested according to the individual performance criteria previously discussed. After

completing the performance requirements a span rating can then be assigned.

Concurrent with performance-oriented tests, a "product evaluation" is also performed. Product evaluation provides for measuring properties unique to the product and suitable for quality assurance measurements. Such data includes bending strength and stiffness, thickness, density, and other manufacturing data which may prove useful in monitoring quality under a third-party basis.

A mill specification (4, 44) is drawn up following this intensive product evaluation. This individualized mill production specification is unique to the mill and product qualified under the performance standard. It pertains only to the mill and product qualified and is not a constraint on other mills or similar products.

The mill specification serves as the quality assurance document for future evaluation. The APA quality program provides for sampling from each mill's production each day with testing and reporting at one of seven regional facilities. In addition, a quarterly sampling program requires ten panels (4 x 8 ft or 1.2 x 2.4m) per mill per quarter to be shipped to the APA Research Center in Tacoma. These panels are tested for conformance to the mill specification and will form the data base discussed later in the paper.

Acceptance. The Council of American Building Officials (CABO) is a joint venture of the Building Officials and Code Administrators International, Inc. (BOCA), the International Conference of Building Officials (ICBO) and the Southern Building Code Congress International (SBCCI). CABO has recognized the APA Performance Standards under their National Evaluation Report NER-108 (17). This research report constitutes approval by the sponsoring model code agencies and subsequent regional acceptances have since been secured by the APA technical staff.

PRODUCT CHARACTERIZATION

In anticipation of the need for new technical data, APA has been in the process of a significant product characterization study. This "in-grade" study is conducted under the provisions of the performance standard, and will lead to development of significant technical data on the character of products produced by members of APA under the performance based standards. The program covers sampling, mechanical properties, physical properties, and data base management. While the example data used in this paper is for structural panels, the same basic concept and techniques are being used for LVL and PSL products trademarked by the APA.

Panel Sampling

Sampling of product occurs at two stages. First, during the product qualification stage previously discussed, a significant sample of product is taken under carefully supervised conditions. That is, the panel product is sampled at minimum manufacturing conditions such that minimum acceptable performance is evaluated. This initial bias provides a measure of the minimum product against the performance criteria, and is an indication of minimum lot performance. Products which satisfy the established performance criteria under these conditions are certified for production at manufacturing specifications at or above the levels sampled. Thus, the data leading to the development of the individual product manufacturing specifications becomes the baseline for future evaluation of the product.

The second level of data collection is a quarterly production sampling program. Under the provisions of the performance standard, a minimum of 10 panels per plant per quarter are tested by APA against the product's individual manufacturing specification. This evaluation provides an ongoing measure of product performance and continuing confirmation that the products are conforming to the provisions of the performance standard.

The panel sampling plan provides two significant opportunities. First, the initial biased sample provides an opportunity to evaluate minimum lot performance. The qualification sample is a snapshot of minimum product performance as produced by individual mills and products distributed over the country. Secondly, the quarterly sampling program provides an ongoing evaluation of products "as produced" and can then be used to establish any trends in product performance.

Mechanical Properties

Panels sampled under the Performance-Rated Panel program are full-sized panels (4 ft x 8 ft or 1.2m x 2.4m). Properties collected under both the qualification or initial bias sample scheme and ongoing quarterly sampling include the following:

- Full-sized bending strength and stiffness.
- Tensile strength.
- Shear strength through the thickness.
- Shear strength in the plane of the product.
- Compression strength and stiffness.
- Bearing strength through the thickness.
- Modulus of rigidity.

Each of these basic mechanical properties are collected with stress along and across the major of the product when appropriate. Products are tested in the dry, as-received condition.

Data Base Management

To accommodate such a comprehensive sampling plan, encompassing a large number of products, constructions and geographic manufacturing regions of the country, a computer data base management system is utilized. Data base management schemes are most often firmware and software based systems which provide for easy assemblage of complicated data schemes providing for quick ad hoc reporting as well as routine data manipulation and updating.

The computer-based data system is utilized for ongoing evaluation of quarterly sampling programs via control chart and

statistical anaylsis schemes, as well as providing overall statistical analysis of mechanical and physical property data.

ENGINEERING DESIGN

Concepts of structural design have undergone radical philosophical changes in recent years. As a result of major research efforts devoted to the applications of reliability analysis concepts to structural design, new reliability-based design (RBD) codes are emerging. Reliability-based design is the method by which the reliability of a structure or permanent component is controlled through appropriate recognition of the means, variabilities, and uncertainties of loads and material resistance (9, 11, 12, 14, 15, 16, 20, 21, 22, 25, 26, 28, 29, 30, 31, 45, 46, 47, 48, 50). The loads are most often specified by regulatory agencies while the material resistance information is supplied by material advocate groups.

Procedures using RBD for steel and concrete building structures have been developed in the United States, Canada and Europe (1, 11, 12, 14, 15). A summary review of these developments can be found in the paper by Goodman (29) and more details can be obtained from the references provided.

The use of RBD methodology for timber is beginning to appear in Europe and Canada (11, 15). Of special interest in Europe is Euro Code 5, a set of common unified rules for timber structures (15) which uses RBD concepts. The draft code has been undertaken by members of the Commission of the European Communities and is expected to have significant influence in Western Europe. In Canada, a new Canadian standard has been devoted to the engineering design in wood (limit states design) (11).

In the U.S., the 1982 American National Standards Institute (ANSI) document "Minimum Design Loads for Buildings and Other Structures" (22) provides RBH methodology to establish the loads. This activity is primarily the result of work by the National Bureau of Standards with support from the concrete and steel interests.

The level of RBD technical activity for timber design in the U.S. is quite low. A task group of the ASCE (American Society of Civil Engineers) Committee on Wood is working on a preliminary design aid, but there is no major research effort underway at the present.

Current design methods and engineering data for structural wood panels are given in the Plywood Design Specification (4) and in other APA technical literature specified to end-use requirements. Currently engineering properties are derived from small clear wood specimen data based on limiting species characteristics in each species grouping. This technical foundation, while adequate in the 1960s is badly outdated in the 1980s due to addition of species (over 70 in use), and rapid changes in production technology. Innovative glued composite products are being introduced in increasing frequency which enhance the potential for full utilization of the wood resource.

The RBD approach is being considered by American Plywood Association (APA) staff in their efforts to develop a rationale for characterizing mechanical properties of structural-use panels and structural composite lumber. Ideally, the program will be compatible with emerging reliability based design (RBD) procedures.

Factors Influencing Engineering Design Properties

A product characterization study will provide insight to performance of products as produced and tested under laboratory conditions. Clearly, there is a myriad of factors which influence the performance of mechanical properties and, consequently, structural design. A few of the most important structural properties will be addressed here in the hopes of stimulating thought toward solutions.

In-Service Performance. A variety of techniques have been used to address the in-service load performance of wood structural systems. These include creep studies, creep rupture studies, and evaluation of product after long-term in-service use. Given the time-consuming factors of creep and creep-rupture studies, it appears that some potential alternative means to

identify the peformance of these products is needed. In conjunction with that, a North American duration of load committee of interested industry principals has been established in cooperation with the Forest Products Laboratory in Madison, Wisconsin and Forintek's western lab. These deliberations may provide a structured approach to providing short-term conservative answers and development of data which will give us longer term information.

Environmental Effects. A variety of environmental factors must be assessed and their influence determined. Such areas include moisture effects, temperature, corrosive chemical environments and the like. A priorities list needs to be developed and assessed so these factors may be included in any design format.

Fasteners. Standardized methods of fastener evaluation for both lateral load-slip modulus and ultimate lateral loads needs to be established. With the significant variation in fastener size and stock stiffness, better methods of grading and identification are needed for engineering design.

Effect of Treatments. Little data exists on the effect of pressure treatments for preservatives and fire retardants on mechanical properties of structural-use panel products. Basic impact of these procedures is needed as volumes of treated material grows.

Commentary on Factors. This brief discussion indicates that there are many strength and stiffness reducing factors which must be considered by the design engineer. A preliminary review of the existing literature and discussions for determining factored resistance have shown that these procedures and techniques are not well established. Consequently, establishing factors which could have great influence on the resulting design and the economics of the use of the product should be carefully contemplated by the architects of an RBD format. Sample sizes, study designs, requirements for establishing these factors and the reliability of those factors needs to be addressed by the proponents of this design format.

SUMMARY

Our discussion has reviewed the commercial "facts of life" that a significantly different set of generic product types is being manufactured and marketed under a uniform span rating system for use in light-frame construction. The system represents a vast production volume, inclusion of over 70 some species and many product types thus demonstrating the power of the performance standard system.

In reviewing the performance based standards under which these products are rated, it was indicated that a significant in-grade sampling and testing procedure is underway. This data will provide the ability to characterize minimum product as well as product produced over time. This is providing a significant data base from which the resistance of products rated under this system can be further characterized.

Additionally, it was pointed out that to successfully characterize products for engineering design factored resistance data needs to be developed to indicate strength reducing and/or stiffness reducing criteria.

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RECENT DEVELOPMENTS IN THE AUSTRALIAN PLYWOOD INDUSTRY AND THEIR LIKELY INFLUENCES ON FUTURE RAW MATERIAL NEEDS

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ABSTRACT

Plywood, the nineteenth century prototype wood-based panel, sparked the development of rival sheet materials made variously from wood fibres, chips, wafers and oriented strands of wood. Each of the new materials gained acceptance by providing minimum cost solutions for particular end-uses.

To maintain its viability against such competition, the local plywood industry had to resort to a variety of tactics, the most fruitful being to exploit plywood's inherently superior strength properties. Today, panel constructions are often custom-designed to suit loading conditions and machine stress-grading is being widely used so that the strength advantage can be fully utilised.

Eucalypts, which tend to be troublesome in production, had no special value as peeler material in the past, but now are being appreciated for their good bending strength and hardness, especially when used for face veneers.

The manufacture of laminated veneer lumber (LVL) in Australia will put the industry's product in competition with glulams and perhaps imported Douglas fir timber. Here, again, eucalypts could play an important role.

When in competition with plywood, the rival panel materials often have a decisive price advantage due to a lower unit raw material cost and a higher recovery of product from logs. However, new technology in veneer manufacture, in the form of the 'spindleless' lathe, powered back-up rolls and second generation computerised billet centering is expected to boost recovery significantly and, hence, reduce the rival panel materials price advantage. This new technology will at the same time allow smaller diameter raw materials to be used.

INFLUENCE OF SITE QUALITY, MANAGEMENT AND GENETIC FACTORS ON PLANTATION-GROWN WOOD

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ABSTRACT

There are many opportunities to influence the quality of wood grown in plantations. Although lead times for this have often been long, they are becoming shorter. A pre-requisite for optimum decisions is an understanding of the variation in wood properties, the factors which cause this variation, and its industrial importance. This understanding is far from complete, particularly for eucalypts.

Increasing industry support for R & D is able to build on a good foundation of knowledge and material to which Commonwealth-funded work has contributed significantly. Commonwealth policy is changing the pattern of funding, however, and CSIRO's role in the past may not be a good guide to the future.

INTRODUCTION

When wood is drawn from established indigenous forests, little can be done about its intrinsic character. Although in theory the age of cutting could be altered, or stand density changed, in practice neither is easily varied. Those improvements in end use which have occurred (and they have been quite important) have come about through an improved understanding of the properties of the many species present, coupled with the development of marketing. Examples are the recognition of the value for pulp of the acacia understory of southern eucalypt forests (Batchelor et al. 1970), and the grouping of species into a small number of strength and durability classes which emphasise suitability for particular end uses.

Regrowth forests, which will be of major importance in Australia in the coming decades, are in some respects intermediate between old-growth and plantations. There is usually little control over their composition, but their density can be varied. Rawlins, in a subsequent paper, will describe a project in which options for thinning, and the consequences, are being carefully examined. It is clear from early studies (Table 1) that diameter growth on the residual trees can be greatly stimulated by thinning. In addition to the improved recovery which is a direct result of dealing with larger material, there is now evidence that growth stresses are minimised in the larger trees (Kininmonth et al. 1974). Better methods of assessing growth stresses in standing trees will be most useful; Krilov will describe progress in this area.

TABLE 1

The effect of thinning Eucalyptus pilularis regrowth at 8 yr on stand development at 41 yr (adapted from Henry 1965)

Stems per ha at 41 yr	1300	810	250	178
Mean diameter (cm)	23	28	45	52
Merchantable volume (m^3/ha)	340	380	390	380

Plantations afford a maximum opportunity to influence the nature of the wood produced. Before full advantage can be taken of this opportunity it is necessary to appreciate the way in which wood properties can be changed.

There are several useful reviews of the quality of wood from plantations. Fielding (1967) considered the influence of silviculture; FAO (1975) covered 61 hardwoods for pulping and papermaking. Bamber and Burley (1983) dealt with radiata pine, while Kinninmonth (1985) wrote from a New Zealand/Southern Hemisphere perspective. There is a tendency for research, and these reviews, to emphasise properties such as density, fibre or tracheid length, spiral grain, heartwood incidence, shrinkage, etc - properties easily assessed in small samples in the laboratory - and to ignore factors such as the incidence of resin pockets; branch frequency, size, angle and distribution; and log taper and sweep.

The following account will emphasise points which are of particular interest in the Australian context.

SITE FACTORS

These can be varied through the initial choice of planting site. Any significant variation in wood quality arising from variation in site factors in or between established plantations may be utilised by fulfilling specific demands from those areas best able to produce the material sought.

The term 'site quality' is used to denote the relative productivity of a site for a particular tree species. It is resultant of temperature, solar radiation, rainfall and soil depth and fertility. These factors have an obvious effect on the rate of growth, which (other things being equal) will be reflected in economically-important differences in log size as well as total volume yield. There are less evident but nevertheless significant effects on wood properties.

The influence of site factors has been most extensively examined in widely-planted conifers. Studies of Pinus elliottii, P. patula and P. taeda in South Africa (Boden 1982) and P. radiata in New Zealand (e.g. Cown et al. 1984) show that altitude and latitude are inversely correlated with density. Cown and McConchie (1983) concluded that mean annual temperature is the major environmental determinant of wood density in P. radiata. The scale of the effect in the Bay of Plenty/Taupo region of New Zealand is illustrated in Figure 1; there is a 20% difference between Auckland and Canterbury (Cown and Kibblewhite 1980).

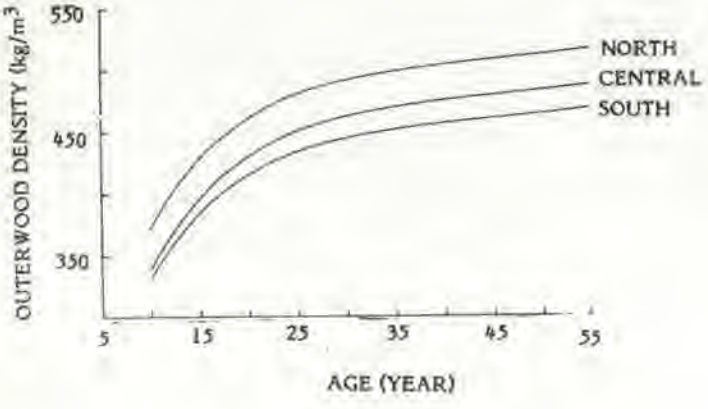


Fig. 1. Relationship between age and outerwood basic density. P. radiata, Bay of Plenty/Taupo. (Cown et al. 1984).

The likely effect of differences in available soil moisture (due to the combination of rainfall, soil characteristics and the density of the stand) may be inferred from Nicholls and Waring (1977). These authors examined breast-height samples from trees subject to partial drought and irrigation, as well as untreated trees. The two treatments had complex effects, the net result of which was a slight increase in wood density in both cases. The season in which the drought or irrigation occurs is important - e.g. more growth in summer tends to produce more wood of high density.

As eucalypts have been planted on a limited scale in Australia there has been less opportunity to work out relationships between environmental factors and wood quality. The observation of Ilic and Hillis (1985) that volumetric shrinkage (and collapse) of E. regnans and E. delegatensis varied between samples from five sites in Victoria is difficult to interpret further because environmental and genetic effects are confounded. The same difficulty arises with the finding of Turner et al. (1983) that the pulp yield of E. globulus from stands in 20 localities varied between 40% and 56%.

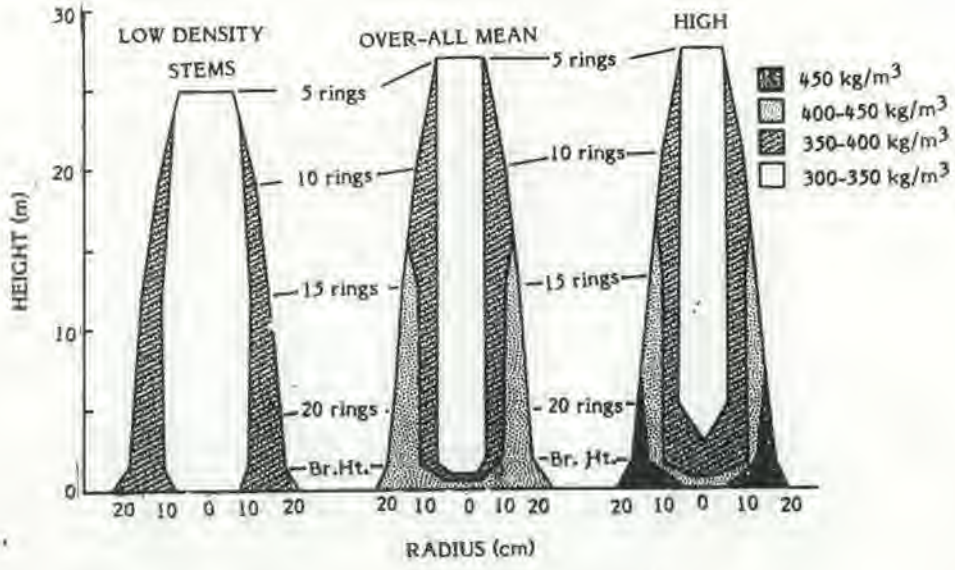
The development of kino veins is often related to stress, e.g. moisture stress (Day 1959). In a study of trees from a provenance trial of E. regnans replicated on two sites 8 km apart in Gippsland, trees at the lower site where growth was faster had more numerous (x2) and more extensive (x3) veins than those at the other site (Doran 1975). This substantial variation between two fairly similar sites suggests that this species may be quite sensitive in this regard to seemingly small environmental effects.

MANAGEMENT FACTORS

These can be readily manipulated (at least for individual stands) and include rotation length, spacing, fertilization, irrigation, pruning and the physiological age of the trees. The reason for qualifying the ease with which they can be modified for forest areas as a whole is that there is commonly a need to maintain continuity of supply of particular classes of product (e.g. Grayburn 1986). Although genetic features of the stand are also susceptible to manipulation, for convenience these will be discussed separately.

The age at which trees are harvested has a profound effect on the quality of the wood produced. The situation is simplest and best understood (e.g. Anon. 1981) in conifers where the change in wood quality from pith to bark is generally greater than in hardwoods. In radiata pine, for example, wood density is low near the pith and rises towards the cambium (Figs 1 and 2). In other words, there is a distinct cylindrical core of relatively weak, low-density wood at the centre of the tree. As the tree grows older this core remains unchanged in size but constitutes a decreasing fraction of the total volume of butt logs. Ring for ring, slow-growing and fast-growing trees will be almost of the same density, but a tree which produces a butt log of 40 cm s.e.d.u.b. at 25 years (on a good site and with low stocking) will have a much wider core of relatively weak, low-density juvenile wood than would the butt log of a tree which took, say, 45 years to reach the same diameter. Old trees thus have a higher density (and greater heartwood content) than do young ones.

Fig. 2. Within-tree distribution of basic density, P. radiata (Cown and McConchie 1983).



The transition from 'old-crop' radiata (trees planted before 1940) to younger 'new-crop' material is causing a significant change in log quality in several major radiata-growing areas. The rapidity of the change for NZFP is illustrated in Figure 3.

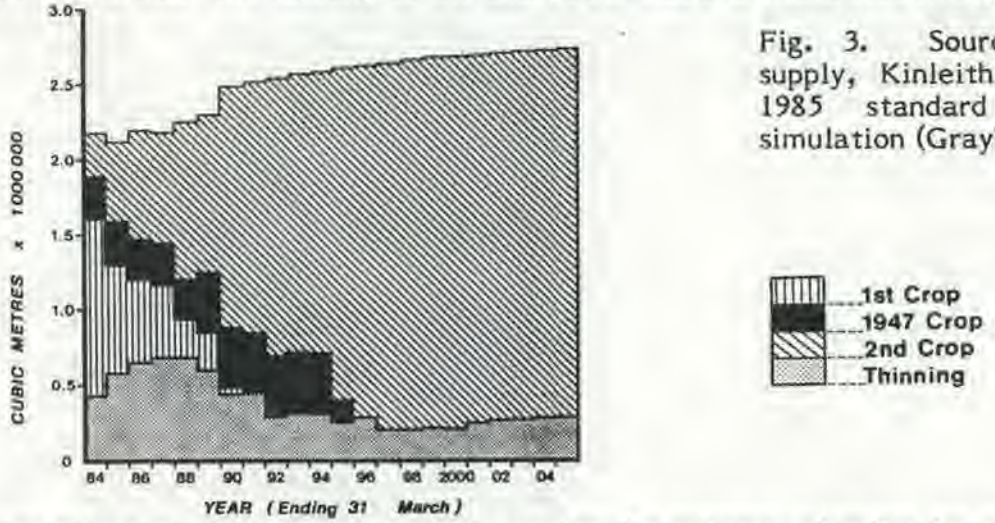


Fig. 3. Sources of wood supply, Kinleith forest, from 1985 standard data base simulation (Grayburn 1986).

The effect of age is so great that it may be the primary criterion for segregating raw material for pulping - e.g. at Kinleith, three chiplines produce separate feedstock which is blended to provide pulp of the quality required at any one time (Grayburn 1986) -

- Corewood or young wood - logs with up to 20 annual rings, mostly from thinnings, producing dense, even-textured pulp. (Technically a limit of 15 rings would be preferred.)

- Slabwood - residues from 30th ring or older, producing porous, bulky, strong pulp.

- Mixed wood - from all ages, as well mixed as possible.

In eucalypts, where the differences between juvenile and mature wood are commonly less than in conifers, the pattern of variation in density in trees grown in New Zealand has been found to be highly variable (Harris and Young 1980). Phillips (this meeting) will report current studies of some properties of regrowth eucalypts in Australia.

Stand density affects the rate of diameter growth, the depth of green crown, branch size and stem taper. Silvicultural regimes have varied over time and from place to place. Where thinnings have a ready market, close initial spacing and an absence of non-commercial thinning have been the order of the day. If the thinnings market does not materialise, however, the stands will become heavily stocked and diameter growth will be disappointing.

Although 'agroforestry' regimes - entailing very wide spacings - have tended to be regarded as being distinct from those used in normal production forestry, it is likely that this originally-clear distinction will be lost as investors demand shorter rotations to obtain quicker returns and managers select stand densities which meet their particular requirements for diameter growth, pasture production and water yield.

When stands of low stocking are produced by heavy thinning of the small trees, there is evidence that the average density of the wood in each ring may sometimes be lowered because of a weak negative correlation between tree size and density (Cown and McConchie 1982). Nicholls (1971) reported that density was only slightly decreased in P. pinaster following thinning and fertilizing. Deane (this meeting) will discuss the relationship between rate of growth and density in more detail.

Fertilizer will stimulate growth on many sites. Phosphorus has been widely used for conifers, and more recently there has been an interest in nitrogen, especially to minimise the effects of the discontinuity in age classes in radiata pine mentioned earlier. Although there is some inconsistency between reports, there are cases in which increases in volume growth have been partially offset by a reduction in wood density - e.g. of the order of 20% (Cown and McConchie 1981). While not important for many end-uses, such a change would be unfortunate if the yield of timber in particular structural grades was to be disproportionately depressed because of a marginal change in density.

Irrigation is limited at present to poplars and to plantings to assist sewage effluent treatment. Cromer (1980) concluded that both volume production and wood quality of radiata pine would be improved by irrigation. McKimm (1984) assessed the value for fence posts of E. grandis, E. botryoides and Casuarina cunninghamiana irrigated with sewage effluent and concluded that, if the wood is preserved, the two eucalypts would be satisfactory. A recent report (Tischler and Heth 1985) that irrigated E. camaldulensis and E. maculata can yield high-quality sliced veneer, and the latter quality rotary-cut veneer, is of interest.

Pruning is a critical operation in those silvicultural regimes which promote diameter growth through wide spacing. Over several years prescriptions to improve the effectiveness of the work have been developed. 'Variable lift pruning' (Koehler 1984) has the potential to reduce the mean stem diameter over pruned branch stubs and to reduce the standard deviation in this diameter.

The physiological age of planting stock has a potential to influence silvicultural costs and product quality. If cuttings are taken from seedlings a few months old, the resulting plants closely resemble seedlings. If however cuttings (in P. radiata) are taken from older plants (say up to 5 years of age) they differ significantly from

seedlings (e.g. Fielding 1970). Thus Arnold and Gleed (1985) report that pruning costs in P. radiata stands grown from cuttings are two-thirds of those in stands grown from seedlings. Spencer (this meeting) will provide a detailed account of the yield of ply and sawlog from a stand of cuttings near Canberra.

The rapidly-expanding role of cuttings in Australia and New Zealand was examined in a workshop at Rotorua in May 1986. The Proceedings of the workshop, which will be published late in 1986 as a Bulletin of the N.Z. Forest Research Institute, will contain a paper by Eldridge and Spencer on Australian field experience with cuttings, a paper by Cown on wood properties of cuttings, and many papers on raising cuttings and their early performance in the field.

GENETIC FACTORS

These form a hierarchy - species, provenances, 'breeds' and clones.

SPECIES

At the species level it has been fortunate that several conifers have been identified which not only grow well but produce wood of high quality for many end uses - P. radiata, P. caribaea and Araucaria cunninghamii. P. radiata for example has a texture better suited to machining than P. elliottii which in turn is better than young-growth Pseudotsuga menzesii.

The properties of plantation-grown hardwoods are less well known, and indeed the use of eucalypts instead of pines for plantations has not been thoroughly explored (Cotterill et al. 1985).

It would be desirable to have a suite of silviculturally-successful species which would produce high-quality cabinet woods; Acacia melanoxylon is an interesting candidate which deserves more research attention (e.g. Applegate and Nicholson 1986; Gleason 1986).

PROVENANCES

Many species exhibit significant genetic differences throughout their geographic range. In Pinus caribaea, for example, a study of material from seedlots from 19 sources concluded that, because of extreme variability, it would be unwise to generalise on the properties of plantations of this species (FAO 1975). In P. radiata, now grown in Australia for 100 years, it has only recently been recognised that the population from Guadalupe Island produces trees with particularly straight stems and corewood density about 10% higher than mainland material. Although the island population grows more slowly than mainland material, crosses between the two are arousing especial interest : the F1 hybrids generally show good straightness and some gains in wood density while retaining full vigour (Nicholls and Eldridge 1981; NZ FRI 1983).

Field experiments comparing provenances of several major eucalypt species have now reached the stage at which detailed studies of the genetics of wood properties are possible. These studies enable the relative contributions of genetic and environmental factors to be determined, and provide a basis for selecting provenances for immediate operational use as seed sources and for further development. Examples of studies of wood quality undertaken in these trials are those of Doran (1974) (wood density, E. regnans) and (1975) (kino incidence, E. regnans), McKimm (1985 I & II) (various properties, E. nitens) and Matheson et al.

(1986) (pulp qualities, E. obliqua). As an example of the results, the last study showed that the fastest-growing trees not only produced the strongest pulp but yielded more pulp per unit mass of wood. They also were cheaper per unit mass of wood to pulp to a standard Kappa number.

'BREEDS'

The products of a breeding program may conveniently be referred to as 'breeds'. The trees from the first seed orchards in Australia - planted more than 30 years ago - grow faster, straighter and with less malformation than unimproved stock. Mill studies are in progress of seedling progeny of some of the clones in these orchards; these studies will quantify some of the effects of improvements in straightness and branch habit. Clones now available for seed orchards, or families being multiplied by cuttings, are much better than those used in the early orchards. In New Zealand, orchards have been developed for special purposes - seed of a long internode breed is now available, while seed of high wood density breeds will be available in future. These attributes (long internodes, high density) may be less important in Australia than New Zealand; Australian tree breeders would welcome discussion of appropriate goals here.

In eucalypts, improvement via the seed orchard route is less advanced in this country than in pines. An orchard composed of seedlings raised from selected E. regnans trees was established in Gippsland in 1969, one of E. grandis at Coffs Harbour in 1972, and one of E. diversicolor near Manjimup. Although there has been considerable effort on breeding in other countries, the progress in at least some cases has been disappointing because the work started with sub-optimum material (e.g. Ades and Burgess 1982).

CUTTINGS AND CLONES

Poplars have been grown as clones for many years and this method has been important in obtaining high growth rates, disease resistance and acceptable wood quality. Following work extending over 50 years, clones of Pinus radiata are now becoming commercially available. Spencer will describe the improvements in product yield obtained from an early plantation of cuttings for which the degree of genetic selection had been quite small. The material available now is from much more intense selection, often extending over more than a single generation. It would now be possible to search among hundreds of good families in Australia for families or individuals with wood attributes required for a particular purpose, and to produce planting stock reflecting that objective.

Among eucalypts, the clonal programs in the Congo and Brazil have had wide publicity. At Aracruz in Brazil, it is claimed that increment has been raised by 112% (from 33 to 70 m^3ha/yr), wood density by 25% and cellulose content by 23%; the stands are extremely uniform and the fraction of stumps that coppice following the first and subsequent harvest approaches 100% (Anon. 1985).

It is important to understand that vegetative propagation must be coupled with effective work at the other levels in the hierarchy, viz. species and provenance selection, and breeding. It is not a substitute for these time-consuming steps, but it can make their products quickly and widely available (Matheson and Lindgren 1985).

DISCUSSION

A large amount of information is available on the wood properties of radiata pine and the influence of environmental factors and management practices on these. Although much of this has come from research, critical observation and reporting by wood processors who see much larger samples of wood than researchers ever can is also important. The wood from 'new-crop' plantations - where intensive site preparation, fertilization, wide spacing, improved seed or cuttings and short rotations are likely to be the norm - may well be different, in economic as well as physical terms, from 'old-crop' supplies.

Understanding of the factors affecting the quality of eucalypts in plantations (and regrowth stands) is much less complete, and yet there are clearly factors which can be manipulated in the forest to produce effects which may be of great importance to the processing industries.

Although activities like genetic conservation, seed collection, provenance testing and selection of material for breeding may seem remote from the sawbench, they are fundamental if the supply of raw material for the forest products industry is to be in keeping with developments in competing countries. Although historically the pipeline has been very long, knowledge now on hand, plus the move to shorter-rotation crops, could mean that the interval between basic work and harvesting can be much reduced. In the Aracruz case, work started in 1974, clones were first planted in commercial quantities in 1979, and in 1983 10 million plants were put out. This was expected to rise to 15 million in 1984, or essentially the whole of the company's planting program.

To achieve this, Aracruz invested about 12% of its annual forestry budget in forest research over the decade.

In Australia, much of the basic work mentioned above has been funded by the Commonwealth. Work by the CSIRO Division of Forest Products and its successors has contributed greatly to our understanding of wood properties. The CSIRO Division of Forest Research (and its predecessor, the Forestry and Timber Bureau), with great help from collaborators, has undertaken range-wide seed collections of P. radiata, E. grandis, E. regnans, E. obliqua and E. delegatensis, and assisted with E. globulus and E. nitens. This material has been planted in collaborative trials, and in some cases studies of wood properties have followed. We have been encouraged by the expanding interest of industry in research to further develop this basic material : for example, the Division of Forest Research has entered a cooperative arrangement with APPM at Burnie to work on the genetics and breeding of eucalypts for plantations. This industry support is essential if the more basic findings are to be taken and developed to the point of application.

It is important to recognize, however, that direct Commonwealth support for the basic work is declining. The Government is seeking a greater involvement of industry in research. In CSIRO, although there is considerable emphasis on research to assist manufacturing industry, resources for work in forestry have fallen steadily and significantly for a number of years. In some respects we are seeing more application of basic work done in Australia in overseas countries than is taking place here. Forest research in Australia is also disadvantaged (at least in comparison with New Zealand) because of the fragmentation of the national effort which is a consequence of the federal nature of this country.

The following speakers, several of whom are from CSIRO, will provide details of some exciting developments in aspects of wood quality : I hope that we will continue to be able to report such work in the future.

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TOWARD NON-DESTRUCTIVE MEASUREMENT OF GROWTH STRESSES IN LIVING TREES

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ABSTRACT

The influx of highly-stressed regrowth material on the timber market has warranted the necessity of rapidly developing a practical method which should be capable of measuring in a non-destructive manner the level of growth stresses in tree stems.

Both, the traditional measuring techniques and a number of original concepts based on the non-destructive measurement of stresses in living trees, are critically assessed in this paper.

The results of this assessment indicate that, although only partly successful, some of these new methods are sufficiently innovative to provide scope for further improvement and practical use.

INTRODUCTION

NATURE AND ORIGIN

Growth stresses are complex forces which often occur within the stem of a living tree. They can be found in numerous species (Jacobs 1965) and are one of the major causes of a serious timber degrade (Boyd 1950-B, Hillis 1978, Chafe 1979, Krilov and Dowden 1986). Their existance in wood has been known for many years. The pioneering works of Martley (1928), Koehler (1953), Tredelenburg (1935), Munch (1938) and Jacobs (1938, 1939 and 1945), have contributed greatly to establishing the basis of this knowledge.

An extensive literature survey indicates that although the origin of growth stresses in wood is generally attributed to the longitudinal contraction of wood fibres, the mechanism for this has never been fully explained in an acceptable manner. It has been suggested lately that a combination of the 'lignin swelling' and the 'cellulose tension' hypotheses may go part of the way to providing the necessary explanations of this phenomenon (Wilkins 1986-A).

TYPES AND DISTRIBUTION

Both the magnitude and orientation of growth stresses in a living tree are subject to extreme variations. They appear to be genetically controlled and, according to certain authors, are modified by the environmental conditions (Lenz and Strassler 1959, Nicholson 1973). Some species, particularly eucalypts, are more prone to develop high growth stress levels than others (Chafe 1979) and, therefore, present greater problems in their conversion and utilization (Hillis 1978, Krilov 1981-A, 1981-B, Krilov and Dowden 1986). These are exacerbated considerably by the fact that the stress distribution pattern throughout the stem is irregular (Atanackovic 1977) and may occur in longitudinal, tangential or radial direction.

From the utilisation point of view, the most severe and variable form of growth stress, which is mainly responsible for a serious timber degrade such as the log end splitting, is longitudinal. This form of stress is caused by forces producing longitudinal tension with the outside portion of the stem and longitudinal compression near the centre. Its importance has been demonstrated by numerous researchers including Boyd (1950-A), Perkitny *et al.* (1951), Striha (1954 and 1955), Mayer-Wegelin (1955), and Kubler (1959-A). Other specific aspects of this complex phenomenon were

explored in further works by Boyd (1950-B and C), Kubler (1959-B and C), Hallock (1966), Kikata (1972), Gueneau (1973), Archer and Byrnes (1974), Seurat and Gueneau (1976), Vendhan and Archer (1977) and others. In the majority of the above studies attempts were made to determine the origin of these stresses in wood, their development, distribution, variability and the methods suitable for their measurement. In a few studies only, some practical means of growth stress alleviation have been suggested (Striha 1954, Mayer-Wegelin and Mammen 1954, Platon 1959, Barnacle and Gottstein 1968, Giordano *et al.* 1969 and 1973, Stubbings 1973, de Villiers 1973).

Generally limited in scope, these did not offer many feasible solutions; thus, in practical terms, the conversion and utilisation problems generated by growth stresses have remained largely unsolved.

Before any constructive suggestions for the relief of stress can be formulated, it is essential to obtain quantitative data on the extent and variability of the problem.

MEASUREMENT

Collection of this data requires a reliable measuring technique. The difficulty, however, lies in the fact that the very nature of growth stresses prohibits their direct measurement. Thus, all methods used for the approximation of stress are based on the measurement of strain, the strain being the displacement produced by the release of stress, which is essentially a physical process achievable in many different ways.

The magnitude of longitudinal, in comparison to transverse growth stresses, makes them not only easier to detect but also more important in the degradation of timber. This is the reason why most measurement techniques are designed specifically for the assessment of the longitudinal growth stress.

The majority of these, however, are laborious and not always very reliable. They are also destructive. Hence, the development of an improved method of growth stress measurement becomes indispensable.

OBJECTIVE

It is, however, well beyond the scope of this paper to review the extensive literature existing on this subject. Instead, it will endeavour to provide a constructive criticism of only those methods for growth stress measurement, which are considered promising. It is hoped that these assessments might pave the way toward development of an improved strain-measuring concept which, in principle, should be more practical, reliable and definitely non-destructive.

DISCUSSION

The simplest way to assess the general level of growth stress is to fell the tree and observe the deformations occurring where the log is split, the degree of splitting being the stress-related strain. These deformations resulting from the relief of the longitudinal growth stresses within the wood tissue are known in industrial practice as "spring".

Although somewhat crude, this earliest method of growth stress measurement was capable of providing simple and direct readings, which were of an immediate, practical value to the conversion industry. A modified version of this technique has been used by Jacobs (1938), who measured the degree of spread at the crosscut surface of a diametrical plank (Fig. 1). In 1965, Jacobs presented another variation of this method. It was based on the range of lengths present at a crosscut surface after stress release, the change of length across the board from bark to pith being representative of the longitudinal growth stress level. Unfortunately Jacob's techniques were destructive and, therefore, non-repeatable.

Boyd (1950) cut slots into logs and inserted strain gauges to measure the longitudinal strain, which was released by crosscutting the log at the proximity of the gauges. He found that stress release was essentially confined to within a distance of approximately three log diameters from the crosscut end of a log. Boyd's observations agreed with previously described patterns of longitudinal stress distribution, but his method was no less destructive.

Another variation of measuring stress distribution longitudinally and transversly, particularly in log ends where severe splitting occurs, has been carried out by Wilhelmy and Kubler (1973). The measurements were made through a drillhole with a special probe. The drillhole diameter was measured at various depths. Then, longitudinal stresses were relieved by crosscutting the log and the drillhole diameter remeasured. Although innovative, this procedure was destructive and therefore non-repeatable, as previous.

Nicholson (1971) proposed a relatively non-destructive method for measuring longitudinal growth stress in living trees. Using this method, three gauge points are applied to a debarked area of tree trunk. The distance between the outer two points is recorded. Stress in the wood between the gauge points is then released by removal of a block of wood from the tree containing the gauge points. The central gauge point provides a means of correcting for the curvature of the removed wood block. Remeasuring the position of the outer gauge points after stress release provides a measure of strain, which can be converted to an estimate of stress using the measured modulus of elasticity of the wood (Fig. 2).

According to Nicholson, a reasonable accuracy of readings could be obtained without correcting for curvature, which simplified the procedure and made it suitable for use in the field.

The novelty of Nicholson's approach to growth stress measurement has attracted considerable interest. Independent assessments, however, have shown later that although original, this method in reality is fairly complicated and much too laborious to be practical for field work; extremely sensitive, it is also incapable of producing repeatable results (Wisgrill 1973; Foers 1974; Atanackovic 1976; Waugh 1986). It has been argued also that Nicholson's method requiring physical extraction of a block of wood out of a living tree cannot possibly register the original stress. By cutting the wooden block out, most of the stress is released but residual stress still remains and is unaccounted for.

Alternative methods of measuring longitudinal growth stress which were essentially variations of Nicholson's technique, were tested by Gueneau (1973); Gueneau and Kikata (1973); Gueneau and Saurat (1974) and Saurat and Gueneau (1976). Instead of the mechanical gauge, electronic strain gauges were used. This, however, resulted in some loss of portability of the measuring equipment and added a quite unnecessary degree of sophistication which made precision measurements in rough field conditions difficult.

A new method for measuring growth stresses proposed by Mariaux (1981 and 1983) appeared to be superior to others. This method is based essentially on the measurement of strain between four gauge points disposed perpendicularly to each other, whilst the stress is released by drilling a hole between them (Fig. 3).

An obvious advantage of this method is that it can provide simultaneously and non-destructively both longitudinal and transverse growth stress readings. On the negative side, however, it can be argued that, whilst using this particular method, the stress release might be

incomplete, due to the considerable portion of remaining wood able to resist displacement of the gauge points.

Another non-destructive method of estimating the magnitude of longitudinal tension stress in trees has been proposed by Polge and Thiercelin (1979). The major advantage of this method is that it is extremely simple. It consists of measuring tangential diameters of cylindrical cores removed from standing trees which, according to Polge and Thiercelin (1979) have a negative correlation with longitudinal growth stress ($R = -0.578$). Longitudinal correlations of both core diameter and growth stress, however, proved to be insignificant ($R= -0.068$). Polge and Thiercelin explained the unexpectedly low correlations obtained in the longitudinal axis in terms of the anisotropy of wood fibres: a high modulus of elasticity in the axis of the fibre allowing only small changes in axial core diameter as a response to released stress.

In 1981, this method has been extensively used by Ferrand on a range of Australian hardwoods. Ferrand confirmed the existence of a negative correlation between longitudinal tensile stress in a tree and mean tangential core diameter claimed by Polge and Thiercelin (Ferrand 1982-A and 1982B). He concluded that, although not sufficiently suitable for measuring individual trees, Polge and Thiercelin's method is viable and can be applied successfully to large scale silvicultural studies (Ferrand 1982-A and 1982-C).

Original, simple, non-destructive and claimed being successful for large scale silvicultural studies, Polge and Thiercelin's method had an immediate appeal to a number of potential users, in particular, the Forestry Commission of New South Wales. It is for these reasons that a careful examination of this method has been carried out by the research

staff of W.T. & F.R.D. The results of these observations were negative (Wilkins 1986-A). They questioned not only the statements of Ferrand (1982-A and 1982-C), but the validity of the method itself (Wilkins 1986). Indeed, the preliminary findings of Wilkins and Bamber (1984) have established the non-repeatability of measurements undertaken by Polge and Thiercelin, as well as Ferrand, by demonstrating that core diameters, which are fundamental to the success of this method, vary with time after sampling (Figs. 4 and 5). Further works of Wilkins (1984-B) have confirmed this specific property of cores to decrease in diameter within two to three days after core removal from living trees. Whilst the contraction was most significant in the first hour, differences in core diameter as great as 50µm were observed. It has been noticed also that the fluctuations in readings due to the core borer technique were excessive. This provided an additional element of complexity and distortion to the obtained results. Finally, no correlation was found between expected longitudinal stress and tangential core diameter.

On the basis of these experiments, therefore, it was concluded that the technique of Polge and Thiercelin, when using small numbers of *Eucalyptus pilularis* trees, is unable to provide correct estimates of growth stress (Wilkins 1986-B; Wilkins and Bamber 1986).

A novel non-destructive method for the approximation of longitudinal growth stress based on cell wall deformations, commonly known as 'slip planes' (Wilkins, 1986-D), has been tested recently by Wilkins (Wilkins *et al.* 1986).

The basic concept behind this method has been the knowledge that fibre cell wall deformations form as a response to longitudinal compressive stress (Dinwoodie 1968) and occur more frequently in those fibre walls

which are adjacent to rays (Wilkins 1986-C). Longitudinal growth stress near the pith may be, therefore, a source of the compressive stress which causes these deformations (Dadswell and Langlands 1934; 1938). Hence, the abundance of deformations in the fibre walls adjacent to rays near the pith may possibly represent an adequate indication of the maximum level of longitudinal growth stress experienced by the tree during its lifetime (Wilkins *et al.* 1986).

The concept of this new anatomical technique using the counts of the number of slip planes in these areas of greater sensitivity, has been tested on trees of *Eucalyptus pilularis* Sm. (blackbutt). The results obtained were compared to the field measurements of longitudinal growth stress in the same species, which were based on the destructive method used by Krilov and Ades (1985).

Although it was expected that both the abundance of cell wall deformations and tree diameter should produce a negative relationship with strain, neither relationship occurred (Fig. 6). A significant, but weak, correlation, however, was found between the number of cell wall deformations in fibre walls adjacent to the second marginal ray cell and field measurements of the longitudinal growth stress. No such correlation was observed in fibre walls adjacent to the marginal ray cell.

This led to the conclusion that the proposed method is apparently not suited for measuring growth stress levels in individual trees. Further investigations, however, may show that Wilkins' technique might still be useful for approximations of relative growth stress in large timber stands.

In an endeavour to solve the problem of growth stress measurement in the light of the requirements set in the introductory part of this paper, another development has occurred recently at W.T & F.R.D.

A new concept of an original stress measuring method has been suggested and SMA (Stress Measuring Apparatus) capable of non-destructive measuring of growth stresses in living trees was developed. A prototype model of SMA Mark 1 was built and tested locally in field trials. The results of these trials were encouraging. It has been shown that this new apparatus is capable of providing consistantly repetitive measurements of longitudinal growth stresses in living trees with sufficient precision and in a non-destructive way.

Based on the experience gained during these preliminary series of trials, SMA Mark 1 was redesigned and improved. Whilst its general performance has been greatly enhanced by the addition of new components, SMA Mark 2 model became now an infinitely simpler and more effective instrument, capable of operating in harsh field conditions.

Since, three series of field trials were carried out with SMA Mark 2:

* The initial trials designed to assess whether the precision of SMA readings is adequate, specifically for the lowest limit values of the longitudinal growth stress. These tests were conclusive.

* The second series of tests intended to assess the magnitude of the 'human error' and its influence upon the final readings. These tests were also conclusive and for this type of measurement have shown an excellent repeatability (96%).

* The final series of field tests were carried out recently in a stand of young, fast-grown Blackbutt (*E. pilularis*). These measurements were carried out with the intention of establishing the very first numerical growth stress data base for the above species. These tests were designed also to co-relate the SMA

measurements on living trees with the longitudinal splitting occurring in young Blackbutt logs in practice. The results of these trials are presently being analysed and will be reported.

CONCLUSIONS

It has been widely acknowledged by both science and industry, that an eventual solution to the long-standing problem of growth stresses in timber can produce extremely lucrative results. However, the great complexity of this problem has precluded a practical solution for a long time.

The literature survey clearly shows the extent and variety of theoretical studies in this field, which have been carried out in the past. Compared to the large body of theoretical work, there have been only a few specific investigations aimed at resolving the practical problems created by growth stresses in wood. These studies are generally limited in scope and do not offer many feasible or economically acceptable solutions.

One of the fundamental problems addressed by this paper, is an evident lack of practical information on the magnitude of deformations caused by growth stesses: a consistant, uniform and comprehensive data base simply does not exist.

Different methods of measurement initiated in the past by a number of researchers proved to be unrepetitive, contradictory and generally unreliable. Moreover, nearly all of these methods are destructive.

To overcome this problem, it is evident that a new insight into the basics of growth stress measurement was needed. Consequently, a number of original concepts based on the non-destructive measurement of stress in living trees were formulated. Their analysis is encouraging. Although

only partly successful, some of these are sufficiently innovative to provide a scope for further improvement. They also represent the practical experience lacking in this extremely complex field of research and are, at the same time, a potential source of new ideas.

To summarise, marked progress has been made in this field.

The problem of growth stresses in wood will not disappear. With the influx of vast quantities of regrowth material, it is expected that the practical importance of this problem will only escalate in the future. This, however, should provide a powerful incentive for further research.

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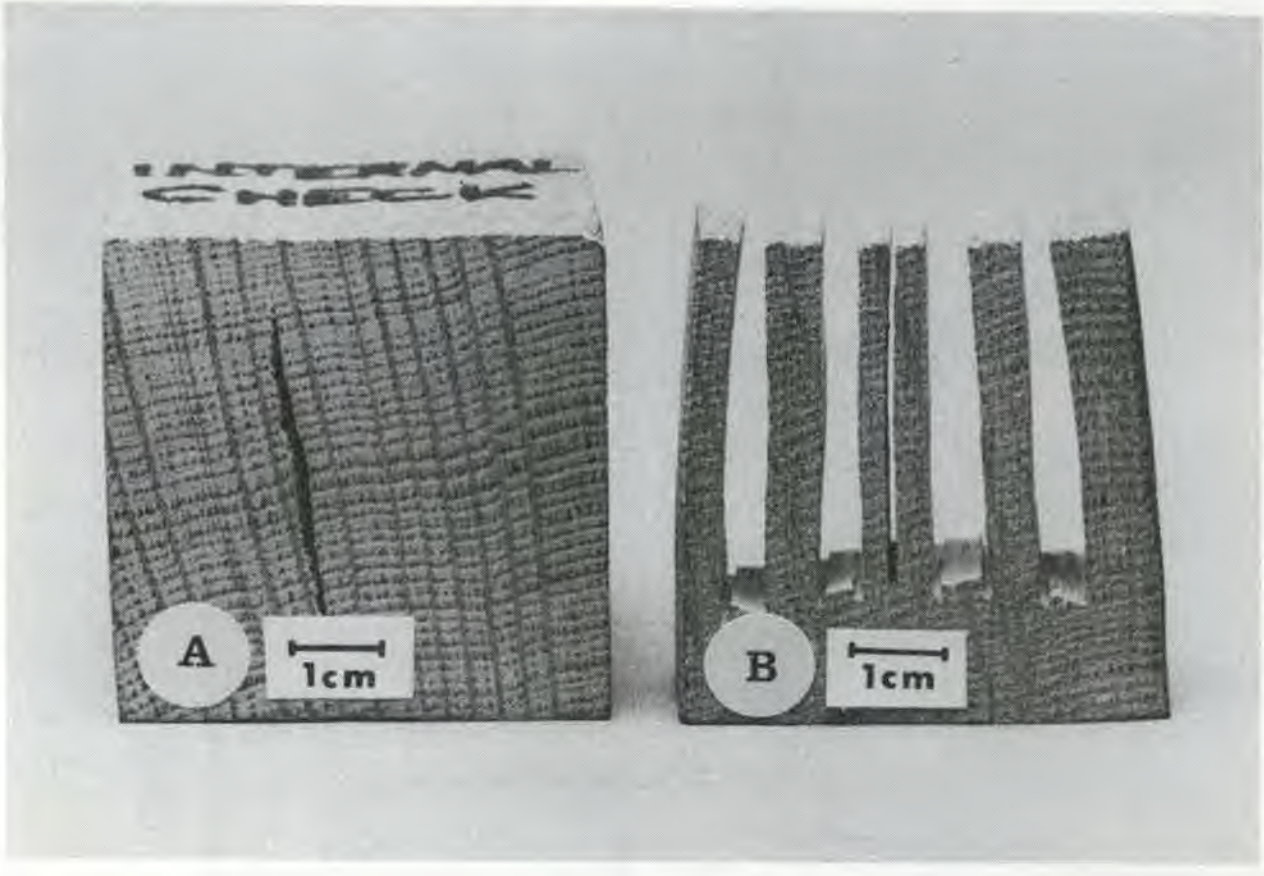
Figure 1.

A significant degree of spread and internal checking in a sample of European oak (*Quercus* spp.) due to incipient growth stresses.



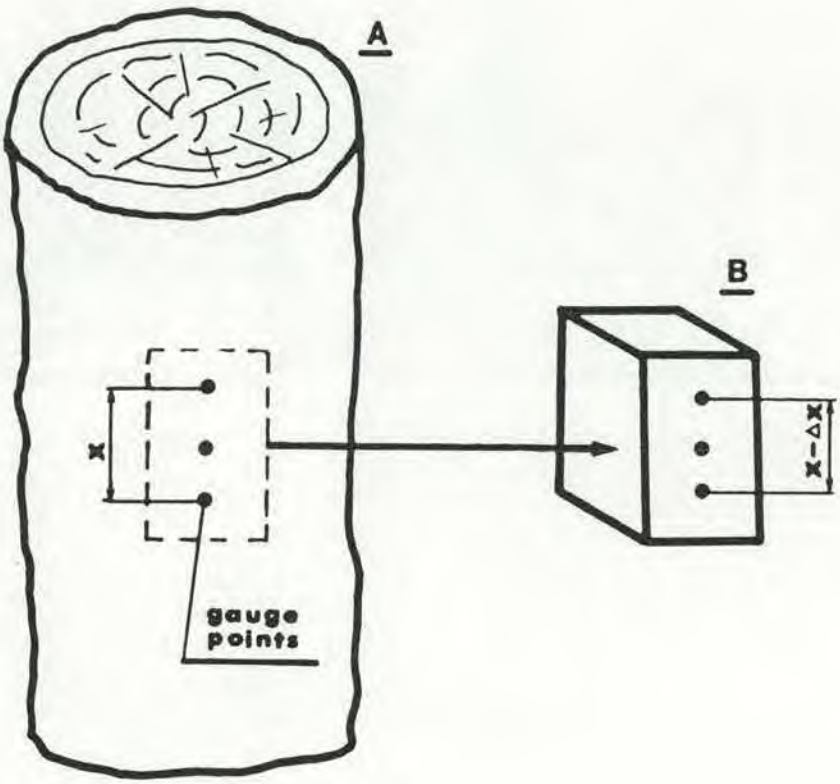
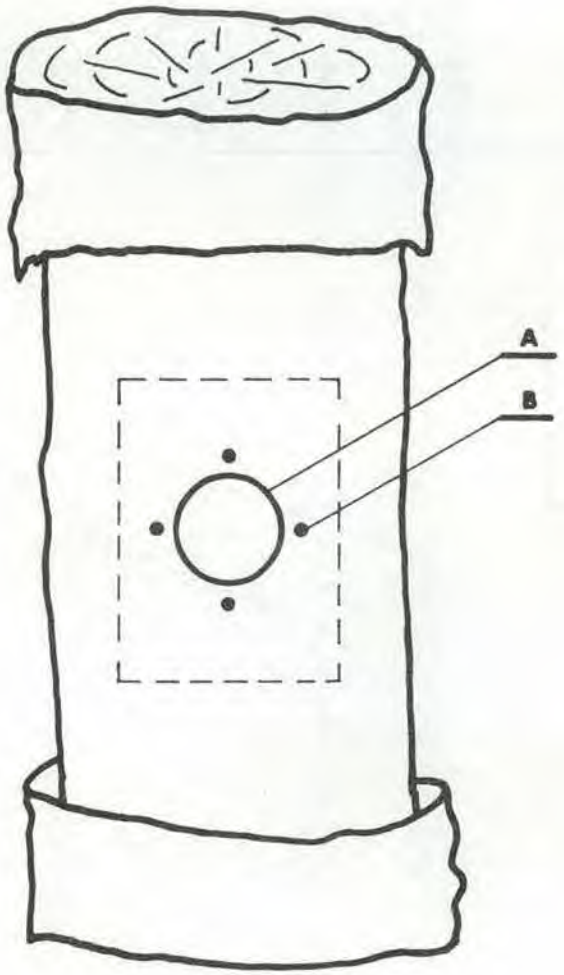


FIG. 2. Nicholson's method for longitudinal growth stress measurement.



A– HOLE BORED IN STEM
B– GAUGE POINTS

FIG. 3. Mariaux's method for longitudinal growth stress measurement.

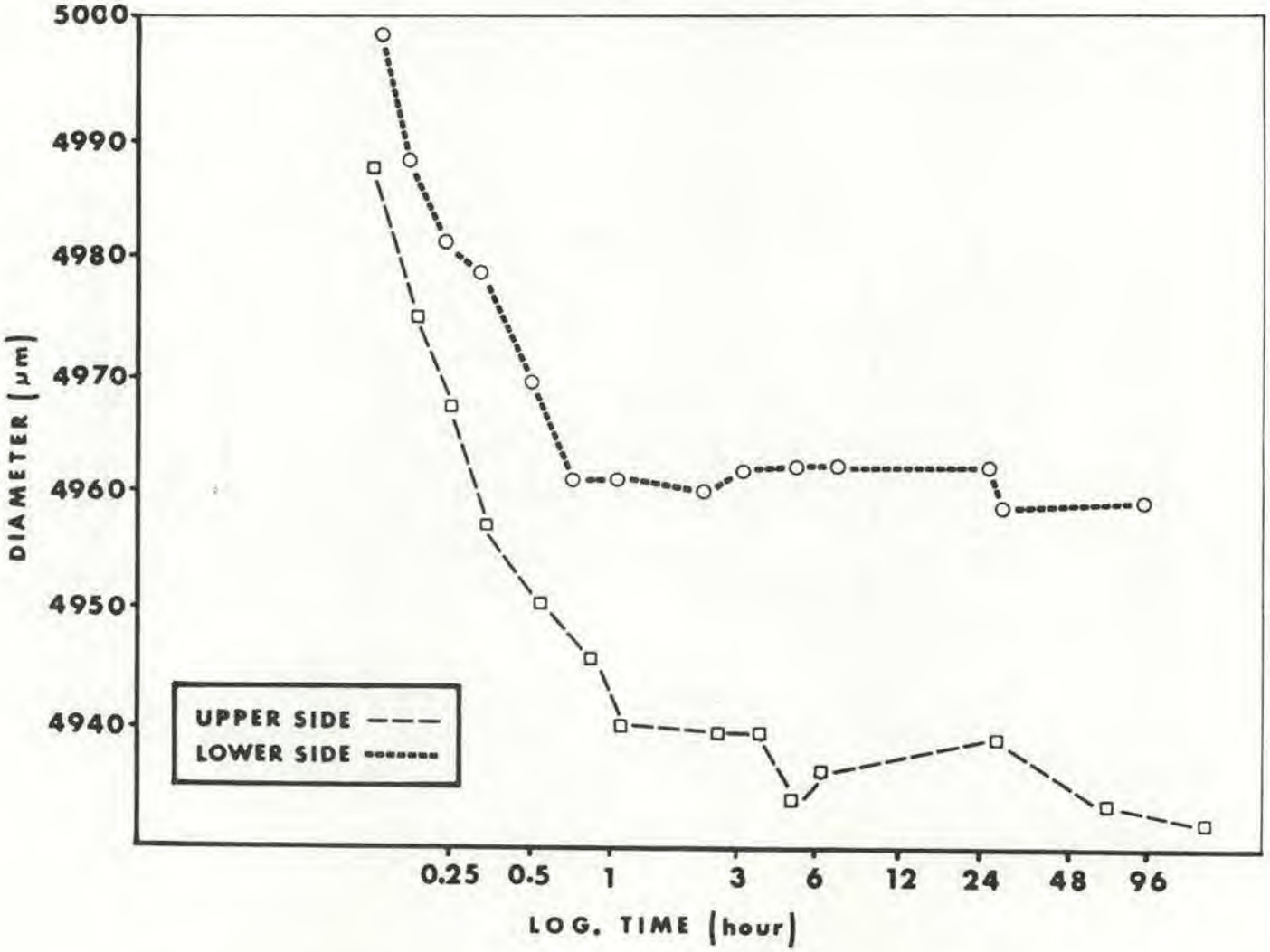


FIG. 4. Movement in tangential core diameter in a 40 year old *Eucalyptus pilularis* (lean:4°).

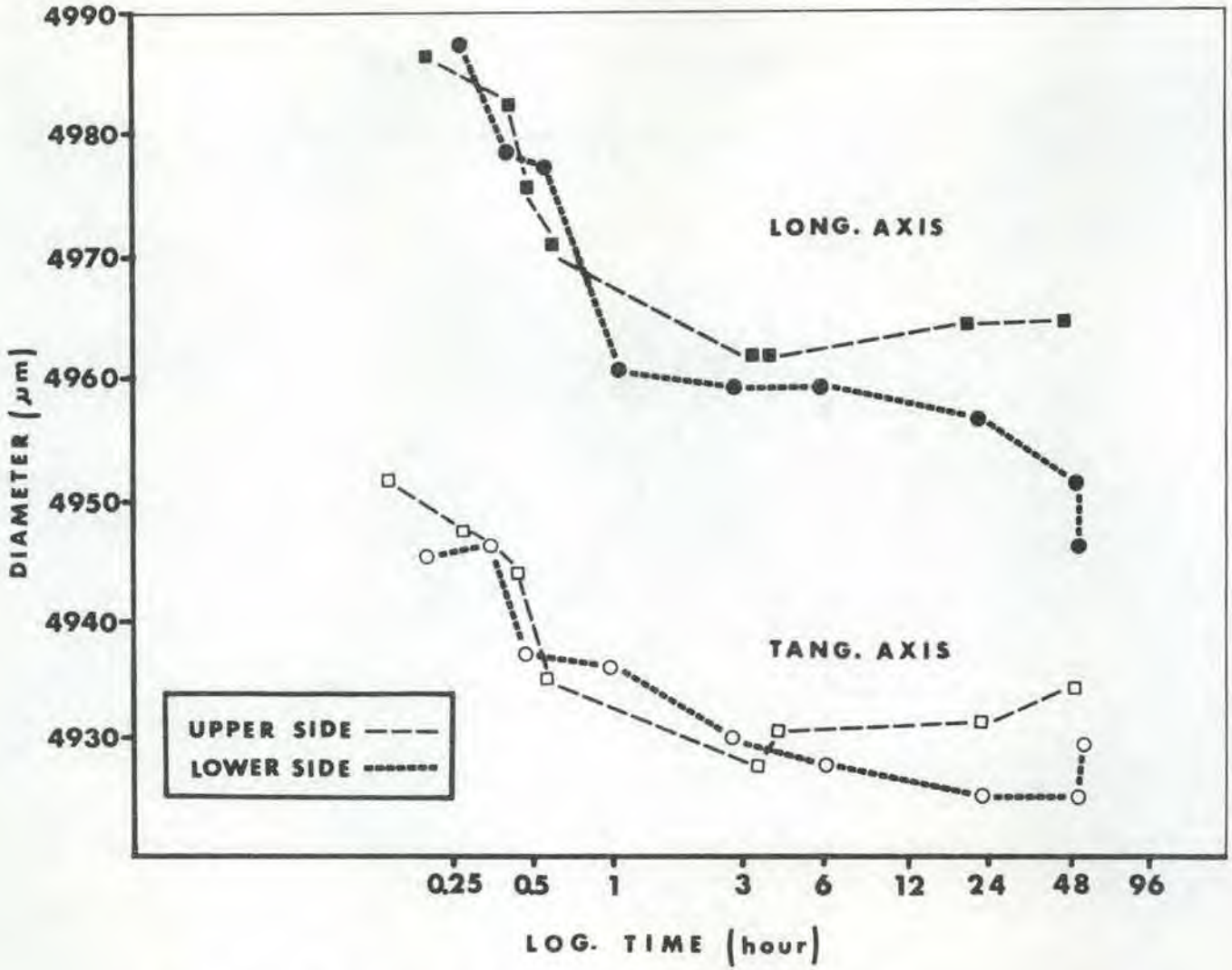


FIG. 5. Movement in tangential and longitudinal core diameter in a 15 year old *Eucalyptus pilularis* (lean: 4°).

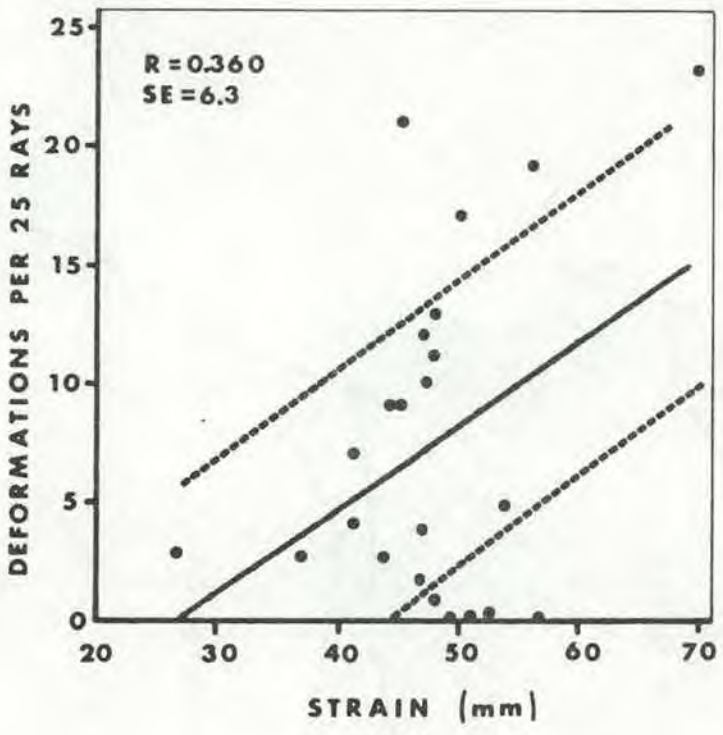


FIG. 6. Relationship between strain and the number of cell wall deformations at ray cell position 2.

RAW MATERIAL REQUIREMENTS FOR THE PULP AND PAPER INDUSTRY

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ABSTRACT

The pulpwood requirements for the pulp and paper industry in Australia are discussed. A brief consideration of the current market situation and a review of the pulping processes which can be applied together with the properties of the resulting pulps are included. The properties of both softwood and hardwood fibre resources available for the industry vary considerably and the separate characteristics of these materials must be used to advantage for economic production.

Following a general description of pulpwood plantation establishment in certain overseas countries an outline is given of the requirements for the supply of future fibrous raw materials for the Australian industry.

INTRODUCTION

Since paper was first made from materials such as hemp, rags and rope pounded in a mortar, with water, a great variety of raw materials have been used. The materials, like cotton rags and hemp and other cellulosic fibres, were essentially of the same chemical composition as in the final product. In contrast, modern technology makes predominant use of a raw material that is radically altered chemically and physically during the pulping and papermaking process (1).

The range of materials used commercially throughout the world includes annual crops, agricultural residues and similar fibres, but generally for reasons of local availability, in small-scale operations and often for specialised end-products. Some recent developments include the establishment of a mill in Thailand to produce kenaf pulp (2), the use of bagasse for mechanical and chemical pulp production of newsprint and including microbially controlled fermentation to inhibit deterioration of the bagasse in storage (3) and the continuous extraction of abaca fibres in yields 50 to 60 per cent higher than previously obtained (4). However, the world-wide trend to larger-scale operations which are often considered as the only possibility for economic processing needs to be reviewed. In many

countries, it could prove economic to modify accepted mill practices to suit the available non-wood resources and operate on a smaller scale.

The principal fibrous raw material used in the pulp and paper industry is wood, admittedly in many different forms, and this discussion will be confined to such materials. Furthermore, I believe it is preferable to concentrate also on the requirements of the Australian pulp and paper industry.

MARKET ASPECTS

The pulp and paper industry in Australia is comparatively young. Some handmade paper was produced in New South Wales in 1818 but it was not until half a century later that the industry was properly established. Two mills with paper machines were started up, at Liverpool, NSW and Melbourne, Victoria. Commercial pulp production began in 1938 and by 1941 pulps were being made for wrapping papers, writing and printing papers and newsprint with native eucalypts as the main raw material. By the mid-1940s total paper and paperboard production was about 150,000 tonne per annum with an annual pulp production of less than 100,000 tonne.

In 1984 Australia was producing over 1.5 million tonne paper and paperboard and approximately 700,000 tonne pulp per annum. Australia has not reached the point of producing the total requirement of pulp for local paper and board production. At present we produce c. 80 per cent of the pulp used. Furthermore, Australia has no export market for either softwood or hardwood pulps.

Apparent consumption of various paper and paperboard products together with an indication of self sufficiency is shown in Table 1. Imports are an

TABLE 1

APPARENT CONSUMPTION PAPER AND PAPERBOARD IN AUSTRALIA, 1984

	Consumption ('000 tonne)	Self Sufficiency (%)
Newsprint	628	59
Printing & Writing	437	52
Other paper	652	75
Paperboard	507	91
Total	2224	70

appreciable component of the market and mainly in newsprint and printing and writing grades. The figures suggest that there is potential for expansion of production of various pulp and paper grades to meet local market requirements. Fibrous raw material additional to the current supply would be needed for this future expansion irrespective of any considerations to establish export pulp or paper operations.

PROCESSES AND PRODUCTS

Cellulose fibres from almost any kind of plant can be made into some kind of paper or paperboard. Thus the fibres from almost any wood supply can be treated to produce a pulp for use in paper or board furnishes. However, very strict limitations apply to the raw materials when technical and economic efficiency in pulp production are important and when pulp quality to meet end-use requirements is specified.

Historically, pulping was principally a mechanical process. Groundwood pulping, invented in 1840, involves defibration of wood billets by pressing against a revolving grindstone. Chemical treatment of wood is necessary for the production of strong pulps and involves the removal of non-fibrous components in whole or part. Figure 1 illustrates the range of commercial processes involving the application of mechanical energy, chemical energy, or both, to achieve fibre separation.

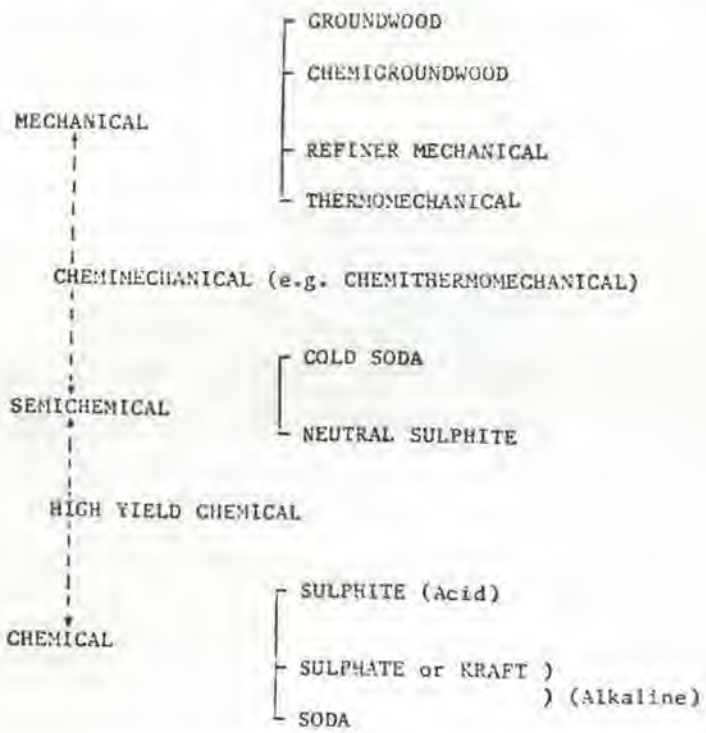

Figure 1. Classification of Pulping Processes

No clearly defined classification exists for all possible modifications and with a slight change of conditions the process may easily be described more suitably under a different category. In the classification shown, mechanical pulps will contain substantially all of the lignin originally present in the wood and require considerable mechanical energy to separate the fibres. Certain mechanical pulps such as refiner groundwood and thermomechanicla pulp (TMP) are produced from woodchips in a disk refiner rather than from wood billets in a grinder, as occurs for groundwood pulp.

Chemimechanical and semichemical processes depend on chemical treatment of woodchips but the action is relatively mild and considerable mechanical energy is subsequently required to produce fibre separation. By contrast, chemical pulping processes aim to free the cellulose fibres from lignin and extractives, releasing them substantially pure and whole by chemical means with a minimum of mechanical energy.

Naturally, the properties of the various pulps are very different and affect their potential for use in paper and board products. The pulp quality requirements for operations such as bleaching, beating, paper machine runnability, converting or printing are relevant and the suitability of any grade must be considered in these terms. However, the yield of pulp from a given quantity of wood is one of the most important economic factors affecting the selection and use of raw materials and processes. The variation in the yield of pulp obtained from different processes is shown in Figure 2. A variation from 40-50 per cent yield with chemical processes to over 90 per cent yield for mechanical pulps exists and for reasons of conservation of natural resources efforts should be made to use the highest yield pulp from a given material and/or process. However, often the lower yield pulps have the better quality and are the most versatile for use in end products and, furthermore, are generally suitable for application to the widest range of woods.

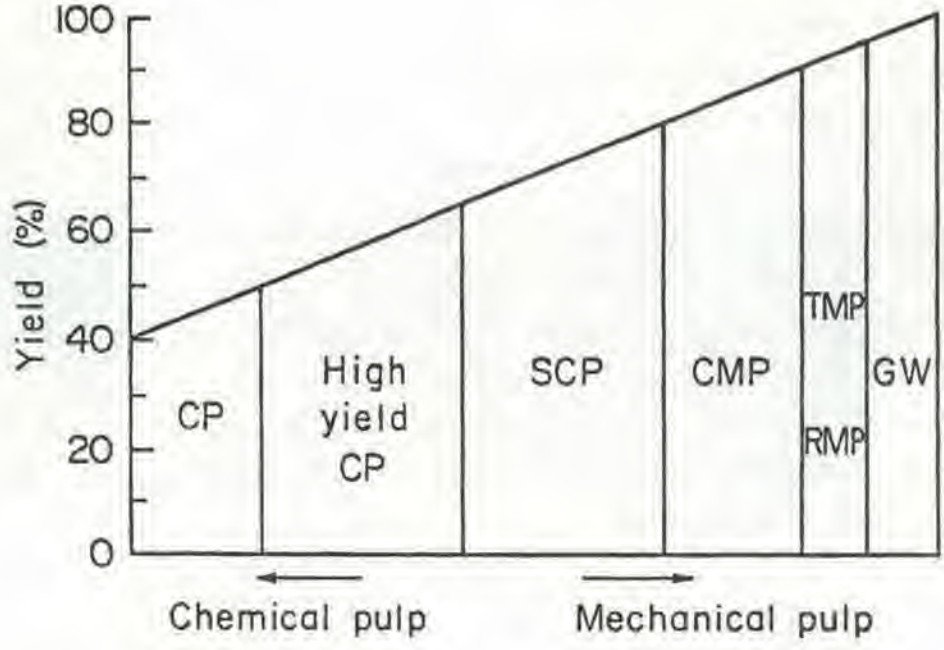

Figure 2. Yields of Various Pulp Grades

Clearly, the pulping technique to be used can be chosen to produce a pulp in the desired yield range and with a certain level of chemical purity and mechanical strength. However, the inherent properties of pulps depend on the nature of the raw material and the morphological properties of the constituent fibres.

In addition to the process range discussed consideration must be given to the product range and the properties required.

The requirements for printings and writings include adequate, although not necessarily high, strength properties, good optical properties, including high brightness and opacity, good formation, smooth surface compressibility and surface strength. Many of these properties can be obtained with hardwood pulps (5). Irrespective of the fact that the Australian newsprint industry was established, and continued for c. 40 years, with eucalypt pulpwood as the major raw material, softwood resources are much preferred throughout the world. The choice is strongly influenced by the need to use high yield, mechanical type pulping processes for economic operation rather than the properties of hardwood pulps available from other lower yield processes.

Whereas long-fibred softwood pulps are preferred for wrapping papers, basically for high tearing strength which is not attainable with hardwood pulps, and for kraft liners, the hardwoods are eminently suitable for corrugating medium in which crush resistance is important.

In practice, it is unlikely that a single raw material source or a single grade of pulp will satisfy the requirements for even a moderate range of end products, especially when environmental requirements are added to production demands and quality specifications. The blending of various pulp grades from a range of raw materials has proved to be essential for the establishment and development of the pulp and paper industry in many countries, including Australia.

RAW MATERIAL REQUIREMENTS

Some of the advantages of hardwoods and softwoods for pulping and papermaking have been summarised by Higgins (6). Table 2 is taken from that publication. More recently, as indicated by Meadows and Saul (7), there has been an upsurge of interest in refiner groundwood and thermomechanical pulps with their high yield advantage. Softwoods are eminently more suitable for such processes.

TABLE 2

SOME ADVANTAGES OF HARDWOODS AND SOFTWOODS FOR PULPING AND PAPERMAKING
After Higgins, H.G. (6)

	Wood	Pulp	Paper
Hardwoods	Lower lignin content	Lower flow resistance	Better formation
	Higher hemicellulose content	Rapid strength development on beating	Smoother surface
	Higher sensitivity to swelling agents		Better strength-opacity relationship
	Higher digester capacity*		Higher bulk+
Softwoods	Easier mechanical removal of bark	Better wet web strength	Better tearing strength
	Extractives problems less serious in alkaline pulping	Better drainage properties	Better folding endurance
			No vessels

* For wood of intermediate and high density

\+ Advantage for fine papers; disadvantage for most wrapping papers

In considering the raw material situation for industry, the possibly conflicting requirements of various segments make for a complex pattern. The pulp producer wants to obtain a high-yield, light-coloured pulp which is easy to bleach and therefore prefers low-density, extractive free pulpwood. The paper maker requires pulp with adequate strength, high brightness for bleached grades, which is easy to beat and has good machine runnability. Can these properties be matched with the desires of the paper user for adequate strength, high brightness and opacity, good handling, softness, ink receptivity etc., depending on the product, and above all at an acceptable price?

In Australia, due to the increasing availability of softwood resources and the establishment of processes to take advantage of these materials, the pulping industry is approaching a utilization pattern based on 50 per cent hardwoods/50 per cent softwoods. The balance is likely to continue because both resources will be required for the range of processes and products needed for the domestic market. Of course, if the industry expands to produce pulp for export the balance could vary depending on the market requirements.

In the foreseeable future it would be expected that *Pinus radiata* plantation pulpwood, together with smaller amounts of, for example, *Pinus caribaea*, *Pinus elliottii* and *Pinus pinaster* would provide the softwood raw material for the industry. *P. radiata* has advantages in respect to pulp quality, but other species may be desirable for plantation establishment in particular areas. Furthermore, as many coniferous species do not develop optimum pulping characteristics and fibre morphology until they have matured to an age approaching that acceptable for sawmilling, end-use conflicts may not be a serious problem (7). Utilization patterns are further simplified because thinnings can be employed satisfactorily for mechanical pulping.

The situation with hardwood raw material for the pulp and paper industry is more complex. Large quantities of forest residues and sawmill waste are used for particular processes on economic and environmental grounds. However, pulp yield, quality and cost of production depend on the nature of the raw material and waste wood tends to be inferior to the bulk of the tree which is used for other purposes. Further, the lumber tree is not necessarily the ideal pulpwood tree (8). Meadows and Saul have stated

that eucalypt pulp from selected species grown under more or less ideal conditions is equal or superior to other hardwood pulps e.g. birch kraft pulp (8). However, this does not apply to the bulk of domestic eucalypt pulp made in Australia or to the potential of a large part of the current eucalypt wood resources. These resources are mainly mixed-aged, mixed-species, cut-over native forests and will not provide premium-grade pulpwood.

With respect to the raw material supply, perhaps the options available in an endeavour to meet the requirements of pulpwood producers, pulp producers, papermakers and customers, would be:

(i) Accept whatever raw materials are available and by a variety of pulping and processing methods make a variety of pulps for blending to meet the specifications of one or more end-products, e.g. the production of hardwood groundwood, and cold soda pulps and softwood, TMP for newsprint at ANM Ltd, Boyer.

(ii) Use a particular wood resource and make one type of pulp suitable for a specific end-use, e.g. the production of TMP from *P. radiata* for newsprint at ANM Ltd, Albury.

(iii) Consider the end-use requirements, decide on the optimum pulp and other process to achieve these requirements and then grow the raw material to suit the need.

Australian market growth is not high and it is probable that in future the industry will need to develop export markets to achieve the level of production necessary for more economic operation. High quality raw material will be essential to achieve acceptable production costs and pulp quality for export activity. Already we know that particular species of both softwoods and hardwoods can be grown satisfactorily and provide eminently suitable pulpwoods. Admittedly, improvements could be achieved as, for example, has been shown in Brazil where growth rates of up to 75 m^3/ha/yr are possible with eucalypts. However, some balance is essential between endlessly pursuing better species, better silvicultural returns and better pulping properties and improving the processes being applied to existing pulpwood supplies. Furthermore, a halt is required in the pursuit of higher quality products at higher cost, just to satisfy marketability. Perhaps our society needs to be educated to accept products suitable for the job in hand rather than demand over-processed, over-specified products which do little more than waste resources in their manufacture.

PULPWOOD PRODUCTION IN SELECTED COUNTRIES OVERSEAS

The development of softwood plantation resources for the industry in New Zealand has been well documented. Earlier plantings were the basis for the establishment of mills to meet both domestic and export markets. New plantings of *P. radiata* to provide pulpwood and lumber will mature in the 1990s and beyond, and create opportunities for further expansion (9). Similarly *P. radiata* plantations in Chile which extend over about 1 million ha and have a mean growth rate of 22 m^3/ha/yr for a 25 year rotation are now being used for pulp production (10). Considerable quantities of pulp are being exported to earn foreign exchange. Japan with a very great dependence on imported pulpwood to maintain pulp and paper industry operations is also extending the establishment of conifer plantations for use as lumber and pulpwood. Australia's efforts in expanding softwood resources in recent years and the current level of utilization for pulp and paper manufacture is not different to the trends in these countries.

Among the structural changes taking place in fibre consumption in the world paper industry, such as the lower fibre usage and the introduction of thermomechanical and chemithermomechanical pulps, one of the most important is the increase in the use of bleached hardwood pulp. Use in printings and writings, tissue and sanitary papers, laminated and document papers and wrapping and packaging grades represents c. 40 per cent of the total world bleached pulp consumption. Ten years previously the figure was c. 28 per cent (11). In 1985 eucalyptus pulp represented 21 per cent of the world's total bleached hardwood pulp production. In terms of bleached hardwood market pulp, eucalypt pulp represented one third of the total (11).

The main producers of eucalyptus market pulp are Brazil, Spain, Portugal, South Africa and Morocco. Recently, production has increased rapidly to meet market demand and whereas, in 1983, total capacity was c. 2.1 million tonne per year (Brazil: 50 per cent; Iberian Peninsular: 40 per cent) in 1985 production capacity had increased to 3.1 million tonne per year (Brazil: 39 per cent; Portugal: 29 per cent and Spain: 23 per cent). Over the next five years an estimated 1 million tonne per year is to be added to mills producing eucalyptus pulp throughout the world (11,12,13).

The production of pulpwood in these countries is quite different to that in Australia. As mentioned, industry in Australia, in the main, relies on State forest resources for pulpwood and utilizes mixed-species, mixed-aged stands for a variety of pulp grades. In Portugal sulphite pulp from plantation-grown *E. globulus* was first produced in 1906 and, by 1920 regularly shipped to England (14). Somewhat later kraft pulp production commenced and, with increasing production, the eucalypt plantations have been expanded to over 300,000 ha (mostly since 1956) (15). The major species is *Eucalyptus globulus* and further expansion is planned with this and other species. It is interesting to note that the pulp producers own about one third of this eucalypt wood supply (15). In Spain, also, the industry relies on hardwood plantation material for pulpwood supplies and some 400,000 ha are planted with eucalypts, mainly *E. globulus* with some *E. camaldulensis*. About 150,000 ha is directly controlled by the major pulp producers, the remainder by public administrations and private owners (11).

The other area of particular interest in regard to hardwood pulpwood production is Brazil with a capacity to produce c. 1.2 million tonne eucalypt market pulp per year (13). Brazil's eucalypt plantations consisting mainly of *E. grandis* are now being extended with material producing an average annual increment of 70 m^3/ha in 7-year-old forest. Furthermore, these trees have higher basic density and produce a higher yield of pulp from a given weight of wood (16). The significance of this pulpwood production achievement can be gauged from the fact that 18 tonne/yr of bleached pulp can be made from only 1 ha of forest compared to only 8 tonnes just 10 years ago (16). By contrast, 6-year-old fertilised *E. globulus* grown in plantation trials in Victoria, as reported by Farrington *et al* (17), would produce 2.4 tonne/yr of bleached kraft pulp from 1 ha.

FUTURE RAW MATERIAL SUPPLIES FOR AUSTRALIAN INDUSTRY

Meadows and Saul (7) stated that essentially the pulp and paper industry seeks the greatest yield of usable fibre, optimum fibre properties for a given end use and the minimum processing cost in totality from the standing tree to the finished product in the hands of the ultimate consumer. Future pulpwood supply involves the economic balance between the normally lower cost of natural forest management and the improved yield and pulping properties from plantations having higher establishment and maintenance costs.

It is desirable to have both long fibre and short fibre pulpwood resources for our industry, perhaps in roughly equal amounts and provision of the former by plantation establishment has been achieved. However, upgrading of our eucalypt pulpwood resources through plantation establishment must be pursued with vigour. There is a need to establish a climate for intensive management of the indigenous eucalypt resources to provide good quality material for processing. With eucalypt pulps expected to become the predominant supply of short fibre in the world, as in the local scene, our resources must be competitive in quality and processing efficiency with other sources of eucalypt pulp (7).

These factors add up to a need for extensive plantation establishment, especially for hardwood pulpwood resources. It is probable that greater pressure will develop to convince industry that provision of raw material resources should become a company rather than a state responsibility. With the increasing interest in the multiple use of forests and resistance to clear-felling and current regeneration practices and especially because of the establishment of wilderness areas and the reduction in the area of production forest for environmental reasons, it may become essential for the pulp and paper industry to provide a greater proportion of their raw material requirements.

Emphasis must be given, however, to the production of fibre resources to suit the needs of the industry. It has often been the practice to select plantation species on the basis of silvicultural criteria with little attention being paid to the specific requirements of the pulp and paper industry (18). From the forestry point of view fast growth, tolerance to site quality, ready availability of seed supply and adaptability in respect to genetic improvement are necessary. However, for the pulp and paper industry consideration must be given to the chemical and morphological characteristics of the wood, the response to various pulping processes and the suitability of the pulp for various end uses. It is essential that once the silvicultural requirements have been met, actual pulping and papermaking tests are carried out on samples of potential pulpwood species before acceptance for pulpwood plantation establishment. Close liaison is therefore essential between silviculturalists, pulp and paper scientists and pulp and paper production personnel if the future raw material requirements for the industry are to be met.

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INCREASED YIELDS OF HIGH QUALITY VENEER AND SAWN TIMBER FROM CUTTINGS OF RADIATA PINE

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SUMMARY

A mill study was organised to sample material from a 36-year-old stand (600 spha) of cuttings and adjacent seedlings (600 spha) planted in the same year and from the same ultimate seed source as the cutting material. The cuttings were taken from 6-year-old seedlings (7 year old from seed) of good vigour, stem form and branching, planted in 1941.

Cuttings produced in total 106% more face-grade veneer sheets (grades A, B and C) than the seedlings. The overall yield in volume of veneer was 43% greater for the cuttings.

Sawn timber log volumes and recovery results show a 8.0% greater volume yield of final products for the cuttings compared with the seedlings.

Total volume of logs harvested and merchantable product produced from the sample shows the cuttings yielding more merchantable volume than the seedlings in each operation.

Results from this study, which used cuttings from trees selected at a low intensity, demonstrate that substantial gains in recovered volume and quality of timber product can be achieved by using cuttings rather than seedling stock.

INTRODUCTION

The objective of breeders of radiata pine (Pinus radiata D. Don) in Australia over the last 35 years has been to produce trees which, in a stand, will yield harvests of greater volume and higher quality timber.

Two main approaches have been recognised by tree breeders; propagation of stock for plantation forests by seed or by vegetative material. The idea of using rooted cuttings of radiata pine from selected young trees as a source of improved material for plantation forests was first suggested by Jacobs (1939) long before seed orchards were considered. Most of the breeding effort to increase yield and quality of plantation forests has been through the development of seed orchards. This has involved the selection at high intensity (1:10 000 or more) of individuals which have straight stems, fine branching and vigorous growth.

Plantations grown from seed orchard seed are only now reaching maturity and the full potential gain (quality and quantity) from early tree breeding has yet to be realised. Substantial gains in volume have been reported for early plantations grown from seed collected in seed orchards (Eldridge et al. 1977; Eldridge 1982; Gleed 1983; Pederick & Eldridge 1983) also the profitability of using seed orchard seed has been examined by Wright & Eldridge (1985).

During the period of developing strategies to increase gain through the use of seed orchards the idea of using mass propagated cuttings for plantation establishment was frequently raised (Fielding 1963, 1969(b); Thulin & Faulds 1968), but did not receive wide-spread acceptance because forest managers considered propagation by cuttings to be more expensive and less reliable than propagation by seed.

Interest in using cuttings for plantation forests however, was maintained on an experimental level and resulted in the planting of thousands of cuttings in trials since 1938. Many propagation techniques were tried with varying degrees of success. More recent research and development (Clarke & Slee 1984; Arnold & Gleed 1985; Eldridge & Owen in press,) now show propagation by cuttings to be a viable alternative to seed.

Between 1961 and 1971 a series of investigations was carried out to determine whether cuttings would differ greatly from seedlings in wood characteristics (Dadswell et al. 1961; Nicholls et al. 1971, 1974, 1976, 1977) or growth and form characteristics (Pawsey 1950, 1971; Fielding 1954, 1969(a), 1970; Libby et al. 1972; Brown 1974; Eldridge 1981).

Differences were found, some advantageous to cuttings, others disadvantageous. However, no investigations were carried out to determine whether trees from cuttings of radiata pine would produce significantly better quality and quantity of timber than seedlings.

This paper gives the results of a study in which trees of the same size and age from cuttings and from seedlings were processed through a sawmill and plymill to compare the quantity and quality of merchantable product.

MATERIALS AND METHOD

SOURCE OF CUTTINGS AND SEEDLINGS

The trees used in the study came from a 36-year-old stand of cuttings and an adjacent routine planting of seedlings both established in 1948 in Uriarra Forest 20 km east of Canberra. The cuttings were collected in 1947 from trees chosen at a very low selection intensity in a routine plantation planted in 1941 (7 years from seed). The genetic origin of both seedlots used was apparently identical as both were collected in 1939 by Kingsland of Nelson, New Zealand.

The selection in 1947 was based on "superior height growth and trunk straightness as well as favourable branching". The intensity of selection is difficult to estimate from exisiting records but was probably less than 1 in 200. There were originally 97 clones whose ramets were planted at 2.4 x 2.4 m. Thinnings at ages 20 and 31 had reduced both cuttings and seedlings to a stocking of approximately 600 spha.

SAMPLING AND HARVESTING

The cuttings were not planted in a replicated design which would have allowed precise comparison of growth of the cuttings and seedlings. Mean heights of the cuttings and seedlings were 34.0 m (s.e. $\pm$ 0.6 m) and 35.8 (s.e. $\pm$ 0.6 m) respectively when felled. This situation was similar to that at age 16.5 years (before thinning) when the mean height of the cuttings was 22.1 m (s.e. $\pm$ 0.4 m) and the seedlings 22.6 m (s.e. $\pm$ 0.3 m), indicating that over the last 20 years both cuttings and seedlings had grown at fairly similar rates.

Since the stocking rates were approximately the same and the sites were adjacent and, from growth rates of trees, reasonably uniform, it was decided to treat the combined material as a single stand and to take stratified samples of trees from the cuttings and the seedlings. Six classes (d.b.h.o.b.) were selected to cover the range of tree sizes. Each class had a 5 cm range. The lower and upper limits were 25 and 55 cm respectively. For each class 6 trees from cuttings and 6 trees from seedlings were chosen. Trees were allocated to diameter classes until each class was full. Selection entailed rejecting any trees which had:

- a broken top or clear indications of having had a broken top
- a fork below 1/4 of the trees' height
- a series of bends or kinks which caused the stem straightness to deviate more than 1/2 the diameter of the stem at any 2.4 m length. A tree with a single distinct bend resulting in a change of axis, was acceptable
- benefited in growth from being on the perimeter of the stand.

After felling, each tree was assessed first for log lengths suitable for peeling then for sawlogs. Logs for peeling (usually dual billets each of 2.65 m) were graded on the minimum requirement of the ply mill: viz. billets were to be straight with a minimum small-end diameter under bark of 30 cm, a pith which had an eccentricity of less than 5 cm and no visible branches with diameters greater than 5 cm. The remainder of each tree was assessed for sawlog lengths down to 15 cm small-end diameter under bark. The optimum sawlog length was 4.85 m and the minimum length was 2.45 m. Logs could be cut to any length above 2.45 m in increments of 0.3 m. Criteria for rejecting a log were minimal viz. severe malformation, forks or a stem fractured from felling.

The billets for peeling were removed from the plantation first and taken to the ply mill for coding and processing. The sawlogs were then gathered and taken to a different mill for coding and processing.

MILL PROCESSING

(a) Peeler billets: Rotary peeling was carried out by APM Forests Pty Ltd mill at Hume, ACT. The billets were processed in a routine manner to 2.5 mm thick continuous veneer strips which were dried and guillotined into 1270 x 2550 mm sheets and stacked according to the mill's grading, which does not segretate the 3 grades of face ply. Sheets of veneer produced were then graded to Australian Standards Association (ASA) standards for data compilation. ASA grades (A B C & D) are based on knot size and frequency on each sheet. Grades A B & C are facing quality material; grade D is used for facing on formwork and for interply veneers. Any material in pieces less than a whole sheet are also used as interply (Grade X). Throughout the whole study each billet was uniquely identified with a plastic numbered tag embedded in the butt and the veneer from each billet was recorded separately.

(b) Sawlogs: The sawing operation was carried out by Smith Bros Pty Ltd mill at Hume, ACT. Sawlogs from each tree were uniquely colour coded on their ends and the whole consignment of cuttings and seedling logs was processed as a mixed batch in a routine operation. Sizes sawn were aimed at recovering the final (kiln dried and dressed) products of 90 x 35 mm, and 70 x 35 mm structural pieces, 135 x 25 and 90 x 19 mm boards and furniture pieces from the smaller sizes. Pieces shorter than 2.4 m were recovered and reprocessed for specific orders but these are not recorded in the recovered volumes.

All material was kiln dried to 13% moisture content, dressed and docked to standard mechantable lengths. The volume lost in processing, trimming and planing was not recorded. Except for the boards, all pieces of timber were stress graded on a stress grading machine programmed with recently upgraded standards (requiring increased stiffness in each grade) prior to the final assessment of recovery and packaging for sale.

RESULTS

PRODUCT RECOVERY

The total volumes harvested and recovered by product are tabulated to give an overview (Table 1). The veneer and sawn timber recovery results are tabulated separately (Tables 2 & 3 respectively) to show the actual total volume of merchantable product recovered from each of the six tree diameter classes in the samples. Recovery percentages are the total volume of merchantable product recovered expressed as a percentage of the total log volume harvested for each product i.e. veneer or sawn timber. The intention is to demonstrate the volume of merchantable product, by grade, that can be expected from trees in a given diameter group. Differences between cuttings and seedlings mentioned in the text are expressed as a percentage of the seedling yield.

VENEER RECOVERY

The total volume of peeler billets harvested and the veneer volume recovered (sum of volumes in each diameter class) was much greater for the cuttings than the seedlings 11.1 m^3 cf. 7.8 m^3 (Table 1). More logs were selected in the cuttings for processing as peelers across nearly all diameter classes, and the number of sheets of veneer produced under each grade in each diameter class reflects the higher quality of billet produced by the cuttings in comparison with the seedlings (Table 2). The expected trend of increased recoveries from larger diameter billets is apparent. Cuttings produced in total 106% more face grade veneer sheets (A B & C) than the seedlings and 37% fewer D grade sheets (Table 2). The overall yield in volume of trimmed sheets of ply from the veneer billets was 43% greater for the cuttings.

SAWN TIMBER RECOVERY

Sawn timber recovery results (Table 3) show only an 8% greater volume yield of merchantable products for the cuttings compared with the seedlings. This result was not altogether surprising considering that more peeler billets were taken from the trees of the cuttings than the seedlings. The effect of the loss of the peeler logs (from the cuttings) is seen in the smaller number of logs available for sawing in the 35-45 cm range.

The measure used for product quality was stress grading. The results (Table 3) show the cuttings producing marginally less high quality material (F11 & F8) and structural grade timber (F11, F8 & F5) than the seedlings. Down-grade from F5 to F4 is generally due to weakness from excessive juvenile wood or large knots. The defective portions are removed in many mills and the shorter pieces rejoined to produce finger-jointed studs of 2.4 m. This improves overall mill recovery. This procedure was not carried out by the mill sawing the timber, but results indicate the percentage recovery had this been done. Reject grade marking on any piece of timber downgrades the whole length of timber which then, if possible, can be cut and finger jointed to a 2.4 m stud or, if possible, cut to the nearest 0.3 m multiple of length greater than 2.4 m.

When comparing the total volume of merchantable product produced (veneer plus sawn) from the sample (Table 1), the cuttings yielded more product in every tree diameter class than the seedlings, particularly in the 35-45 cm range.

DISCUSSION

Both selection and physiological age would have contributed to the gain in the merchantable volume and quality of timber recovered from the cuttings, but it is not possible to exactly apportion the gain between the two sources. In my opinion the increased yield in the cuttings was due mainly to the physiological age rather than the genetic selection, which was not intense. Considering that the total volume of logs harvested from each sample was similar (59 m^3 for the cuttings; 57 m^3 for the seedlings) and that the mean tree heights were not markedly different (although slightly favouring the seedlings), the larger volume of merchantable material that the cuttings yielded compared with the seedlings could only be attributed to the morphological features associated with the physiologically older cuttings: much thinner bark, more uniform stem cross-section, smaller, more horizontal branches and less stem taper on the lower, more valuable part of the stem (Jacobs 1939; Fielding 1963, 1970; Nicholls 1971; Pawsey 1971).

Detailed morphological comparisons between trees aged from 4½ - 16½ years derived from seedlings and cuttings and the heritabilities of wood characteristics have been reported previously (Dadswell et al. 1961(a) Fielding 1969; Nicholls & Brown 1971). All agreed that there are real differences between cuttings and seedlings. Most are basically effects of cyclophysis - a carryover into the rooted cutting of the individual characters associated with the developmental age of the propagated material. Most differences are of benefit although some, such as a tendency to a decrease in wood density, and a slower growth rate associated with increasing age of cutting, are not desirable.

The low rate of taper of the cuttings (Pawsey 1971) is undoubtedly a major factor in the higher yield of ply sheets in the smaller diameter classes (Table 2). Thinnings in the 35-45 cm range which could be peeled would provide a greater economic return than if processed as sawlogs. This factor could have a pronounced influence on silvicultural management. It is not known why the cuttings produced slightly more F4 and R grade material than the seedlings (Table 3). The larger volume of timber from the seedlings processed as "odd size ungraded" is more than likely due to the greater taper of the seedlings which would result in flitches of recoverable size being cut but shorter than 2.4 m.

The main constraints to the wider use of cuttings in the past appear to have been higher nursery costs and some technical difficulties in successfully raising more than a few thousand cuttings each year. Successful techniques for raising several hundred thousand cuttings of radiata pine per year have been developed (Clarke & Slee 1984; Owen 1986) and proven in the field (Arnold & Gleed 1985). The latter have shown that the higher initial costs of producing larger numbers of rooted cuttings from 2-4 year old seedlings, compared to seedlings, are more than offset by age 7 if the total silvicultural and establishment costs are discounted to year zero (interest 6%). Substantial savings in pruning costs have also been demonstrated (Gleed 1986, unpublished).

When the more obvious advantage of using cuttings are considered, e.g. uniformity of stock in the field, straightness, thinner bark, smaller branch size, reduced plantation costs, lower initial stocking rates and reduced stem taper, then the potential to produce

more quality products per unit area is greatly enhanced. These advantages have long been recognised and substantiated with results from various studies (Fielding 1964 & 1970; Libby et al. 1972; Gleed 1983), however, examination of theory and practice on the benefits of clonal foresty has only been recently addressed. (Libby 1980, 1983; Libby & Rauter 1984).

CONCLUSION

Results from this study clearly show that by using cuttings a greater proportion of the tree will yield a high value product (veneer) and that the total product recovery from logs, both sawn and veneer, will be greater and of higher quality. The cuttings yielded (as merchantable product) 43% more veneer and 18% more sawn timber from almost identical log volumes harvested.

These substantial gains in production were obtained from improved log quality and not from the greater total standing volumes of wood as recently demonstrated from use of seed orchard seed. It would be expected that considerable additional improvement (in genetic gain) would be obtained by effective clonal selection of individuals within selectively bred families, followed by vegetative propagation (Matheson and Lindgren 1986).

On the basis of the results of this study, the use of cuttings particularly from seedlings up to seven years old, would almost certainly guarantee a higher quality product with greater financial return to the grower than would trees grown from seedlings.

ACKNOWLEDGEMENTS

In any complicated project in which there are many processes, many people, and often organisations are involved. Those who made a significant contribution are warmly acknowledged. To the many others who assisted, many thanks. In particular, I wish to mention Mr L. Sar and colleagues of the Bureau of Agricultural Economics who were my main supporters; Mr K. Groves and Mr A. McNaught, Australian National University; Mr J. Broom and Mr J. Swan of Smith Brothers Sawmill (who assisted in the sawn timber operation); Mr T. Connolly and Mr M. Thorburn of APM's mill at Hume, ACT (who assisted in the log peeling and stress grading operation); Mr A. Fearnside and other officers of the ACT Forests, Parks and Conservation Branch, and Dr K.G. Eldridge and other colleagues in the Genetics Program, Division of Forest Research CSIRO.

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TABLE I.

The volumes harvested and merchantable volumes recovered from the sample of 36 trees from each origin.

Origin of trees	Volume harvested (m^3)		Merchantable product recovered (m^3)	
	Sawlog	Peeler billets	Sawn timber	Veneer
Cuttings	34.9	24.3	13.3	11.1
Difference %*	**-10.8**	**+34.3**	**+8.1**	**+42.8**
Seedlings	38.9	18.1	12.3	7.8

* The difference between cuttings and seedlings is expressed as a percentage of the seedlings. The (+)ve, (-)ve signs indicate advantage or disadvantage to the cuttings.

TABLE 2.
Veneer Recovery

Diameter class over bark (cm)	No. of 2.6m billets	Billet volume harvested (m^3)	Volume recovered in sheets 2400 x 1200mm (m^3)	No. of sheets of veeneer Grade (2400x1200x2.5mm)						Recovery (%)
				Tot.	A	B	C	D	++	
FROM TREES FROM CUTTINGS										
30-34.9	4	0.6*	0.16	21	1	5	12	-	3	26
35-39.9	18	3.86	1.76	245	10	6	167	43	19	45
40-44.9	28	6.88+	2.87	399	17	2	298	50	32	41
45-49.9	20	6.21	2.95	410	9	17	298	45	41	47
50-54.9	18	6.77	3.4	471	8	27	310	109	28	50
Total	90	24.32	11.14	1547	45	47	1073	247	120	45
Total sheets of face grade ply = 1165										
FROM TREES FROM SEEDLINGS										
30-34.9	-	-	-	-	-	-	-	-	-	-
35-39.9	4	0.92	0.34	47	-	-	25	18	4	40
40-44.9	13	3.25	1.33	184	-	1	91	75	17	40
45-49.9	17	5.42	2.43	337	3	4	152	136	42	44
50-54.9	22	8.56	3.70	514	8	8	274	165	59	43
Total	54	18.15	7.80	1082	11	13	542	394	122	43
Total sheets of face grade ply = 556										

Difference in volume of product recovered = 3.34 m^3 = 42.8% more for cuttings

Difference in no. sheets of face grade veneer = 599 sheets = 106% more for cuttings

* 0.14 m^3 not processed - log lost

\+ 0.47 m^3 not processed - log lost

++ adjusted for piece sizes to full sheet equivalents

TABLE 3.

Sawn Timber Recovery

Diameter class (over bark) (cm)	Log volume harvested (m^3)	Vol. merch product recovered (m^3)	Merchantable volume recovered by grade (%)						Recovery (%)
			F11	F8	F5	F4	other	reject	
FROM TREES FROM CUTTINGS									
25-29.9	3.29	1.61	-	19.9	43.6	10.7	25.1	0.7	48.9
30-34.9	5.08	1.92	5.2	23.9	38.2	11.7	19.8	1.2	37.8
35-39.9	4.82	1.58	2.3	25.8	42.2	7.4	20.3	2.0	32.8
40-44.9	3.70	1.44	-	17.1	44.6	18.3	17.8	2.2	38.9
45-49.9	6.99	2.70	1.90	23.0	41.4	20.0	12.5	1.2	38.6
50-54.9	10.79	4.05	2.3	24.7	45.2	15.0	11.1	1.7	37.5
Total	34.67	13.30	*2.1	*23.0	*42.7	*14.5	*16.2	*1.5	*38.4
FROM TREES FROM SEEDLINGS									
25-29.9	3.14	1.62	2.1	8.2	56.4	10.7	22.5	-	51.6
30-34.9	5.76	1.79	5.0	24.3	31.0	10.6	27.8	1.3	31.1
35-39.9	6.60	2.25	2.7	28.0	36.9	13.0	16.8	2.6	34.1
40-44.9	7.65	1.66	2.7	27.1	37.7	10.5	20.8	1.2	21.7
45-49.9	7.94	2.77	3.5	29.0	39.8	12.1	13.2	2.4	34.9
50-54.9	7.83	2.22	1.4	21.3	50.4	12.0	13.1	1.8	28.4
Total	38.92	12.31	*2.9	*23.8	*41.8	*11.6	*18.2	*1.7	*31.6

Difference in volume of product recovered = 0.99 m^3 = 8% more for cuttings

* These values are % of total - not mean

THE YOUNG EUCALYPT PROGRAM
- A PROGRESS REPORT 1985/86

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ABSTRACT

This paper reports on the progress of a research program which started in June 1985. The program's objective is to provide the research results necessary for the management of the eucalypt regrowth forests for commercial wood production. So far, its major interest has centered on the question of whether we can profitably thin the Tasmanian and Victorian regrowth forests. Personnel in the program come from CSIRO, the state governments of Victoria and Tasmania and the forest industries of those states. The program is managed by a Board from industry, State Government and CSIRO.

INTRODUCTION

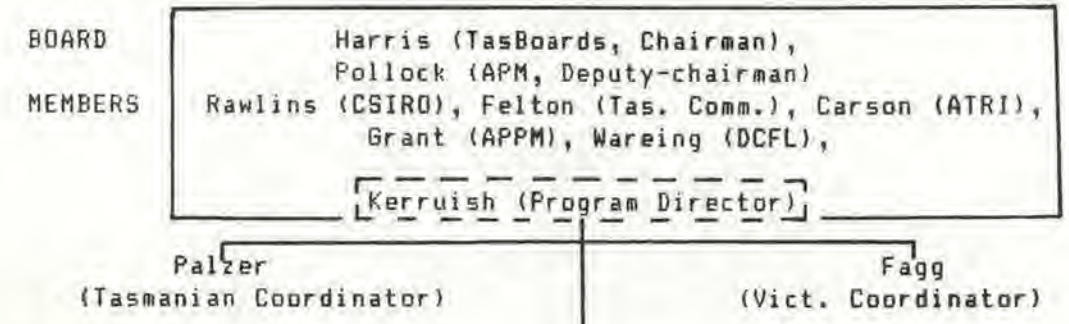
Research into the more intensive management of some naturally regenerated eucalypt regrowth stands has been recently stimulated by a desire to increase wood supplies close to processing centres, a desire to set aside forested land for conservation and recreation and some new ideas in forest technology. Rawlins, Kerruish and Incoll (1985) reviewed available data on Victorian *Eucalyptus regnans* regrowth and concluded that further research was warranted. A task force, convened by the Tasmanian Forestry Commission in 1985, recommended in a working paper, a program of intensive eucalypt production. The research program presented here grew from these two reports.

RESEARCH PROGRAM STRUCTURE AND PEOPLE

The chart overleaf gives the names and positions of people in the research program and the organisation of the program under research project headings.

Some projects, particularly sawing and thinning, have project groups composed of managers and researchers directly involved in the work. They are listed below the project leader with their professional affiliation. Thus we have a group of about 30 professionals with a common focus in research for managing the regrowth resource.

ORGANISATION CHART OF THE YOUNG EUCALYPT PROGRAM



PROJECTS & LEADERS

Growth	Damage	Debarking	Thinning	Pulping	Sawing	Res.& Mkts
West	Kile	Wingate-Hill	McCormack	Phillips	Waugh	Gartside

PROJECT GROUPS

Wells (CSIRO)	Old (CSIRO)	MacArthur (CSIRO)	Raymond (APM)	Logan (CSIRO)	McNair (FIAT)	Smith (DCFL)
Incoll (DCFL)			Henderson (TPFH)	Clark (CSIRO)	Shafner (Tas TPB)	
			Trail (Tas Comm)		Lulmley (Tas TPB)	
			Manson (For. Res.)		Jessop (For Comm)	
			Roberts (CSIRO)		Adams (TasBoard)	
			Beardsal (CSIRO)		Roza (CSIRO)	
			Simpson (ANM)		Hazlett (NZFRI)	

ACTIVITIES IN 1985/6

Stand Response to Thinning

Work in this first year has involved developing the theoretical model, planning experiments and securing funding through a Reserve Bank grant (Rural Credits Development Fund). The experiments have been designed to explain thinning response in terms of the increased light available to the trees remaining after thinning. Key variables to be measured are the leaf and branch development after a variety of thinning intensities in a young stand (5 to 15 years) in Victoria and Tasmania.

Damage Done to a Stand During Thinning

This work has been confined to planning and securing funding (Australian Special Rural Research Grant). The project will compare the development of discoloration and decay in stands thinned at an early age and in unthinned stands. The principle interest is in gauging the level of damage that occurs when new machinery designed specifically for thinning is used.

Thinning Techniques

Five studies were implemented to provide data on the productivity and costs of selected thinning technologies in a number of young stands, and how these costs may be influenced by tree size and terrain. These include:

Spacing Young Stands with Husqvarna Clearing Saws: A Swedish consultant was hired to train an experimental crew in the use of clearing saws for non-commercially thinning 3 to 9-year-old stands of *E. regnans*. A series of production studies were completed in Tasmania's Geeveston district; results are being analysed and reports will be available in the final quarter of 1986.

Spacing Young Stands with Herbicides: Two injection techniques were studied to establish productivity and costs of reducing the stocking of *E. regnans* in a series of sites near Toolangi, in Victoria. Follow-up work on the effectiveness of the treatments is yet to be completed. Further work on different methods of application are planned

Thinning with the OSA Feller-Forwarder: This 8 wheeled forwarder with a long reach crane and felling head, was used to thin a 19 and 24-year-old stands of *E. regnans*. The terrain going capacity of the 8 wheel drive chassis and the low levels of damage to remaining trees was impressive; it could move effectively, though slowly, over logs of 70-100 cm in diameter. Alternative felling, bunching and forwarding combinations were explored. A report on this study is scheduled for the third quarter of 1986.

Thinning with a Timbco Feller-Buncher: This tracked machine has a levelling mechanism and a boom designed to operate in confined spaces and in a range of terrain conditions. A three week study near Geeveston has enabled data on its productivity in 19-year-old *E. regnans* stands to be obtained. The operator who worked the machine for these trials had limited experience, however, and further studies of this machine are required.

Forest Classification: The classification of regrowth forest with respect to stand and terrain is required for operational planning and for the wider application of research results. A project group involving the two forest services has met and established a draft classification which is being evaluated. A post-graduate scholarship to develop the use of large scale aerial photography for planning thinning in regrowth forests has been provided by the Commonwealth Department of Primary Industry.

Debarking

A preliminary "desktop" analysis of the costs of debarking options has been prepared and is now being reviewed. It favours debarking in the forest rather than at a mill because of expenses not incurred in bark transport, bark disposal at the mill and replacing nutrients taken from the forest in bark. Experimental work is beginning on debarking using compression heads.

Sawing and Drying

An initial sawing/drying trial began in May 1986 when 18 small logs from a 55-year-old stand were back-sawn into 50 cm boards using either a line bar carriage or log edger. The timber from these logs are now being dried using five alternative practices. These are: plastic wrapped air dried; uncoated air dried; pre-dry part air dry; dehumidify from green; pre-dry from green. After reconditioning and final drying all timber will be graded. Distortion, shrinkage collapse, face and internal checking, appearance and clear length availability will be recorded. The timber will be made up into a variety of finished products to assess potential and provide samples of products.

A second trial is being planned based on logs of different ages from a variety of sites. The sawing pattern will be designed by industry to maximize the recovery of products. The logs will be back sawn or quarter sawn into 25 cm or 38 cm boards as appropriate and will be dried using a variety of techniques.

Pulping

The initial project is aimed at evaluating the pulp and paper making potential of wood from Tasmanian *E. regnans* and *E. obliqua* at ages from 10-years-old to greater than 110-years-old at 10 year intervals.

Experimental studies producing bleached Kraft pulps have been completed on *E. regnans* and the experimental results on *E. obliqua* have been completed except for age classes less than 40 years.

Pulp and paper making properties improve from "below age 10" to "age 20 to 30", remain fairly constant and then deteriorate in the old growth sample of over 110 years of age. As well as the completion of the *E. obliqua* studies, an attempt is being made to assign dollar values to the pulpwood of different ages. It is interesting that the ages when pulp values are improving most rapidly are the ages when thinning is of interest.

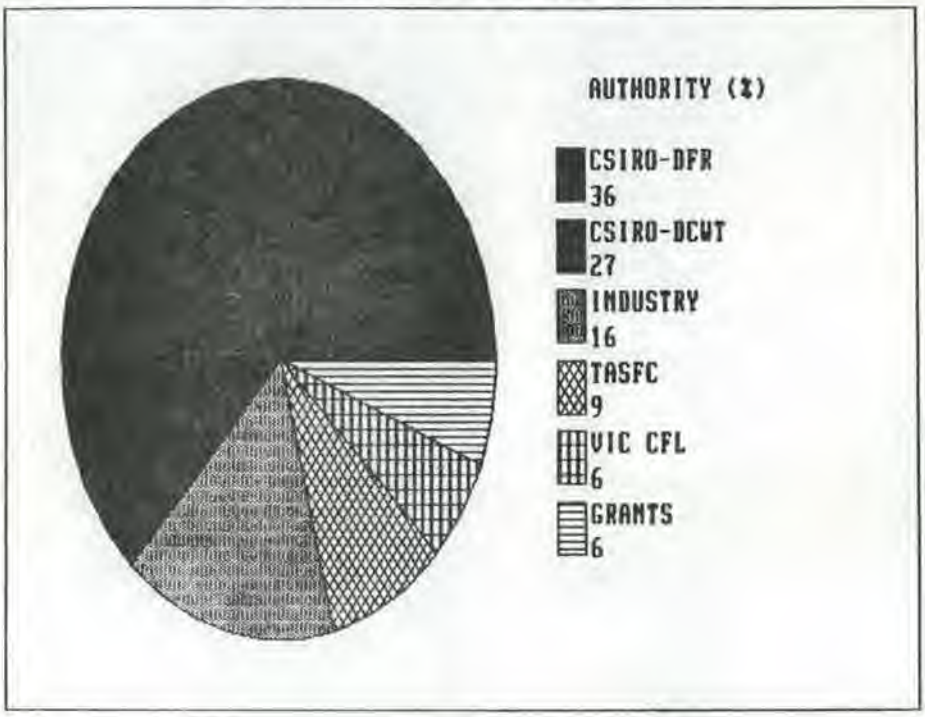
Resources and Markets

This project is intended to review existing information on the extent and nature of the resource and the prospects for marketing the products which can be made from the regrowth resource. It is intended to provide "in-house" expertise on these aspects of the commercial environment within which the experimental projects take place. This work has just started.

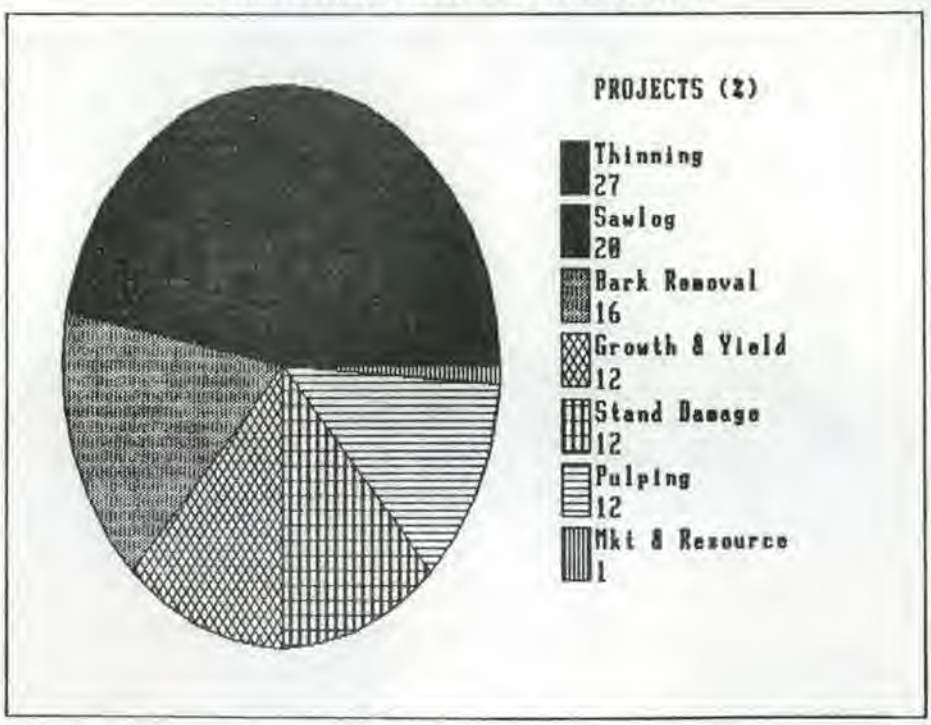
SOURCES AND USES OF FUNDS

The pie chart below illustrates sources and uses about which we are reasonable confident at this time. The target funding for the whole program should be CSIRO 60%, State forest services 20%, and industry 20%.

YOUNG EUCALYPT SOURCES OF FUND-13/10/86



YOUNG EUCALYPT USES OF FUNDS-13/10/86



Total expenditure over the four year period is expected to be in the vicinity of 2.9 million dollars.

DEVELOPING INTERACTIONS IN THE RESEARCH PROGRAM

The research program has been operating in most of its projects for about one year. While the program has been beginning, individual projects have used its integrated nature in a variety of ways but real interaction has yet to take place. A next stage in program management could be aimed at exploring/encouraging the interactions between disciplines and projects which have come up so far. Amongst these are:

1) Thinning for pulpwood: we should by the end of 1986 have some data to set thinning costs against pulpwood $ values where thinning costs vary with stem diameter and pulpwood costs vary with age.

2) Pulping and bark removal: pulping values with differing degrees of bark removed and the costs of removing different proportions of the bark.

3) Branch development after thinning and knots as a sawing problem. This is appearing as a key determininant of silvicultural practice.

4) Modelling response to thinning based on some tree-physiology considerations should bring together tree physiologists and management modellers.

5) We are keen to establish the link between stand damage and the economics of damage.

SUMMARY

The Young Eucalypt Research program is a group of researchers with a variety of skills from a variety of organisations with a common goal - to provide research results for the improved management of the Victorian and Tasmanian regrowth eucalypt forests. The researchers are collaborating in a unusual organisational structure in forestry/forest products research in Australia. The program has been going for one year and most projects have begun experimental work. The next two years should see much more activity and will be a real test of the gains which might be made from research across disciplines and organisations.

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FIBRE AND CHEMICALS FROM WOOD

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ABSTRACT

Trends in the world production from wood of fibre, polymers and chemicals are reviewed. Bleached kraft pulp as a proportion of total world production of papermaking pulp will probably increase, whereas that of mechanical pulp will remain steady. There has been a shift of chemical cellulose production towards Eastern Europe and less developed countries and away from Western Europe and North America, although the total production has not changed. Other opportunities for forest-derived chemical products include high value carbon, bark tannins and eucalypt oils.

INTRODUCTION

At the 21st Forest Products Research Conference, the Australian usage of wood fibres was reviewed, and the emerging technology in wood pulping was discussed (1). In addition, the various ways of obtaining chemicals from wood and from by-products of wood processing were outlined. In this paper, trends in world production and usage of wood fibre, chemical cellulose, carbon from wood, and chemicals, are presented.

DISCUSSION

PULP AND PAPER DEVELOPMENTS

In spite of wide production fluctuations, the world-wide cumulative capacity increase from new paper machines has been steady for the period 1970-1985 (2). The structure of the paper industry has continued to change, with fewer paper machines but with higher overall capacity. The comparison of paper machine capacity by grade shows that in the period 1980-1985, tissue, printing and writing, linerboard and newsprint capacity have increased their shares of total capacity, while corrugating medium, cartonboards and all other grades have lost ground.

Forecasts indicate that the world paper demand growth will continue, but at a lower rate than in the past (2). The reasons for this are lower economic growth prospects in the industrialized countries leading to lower demand for paper, and the restricted possibilities of some newly industrialized and developing countries to increase domestic pulp and paper supply in spite of economic growth. Changes in demand growth pattern for different grades will arise in response to changes in the nature of economic growth, i.e. a switch from growth of industrial production to growth of services and bureaucracy.

The use of recycled fibre as a proportion of fibre consumption has increased in practically all regions except North America (2). There has been an increase in the share of bleached chemical pulps, and a decrease in unbleached pulps, and this trend is expected to continue. The proportion of mechanical pulp has decreased in relation to all virgin fibre, from 25% in 1965 to 21% in 1985. Because of the emergence of chemithermomechanical pulp (CTMP) and other developments in mechanical pulping, mechanical pulp is expected to hold its relative share in fibre furnishes (2). In certain regions where the wood is suitable for CTMP and other mechanical pulps and the power prices are low, the share of mechanical pulp could even increase.

The nonwoven segment of the speciality pulp market is an area which has recently undergone a large expansion and this trend is expected to continue (3). The main application is absorbent products for medical use, particularly for adult incontinency products. "Fluff" pulps for absorbent products are usually bleached chemical pulps, although small amounts of CTMP are used (4).

CHEMICAL CELLULOSE

An examination of the worldwide cellulosics market reveals an apparent maturity and stability, as there has been neither growth nor decline of major significance in recent times (5). Even though it is only a relatively small part of the total pulp market, the chemical cellulose business is quite large, with about 5.5 Mt/yr capacity in place worldwide. Although new chemical cellulose production and cellulose

conversion capacity will be installed, total world capacity will change little in the near future. The expected growth in some regions is likely to be offset by plant closures in other areas. Most of the projected capacity increase will be accounted for in Eastern Europe, Africa and Asia.

Over 75% of the consumption of chemical cellulose is in the production of man-made cellulosic fibres, both viscose rayon and acetate fibres, and most of the remaining consumption is in other chemical conversion applications. These include viscose and acetate film, cellulose ethers such as carboxymethyl cellulose, propellants, lacquers and coatings, plastics, sponges and sausage casings. None of these categories is expected to show significant growth in the next decade, but regional growth will take place in certain product areas.

At a time when the total world fibre production is increasing, the production of man-made cellulosic fibres, with the exception of cellulose acetate cigarette tow, has begun to decline (6). The most striking trend is the shift in production of rayon staple, the largest part of the cellulosic man-made fibre industry, from North America, Western Europe and Japan to Eastern Europe and the rest of the world. This is because there has been a shift in production, particularly of commodity textiles, to less developed countries. The second reason is the fall in consumption of rayon caused by competition from synthetic fibres. The viscose rayon industry has now been in place for over 80 years, and current efforts to develop new technology for cellulose regeneration could herald a resurgence of interest in man-made cellulosics.

CHEMICALS FROM WOOD

From marker prices of around US$28/barrel in late 1985, the price of crude petroleum decreased to the $12-15/barrel range by mid-1986 (7). This has had the effect of increasing chemical output because of economic demand increases and because the prices of synthetic materials made from chemicals fall relative to the prices of natural materials. This means that while the low petroleum prices are operative, the economics of using wood, or even natural gas, as a competitive feedstock to petroleum become more difficult.

As a source of chemical products, wood may either be separated into its constituent polymers and extractives or degraded to low molecular weight chemicals. Developments in chemical cellulose have already been discussed, and lignins are important as by-products of wood pulping, particularly as lignosulphonates. Tall oil and turpentine extractives are also important by-products of wood pulping. Wood may be degraded to low molecular weight chemicals by pyrolysis, gasification, liquefaction or hydrolysis. Of these processes, the most important in current practice is pyrolysis to give a carbon residue.

Charcoal is a basic fuel in emerging countries, whereas in developed countries it is used in the form of carbon as an industrial raw material. The leading producing country is Brazil, which produces 5 Mt/yr, while Indonesia, India and Central Africa each produce about 1.6 Mt/yr (8). Australian imports of activated carbon amount to *ca.* 0.3 Mt/yr, and carbon from wood may be able to satisfy part of this market.

As by-products of forestry operations, bark and foliage are potential sources of chemicals. *P. radiata* bark is currently used in horticultural applications or as a boiler fuel, and its potential as a source of tannin extracts for adhesives awaits successful research and development. Eucalypt foliage is a valuable source of oils, and the market for these oils has been satisfied by production from plantation eucalypts overseas. However, there have been recent commercial developments in which oils are produced from eucalypts growing in Victoria.

In general, the best prospects for chemicals from wood are seen as those in which advantage is taken of the chemical structures which are inherent in the wood components, rather than as a source of low molecular weight products by degradation of the wood.

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Waste paper → 32% of consumption in Aust.
Bleached chemical wf pulp now $1000/ton !
APPCOR are putting in more capacity, at Maryvale (1000 tons/day)
220 → 300 000 tons local prodn
stimulated by world demand for fine papers.

STRUCTURE/ACTIVITY RELATIONSHIPS IN CARBON FROM WOOD

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ABSTRACT

The nature of adsorption by carbon is discussed and a number of factors are listed which could be expected to influence the extent of carbon sorptivity. For the highly desirable characteristic of large surface area, it is proposed that for all but the smallest particles, carbon porosity is of greater importance than particle size *per se*. The thermal effects of high temperatures during carbonisation and activation are thought to have more physical than chemical significance.

Due to the chemical heterogeneity of the woody substance, thermal erosion may take place preferentially from the lumina walls and proceed through the cell wall substance to the middle lamella, the region of highest lignin concentration.

Of significance to the development of carbon surface area is the apparent "fusion" effect, noted at carbonising temperatures.

Wood carbon is indicated to have pores of shapes similar to those of the wood fiber precursors, with sizes of *ca* 100 Nm and 10,000 Nm predominating.

INTRODUCTION

The use of charcoal for purposes other than as a fuel or in metallurgy, dates back to ancient times, being mentioned as a medicinal aid in an Egyptian writing of *ca* 1550 BC. Wood chars were used to treat various medical conditions in the time of Hippocrates and Kehl described the use of char in the late eighteenth century for the removal of odours emanating from wounds.

The most definitive recognition of the adsorptive powers of carbon was attributed to Scheele (1) in 1773 when he described experiments with gases. In 1785, Lowitz (2) noted the decolorizing effects of charcoal on

solutions, and in the early years of the nineteenth century, wood char was employed as a purifying agent in the cane and beet sugar industries. Developments in the use of carbon adsorbents were sporadic over the next hundred years and it was in 1900 that modern commercial active carbons were described in a patent by Ostrejko (3). Many methods for the preparation of active carbons were disclosed during this time, but commercial scale development was retarded due to the non-existence of appropriate methods and structural materials necessary to support the process technology.

However, the real thrust for the rapid development of an active carbon industry was provided by the dramatic events of World War I, when in 1915, armies were forced to seek protection against chlorine gas warfare. From those early days of gas masks using activated carbon, the post-war years saw the development of new source materials and new processing equipment.

Activated carbon technology is now involved in several major markets including industrial and municipal purification of water and air, sugar treatment, dry cleaning, organic solvent recovery and gas adsorption.

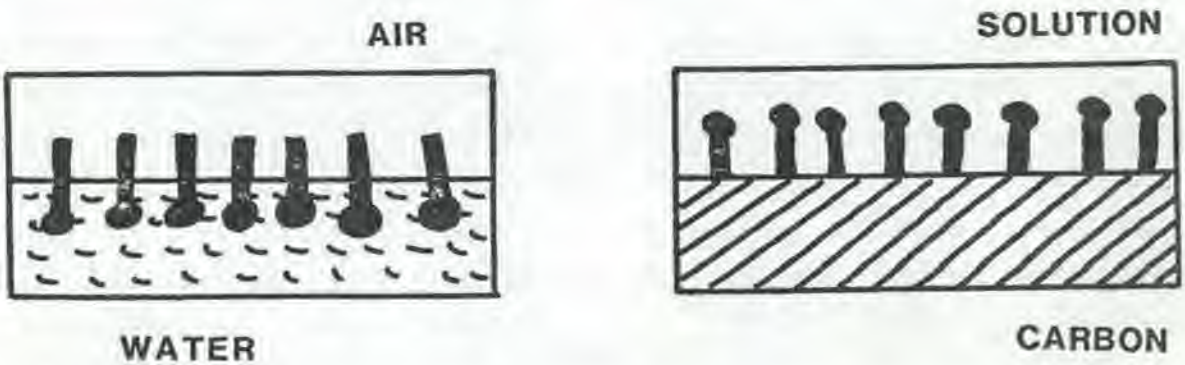
Today, many different activated carbons exist, with properties influenced by both the nature of the starting material and the conditions of manufacture. Given an adequate understanding of the nature of a particular sorptive process, modern carbons can be produced to exhibit a high degree of sorption specificity.

This paper will discuss something of the nature of sorption and active carbon, the production of carbon from wood, and the particular properties of wood which may be important in the production of a versatile range of active carbons.

CARBON AS AN ADSORBER

Adsorption is viewed as a surface phenomenon and it is essential to understand the full significance of that concept. A surface is a boundary where the mass of one substance ends and the mass of another substance begins. For example, where a solid is immersed in a liquid,

the surface of the solid faces a corresponding surface of the liquid. The region enclosed by these two surfaces is the interface. It is within this critical interfacial region where adsorption takes place. A most important consequence of this boundary condition is that forces of attraction which may act to draw molecules towards the interface can be assisted or opposed by forces on the other side of the interface. Thus the very nature of sorption and desorption, the extent and tenacity with which sorbed species adhere to the surface and the orientation of incoming molecules on the surface are all influenced by the conditions prevailing at the interface. Some of these conditions are contributed by the receiving adsorbent (carbon) and others by the donating medium (liquid, air).



Factors which may act at the interface to influence the ability of carbon to adsorb include the following:-

Contributions from the media

- solubilizing power of the solvent for the solute
- effect of solvent on orientation at the interface
- competition for the interface in the presence of multiple solutes
- interaction of multiple solutes
- association and ionization
- co-adsorption (synergistic effects have been reported)
- size and shape of molecules in the system
- concentration of constituents

Contributions from the carbon

- attraction of carbon for incoming species and components of the media
- carbon surface area
- shape and size distribution of porous cavities in the carbon.

We can now focus attention on the factors listed above which relate to the carbonaceous adsorbent and which may be modified by choice of carbon source and conditions of manufacture.

Attraction of Carbon for Adsorbates

A substance may adhere to a carbon surface by a process of physical adsorption or chemical adsorption (chemisorption). In the former case, the incoming molecule retains its chemical integrity and individuality, and in general experiences forces of adhesion similar to those operating between gas molecules in their ground state, e.g. dispersion forces, repulsive forces, polarization forces and electrostatic forces between permanent electric moments and the electric field of the sorbent surface. Physical adsorption is usually reversible with relative ease.

In the latter case, the incoming species undergoes an electronic interaction with sorbent surface molecules whereby the electronic arrangements of both species are greatly perturbed, resulting in the formation of legitimate chemical bonds, and thus becomes a quasi-chemical constituent of the adsorbent, in this case, of the carbon. Substances which are truly chemisorbed will require much more energy for their desorption, if in fact they can be recovered in their original form. For example, nitrogen physically adsorbed to carbon is easily desorbed by the application of moderate heat at reduced pressure (de-gassing), whereas oxygen chemisorbed to carbon is usually removed only as a carbon oxide.

Sorption (or "active") sites may be introduced on wood carbon by oxidation either by air, steam or carbon oxides (CO_2, CO) at high temperatures (500°C plus), or by treatment with metal salts (e.g. $ZnCl_2$) at more moderate temperatures. It is thought (4) that the active sites may be the result of the formation of phenolic or lactonic groups on the carbon surface.

Surface Area

One of the most important properties of an adsorbent is its capacity, i.e. the extent to which it may be loaded with an adsorbate. Since adsorption has been described as a surface phenomenon, it is of obvious importance that the adsorbing solid presents a large surface area to the incoming species.

Surface Area and Particle Size

In general, for a given weight of a non-porous adsorbent, the surface area will increase as the particle size decreases. This effect is shown in Figure 1, together with the influence of particle shape on surface area.

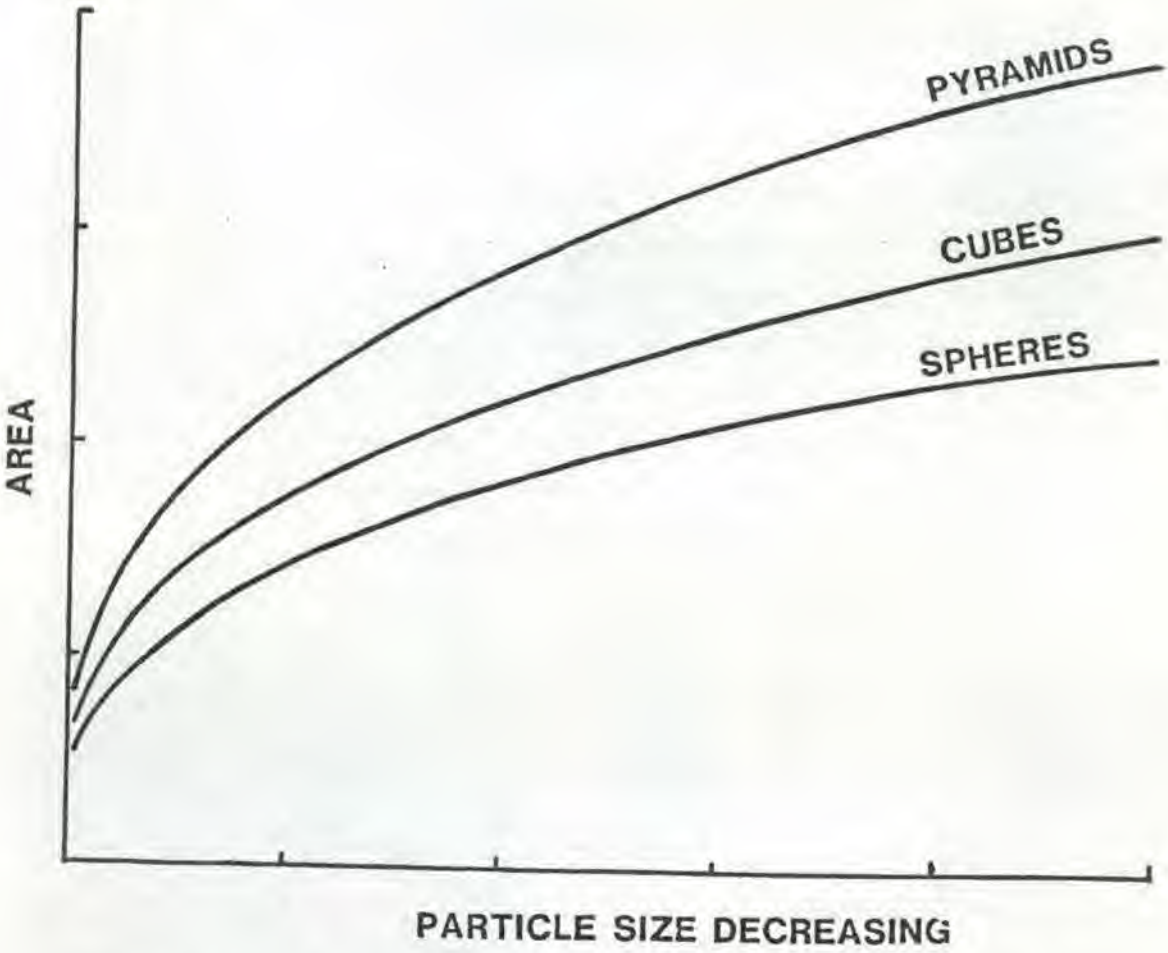


Fig.1 Effect of particle size and shape on surface area

The implication of these data for adsorbent carbon is that, for maximum surface area to be available, particles should be small and of an irregular (non-spherical) shape. However, since carbon is a porous substance, most of the surface area (of all but the smallest particles) is generated by the internal pore structure, so that the contribution of the external (shape) surface is of lesser importance (Table 1).

TABLE 1

Effect of Particle Size on Carbon Surface Area

Particle Size (mm)	Surface Area Argon, m^2/gm)
Less than 0.16	> 1100
0.16 - 0.5	1267
0.5 - 1.0	1198
1.6 - 3.2	1302

Pore Size and Shape

The spectacular development of surface area experienced by carbon on activation is due to the thermochemical erosion of the macrostructure and the accompanying production of microscopic cavities or pores. These pores have a dual function in that they (i) may increase the surface area, often by an order of magnitude and (ii) they may impart a degree of selectivity to incoming sorbate molecules, based on their own size and shape. Hence the performance of a carbon adsorbent will depend to a considerable extent on the nature of its pore structure (Fig. 2).

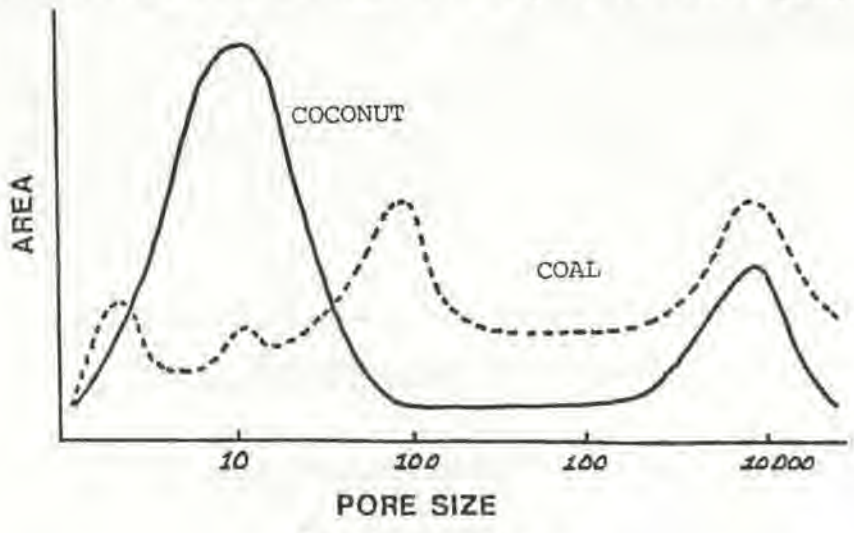


Fig.2 Pore size distribution for coconut and coal carbons

In summary, it can be seen that for adsorption to occur, contributions must come from the adsorbent, the incoming adsorbate and the media. Principal factors influencing the performance of the adsorbent are surface chemistry, surface area and the distribution of pore size and shape. Let us examine now how these properties may be optimised in the production of active carbon from wood.

CARBONIZATION (PYROLYSIS) OF WOOD

It appears likely that the final chemical characteristics of the carbon surface have little to do with the chemical composition of the carbon precursor. Rather, it would seem that the carbonizing and activating processes are best designed to prepare suitable physical surfaces on which relatively simple chemical sites may be generated and located (5). To this end, it is useful to examine the course of carbonization of a common Australian hardwood.

The principal components of wood are typically cellulose, hemicelluloses and lignin, occurring in the approximate proportions of 50:30:20. Thermal analysis (6) has indicated that, after an initial loss of water, wood undergoes degradation firstly via the hemicelluloses, then through the cellulosic components, with the lignin being the last to degrade. Most "organic" changes appear to be complete at *ca.* 500°C. Infrared spectral analysis (Fig. 3) shows that wood carbonised in a restricted air supply at 500°C has lost most of its chemical "fine structure". Thermal treatment beyond this region could only be expected to modify the physical characteristics of the carbon and, if carried out in a suitable atmosphere, to introduce oxygenated sites on the carbon surface.

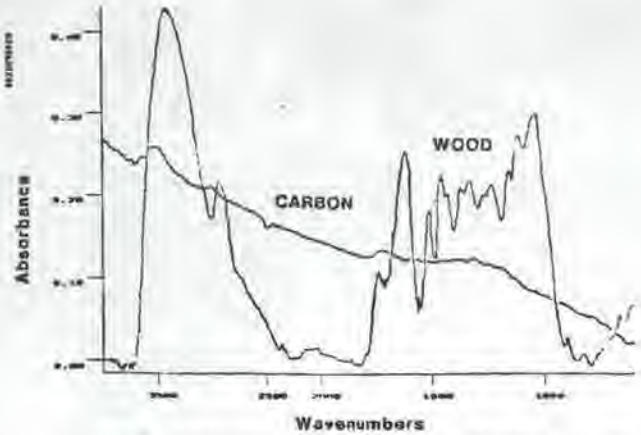


Fig.3 Infrared spectra of wood and wood carbon

On the other hand, the morphology of the woody substate may be vastly modified by the process of carbonization, with such modifications having a marked influence on the sorption characteristics of the carbon product. For example, for a woody cell imbedded in a highly lignified matrix, thermal erosion may take place initially at the lumen walls and proceed towards the intercellular space, since the cell wall material (carbohydrate) is less thermally stable than the intercellular substance (lignin). Furthermore, there would presumably be more air available in the lumina regions to accelerate thermal decomposition. Scanning electron microscopy of some jarrah wood specimens suggests that thermal erosion may proceed in the opposite direction (Fig. 4).

Fig.4 Jarrah wood carbonised at 600°C

Of particular interest is a thermally-induced phenomenon which may be described as "cell-fusion" (7,8).

Examination of jarrah wood blocks heated to several hundred degrees in limited air shows a very definite "molten" effect in the cell substance which cannot be attributed to any known artefact. If real, the consequences of this "melting" in the development of surface area are highly significant.

POROSITY OF WOOD CARBON

It can be expected that the porosity of carbon derived from wood will depend on both the morphological nature of the wood precursor and the actual process of thermal decomposition undergone during carbonisation and activation. Figure 5(a) shows that wood carbon adsorbs and desorbs water vapour with a hysteresis pattern similar to that of a substance having cylindrical capillaries with hemispherical ends (wood fibers). On steam activation at high temperatures (800°C), the sorption hysteresis loop changes (Figure 5(b)) to be more characteristic of a substance having tubular capillaries with wide parts of varying widths, separated by short necks of narrow dimensions (9,10).

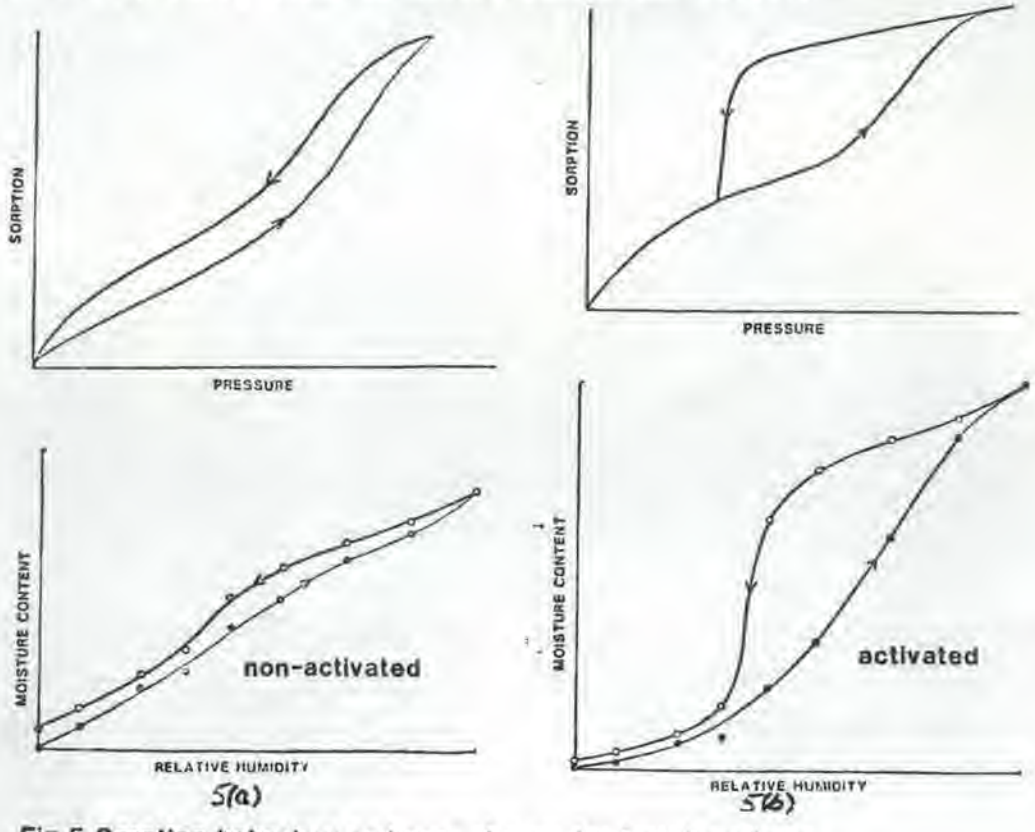


Fig.5 Sorption behaviour and pore shapes for jarrah carbons

A study of wood carbon using mercury intrusion (11) has indicated that most of the pores fall into two size categories viz. 100 Nm and 10,000 Nm, and that the pores are approximately evenly distributed over these two dimensions.

The interpretation of porosity data for wood carbons is conditioned by the uncertainty that "soft" carbons such as those derived from wood, may be mechanically damaged by the somewhat rigorous techniques of liquid metal penetration, a method widely used for the measurement of pore size and shape (12).

ACKNOWLEDGEMENT

The technical assistance of Miss Jenny Carr in aspects of this work is acknowledged with thanks.

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STUDY ON THE PRODUCTION AND PROPERTIES OF ACTIVATED CARBON FROM EUCALYPTUS MARGINATA FOR GOLD EXTRACTION

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ABSTRACT

Activated carbons were prepared from *Eucalyptus marginata* (jarrah) by both steam (SA) and chemical activation (CA) methods. The performance of these carbons was compared to those of three commercial coconut shell carbons, namely PICA G210AS, Calgon GRC-22 and a Sri Lankan carbon. Gold adsorption kinetics of CA jarrah carbon were 2.4 times faster than for the commercial carbons and the SA carbon was 1.9 times faster. Gold adsorption capacity for the SA and CA carbons was 21.2 and 13.3 kg Au/t C respectively compared with a range of 24.4 - 28.9 kg Au/t C for the commercial carbons. However, this property is not expected to affect performance since the carbons are only loaded to 3.5 kg Au/t C in practice. Hardness of the jarrah carbons was also lower with ball-pan hardness numbers for SA and CA carbons of 90.3 and 89.0 respectively compared with 94.3 - 98.1 for the commercial material. The gold stripping kinetics value for SA carbon was 14.9 kg Au/t C/h (initial rate) which was considerably faster than the commercial carbons' values of 7.6 - 8.7 kg Au/t C/h. It was less affected by fouling on the level of gold stripped from the reloaded carbon in a second extraction. The effect of fouling on the stripping kinetics of SA carbon was also less than for PICA G210AS but was not as good as for the commercial Sri Lankan carbon. Activated jarrah carbons could be considered for use in carbon-in-solution operations where there is minimal attrition or as a once-through carbon in other gold extraction processes where the fast kinetics and low residence times may result in acceptable levels of carbon attrition. Benefits of the use of once-through carbons are reduced capital and operating costs of the process plants and the elimination of carbon regeneration.

INTRODUCTION

Activated carbon is an important adsorbent used by many industries. Australia currently imports all of its activated carbon requirements

from various countries. Imports have jumped from 2603 tonnes worth $3.79 million in the 1983/84 fiscal year to 4263 tonnes with a value of $8.90 million during 1985/86, as shown in Table 1. These figures reflect a substantial increase in both consumption of activated carbon and unit product price (from an average of $1456 to $2086/tonne). Although the values refer to average consumption and cost figures spread across the range of applications, a major influence has been its increased use by the gold mining industry employing the carbon-in-pulp (CIP), carbon-in-leach (CIL), carbon-in-solution (CIS) and carbon-in-column (CIC) operations. These processes have revolutionized

TABLE 1
Australian Imports of Activated Carbon

Country	1983/84			1984/85			1985/86		
	Quantity (tonnes)	Value ($)	Cost ($/t)	Quantity (tonnes)	Value ($)	Cost ($/t)	Quantity (tonnes)	Value ($)	Cost ($/t)
Belgium-Luxembourg	106.131	224 888	2 119	19.060	51 748	2 715	119.748	241 959	2 021
Brazil	-	-	-	0.315	359	1 140	-	-	-
Canada	-	-	-	0.900	2 067	2 297	0.467	2 630	5 632
China (excl Taiwan)	308.690	256 415	831	538.940	535 736	994	768.897	798 607	1 040
China-Taiwan	51.000	61 817	1 212	12.137	34 414	2 835	54.400	96 170	1 765
France	107.200	219 888	2 051	197.490	545 641	2 763	276.510	991 193	3 585
Germany, Fed. Rep.	42.812	35 408	827	35.326	19 536	553	20.036	81 424	407
Hong Kong	21.050	22 200	1 055	9.000	9 123	1 014	0.082	391	4 768
Italy	0.010	614	61 400	0.018	243	13 500	0.002	52	26 000
Japan	889.497	1 102 523	7 239	575.292	1 067 459	1 856	420.614	884 574	2 103
Korea	-	-	-	-	-	-	13.600	24 445	1 797
Netherlands	226.840	256 268	1 130	150.727	162 958	1 081	596.489	1 202 052	2 015
New Zealand	-	-	-	-	-	-	0.002	551	275 500
Philippines	434.840	969 476	2 230	525.526	1 352 639	2 573	875.890	2 480 477	2 832
South Africa	-	-	-	-	-	-	0.122	532	4 361
Sri Lanka	217.700	256 932	1 180	223.100	448 975	2 012	495.000	1 128 122	2 276
Switzerland	0.001	28	28 000	-	-	-	-	-	-
United Kingdom	45.324	71 967	1 588	31.696	48 819	1 534	90.169	312 165	3 462
U.S.A.	151.424	309 890	2 047	155.365	445 293	2 866	351.050	649 839	1 851
Total: All Countries	2 602.518	3 788 313	1 456	2 474.892	4 724 809	1 909	4 263.231	8 895 183	2 086

gold mining with gold ores of grades as low as 1 g Au/tonne of ore being economically recoverable. Extensive deposits of low grade ores have been unlocked as a result, creating a second gold rush in some old gold-mining towns such as Kalgoorlie and other locations both in Australia and overseas. Old mines have been re-opened, tailings are being re-processed and prospecting has been pursued vigorously. Many new mines with extensive low to medium grade reserves have been opened. For the quarter ending June 30, 1986, Table 2 lists the gold production from mines producing in excess of 311 kg (10 000 oz) using carbon technology. Since the total production from the larger mines amounted to 10 260 kg, some 96% of them are employing activated carbon extraction methods.

TABLE 2
Gold Production from Mines* Using Activated Carbon, 1986

Company	Location	Production (kg) Quarter ended June 30
Kidston	Kidston	2 055.7
BHP/Newmont	Telfer	1 378.1
Cent. Norseman	Norseman	1 157.4
North Kalgurli	Fimiston/Paringa	831.7
KMA	Mt Charlotte	763.1
Hill 50	Mt Magnet	586.5
Pancontinental	Paddington	559.8
Barrack/Eastern Div.	Horseshoe Lights	513.2
Sons of Gwalia	Sons of Gwalia	457.9
Peko/Anglo	Mt Morgan	414.6
Esso/Carr Boyd	Harbour Lights	402.2
Renison/Enterprise	Pine Creek	381.6
WMC	Kambalda	357.0
TOTAL: Main producers using activated carbon*		9 858.8
Main Producers*		10 259.6
Australian Production		17 550.8

*For mines producing greater than 311 kg (10 000 oz.) per quarter

The processes involve the leaching of the finely crushed ore with cyanide solution sparged with air. The combined oxidation with atmospheric oxygen and complexing with the cyanide ligand solubilizes the gold which forms the stable Au(I) (aurous) cyanide according to the equation:

$$4\ Au + 8\ CN^- + O_2 + 2H_2O \rightarrow Au\ (CN)_2^- + 4\ OH^-$$

Although gold readily dissolves in the cyanide leach, a whole range of other metals and metal compounds are also solubilized to form cyano-complexes. However, when activated carbon is added to the leachate, it selectively adsorbs the gold from solution. This adsorption is specific, preferentially adsorbing the gold and concentrating it into the carbon phase even though its concentration in the solution phase is very low. The gold laden carbon is removed by screening, the gold content in the carbon is stripped with fresh cyanide at elevated temperature and pressure and is recovered from solution by electrowinning to produce cathode bullion.

The activated carbon used is almost exclusively based on coconut shell because it has good gold adsorption properties and is resistant to attrition. Any fines produced during the recovery of gold would be lost through the filtration screens and carrying away with them in the tailings the adsorbed gold. However, activated coconut shell carbons for this application are expensive, its cost having risen to around $3500-$5000/tonne. In some of the earlier CIP processes, for example in South Africa, the carbon was used in a once-through operation after which it was incinerated and the gold recovered from the ash in a simple batch smelting operation. For one operation in Johannesburg, the price of their carbon rose to $2600/t in 1985 with prospects of further price escalation. This operation was forced to look at converting over to carbon stripping, electrowinning and carbon regeneration which would substantially increase their overall plant capital and operating costs.

Another disadvantage for coconut shell carbon is its susceptibility to fouling. This results in a significant downgrading of the gold adsorption properties of regenerated coconut shell carbon by over 50% compared to new carbon. The high temperatures required to restore acceptable activities results in high carbon losses. The average life of the carbon is estimated to be about nine cycles. Maintenance costs on regeneration furnaces are also high because of the severe conditions of high temperature and high salt content.

Because of these limitations, alternative carbons and other adsorbents for gold have been studied. One is the use of pelletted peat

based carbons which, although a lower cost carbon, have somewhat inferior gold stripping properties. Ion-exchange resins are also being studied, and are being used commercially in the Soviet Union. These also have problems and will probably not displace coconut shell carbon in the near future.

Since we were undertaking research and development work on carbonization and energy recovery from wood residues (1-4), it was decided to carry out research on activated carbon. An activated carbon successfully made from bagasse residues showed excellent decolorization characteristics compared to a commercial carbon used in sugar refining. Chemical and steam activated carbons made from *Eucalyptus marginata* chips showed good activity (5).

The production of a high added-value product from a currently unutilized wood residual resource would assist the profitability of the forest-based industries. The manufacture of activated carbon in Australia would reduce our dependence on imports and benefit the local gold mining industry by reducing and stabilizing the activated carbon prices.

Jarrah is a commercial Western Australian species well-suited for timber and sleeper use. However, the species performs poorly in pulping with low recoveries and high chemical use, and is not favoured for wood chip export. It is well known that jarrah produces a high-grade charcoal for metallurgical use and, until 1981 this charcoal supported a spheroidal graphite iron industry at Wundowie, W.A.

A collaborative study was undertaken with WA Chip and Pulp Co. to investigate the production of activated carbon based on jarrah for the gold mining industry. This paper outlines the properties of the carbon produced and its potential application.

SOURCE OF THE CARBONS

From jarrah woodchips obtained from WA Chip & Pulp Co., steam and chemically activated carbons were prepared and sieved to a standard size range of 1.00 - 2.36 mm used by the gold mining industry. Properties of these carbons were determined and compared with those of three

commercial coconut shell carbons used by the industry both in Australia and South Africa. The source of the coconut shell carbons are shown in Table 3.

TABLE 3
Source of Commercial Coconut Shell Carbons

Sample	Source of Sample	Date obtained
Calgon GRC-22	Western Mining Corporation P/L, Kambalda	Nov 1984
PICA G210AS	Carbone Lorraine (Aust) P/L, Vic. Aust	Feb 1985
Sri Lankan Carbon	Golden Dumps P/L, Johannesburg, South Africa	May 1985

COMPARISON OF PERFORMANCE PROPERTIES OF ACTIVATED CARBONS

The relevant properties which determine the suitability of carbons for gold recovery are:

1. The kinetics or rate of gold adsorption onto the carbon, and
2. The hardness.

Another important property is the gold adsorption capacity of the carbon. Most commercial carbons have values of around 20 kg Au/t C or higher when new. However, in practice, the carbons are loaded to only some 3.5 kg Au/t C which is significantly below capacity since it would require impractically long retention times in the carbon contacting tanks to effect near equilibrium conditions. Therefore, the gold adsorption performance is determined by the kinetics of the carbon. The faster the kinetics, the higher the level of gold loading onto the carbon (provided the capacity is adequate) or the lower the retention time required to effect a certain loading. A fast carbon could also result in a smaller number of adsorption stages thereby reducing the capital and operating costs for the extraction equipment. In practice, some 5-8 countercurrent adsorption tanks are used in CIP operations.

The second important property is the hardness of the carbon. Since the separation of the gold-laden carbon from the barren pulp is by wet screening, fines generated by attrition of the carbon would result in the loss of gold. Hence, a high hardness is desired.

In addition to the gold recovery properties of the carbon, for a regenerable carbon, its gold stripping behaviour is also important. This is determined by:

1. The kinetics of stripping gold from the carbon
2. The extent of fouling of the carbon which would impare its performance in subsequent gold adsorption.

Gold stripping is carried out typically at 100-140^{o}C and 400-500 kPa pressure for some 8-16 hours. This operation is usually conducted in conjunction with electrowinning in an integral process. A good carbon is one which has fast gold stripping kinetics.

A major problem encountered during the research was the lack of standard test methods for measuring the various properties of the carbons, particularly for carbons from vastly different precursors, namely, between that of coconut shell and wood. This resulted in the review of five different methods for determining adsorption kinetics, four methods for adsorption capacity, four methods for hardness and three methods for gold stripping. The most suitable procedures selected were those which best reflected the CIP process in practice, within the limits of laboratory simulation and ease of use. A method was then devised for each property, tested and improved where necessary, and finally adopted when satisfactory and consistent results were obtained. In the case of gold stripping, existing laboratory methods were found to be inadequate for comparing carbons containing residual gold with vastly different loading characteristics. Good reproducibility was obtained with an experimental technique based on theoretical considerations. Methods were also devised to analyse and interpret the data so that carbons could be effectively compared. The various standardized methods are detailed in Divisional Reports (6-8).

(a) GOLD ADSORPTION KINETICS

The kinetics or rate of gold adsorption onto carbon were determined by a modified Anglo-American Research Laboratory method (9). The comparison of kinetics of the various carbons is shown in Table 4 and Figure 1. The figure shows that CA jarrah carbon was the fastest carbon, adsorbing gold at almost some 2.4 times the rate of commercial

coconut shell carbon. SA jarrah carbon was 1.9 times faster. Table 4 shows the relative ranking of the carbons.

TABLE 4
Comparison of Gold Adsorption Kinetics

	Gold loading rate $\frac{d[Au]^t_C}{dt}$ (kg Au/t C/h)			
	% Au on C*			
	0%	25%	50%	75%
Chemically activated jarrah	36.6	27.1	17.7	8.2
Steam activated jarrah	29.2	21.5	13.8	6.1
Calgon GRC-22	15.9	11.1	6.1	2.1
PICA G210AS	15.6	11.5	7.1	2.8
Sri Lankan	15.0	9.9	4.6	1.9

*Relative to saturation (CSIRO method)

It can be seen that the initial adsorption rates for the three commercial coconut shell carbons were fairly similar between 15.0-15.9 kg Au/t C/h. The performance of PICA G210AS improved slightly over Calgon GRC-22 at gold loadings greater than about 20% of saturation. The Sri Lankan carbon showed the slowest kinetics. This is a lower grade material used as a once-through carbon in a South African operation.

(b) GOLD ADSORPTION CAPACITY

The method used to measure gold adsorption capacity was based on determining the K and n-values from the Freundlich isotherm. K is defined as the adsorption capacity constant corresponding to the mass of gold adsorbed on unit mass of carbon in equilibrium with a gold solution containing 1.0 mg/L of gold. These values for activated jarrah carbons and commercial coconut shell carbons are given in Table 5. The figures show that the jarrah carbons have lower K-values than the activated coconut shells, with the CA jarrah carbon being significantly less. Since gold loadings are generally around 3.5 kg Au/t c, it is unlikely that the capacity of this carbon would be inadequate. As already discussed, the gold adsorption capacity in general, is not of

major importance in assessing carbon performance provided it is sufficient to do the task.

TABLE 5
Comparison of Gold Adsorption Capacity

Carbon	K-value (kg Au/t C)	n-value
Chemically activated jarrah	13.3	2.75
Steam activated jarrah	21.2	3.30
Calgon GRC-22	25.5	3.11
PICA G210AS	28.9	3.45
Sri Lankan	24.4	3.73

(c) HARDNESS

Losses of carbon by attrition are caused by many factors such as shearing and impact with agitators, screens and solid surfaces in the contacting tanks, as well as abrasion by ore and other carbon particles in the pulp. Further losses occur in the transfer of the carbon from one tank to another, in the gold stripping operation and also in the furnace reactivation. It is very difficult to simulate in the laboratory all the processes which cause attrition. At the present time, there is no acceptable standard method for measuring the hardness of CIP carbon but the method used by most laboratories is based on the ASTM D3802-79 Ball-Pan Test (10) which is a standard hardness test covering activated charcoals in general. This test determines the hardness of dry carbon, subjected to shaking with steel balls based on a scale of 0-100. The relationship derived between ball-pan hardness number, particle properties and particle geometry (7) showed that there are many factors which affect the hardness number and that this test produces indicative results only.

From the hardness numbers determined for the various carbons, it was found that the jarrah carbons had low hardness numbers. However, if the tested material was subjected to a subsequent second test, the hardness improved significantly since areas of weakness in the carbon particles such as fractures and sharp edges were removed by the first test. It was obvious that the commercial coconut shell carbons had been preconditioned, as observed by the rounded edges of the particles.

Table 6 shows the Ball-Pan hardness numbers of the activated carbons based on pre-attrited material. The jarrah carbons with hardness numbers of 89-90 are significantly softer than coconut shell carbons with values of 94-98.

TABLE 6
Comparison of Hardness

Carbon	ASTM Ball-Pan Hardness No.
Chemically activated jarrah	89.0
Steam activated jarrah	90.3
PICA G210AS	98.1
Sri Lankan	94.3

(d) GOLD STRIPPING KINETICS

The gold stripping rate for carbons loaded to 10 kg Au/t C in 2% sodium cyanide/2% sodium hydroxide (w/v) solution at boiling point (100-105^{o}C) is shown in Table 7 and Figure 2.

TABLE 7
Comparison of Gold Stripping Kinetics

Carbon	Gold stripping rate (kg Au/t C/h)			
	% Overall Au stripped			
	0%	25%	50%	75%
Steam activated jarrah	14.9	9.1	5.1	2.0
PICA G210 AS	7.6	4.3	5.3	-
Sri Lankan	8.7	5.9	2.7	-

The values show that steam activated jarrah carbon is superior to the two commercial coconut shell carbons with stripping kinetics around twice that of the commercial carbons. The lower grade Sri Lankan carbon with an initial stripping rate of 8.7 kg Au/t C/h displayed a better performance than the PICA G210AS with a value of 7.6 kg Au/t C/h. The corresponding value for jarrah carbon was 14.9 kg Au/t C/h. Gold stripping kinetics for CA jarrah was not measured.

(e) EFFECT OF FOULED CARBONS ON STRIPPING KINETICS

With successive cycles of carbon loading with gold, stripping, reloading and restripping, there was a reduction in the rate of stripping of the reloaded carbon compared to that of the freshly loaded carbon. The relative reduction of the various carbons is shown in Table 8. The Sri Lankan coconut shell carbon was the least affected with a 5.2% reduction in stripping rate followed by steam activated carbon (13.4%) while PICA G210AS was the most affected by fouling with a relative reduction of 26.4%.

TABLE 8
Deactivation of Carbons with Respect to Stripping Rate

Carbon	Relative reduction in stripping rate (%)*
Steam activated jarrah	13.4
PICA G210AS	26.4
Sri Lankan	5.2

*Based on the initial stripping rate of carbon reloaded to 10 kg Au/t C relative to that of loaded new carbon.

(f) EFFECT OF FOULED CARBONS ON STRIPPING LEVEL

The level of gold stripped from reloaded carbon after 4 × 1 hour extractions compared to that of freshly loaded carbon was also found to decrease due to carbon fouling. The relative reduction in stripping levels for the carbons (Table 9) shows that steam activated jarrah

TABLE 9
Deactivation of Carbons with respect to Stripping Level

Carbon	Relative Reduction in Stripping Level (%)*
Steam activated jarrah	10.3
PICA G210AS	15.6
Sri Lankan	15.5

*Stripped level after 4 × 1h extractions for carbon reloaded to 10 kg Au/t C compared with that of loaded new carbon.

carbon was the least affected by fouling with only a 10.3% decrease while the commercial coconut shell carbons were noticeably more affected with similar relative reductions of 15.6% for PICA G210AS and 15.5% for the Sri Lankan carbon.

PROSPECTS FOR THE USE OF ACTIVATED JARRAH CARBONS FOR GOLD EXTRACTION

Activated jarrah carbons show remarkably high gold adsorption kinetics, with adsorption rates some 1.9 - 2.4 times faster than all the commercial coconut shell carbons tested. The fast kinetics means that the residence time in the carbon contacting tanks can be reduced. In practice, the residence time per stage is about 60 minutes with an overall time of 5-8 hours. The use of jarrah carbon with an activity at least twice as fast as fresh commercial carbon and some four to five times faster than regenerated commercial carbon could result in a 4 to 5-fold reduction in residence time.

Since the attrition of carbon due to stirring of the pulp is proportional to residence time, this would be reduced accordingly. Therefore, although the jarrah carbon is considerably lower in hardness than coconut shell carbon, i.e. 89-90 compared to 94-98, the faster kinetics could possibly compensate for the lower hardness by producing an acceptable level of attrition provided good carbon transfer and handling procedures are also practiced. Obviously, any improvements in hardness of the jarrah carbon would also vastly improve its commercial prospects. However, it could be now be considered for use as a once-through carbon to take full advantage of the fast kinetics to overcome its hardness shortfall. The jarrah carbon could also be used to advantage in CIS operations where there is minimal attrition.

Perhaps the most cost-effective way of recovering gold from the carbon is by combustion followed by the smelting of the ash to produce gold bullion. In Australia, however, most CIP plants use pressure stripping and electrowinning for gold recovery. Here, the fast stripping kinetics of the jarrah carbon would be a distinct advantage.

COMPARATIVE CARBON COSTS FOR ONCE-THROUGH VERSUS REGENERATED CARBON

The carbon consumption at plants which strip and regenerate their carbon depends on plant practice. Australia's largest gold producer has a carbon consumption of some 44 kg C/kg Au produced. At a more efficient CIP plant, this figure was 27 kg C/kg Au. For a carbon price of $4500/t, the average carbon cost would therefore be $162/kg Au production. Using this cost as a basis for direct comparison with a replacement once-through carbon, the equivalent prices for the carbon are shown in Table 10. It can be seen that these are directly related to the gold loading on the carbon. Obviously, the higher the loading used, the greater the value of the once-through carbon and the lower the consumption. The range of equivalent prices for the once-through carbon is $570-$1620/t for gold loadings of 3.5-10 kg Au/t C.

TABLE 10
Direct Replacement Price of a Once-Through Carbon for a Regenerable Carbon*

Gold Loading (kg Au/t C)	Carbon Consumption (t C/kg Au)	Direct replacement price of carbon ($/t)
3.5	0.286	570
5.0	0.200	810
10.0	0.100	1620

*Basis: cost of regenerable carbon = $4500/t

This simplistic approach, however, neglects the benefits of using a once-through carbon. For example, costly carbon regeneration would not be required and the subsequent decrease in activity of the carbon need not be monitored. In addition, the gold adsorption stages could be smaller with fewer stages due to the faster kinetics of the carbon or else the capacity of an existing system could be increased. These combined benefits would significantly increase the value of the once-through carbon.

An estimate of the current consumption of activated carbon for gold recovery in Australia is some 1500-2000 t/y. This would be equivalent to 4200-15 900 tonnes of a once-through carbon depending on the gold loading level used.

CONCLUSIONS

E. marginata produces highly active carbons using either chemical or steam activation methods. These carbons show vastly superior gold adsorption kinetics compared to three commercial activated coconut shell carbons. Gold stripping kinetics for the steam activated jarrah carbon were also superior to the commercial carbons. However, the hardness of the jarrah carbons was lower. Nevertheless, the faster jarrah carbons could be considered for use in carbon-in-solution operations and as a once-through carbon for the carbon-in-pulp process: the greatly reduced residence times in the adsorption process could result in an acceptable degree of attrition compared with coconut shell carbons. The advantages gained are lower capital and operating costs for adsorption equipment, faster processing and the elimination of carbon regeneration with jarrah carbons.

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Kaye Harvey, an experimental scientist employed on this project, conducted the detailed chemical analysis work on the carbons.

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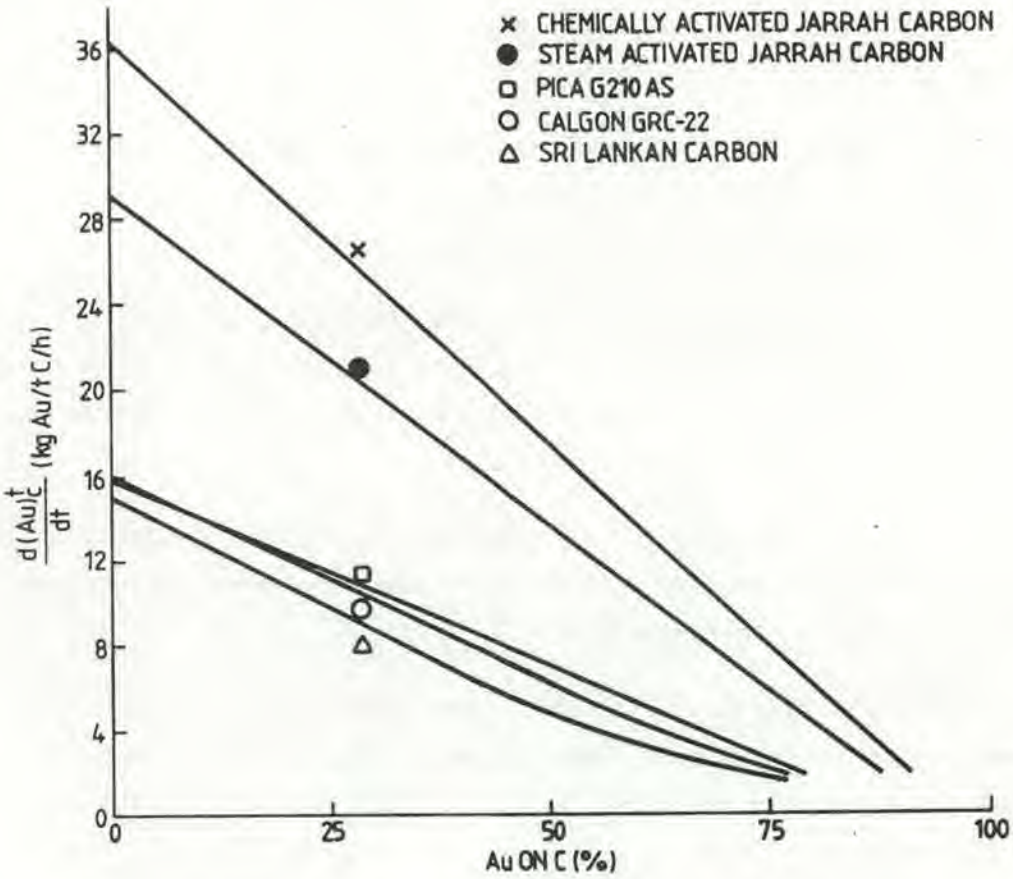

Figure 1. Gold adsorption kinetics of various carbons.

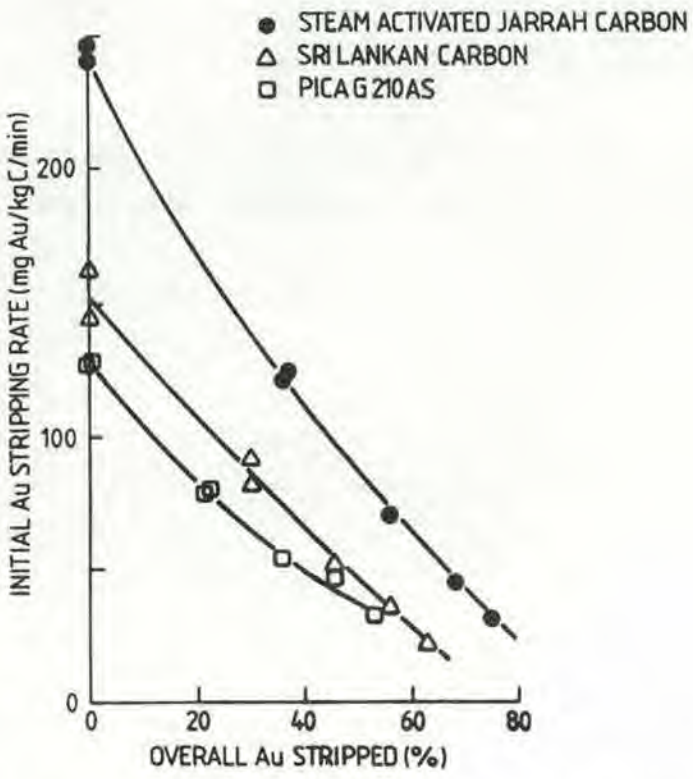

Figure 2. Gold stripping kinetics of various carbons.

PULPING DEVELOPMENTS

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ABSTRACT

Recent developments in chemical and mechanical pulping are reviewed. The main effort in the development of new chemical pulping processes over the past five years has been directed towards the use of organic solvents for pulping (organosolv pulping). None of the proposed processes has advanced beyond the pilot plant scale and in some cases there is insufficient information available about the papermaking properties of the pulps.

The main developments in mechanical pulping have been in refiner technology, bleaching of pulps, and modification of existing procedures rather than the invention of major new processes.

INTRODUCTION

The four basic wood pulping processes (soda, groundwood, sulphite, and kraft) were invented over one hundred years ago. The various pulping procedures used today are modifications and combinations of these early mechanical and chemical pulping methods.

The main chemical pulping processes in use throughout the world are the kraft and sulphite processes. The kraft process is by far the dominant process and is superior to sulphite pulping with respect to pulp quality and ability to handle a wide range of raw materials. The search for alternative chemical pulping procedures is motivated by the high capital cost and expensive pollution abatement equipment required for a kraft pulp mill. In a conventional chemical pulp mill the carbohydrates and lignin dissolved during pulping of the wood are burnt in the chemical recovery stage to produce heat energy. One attraction of an alternative chemical pulping process is the possibility that the lignin and carbohydrates can be recovered from the pulping liquor and converted to products with values considerably higher than the fuel value of spent liquor.

CHEMICAL PULPING

Recent developments in chemical pulping have occurred mainly in the field of organosolv pulping (pulping with organic solvents). The possibility of delignifying wood with alcohol-water mixtures has received a lot of attention. Pulping of lignocellulosic materials with ethanol-water mixtures at 180-190°C was studied as early as 1931 (1). Since 1971, three patents have been issued for pulping with alcohol (2,3,4). One difficulty with these organosolv pulping processes is that they are not well-suited for the delignification of softwoods. Recent studies have included a catalyst in the pulping liquor to increase the ease of delignification of softwoods. A common feature of most of the recently proposed organosolv pulping procedures is the recovery of the lignin and carbohydrates from the spent pulping liquor and the inclusion of the value of these materials as by-products in calculations of the cost of the processes. Recovery of lignin is easy with organosolv liquors containing alcohols because the lignin is precipitated from the spent liquor when the alcohol is evaporated. The isolated lignin is less degraded than that which can be recovered from conventional chemical processes and has a wide range of potential uses. The carbohydrate material in the remaining aqueous phase can be used for production of ethanol or furfural or as an animal feed.

Paszner and Chang (5) have developed an organosolv procedure in which a methanol-water mixture (80:20) containing a catalyst such as calcium chloride or magnesium sulphate is used as the pulping liquor. Typical pulping conditions for a softwood are 200°C for 20-30 min whereas a hardwood such as aspen can be delignified at a temperature of about 180°C. A pulp from *P. radiata* wood had papermaking properties which were superior to those of a sulphite pulp but a little lower than those of a kraft pulp prepared from the same wood sample (6). The inventors of this procedure claim that a pulp mill based on this process would be profitable with a daily production of 200 tonnes compared to 800-1000 tonnes for a conventional kraft mill.

Two American companies, Biological Energy Corporation and Foster Wheeler Energy Corporation, are promoting the APR (Alcohol Pulping and Recovery) process which uses 50 per cent aqueous ethanol at a temperature

of 190-200°C for pulping (7,8). A catalyst, the nature of which is not disclosed, is present in the pulping liquor. Pulps from hardwoods were as strong as kraft pulps from the same species whereas pulps from softwoods had strength properties similar to those of conventional sulphite pulps. On the basis of engineering and economic evaluations it is claimed that an APR mill can be built for 40-50 per cent of the cost of a kraft mill and this capital cost advantage is large enough to allow an APR mill of 150 tonnes/day to be economically attractive. It has yet to be demonstrated that the proposed process is well-suited for the delignification of softwoods and until this has been done it cannot be a serious competitor to the kraft process.

A German company, MD Papier, has developed an organosolv process which is capable of delignifying softwoods in two stages (9). The first stage uses a methanol-water mixture at 195°C to remove about 20 per cent of the lignin in the wood and the second stage employs a solution of sodium hydroxide in aqueous methanol at 170°C to complete the delignification. The total digestion time is about 45 min. It is claimed that the lignin and alkali from the second-stage liquor can be recovered by the use of an electrochemical procedure which precipitates the lignin and enables recovery of the sodium hydroxide without addition of further chemicals to the system. A pilot plant has been built and further studies are being carried out.

Another variation of organosolv pulping is the CAPS (Continuous Accelerated Pulping System) in which aqueous ethanol buffered with sodium bicarbonate is the pulping medium (10). Initial studies were carried out with poplar wood and the optimum pulping temperatures were in the range 220-240°C. The use of anthraquinone and its derivatives was beneficial. No details were given about the proposed recovery system.

Ester pulping of wood has been promoted as a new pulping process capable of preparing chemical pulps from softwoods and hardwoods in either a batch or continuous operation (11). The pulping liquor is a mixture of acetic acid, ethyl acetate and water. Pulping temperatures are in the range 160-200°C. The chemical recovery system is based on liquid-liquid phase separation. Detailed information on the papermaking properties of the pulps is not available but a pulp from aspen had

strength properties similar to those of a sulphite pulp from the same species.

Organosolv processes utilizing phenols have been proposed by two separate groups. The Battelle-Rintekno process uses a mixture of phenol, water and hydrochloric acid at 100°C as the pulping agent (12). Softwoods can be delignified easily under these conditions. The available data indicate that the strength properties of the pulps are lower than those of kraft pulps and are similar to bisulphite pulps. The spent pulping liquor is homogeneous when hot but on cooling it separates into two layers - the aqueous layer containing the carbohydrate material and the phenol layer containing the lignin. Residual phenol is removed from the pulp by washing with sodium hydroxide. A similar process has been developed by a Japanese group who use a mixture of cresols, water and acetic acid at 170-190°C as the pulping medium (13). In general, pulps prepared by this procedure had lower tearing strengths than kraft pulps. It is proposed that the recovered lignin can be converted to low-boiling phenols by pyrolysis and hydrocracking and these can be used as make-up chemicals for pulping.

A critical review of recently developed organosolv pulping processes has been published (14) and the conclusion was that considerable developmental work needs to be done to answer questions about the pulp quality, overall economics of the process and viability of the proposed chemical recovery procedures.

The main development in pulping of wood with inorganic chemicals has been the modification of the alkaline sulphite-anthraquinone process by the addition of a relatively small amount of sodium sulphide to the pulping liquor. The MSS-AQ (Mini-Sulphide Sulphite-Anthraquinone) process is under investigation at the Swedish Forest Products Research Laboratory (15). Addition of sulphide to the liquor increases the rate of delignification considerably and this effect is particularly pronounced at low concentrations of sulphide but becomes smaller as the sulphide concentration is increased. The strength properties of the pulps are equivalent to those of kraft pulps. No details of a proposed chemical recovery system have been given.

MECHANICAL PULPING

The developments in mechanical pulping over the past five years have been mainly in the equipment used for pulping, recovery of heat, and in the procedures for bleaching pulps. The most recent innovation in mechanical pulping, pressurized grinding of wood, is now a commercial reality as this equipment has been installed in a number of pulp mills and is operating satisfactorily. A new large disc refiner is under development by Hymac Inc and the objective is to combine first and second stage refining within the same unit. One advantage of this design is a saving in capital cost of equipment. A new type of refiner plate has been developed by Empire State Paper Research Institute (ESPRI) at the State University of New York. A conventional refiner plate has a pattern of grooves and bars on its surface whereas the one patented by ESPRI is flat and plasma coated with tungsten carbide grit. This new type of plate will be manufactured by the Sprout Waldron Company in USA. A new type of grinder, the Koehring Waterous centri-grinder, which enables wood chips to be sulphonated prior to grinding is currently under development but very few details are available.

Studies on the chemical treatment of wood prior to mechanical pulping have continued with the aim of preparing high yield pulps which have high strength properties and can be easily bleached to a high brightness. Marton and co-workers at ESPRI have set a goal for a high yield pulp based on specifications given by Nissan (16). The ideal pulp should be prepared in 90 per cent yield, have a breaking length of 9 km and a brightness of 90 per cent. Nissan claimed that a pulp with these properties would be necessary if the paper industry was to survive the competition from polymers in the field of packaging and from electronics in the field of information storage and transfer (17). Marton and co-workers at ESPRI have reached the requirements of yield and strength with pulps from spruce and aspen woods but have not attained the specified brightness level. Sodium percarbonate was one of the pretreatment agents used in their work but a detailed economic analysis of its industrial use was not given (18).

A great deal of research and development is being carried out on the bleaching of mechanical and chemimechanical pulps because the use of

pulps of this type in high-value papers requires brightness values of 75 to 90 per cent. The Östrand pulp mill of the SCA company in Sweden uses a recently developed procedure for bleaching spruce CTMP with hydrogen peroxide in two stages (19). Key features of this process are the efficient washing of the pulp to remove residual chemical and metal ions prior to the bleaching stages and the recycling of residual hydrogen peroxide from the second to the first stage. Brightness levels of about 80 per cent are achieved with a hydrogen peroxide consumption of about 3.5 per cent.

A bleaching procedure currently undergoing commercial trials is the PRP process developed by the Pulp and Paper Research Institute of Canada (20). The process consists of three stages - an initial hydrogen peroxide bleaching followed by a reductive bleaching stage with an undisclosed reducing agent, and a third stage with hydrogen peroxide. The use of a reductant between the two hydrogen peroxide stages results in a pulp of higher brightness than if the two peroxide stages were used.

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REVIEW OF RAYON PROCESSES OLD AND NEW

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ABSTRACT

The viscose process has dominated the rayon industry for almost ninety years. The history of the development of rayon and the efforts to find suitable solvent systems for the production of cellulosic fibres with desired properties are reviewed.

INTRODUCTION

Cellulose, the most abundant renewable organic raw material, is produced and utilized in tremendous quantities daily. Despite its availability and usage cellulose has not reached its potential in many areas of application, because the natural cellulose is unsuitable for many applications. In order to convert cellulose into the desired products it is often necessary to dissolve it in a solution and form appropriate derivatives or regenerate it as cellulose fibres with the desired properties. In this review the discussion will be concentrated on regenerated cellulose fibre better known as rayon. The dissolution of cellulose in solvents is cumbersome and it is still a challenge to organic, physical and polymer chemists despite their efforts of research over a century since rayon, the first commercial man-made fibre, came into being.

HISTORICAL REVIEW

Audermars, a Swiss chemist, produced the first experimental cellulose nitrate fibre from mulberry leaves in 1855 (1). However, it was later in 1884 that Count Hilaire de Chardonnet (2) produced the first commercial fibres from a solution of cellulose nitrate. The nitrate groups were removed by hydrolysis. Five years later in 1889, the first "artificial silk" fabrics were exhibited at the Paris Exhibition. A year later, in 1890, Despaissis produced filament yarn from a solution of

cellulose in cuprammonium hydroxide (Schweitzer's reagent) which was first reported in 1857 (3). The third method for the production of artificial silk was discovered in 1892 by Cross and Bevan (4) and proved to be by far the most successful commercially. This method was based on the discovery of the reaction between alkali cellulose and carbon disulphide to produce a compound which readily dissolved in water to give a highly viscous solution and hence the name "viscose".

Cellulose acetate is a derivative of cellulose which was commercialized and is often referred to as cellulose acetate rayon. It is not regenerated cellulose. The derivative was first prepared in 1869 but it was much later, in 1921, that the fibre was marketed as artificial silk.

The viscose process proved the most successful commercially and almost all rayon today is produced by this method. Extensive research for new cellulose solvent systems has failed so far to produce a commercially viable alternative to the viscose process.

VISCOSE RAYON

The viscose process has undergone many changes in order to produce fibres with suitable properties for commercial applications. However, the changes are minor, and the process and its basic chemistry remain the same as discovered by Cross and Bevan in 1892.

Chemical Reactions

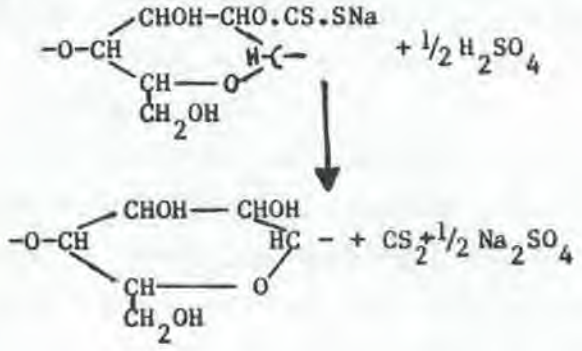
The cellulose is treated with 18% sodium hydroxide to give soda cellulose as shown in the following reaction:

$$(C_6H_{10}O_5)_n + n\ NaOH \longrightarrow (C_6H_9O_4O\ Na)_n + n\ H_2O$$

The soda cellulose is then treated with carbon disulphide to give sodium cellulose xanthate.

$$(C_6H_9O_4O\ Na)_n + n\ CS_2 \longrightarrow [S = C\langle^{S\ Na}_{OC_6H_9O_4}]_n$$

The sodium cellulose xanthate is dissolved in weak caustic soda to form the "viscose". The viscose is very thick but on standing it becomes thinner and later more viscous again. This process is known as "ripening". The viscose is kept for a certain time so that the cellulose will be of the appropriate chemical composition and degree of polymerization (DP) prior to spinning. When the viscose is ready it is extruded through spinnerets (this process is referred to as spinning) into a dilute sulphuric acid bath, where the cellulose is regenerated in the form of continuous filaments (viscose rayon). The reaction that takes place is as shown below:



A flow diagram for the conversion of cellulose to viscose rayon is given in Figure 1.

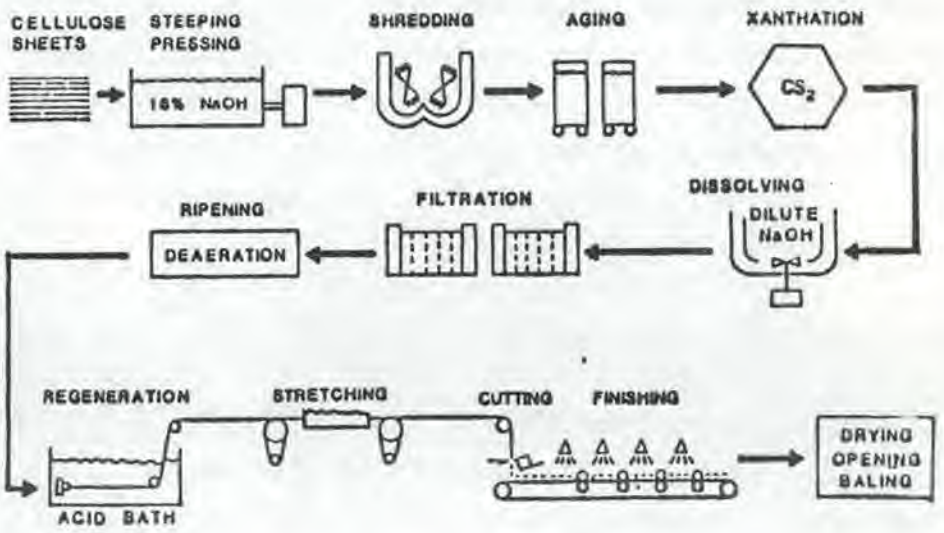


Figure 1. The viscose process

The Product

The term rayon refers to a range of products that have varying properties which depend on the conditions of processing. The versatility of the process is fairly obvious when one considers the range of products that is obtained in order to satisfy particular demands. The hemicellulose concentration, for example, is a significant factor with respect to fibre properties. For regular rayon the hemicellulose content is 2%, for high wet modulus (HWM) fibres it is approximately 0.7% and for tire-cord fibres approximately 0.5%. High hemicellulose concentrations lead to lower strength properties and increased brittleness in the rayon fibres. Of outmost importance with respect to the properties of rayon is the control of DP. The desired DP, usually 270-500, is obtained by monitoring the ageing and ripening processes. The addition of chemicals, such as amines, polyglycols and zinc salts, in the coagulation bath bring about significant changes in the final product. Polynosic fibres, with properties similar to cotton, may be produced employing these modifications to the method. Hollow fibres may be produced by the addition of sodium carbonate. The properties of the final product is of course the main consideration and these properties include tenacity and elongation, moisture content, luster, colour, density, electrical properties, resistance to light, resistance to heat, biological resistance, chemical properties, the hand-feel and the texture of the fabrics. Rayon fibres are available as continuous filament or as staple in a variety of deniers, degree of luster and tenacity. The main uses of rayon are textiles, apparel and tire cords. Rayon has also been used for film (cellophane) which is used for packaging, sausage casing and membranes in artificial kidneys.

Production

Despite fierce competition from synthetics the rayon industry is still producing 3.5 million metric tons of fibre per year. An indication of the growth in industry is given in Table 1.

TABLE 1

World Production of Viscose Rayon

Year	Thousands of metric tons
1900	1
1910	8
1920	15
1930	200
1940	1100
1950	1300
1960	2300
1967	2700
1980	3340

In recent years considerable pressure has been put on the industry because of environmental problems. The recovery of chemicals in the xanthate process is poor as approximately 25-50% of the carbon disulphide is lost. The hydrogen sulphide, and other sulphur containing compounds generated in the process, are unacceptable hazards in western industrialized countries. The cost of building recovery plants is high and as a result of this there is a decline in production of rayon in western countries but there is an increase in eastern and developing countries as shown in Table 2.

TABLE 2
Production of Rayon in Thousands of Metric Tons (*)

Year	U.S.	Americas (Non-U.S.)	Western Europe	East Block	Asia
1971	718	166	1092	879	712
1972	728	172	1085	960	756
1973	731	179	1121	1011	790
1974	668	166	1045	1064	779
1975	470	142	769	1083	698
1976	518	141	884	1115	770
1977	547	145	950	1062	813
1978	560	142	948	1065	851
1979	588	152	963	1047	880
1980	551	147	871	1068	877
1981	539	135	826	1036	927

* Values include acetate textile fibre ca. 5-7%

DEVELOPMENTS IN CELLULOSE SOLVENT SYSTEMS

The toxic vapours from the viscose process can only be contained at great expense, to the point where the process becomes non-competitive and uneconomic. Therefore, it is not surprising that over the years many attempts have been made to dissolve cellulose in a solvent or solvent system which is environmentally acceptable and more economic than that of the xanthate process.

The need to find a more economical system with reduced recovery and recycling costs has long been recognised but so far no system has been found to replace the century old viscose process.

There are many excellent reviews on cellulose solvents (5,6,7,8) and dissolving pulp production (9). Many methods have been proposed for dissolution where the cellulose with its unique properties has been considered as an acid or base. Its ability to complex with various reagents and the many derivatives that can be prepared from cellulose have also been considered. There are solvents where the cellulose retains its morphology and solvents which derivatise cellulose from which it can be regenerated. Solvents that have been tried include inorganic and organic bases, protonic and Lewis acids, inorganic and organic complexes and stable and unstable derivatives. Some solvent systems that have been tried in recent years include ammonium thiocyanate in combination with ammonia, lithium chloride and dimethyl acetamide, dinitrogen tetroxide with dimethyl formamide, dimethyl sulphoxide with paraformaldehyde, amine oxides and in particular N-methylmorpholine-N-oxide (MMNO) and finally alkaline solutions of the carbamate derivative. At this time the last two solvent systems are receiving more attention and have reached to the pilot plant scale.

THE CARBAMATE METHOD

Hill and Jacobson (10) reported in 1938 on the reaction of cellulose with solutions of urea or amines and sodium hydroxide. After drying and heating at elevated temperatures the cellulose contained nitrogen and was soluble in cold sodium hydroxide solutions. Since then a number of

workers have studied the reaction and recently Neste Oy in Finland has put a great deal of effort into the process and their efforts have reached the pilot plant stage. The method by Neste Oy (11) is as follows: In order to achieve an even distribution of urea in the cellulose matrix before the reaction, liquid ammonia at -35°C is employed. The cellulose is impregnated with a solution of urea in liquid ammonia and afterwards the ammonia is evaporated off. After impregnation and drying the cellulose is reacted with urea at temperatures above 130°C and the progress of the reaction is measured by estimating the nitrogen content of the product. Spectroscopic studies of solid cellulose carbamate by ^{13}C NMR (12) indicate that substitution occurs mainly at the C-6 carbon. However in order to have a product with the appropriate DP for the desired properties it is essential to adjust the DP and this is achieved by irradiation of cellulose with an electron beam (13). The fibres are obtained by dissolving the cellulose carbamate in aqueous sodium hydroxide at/or below 0°C and the coagulation takes place in solutions of sulphuric acid. It is claimed that the fibres have properties comparable with those of viscose rayon.

AMINE OXIDES

In 1939 it was reported by Graenacher and Sallman (14) that tertiary amine oxides were useful solvents for cellulose. However, nothing had been done for almost three decades until D.L. Johnston (15) in 1969 reported that certain cyclic tertiary amine oxides were good solvents for cellulose. N-Methylmorpholine-N-oxide (Figure 2) received the most attention. A critical factor in the dissolution of cellulose in these solvents is the concentration of water. With MMNO, a typical solution will contain 10% cellulose and 15.5% water at 100°C. The dissolution of cellulose in MMNO does not involve derivatization of cellulose. Temperatures up to 130°C have been used for the dissolution of cellulose in the amine oxide and therefore the spinning is carried out at these high temperatures. Prolonged periods at high temperatures are to be avoided because they cause significant loss in DP.

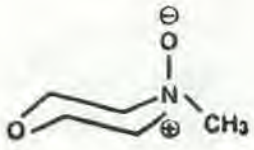


Figure 2. Structure of N-Methylmorpholine-N-oxide

Extensive studies on the process including pilot plant operation have been carried out at American Enka.

Recently Courtaulds Research have announced their Genesis Project in which they have developed to a small pilot scale a spinning process for fibres based on an amine oxide. The fibres are drawn from a hot solution (ca. 120°C) into air before passing through a coagulation bath.

Good quality fibres have been obtained which compare favourably with those of high wet modulus rayon and cotton.

CONCLUSIONS

The need for a rayon type fibre will always exist as most modern textile blends continue to require the aesthetics and moisture absorbing properties provided by cellulose in its native state (cotton) or in regenerated form (rayon).

The viscose process is expensive and there are fears that environmental controls may eventually legislate it out of existence.

Obviously the need for a low cost non-polluting cellulose solvent system is great and the rewards for success will be large.

At the CSIRO Division of Chemical and Wood Technology we initiated a project on new cellulose solvent systems and hope to present our findings at the next Forest Products Conference.

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COMMERCIAL PRODUCTION OF OIL FROM EUCALYPT FOLIAGE

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ABSTRACT

Eucalyptus oil is part of our heritage. It was the first truly Australian product and Australia's first distinctive export.

The industry began over 130 years ago in Victoria. For the last 30 years it has been a marginally profitable business, despite being increasingly mechanised and modernised. Through the establishment of plantations using the latest technology, the industry can enter a new era and become an important rural and export industry and an unusual and interesting tourist attraction.

Over the last 40 years nearly all scientific papers that make mention of eucalyptus oil have been written by overseas scientists. Recent papers on the variety of valuable chemicals obtainable from eucalypt and other forest foliage have come from Russia, China, Japan, U.S.A. and South America. Who knows what treasures are stored in our 600 species of eucalypts.

Our lack of scientific knowledge about eucalypts is bordering on being a national disgrace. We urgently need young, talented scientists to bridge the gap and become world authorities in a high tech field that should be the province of Australians.

INTRODUCTION

Felton Grimwade & Bickford Pty. Ltd., is the largest producer of eucalyptus oil in Victoria and accounts for about one-third of Australia's production.

The Company markets under the trademark "Bosisto's Parrot Brand" which had its origins when Joseph Bosisto founded the industry in Victoria in 1852. The Company sells its eucalyptus oil in bottles to the general public and in bulk to other manufacturers. It incorporates eucalyptus oil into some of its own proprietary products. It exports eucalyptus oil in bottles, bulk and proprietary products.

The Company's eucalyptus oil is produced in the Inglewood and Wedderburn districts of Victoria.

The Company is deeply involved in the eucalyptus oil industry and is keen to foster its development. It is only through vertical integration that the Company can afford to continue to produce eucalyptus oil.

BACKGROUND

The eucalyptus oil industry began in Victoria in 1852 and by the turn of the century was well established with eucalyptus oil being exported to many countries. Over the next fifty years Australia was the major supplier of eucalyptus oil to world markets. Since 1950 Australia's market share has fallen and production is now only 5-10% of world requirements. In fact Australia has become a net importer of eucalyptus oil although still a net exporter of pharmaceutical grade eucalyptus oil.

Eucalyptus oil production has always been a very primitive business. Only natural stands of eucalyptus have been exploited and no Australian plantations have ever been established.

Originally the industry developed and prospered by employing out-of-work gold miners but this changed with World War 11. Australia could not compete against countries with cheaper labour and export markets were lost. In addition vast areas of natural stands were cleared for wheat production. Over the last few years science and technology have helped modernise the industry. By introducing mechanical harvesting and new distillation equipment the cost of production has been reduced. This, together with the natural advantages Australia has in having stands of eucalyptus producing high quality pharmaceutical oils, has given the industry an opportunity to regain some of the lost export markets.

Eucalyptus oil production has been carried on in the Inglewood and Wedderburn districts since the turn of the century. Several of our licences were taken over by J. Bosisto and Company more than sixty years ago. Some of the areas have been harvested on a two year cycle throughout this period without apparent loss of plant vigour or production of oil.

THE MARKET

The world consumption of eucalyptus oil is generally taken to be 2,000 tonnes per year (1). Over 90% of this oil would be of pharmaceutical quality with the remainder being for industrial and perfumery use. On present prices the volume of production would be in the order of A$14 million at farm gate. Our estimate of the total Australian production for all types of oil in a normal year is 150 tonnes. In drought years production could fall to 100 tonnes.

The total Australian production for the period 1939-48 has been estimated to average almost 1,000 tonnes a year (2). This means that the Australian industry has declined by about 85% over the last 40 years. Originally we supplied 100% of world requirements and we now contribute only 5 to 10% of the total.

Many countries which once imported eucalyptus oil now produce their own requirements. The major exporting countries are Portugal, Spain, China, South Africa and Swaziland. The major importing countries are the United States and the E.E.C. countries.

PRODUCTION

Our estimate is that we harvest an area of about 2,000 hectares of *Eucalyptus polybractea* (Blue Mallee) on a two-year rotation. Much of the land has been brought back into production over the last few years.

We employ three men on a full-time basis to harvest and distil eucalyptus oil. All leaf is machine harvested into mobile stills thereby greatly reducing the cost of handling and cartage. Our plant and equipment is the most modern and efficient available and is far superior to the facilities used by overseas competitors. The three man team is able to harvest and distil 20 tonnes of leaf a day.

The quantity of leaf and the yield of oil varies greatly from year to year. These variations are usually caused by seasonal conditions. Over the last 10 years five have been adversely affected by drought. On two occasions consecutive droughts seriously disrupted production.

In an endeavour to utilize unused capacity when oil production is low, we searched for ways of converting spent leaves after distillation to a form that would be marketable. After a great deal of time, effort and money we were able to turn the by-product into a valuable garden mulch.

Our expenditure to develop the mulch concept was considerable. We received no assistance, financially or in any other form from the Department of Conservation, Forests and Lands, or from any other Government Agency. However, having established a market for the mulch we were then informed, without consultation, that we would be charged a royalty on the mulch that we sold.

The sale of mulch is not a very profitable business but it does help minimize losses during downtime.

It seems ludicrous that the Government spends thousands of dollars on advertising to encourage householders to mulch their gardens to save water and at the same time it charges a royalty on the mulch householders buy.

COST OF PRODUCTION

The cost of producing a kilo of eucalyptus oil varies enormously. It depends on the oil yield, the season, the time of the year and the methods used. Government charges such as royalties, Council rates and various licences and charges also have a direct impact on the cost.

We have kept separate accounts to record our costs of eucalyptus oil production. These accounts disclose that eucalyptus oil production is a very marginal business, especially when capital employed is taken into consideration.

It should be mentioned that it is cheaper to purchase eucalyptus oil from China and Swaziland than it is for us to produce oil in Australia. Unfortunately this has been the case for the last 30 years. We import oil to supplement our local production. The price of the imported product is usually 15-20% below our cost of production.

It is uneconomic to clear more natural stands for oil production unless the selling price rises dramatically. About 10 years ago there was a sharp rise in the price of oil during the commodity boom. However, the price soon dropped. Since that time the price has not risen as much as either most other commodities or manufactured goods.

POTENTIAL DEVELOPMENTS

We presently produce eucalyptus oil from *E. polybractea* (Blue Mallee) but in our view it is not economically viable to bring into production more native stands of *E. polybractea* unless the price of oil increases substantially.

We can see no future in the establishment of plantations of high-yielding *E. polybractea* until the technology of tissue culture and robotic planting have reduced the cost of seedling production by about 75%.

We can see a good future for clonal plantations of *E. radiata var. australiana* for oil production once tissue culture techniques have been developed.

Most of the world's annual production of pharmaceutical grade eucalyptus oil comes from *E. globulus* (Tasmanian blue gum) grown in Spain, Portugal and China. *E. globulus* contains 0.7-0.8% oil in the leaves on a fresh leaf basis.

The majority of Swaziland and South African production comes from *E. smithii* which has about 2.0% oil in the leaves.

Most Australian production is from *E. polybractea* (Blue Mallee) which contains about 2.5% oil in the leaves.

E. radiata var. australiana normally contains up to 3.5% oil in the leaves. However, we have located a particular tree with 6.2% oil in its leaves on a fresh leaf basis.

In summary the comparative yields and cineole contents (oil quality) are as follows :-

	Oil Yield	Cineole Content
E. globulus	0.8%	60-70%
E. smithii	2.0%	70-80%
E. polybractea	2.5%	80-90%
E. australiana (normal)	3.5%	70-75%
E. australiana (special)	6.2%	83%

The economic advantage of a 7 or 8 fold increase in oil yield would make a clonal plantation a very attractive investment.

Currently we are :

1. Discussing tissue culture technology with leading Australian experts in this field.
2. Monitoring the progress of robotic planting which would substantially reduce the cost of seedlings.
3. Evaluating trial plots of *E. radiata var. australiana* seedlings in four States to compare growth rates, oil content and evaluate susceptibility to pests and diseases in various locations.

Our objective is to establish a plantation and distillery to produce 60 tonnes of pharmaceutical grade oil a year. Much of the production will replace current imports.

We believe that ten such plantations could be established over the next 5-10 years without disrupting international markets.

The area of land required for each plantation will depend on the growth rates established by the trial plots. It is essential that the distillery handles 18-20 tonnes of leaf a day. This is equivalent to 90 tonnes a week or 4000 tonnes a year.

On present indications the area of land to produce 4000 tonnes of biomass would be 120-240 hectares. Annual rainfall will probably have to be above 1000mm with reasonable summer rain or the plantation will need to be irrigated in dry weather.

The first harvest would commence two years after seedlings are planted out. Just prior to harvesting a distillery, mobile stills and ancilliary equipment will be required.

The oil yield from all the material harvested and distilled is expected to be 2% as up to two-thirds of the material is made up of twigs and sticks which do not contain oil.

The trees can be harvested after two years and then the coppice regrowth can be harvested every 12-15 months.

Three men can handle the through-put of 18-20 tonnes (6 mobile stills) of leaf per day. One man does the harvesting, another ferries the mobile stills to and from the distillery and the third man operates the boiler and distillery. The boiler operator must have a boiler attendant's certificate.

The land on which the trees are grown should be no more than 7 km from the distillery to avoid excessive transport time.

When the initial plantation has been established and proven further plantations could be developed to take advantage of the opportunity to produce low-cost eucalyptus oil to supply world markets at competitive prices.

International buyers prefer to purchase essential oils from the country of origin when other factors are equal. This preference gives Australia an ideal opportunity to recapture lost markets.

The clonal plantations could be established on private or public land. We are considering the following options:-

1. A joint venture arrangement with interested parties to participate in the plantation and distillation operations.
2. A group of farmers in a prospective area could establish plantations which we would harvest and distil under contract.
3. We may take entire responsibility for the plantations, harvesting and distilling operations; possibly with outside financial participation.

UNANSWERED QUESTIONS

You will see from the foregoing that we need more knowledge to be able to clone oil producing eucalypts and prove that clonal plantations will have the same characteristics, the same vigour and the same resistance to disease as the parent stock. These are some of the unanswered questions.

In this industry there seems to be a never-ending list of unanswered questions. For instance, there is no explanation why two apparently identical trees standing side by side can have totally different oil components (3). We don't seem to know why oil is formed or how or when it is formed (4). Our oil yields vary from year to year and plot to plot. All too often a large percentage of oil in the growing leaves disappears within a few days, never to return.

In an endeavour to increase oil yields, various fertilizers have been tried. The results have been disappointing. Leaf production went up but oil yield remained static. In addition, competition from other species increased dramatically. We believe fertilization could be important, but much more and better work is needed to determine the right mixture and its application.

Our eucalypt forests are constantly being attacked by pests. In the area we harvest it is almost impossible to find a two year old leaf that hasn't had a piece taken out of it. Overseas eucalyptus plantations have far better growth rates because they are not under a constant bombardment from insects and fungi. While I am not suggesting we use conventional pesticides, there seems to be an acceptance that we simply allow our forest to co-exist with pests while the rest of the world outperforms us with the tree flora that is native to Australia.

An interesting point is that we know there is a substance in our leaves that is highly toxic to a wide range of pests. No scientific work has been done to develop this substance. Some interesting work is being done overseas evaluating the insecticidal activity of eucalyptus oil itself and in conjunction with pyrethrin (5). Other overseas studies have touched on the anti-bacterial and anti-fungal activity of eucalyptus oil (6, 7, 8, 9).

We have been trying to register our eucalyptus oil and eucalyptus-based products with the U.S. Food & Drug Administration for various pharmaceutical uses. Unfortunately although we know the products are effective for the uses claimed, we are unable to prove that they are effective. We simply do not have enough adequately controlled, double blind, three-way cross-over trials to establish clinical proof.

There are many potential uses for eucalyptus oil awaiting development. For instance eucalyptus oil could have wider application as an industrial solvent and cleaning agent. The Japanese and others have done some work on its potential as a renewable source of alternative fuel (10, 11).

For 130 years we have burnt the spent leaves after the oil has been extracted. As mentioned earlier, we now market this material as a garden mulch. It is highly probable that we are leaving in the garden mulch some very valuable components. These could be worth more than the oil.

Little work has been done on the composition of our blue mallee leaves. However, prior to World War 11, there was an industry devoted to extracting the tannins from this species for use as a rust inhibitor. As testimony to the effectiveness of the tannins, we have been using straight dam water in our boilers for over 60 years and the boilers have never had to be descaled. It appears to me that there must be an opportunity for a water soluble rust inhibitor especially in much of Europe where there is the problem of "acid" rain. Tannins also have potential in the treatment of leather (12).

The Chinese published a paper recently on flavonoid substances extracted from eucalyptus leaves and their application in agriculture (13). It was found that the products obtained could stimulate the growth of some vegetables and fruits as well as afford some protection from disease and viral attack.

The Japanese have isolated natural anti-oxidants from eucalyptus leaf waxes (14).

The Russians have converted forest foliage into a livestock feed supplement. They have also investigated the chlorophylls and carotenoids and other foliage constituents (15). It seems to be that we need to take a serious look at whole tree harvesting and the commercial potential of foliage chemicals.

CONCLUSION

Originally we supplied 100% of world requirements of eucalyptus oil and we were the undisputed world experts. We now supply only 5-10% of the total and our scientific knowledge is so poor that we have been forced to import technology to establish a plantation of eucalypts in the country of its origin.

The reason we continue to produce eucalyptus oil is philosophical rather than economic. We believe that if Australia continues to import goods at the present rate at the expense of local production and manufacture our economic prosperity will be heavily eroded. We need more scientific knowledge and more technical knowhow in order that we can develop the skills and expertise to compete with other nations. Once our base is lost there will be no hope of re-establishing the industry.

Eucalypts are part of our national heritage and I look forward to the day when Australian scientists are again world authorities on all facets of eucalypt production and use.

***

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Forest Products Research Conference Committees

Opening Address by Dr. W. Hewertson, Chief

CSIRO Division of Chemical and Wood Technology

Welcome to the 22nd Forest Products Research Conference. This time we have introduced a number of changes to the program. What I hope we can emphasize in all our presentations is the nature of the research we are doing, extract the industrial content and highlight its application. I think most research organisations in Australia are looking at the application aspects and, in fact, forestry bodies are striving hard to maximise the value of the product we need to process.

At this time it is worthwhile pointing out some of the opportunities in the area of Australian forestry and forest products research. There is currently a very strong drive to adopt a national approach in a number of areas. The initiative of the industry and a number of people involved in research to form a national association of forest industries will culminate in the formation of that body as an operating entity later this month. We also have an initiative by the Department of Primary Industry to put forestry and forest products on the same footing that wheat and wool have been on for 30 to 40 years in Australia. This will allow much greater emphasis to be placed on the importance of research from industry as well as from the government.

The Australian economy benefits from the trade per annum of about $6 billion worth of wood and wood products. Only about $4 billion of that is generated internally but that is $4 billion worth of material we do not have to import. Considering the vast areas of land that we have and the large amount of wood in Australia there is no reason why we should not be exporting high value added products from that particular form of land use by the end of this century. We are beginning to develop

plantation hardwoods. These have made a start mainly for pulp production in the southern states, particularly Tasmania, but plantation hardwoods will certainly be a thing of the future.

This brings us to the point that at this Conference we are hoping to integrate some of the research in forestry with some of the research in forest products utilization. Plantation programs could be planned to produce high value-added material in periods as short as 10 to 12 years. This would be feasible for the paper industry, it probably would also be feasible for products like Scrimber as well as a number of other end-uses that need only preservative processing to make them acceptable. To assist in the intergration process between growing and end-use this Conference, as an innovation, has a specific session, chaired by Alan Brown, concentrating on that subject area.

The other new feature is the poster session. We have progressed from a trial at the last Conference to a strong encouragement for this form of participation. As all papers are now invited we have taken the view that posters are very useful in permitting work that possibly has not reached full paper stage to be presented.

On Tuesday evening we will have the benefit of a talk by Mr. Mike O'Halloran, Manager, Research and Development, American Plywood Association at a function arranged by the Australian Branch of the Institute of Wood Science. To all our overseas guests particularly Mr. John Butcher, Forest Research Institute, New Zealand, and to those who have travelled a long way I extend a cordial welcome.

Last time Ed Dougal gave an excellent summary of the whole Conference proceedings. This time we asked each chairman to summarise their

particular session. This will take place on Thursday afternoon and will be followed by a general discussion period. At the last Conference this resulted in several useful suggestions being raised.

Now it gives me great pleasure to introduce Dr. Ian Bevege, our Keynote Speaker. Ian is now with the Australian Development Assistance Bureau (ADAB) having joined that organisation in October this year. He started out in Queensland, held a very significant position with NSW Forestry Commission for many years and he is now in Canberra. Possibly he is on his way to Tasmania in the near future! Through his training and experience Ian has shown that it is possible to combine forestry with utilization which happens to be one of the main themes of the Conference. I anticipate that Ian's talk will outline the opportunities that are available by such an approach.

May I ask you Ian, to present the Keynote Address.

FOREST PRODUCTS RESEARCH - ITS ROLE IN THE FOREST-BASED INDUSTRIES, PAST AND FUTURE

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Keynote Address: Twenty Second Forest Products Research Conference

CSIRO Division of Chemical and Wood Technology
Melbourne 17 November 1986

FOREST PRODUCTS RESEARCH - ITS ROLE IN THE FOREST-BASED INDUSTRIES, PAST AND FUTURE

D.I. BEVEGE
AUSTRALIAN DEVELOPMENT ASSISTANCE BUREAU*

In presenting this address to the 22nd Forest Products Research Conference, I am mindful of the fact that the Forest Products Research Conference was established 40 years ago, in 1946. This was one of the first joint forest policy initiatives of the Commonwealth and State Governments. It grew in part out of a recognition of the critical role played by the forest products industry during the Pacific War and the concern felt for the maintenance and promotion of a viable industry, under-pinned by a vigorous research effort, into the future.

A generation later, that future is now upon us. We might ask the question - have we fulfilled the expectations of those who went before us, and can we look forward to a further quantum leap in technological achievement over the next forty years? In my opinion, the technological advances since the first FPRC have been considerable, and at least as great as those of the forty years prior to 1946. You may recall that Baker's initial research on eucalyptus essential oils was published in 1902 with a second edition 1920, and Baker and Smith's monumental work on the Pines of Australia in 1910, by the Technological Museum NSW. The publication of these monographs consolidated the pioneer work of Maiden on phyto-chemistry of gums and resins from indigenous timbers, published from 1889 in a series of papers in various State Proceedings and Transactions of Royal Societies (Qld, NSW, SA) and as Reports of the Australian Association for the

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Advancement of Science. That "first 40 years" also saw the publication of a plethora of papers by such giants of wood technology, chemistry, pulping and mechanics as Welch, Langlands, Boas, Penfold, Watson, Clarke, Benjamin, Dadswell, Greenhill, to name a few.

However, while we might consider, in a positive sense, that scientific and technological advances in the last few decades have at least matched, and in some fields, have surpassed those of the earlier period, I feel that a common failing (with a few notable exceptions) has been in the translation of our scientific advances into usable technology for adoption by industry. This inadequacy of our technology transfer activities has almost become a hallmark of forest products research in Australia despite (or perhaps because of) the highly institutionalised nature of our research establishments largely within Government agencies and tertiary institutions (Bevege 1986). The existence of a whole range of industry associations and communications networks which, theoretically at least, are in the technology transfer business has contributed little to alleviating the situation. Perhaps if the user-pays principle had been adopted from the outset, industry would be more responsive than they have been till now, in taking advantage of the research findings and technological developments which are available.

And herein lies the paradox. For the first 100 years of settlement, the forest products industry developed on an ad hoc, trial and error basis with no formalised research input. Let us digress for a while into history and examine our early beginnings. The first export from the infant colony was a quart of eucalyptus oil from Sydney peppermint, distilled from Eucalyptus piperita growing on the shores of Port Jackson. Surgeon-General John White sent this to England in 1788; Captain Arthur Phillip also sent samples to Sir Joseph Banks. However, these initiatives were not followed up until 1854 when Joseph Bosisto established a distillery in Westernport Bay (Vic) - the forerunner of "Bosisto's Parrot Brand" which is still in the market today. Peter Abbott's

paper to this conference therefore marks a point in the longest tradition of any forest products industry in Australia. Perhaps the desultory nature of the development of the essential oil industry, based as it is on a virtual hunter/gatherer economy, is symptomatic of a wider malaise which besets the industry in general.

The "suck it and see" approach also underscored initial attempts to utilise the local species for building timber. Again, John White records in 1788, the disappointment and difficulty in handling Angophora costata as sawn timber, which fell to pieces along the gum veins. By way of compensation he found that the kino was useful for treating dysentery, as was that of Eucalyptus resinifera; thus he gave birth to phytochemistry in this country, but again this was not exploited latterly to any extent. However, the colonists soon discovered the stands of bluegum (E. saligna) and blackbutt (E. pilularis) to the north and west of the settlement and before long, there were sawpits operating at convict outposts such as Castle Hill - Government House at Parramatta, established by Captain Phillip, was floored with 6 inch blackbutt boards which survived through to renovations made this century, when they were replaced through the kind offices of the Forestry Commission. The colonists also exploited the extensive stands of cedar (Toona australis) in the Hawkesbury and Illawarra and an export trade to England had developed by the early 1790s. This industry rapidly spread up the coast - into the Northern Rivers by the end of the 1820s, then into Moreton Bay and eventually to North Queensland where it became the staple of the rainforest-based industry that continues to this day. The importance of this industry to the colony is undoubted. It formed the mainstay of exports (in 1845 the Richmond River exported 624,000 feet of cedar which represented two thirds of the entire exports from the colony for the year, Daley 1966). The other prime target was the "colonial pine" - hoop pine (Araucaria cunninghamii) and Norfolk Island pine (A. excelsa) - which quickly was reserved for mastage for the Royal Navy whose traditional supplies from North America and

the Baltic were restricted by hostilities in Europe and the Americas. Nelson's HMS "Victory" at Trafalgar in 1805 carried spars of colonial pine from New South Wales. Apart from export of shipping timbers, an indigenous shipbuilding industry developed based on both hardwoods and softwoods - mainly small coastal craft, but including whalers and whaleboats to service the local whaling industry; the Tasmanian industry in particular developed rapidly based on Huon pine (Dacridium franklinii) which quickly demonstrated its superiority as a boat-building timber. It survives on a smaller scale today. In 1886, the fledgling Tasmanian Forestry Department issued a Parliamentary Paper (No. 68), "Macquarie Harbour Pine and other timbers of the West Coast", no doubt in response to the demands for information on local timbers for the boat-building industry - surely one of the first documented examples of extension activities in Australia.

Formal study of forest products emerged in the latter two decades of the 19th century - the earliest paper I can locate is that of F.A. Campbell in 1880 in the Transactions of the Royal Society of Victoria on "Tensile strength of a few colonial timbers." This theme was taken up by Warren who published several papers from 1886 on the strength properties of various species. Phytochemical investigations also emerged at about the same time, with the papers of Maiden already alluded to, together with those of Lauterer in 1894. De Coque published on the Timbers of New South Wales in the Proceedings of Royal Society NSW also in 1894 and with Maiden, reported on the resistance of turpentine (Syncarpia laurifolia syn glomulifera) to marine borer attack in 1895.

The publication of monographs was stimulated by the Technological Museum of NSW. Technical Education Series became the vehicle for major treatises by Baker and Smith on the pines of Australia (1910), cabinet woods (1913) and hardwoods (1919). I find it particularly apposite to this conference, which is the first FPRC to consider the interaction between silviculture and wood properties, that Baker and Smith, from the outset, attempted to cover the botany, wood anatomy, chemistry and

timber properties of the species covered in their monographs, a feature which was lost to later writers who tended to specialise on either the silvicultural or wood technology aspects. For example, Swain (1928), Boas (1947), and more recently Bootle (1971, 1983) prepared detailed digests on the wood properties of several commercial timbers. Langlands and Thomas (1939) and Pearson Kloot and Boyd (1958) produced the only reference handbooks on structural timber design. Jacobs (1955) wrote the single extant reference on the silviculture of native eucalypt forests. Penfold and Willis (1961) and Hillis and Brown (1978) have attempted to present more comprehensive treatments covering the biology, silviculture, wood properties and production of eucalypts, but a closer integration of silvicultural influences on wood quality and utilisation parameters has yet to be written, although I prepared an overview recently (Bevege 1984) for plantation-grown species, and Bamber and Burley touched on the subject in their monograph on radiata pine (1983).

This brings me to the second theme I would like to pursue this morning, and that is this relationship between silviculture and product conversion and utilisation. One of the conclusions drawn from the CSIRO Executive Seminar 1983 on Forestry and Forest Products: Research Present and Future, was the need for "closer integration between forest research and product research to ensure forestry management grows wood with the characteristics and properties required by industry; at the same time, industry must recognise the real environmental and silvicultural constraints with which forest managers must operate, and not place unrealistic product quality demands upon them." To some extent, the way in which forestry and forest-products research are currently institutionalised hinders this integration. For example, while some forest services have research divisions which contain both elements, programmes still tend to be organised on disciplinary lines, although there have been attempts at closer integration in more recent times, e.g. in the small hardwood programme and the softwood tree improvement programme in New South Wales. Within

CSIRO, forest research and wood-based research are in separate Divisions (even in separate Institutes), but it is encouraging to see the emergence of programmes cutting across these traditional boundaries, e.g. the harvesting/primary conversion project for young even aged eucalypts and the injection of wood quality considerations into the genetics and breeding programmes with both eucalypts (e.g. E. obliqua provenance trials in Tasmania) and Pinus radiata (CSIRO Division of Forest Research 1981-83 and 1983-85 Biennial Reports). The New Zealanders have also gone a fair way down the track in characterising the wood properties of radiata pine grown over a range of sites and silvicultural regimes (Cown and McConchie 1983). Of great interest in this regard is the study recently completed by David Spencer of DFR, and reported to this conference, on the influence of clonal material on product outturn of veneer and sawn timber. The mill studies of Park (1985) and of Grant et al (1984) on influences of knots (pruning) on clearwood and structural grade recovery also provide the direction for the future in pointing to the very real influence silviculture can have on product quality and utility.

Further efforts are needed by both the forestry and forest products researchers to communicate and co-ordinate research programmes between the sectors. At the present time, institutionalised communication mechanisms which are in place such as Forest Products Research Advisory Panel (FPRAP), Forest Research Advisory Committee (FRAC), and the Directors of Research Committee (DORC) have no formal linkages, although there are some members common to two of these groups. The current review of forest-based industry research in Australia under the auspices of the Australian Forestry Council (AFC), and the initiatives of the Forest and Forest Products Industries Council (FAFPIC), hopefully will resolve this issue which involves communication, co-ordination, direction, priorities, resources and funding of integrated, nationally oriented research programmes. In formulating these programmes it is essential that forest managers in the user-industries be involved as well as the vested interests of the research

organisations. A role must also be found for operational research within the framework of industry itself to complement the basic and strategic research effort within the Government instrumentalities. The Joint Committees of FPRC could well have a role to play in ensuring adequate definition of research priorities or directions, given the close links established over the years between constituent researchers and their industry counterparts. A closer relationship between FPRC and FPRAP would also provide an appropriate mechanism for closer programme co-ordination and priority setting.

I would now like to turn to future directions within the forest products research sector itself. It must be of considerable concern to all of us here that certain structural moves currently in train point to the possibility of a diminution in capability and even of intent, at the very time when reviews are in train aimed at putting in place more appropriate mechanisms for research support. We should all be aware of the Federal Government intent to form a single Building Research organisation out of the existing CSIRO Division of Building Research (DBR) and the National Building Technology Centre (NBTC) within three years - whether this move results in a diminution of research resources only time will tell. However, given the noticeably reduced commitment of DBR to wood-based research (e.g. the current DBR Program of Research 1986-87 lists only 5 such programmes out of a total of 37, while the DBR Research Papers 1984 provides digests on only 9 wood-based projects out of a total of 121), this move may have an effect that is more apparent than real. Within its sister Division, Chemical and Wood Technology (DCWT) there remains a significant wood science and technology programme. One can only look forward to a closer integration of the activities of DCWT with the Division of Forest Research, and continued and closer co-operation with the wood technology groups within the forest services, particularly those of Queensland, New South Wales and Western Australia. There is a need to offset the diminishing human resources within the programme sectors of most of these organisations caused by retirement of experienced senior research staff - shared human

resources and associated skills must lead to closer programme co-ordination in future, accepting the possibility of some loss of institutional autonomy in programming as a result. However, if the review processes mentioned previously result in more nationally-oriented goals and across-institution agreement on priorities and funding formulas for projects of national significance, then resource-sharing should flow more naturally than is presently the case.

I would like to take as my final theme the role of researchers in extension and technology transfer. I have already indicated that, in my opinion, practice lags behind technology, the level of slippage being of the order of several years. This has been recognised by the Building Research and Development Advisory Committee (BRDAC). In its 1986 Report, while considering the building industry as a whole (over all materials), BRDAC indicated that "Many of the research needs identified point to a requirement for increased research effort or for improved information transfer rather than a need for new research directions." This point is reiterated by the industry group of FPRAP, which has identified research priorities in well defined areas of existing research effort - again increased activity and technology transfer appear to be the critical needs. This has been recognised by the Research Institutes, who put considerable effort into technology transfer activities as well as support for research projects whose need has been flagged by industry. The forthcoming Timber Design Handbook being produced by Australian Timber Research Institute (ATRI) is the major technology transfer initiative in the timber engineering field since PKB was published in 1958. This, together with the new Timber Engineering Code (Standards Association of Australia), the Uniform Building Code (Australian Uniform Building Regulations Co-ordinating Council) and initiatives in Computer Aided Design will form the framework (no pun intended!) for many years to come.

It behoves the timber industry to take advantage of the marketing opportunities which these initiatives will create, by

ensuring product availability and quality control and assurance. This in turn can only be achieved by application of existing research knowledge and technology - a critical role for the researcher over the next few years will be to sell the need to apply this available knowledge to industry with the resultant upgrading of mill and manufacturing practices. This will also require a change of attitudes of industry away from producing commodities to providing components and building systems - a further paradox at a time when the commitment to building research and timber engineering within CSIRO appears to be waning. Hopefully, however, this challenge will be taken up by the newly emerging timber engineering units within tertiary institutions such as NSW Institute of Technology, Chisholm Institute, Capricornia CAE etc .

A further negative influence to cloud the picture is the recent recommendation from the Bureau of Industry Economics (BIE 1986) to change the basis of funding of the Research Institutes - changes which may see the demise of the Institutes as we know them, and a diminution of their effectiveness as prime movers in tackling research projects of industry - wide significance and in marshalling the funds from their diverse sources to finance programmes beyond the capacities of individual State organisations or companies. It is to be hoped that the various industry groups will ensure appropriate arrangements are put in place to minimise the effect of reduced access to Federal funds so that hard-won ground and the initiatives so critical to the long term future of the industry are not lost.

In my opinion, the time is now appropriate for the Forest Products Research Conference and its Joint Committees to take an overview and determine the broad directions that research might take over the medium time span - say, next 10 years. Such a role could be wider than its traditional one of maintaining a somewhat narrow focus on immediate research activities and adopting an essentially reporting mode. This 22nd Conference, by its changed format, which aims to step back and assess progress across a number of fronts is, in my

opinion, moving in a direction which will enable it to provide a positive voice in the forums of the decision makers - it remains but for an appropriate mechanism to be devised, and Conference might consider this during the week or ask for recommendations from the Joint Committees. This 22nd Conference also, for the first time, forges links with forest researchers which can only be of mutual benefit to both groups. Ultimately, this should be reflected in closer programme integration between the two research sectors, to the further benefit of the forest and forest-based industries which they serve. An efficient, competitive, viable industry is the ultimate source of all funds for the research which underpins it, so the mutual-causal relationship between research and industry should be accepted as the paradigm for the future.

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REPORT OF THE WOOD PRESERVATION COMMITTEE

22nd Forest Products Research Conference

H. GREAVES, CHAIRMAN

During the two years since the 21st Forest Products Research Conference the Wood Preservation Committee (WPC) has met on three occasions: 18,19 March 1985 in Sydney; 11,12 November 1985 in Brisbane; and 28,29 July 1986 in Melbourne. Following these meetings, the WPC joined with representatives of the technical committees of the Timber Preservers Association of Australia and the New Zealand Wood Preservers' Association Inc. and the Timber Preservation Authority of New Zealand to hold two-day sessions of what has become known as the Joint Wood Preservation Committee (JWPC). This particular Committee is essentially concerned with research, technical, and commercial aspects affecting the preservation industry's operations. The idea was conceived at the 1971 FPRC and the first "joint" meetings were held in April 1972. As mentioned at our last Conference, the JWPC is probably unique in the preservation world in representing an interface between the researchers and the industry.

Membership of the WPC has been drawn from CSIRO, Division of Chemical & Wood Technology (Greaves); Forestry Commission of New South Wales, Wood Technology & Forest Research Division (Johnstone); Queensland Department of Forestry, Division of Technical Services (Leightley); Department of Conservation Forests & Lands, State Forests & Lands Service (Clifford); and New Zealand Forest Service, Forest Research Institute (Hedley/Vinden). Representation from the Office of Forests, PNG has not continued (although their membership is still open), but the Department of Forests, Fiji was invited to join the WPC, and their Principal Utilisation Officer, Mr A.S. Alston, attended his first meeting last July in Melbourne. Fiji has a small but active preservation industry with a treatment capacity of about 100 000 m^3/annum. The Utilisation Division of the Department of Forestry has traditional links with forest products research in Australia, and its preservation programme covers aspects of treatments for green timber, sapstain control and clear finishes testing. The WPC has thus extended its sphere of activity, and as such has become known as the Australasian Wood Preservation Committee.

The Melbourne meetings saw the retirement of Mr W.A. Clifford, who has served both WPC and JWPC for 21 years; he became Convenor of the WPC in 1976. On behalf of both the WPC and JWPC, his former Committee colleagues, and the Forest Products Research Conference, I would like to record our appreciation for his excellent services and wish him well in his retirement.

The topic headings set up as a framework for WPC/JWPC sessions following the May 1979 meetings, have continued to guide our work activities. The following table summarises the major agenda items of the three meetings.

Topic	Sydney		Brisbane		Melbourne		Total
	WPC	JWPC	WPC	JWPC	WPC	JWPC	
Preservatives	7	6	5	5	2	3	28
Treatment Processes	8	5	5	2	2	1	23
Remedial Treatments	1	1	0	0	0	0	2
Biodeterioration	2	1	1	0	3	2	9
Field Testing	7	6	10	9	5	6	43
Laboratory Testing	7	5	2	2	6	2	24
Commodities							
Posts	0	0	1	1	0	0	2
Poles & Piles	2	2	9	8	2	1	24
Sleepers	0	0	1	0	0	0	1
Building Timbers	3	2	2	2	2	4	15
Panel Products	0	0	0	0	2	1	3
Quality Control, Standards, Legislation	5	7	6	9	2	4	33
Environmental Plant Hygiene, Safety	2	1	0	2	0	0	5
Information	3	1	2	0	4	3	13
Miscellaneous	1	0	1	1	1	0	4
Total	48	37	45	41	31	27	229

It will be seen that preservative formulation and testing work occupied a high proportion of the WPC time. Antisapstain chemicals received a deal of attention, and the AAC situation in New Zealand was discussed. Emulsion formulations - PEC family, permethrin-containing emulsions, and water-based organotins - are being researched at CSIRO and FRI. It is interesting that a great deal of attention, world-wide, is currently focussed on developing emulsion-based preservatives, especially in regard to metal soaps, organotin formulations, and synthetic pyrethroids. Research on treatment processes has concentrated on LOSP schedules, particularly in New Zealand, and the effect of steam and moisture content on penetrability; in this context, radiata pine heartwood permeability was of concern.

Both the WPC and JWPC meetings have discussed the difficulties associated with revising AS 1604 in terms of the NSW Timber Marketing Act (TMA), the Queensland Timber Users Protection Act (TUPA) and trans-Tasman unification. The problem of defining hazard levels for treatment has been worked out in Committee, with all agreeing to six defined hazard classes:

H1	Fully protected from the weather. Well ventilated. No termite hazard	Borer attack	Framing, interior joinery
H2*	Partially protected from the weather. Nil to slight leaching	Borer, termites, some decay	Flooring, in damp interior situations
H3	Outdoors, above-ground. Subject to periodic wetting	Decay, borers, termites	Weatherboard, fence palings, decking
H4**	Ground contact. Non-tropical exposure conditions	Decay, termites, borers	Posts, crib walls
H5	Ground contact. Severe hazard, e.g. tropical exposure	Decay, termites, borers	Poles, retaining walls, cooling towers
H6	Marine exposure	Marine borers	Jetty construction, landing steps, piles

* Reserved category in New Zealand and under TUPA
** Reserved category under TUPA

In addition to agreeing on common hazard categories, the JWPC was able to set out retention requirements for LOSP treatments, which, like the hazard classifications, will be incorporated into the long-awaited AS 1604 revision. The figures, while not necessarily being taken directly from any one set of data, were arrived at within Committee, and take into account CSIRO laboratory bioassays, FCNSW field work, FRI data and overseas experience:-

	Individual Retentions (kg/m^3)			
	Copper naphthenate*	Copper 8-quinolinolate*	TBTO	PCP + TBTO
H2	0.5	0.5	0.6	1.2 + 0.3
H3	0.5	0.5	1.0	2.0 + 0.5

* As elemental copper

Much of the JWPC work was concerned with standards, State Acts, etc., and the table of agenda topics shows that in this area the industry representatives brought forward more items for Committee consideration than did the research members. This is to be expected, but on only five occasions did industry through the JWPC contribute items not already dealt with by WPC at their meetings. In other words, JWPC meetings have tended to be one-way information sessions, and I would like to record my view that industry should be bringing more R&D items to future meetings.

In concluding this report, it is clear that WPC meetings - now Australasian-based - are fulfilling the requirements under which they were set up, i.e. "to deal with matters which would otherwise overload the agenda of the Forest Products Research Conference" (Tamblyn in Proceedings of the 15th FPRC, 1971). In addition WPC meetings provide a forum for research planning as well as results exchange while the JWPC offers the possibility for practical R&D input of potential benefit to the preservation industry in the Australasian region.

H. Greaves
Chairman

REPORT OF FIRE RESEARCH COMMITTEE

by R.H. Leicester

INTRODUCTION

The primary activity of this committee comprised a two day meeting in Sydney on 10-11 July 1986. The first day was devoted to an extensive discussion related to research, commercial and regulatory aspects of fire as it affected timber construction. On the second day field visits were made to Elders No. 3 Building, Ultimo and the Wharf Theatre, Darling Harbour; these buildings included exposed timber structures that were fire resistance rated up to two hourse.

The following are brief comments on some of the topics discussed during the first day of the meeting.

EARLY FIRE HAZARD

A summary of the fire retardant industry by Karl Schmalzl indicated that there are currently five retardants used in Australia, with a total annual output of about 1000 tonnes. This is used primarily for door

skins, and to a lesser extent for poles and wall panelling. Inadequate quality control is still a fundamental difficulty in the retardant industry.

WTFRD are currently involved in sponsoring an extensive set of room burn tests on wall linings comprising many of Australia's more commonly used timbers. The tests are being undertaken in the USA.

STRUTURAL PERFORMANCE

The draft AS 1720-Part 4, the design of fire resistance for timber structures appears to be workable, but better data on the charring rates of common construction timbers would appear to be warranted. On the basis of this draft, the structures of several old buildings, including the Elders No. 3 building mentioned earlier have been successfully accepted for specified fire resistance ratings.

BUILDING REGULATIONS

The AMUBC, which contains administrative requirements, is soon to be replaced by the UBC which has a design code format. It is also likely that the criteria of the current AMUBC will be modified.

The ATRI is currently sponsoring an extensive examination of the new UBC; it would appear that this code will cover situations in which fire resistance rated timber constrution will be accepted. In another interesting project the NSWIT is studying the relationship of non-

combustibility and fire resistance with a view to affecting modifications concerning the non-combustiblity requirements in the UBC.

BUSHFIRE RESISTANCE

Investigations of damage following bushfires indicates that while smooth timber cladding does not add to the hazard, timber decking and stumps are certainly attacked in a bushfire and may possibly contribute a significant hazard. However to date this has not been proven statistically, and building regulations do not recognise any danger.

CONCLUDING COMMENT

A discussion on the future role of the Fire Research Committee remained unresolved. If it continues, one role could be to act as a coordinating body for discussions on research aimed at modifying the UBC reulations concerning the use of timber in buildings.

APPENDIX

The June meeting of the Fire Research Committee was attended by John Carson (ATRI), David Gardner (WTFRD), David Gough (QFD), Stephen Grubits (NBTC), Alan Halligan (APRI), Chris Hornsby (NBTC), John Keith (TDA, NSW), Bob Leicester (DBR, CSIRO), Colin McKenzie (TRADAC), Caird Ramsay (DBR, CSIRO), Karl Schmalzl (DCWT, CSIRO), Garry Truswell (Truswell and Assoc).

REPORT of the JOINT TIMBER SEASONING COMMITTEE

to the 22nd Forest Products Research Conference

for the period November 1984 to November 1986

MEETINGS

Two meetings have been held since the 21st Conference on;

28 February 1985 at Canberra

Ms Wendy Parsons of CSIRO Division of Forest Research described to the Committee the program of research of the Division, which kindly provided facilities for the meeting.

and

4 March, 1986, at Tullamarine

The structure and operations of the Timber Industry Training Committee Network was discussed by Mr Peter White. This was very helpful to our discussions on training.

The meeting format has evolved to incorporate short presentations from each member covering his work and concerns, together with discussion of agenda items which have been proposed by members.

The next meeting of the Committee will be held at Clayton on;-

21 November, 1986, at 9.00am

MEMBERSHIP

Current committee members are listed on the last page of this report.

The membership covers all major industry sectors and the various research bodies, in particular;-

- State Forest Service Laboratories
- CSIRO Division of Chemical and Wood Technology
- Timber Industry Associations
- Timber Industry representation through individuals responsible for drying activities of representative companies

Members who have retired since the 21st Conference are:-

Mr. G.S. Campbell
Dr. W.E. Hillis
Mr. B.A. O'Brien
Mr. B.L. Rumball

Members of the Committee were saddened by the death of Mr. John Ibell who contributed much to discussions while a member.

New members of the Committee are:-

Mr J. Dunstan
Mr J. Ilic
Mr R. McKimm
Mr P. Shedley

ROLE OF JTSC

The role and effectiveness of the JTSC has been the subject of debate over recent years, both from within and outside.

The JTSC at its meeting on the 28th February 1985 addressed this subject and redefined its objectives.

The objectives of JTSC are:

1. Establish and maintain communication links between researchers in the various government organisations, industry association researchers and other industry reseachers to facilitate the exchange of information, data and results, with particular attention to perceived needs of industry.

2. Engender and facilitate communication between researchers and industry.

3. Summarize the general state of knowledge in the area of seasoning and relay this information back to the Forest Products Research Conferences.

4. Assist the promotion of adequate training and education in the field of timber seasoning at three levels -

   - Management
   - Technologists
   - Operators

The Committee also discussed possible ways and means of widening Committee activities in order to improve its role and effectiveness.

The Committee resolved to regularly submit a summary of its discussions to the Australian Forest Industries Journal for publication. The first such item appeared in the April 1985 issue and the second in the August 1986 Issue.

It is difficult to gauge the effectiveness of such items. Only a few contacts identified as having been prompted by either of these items have been received by the Secretary.

Forest Products Research Advisory Panel (FPRAP)

One means of improving the effectiveness of JTSC involves establishing a communication link with FPRAP on matters relevant to timber seasoning etc.

Specifically, this link is seen to embrace the following:-

Forwarding minutes of JTSC meetings to FPRAP

FPRAP referring to JTSC for advice on seasoning matters when deemed appropriate. This advice would take the form of position papers and/or recommendations on research needs.

A proposal to this effect was prepared by this Committee and submitted to FPRAP and considered at their meeting in December 1986.

FPRAP has responded positively to this initiative and the Committee expects that this link will be developed to the benefit of both bodies and, more importantly, of the industry.

Forest Product Research Conferences

JTSC will, of course, continue to report to the FPRCs as it has done since its formation.

In addition to having this relationship with FPRAP, JTSC intends to further develop its role as the national advisory body on aspects of seasoning and wood moisture content, and through sub-committees address particular subjects such as the following examples:-

Methods of testing the moisture content of timber.

In Australian Standards, in particular those relating to the use of timber in buildings, furniture etc. work to ensure that the moisture content specified is adequately related to the equilibrium moisture content of wood in service environments.

Ensure that knowledge of the most appropriate drying schedules for species, equipment, end use etc. ia available to industry and that these schedules are used effectively.

IMPORTANT ISSUES

Several issues which were mentioned in the report of the Committee to the 21st Conference are still of concern, e.g.

Utilisation of Young Pine

Small eucalypts

In both these cases the problems are broader than drying alone and are addressed by this Conference.

RECOMMENDATION

The Committee believes that it continues to perform a valuable role as a forum for exchanging information between research workers and industry. This is essential for stimulating sound and relevant research and for ensuring that research results are made available to industry. The Committee recommends that it continue.

JOINT TIMBER SEASONING COMMITTEE MEMBERS

Mr R.J. Adams
Bunning Bros. Pty Ltd W.A.

Mr W.J. Atyeo
Commercial Division, Woods & Forests Dept S.A.

Mr J. Carson
Australian Timber Research Institute

Mr F.J. Christensen
CSIRO Division of Chemical & Wood Technology

Mr J. Dunstan
A Dunstan and Sons and Victorian Sawmillers Association

Mr D.K. Gough, Chairman
Queensland Department of Forestry

Mr J.N. Hartley
Forestry Commission of NSW

Mr A.C. Hogarth
Boral Timber Division N.S.W.

Mr R.L. Hyne
Hyne & Son Pty Ltd Qld.

Mr J. Ilic
CSIRO Division of Chemical & Wood Technology

Mr R. McKimm
Department of Conservation Forests and Lands Vic.

Mr R.L. Northway, Secretary
CSIRO Division of Chemical & Wood Technology

Mr P. Reed
Radiata Pine Research Institute

Mr R. Schaffner
Tasmanian Timber Promotion Board

Mr P. Shedley
Department of Conservation and Land Management W.A.

Report of the Structural Timber Evaluation Committee (STEC) - November 1986

W.G. Keating, Convenor

STEC has not met as a committee in its own right since the 1984 conference but it has continued to be active as part of the relevant Standards Association Committee. Such a development was indicated in the previous report.

The main item of interest is that Australian Standard 2878 - 1986, Timber - Classification into Strength Groups, has now been issued. This revision of SAA MP45 - 1979 is a major reference document containing as it does a tabulation of the strength grouping, in both the green and dry condition, for over 600 Australian and 60 imported species. It will be recalled that the assessment for those species that make up the bulk of commercial consumption is made on the basis of a series of small clear laboratory tests. This leaves a smaller volume but much larger number of species for which test data, apart from density, was not available. Although very few of the individual species within this group comprise a significant proportion of the total usage it is often critical that an indication, at least, of their strength grouping be available. An assessment technique based on density is described in the Standard and those species assessed in this way are clearly indicated. By necessity the technique is most conservative but it does allow many species that might not be utilised to be now used with confidence.

The question of imported NZ radiata pine mentioned in our 1984 report took up a considerable amount of discussion time. The committee needed to be convinced that the most recent sampling, testing and data analysis of NZ radiata pine has been in accordance with the procedure required

for a major Australian species and that the results justified the rating.

In a similar situation the assessment of Douglas fir imported from the west coast of North America was also closely examined. From reports and recent changes to engineering codes in USA and Canada respectively, the indications were that the younger, smaller Douglas fir material currently being imported sawn to size may not possess the same structural properties as the older material cut from big trees that traditionally has been received in Australia in large baulks. The SAA technical committee met with Dr. Henry Montrey, Deputy Director, USA Forest Products Laboratory, and Professor Dave Barrett, University of British Columbia, and following further discussion a slight modification was made to the Douglas fir entry in the Standard to indicate the doubts being raised. However, a recommendation was made to the SAA committee preparing the combined softwood standard that cognizance be given to the in-grade test results for Douglas fir becoming available from North America.

The issue of AS 2878 probably marks the beginning of the end of the small clears era in Australia. In accordance with world-wide trends in-grade testing is likely to be the preferred way of assessing the appropriate stress grade combined with visual grading for the major species, at least, in the future. However, as the amount of testing involved is substantial the transition process will be slow. In the meantime it has been suggested that current sampling and resource monitoring techniques used with small clear testing be upgraded to take account of the relative consumption volumes of the individual species.

The present composition of the STEC committee is as follows:

W.G. Keating, Convenor Dr. P.U.A. Grossman	CSIRO Division of Chemical and Wood Technology.
Dr. R.H. Leicester	CSIRO Division of Building Research.
D.J. Grant	NSW Forestry Commission.
W. Kyanston	Queensland Department of Forestry.
Dr. G. Siemon	WA Forests Department.

POSTER INDEX

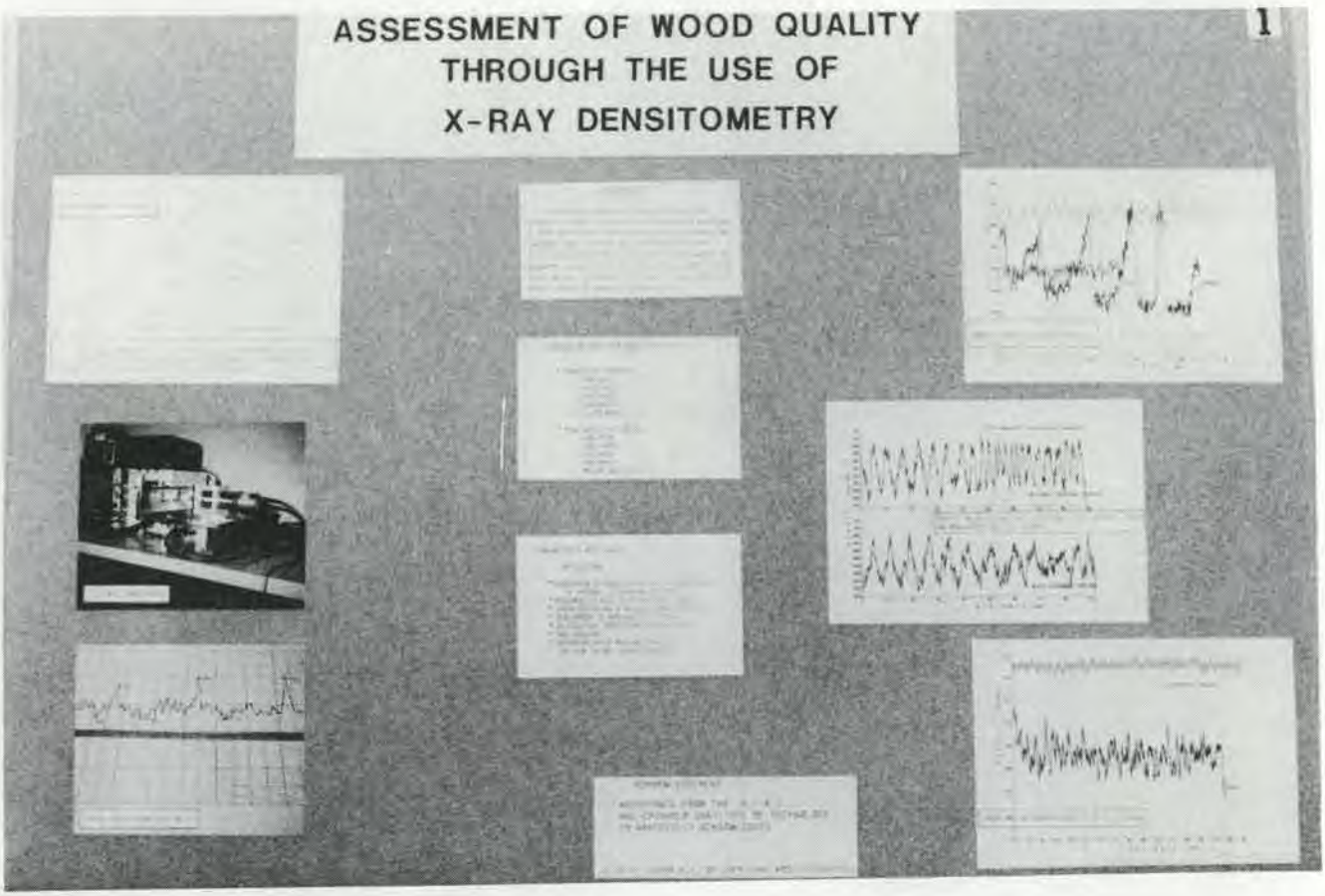
Poster Number	Title	Author(s)
1	Assessment of Wood Quality Through the use of X-ray Densitometry	J. Ilic
2	The Morphology of Collapse in *Eucalyptus* spp.	A.P. Wilkins J.F. Wilkes
3	Relationship Between Toughness and some Wood Anatomical Properties in *Eucalyptus pilularis*	A.P. Wilkins M. Ghali
4	'Type a Bond' Adhesives from *Pinus radiata* Bark	Y. Yazaki P.J. Collins
5	Density of Radiata Pine in the Central Highlands of NSW	J. Wilkes
6A	Developing Termite baits for the Protection of Timber in Service	J.R.J. French P.J. Robinson
6B	Wood Preservation in the Australian Bee Keeping Industry	P.J. Robinson J.R.J. French
7	Heartwood Development in Queensland Plantation Conifers	K.J. Harding
8	Connectors in Juvenile and Defective Wood	E.P. Lhuede S. Towstoless
9	Shrinkage of Queensland Timbers	K.J. Harding
10	Two Piece Softwood Rail Sleeper	P. Shedley J. Syers
11	The Use of Low Cost Analyzers in the Timber Preservation Industry	J. Norton L.E. Leightley D. McIntosh
12	*Glyptotermes tuberculatus* Froggatt (Isoptera:Kalotermitidae and Some Associated Wood Inhabiting Fungi	R.H. Eldridge J.A. Simpson
13	A Novel Method for Evaluating Water Repellent Preservatives	A.R. Moffat
14	Performance of Particleboard Flooring in a Moist Environment: Structural Stability and Biodeterioration	J.A. Simpson W.D. Gardner
15	Chemical Differentiation of Heartwood and Sapwood in *Araucaria cunninghamii*	L.E. Leightley R.I. Davis

17	A Revised Method for Field Assessment of Railway and Sugar Cane Tramway Sleeper Trials	M.L. Cause A.R. Moffat
18	Electronic Stress Grading	P.J. Moglia
19	The Evaluation of Above Ground Durabilities for a Range of Timbers and Sites in Eastern Australia	M.L. Cause
20	CSIRO Continuous Feed Timber Kiln	F.J. Christensen R.L. Northway
21	Wood Fibres in Plaster	R.S.P. Coutts
23	Development and Commercial Application of Maintenance Procedures for the Protection of Wooden Poles from Biological Deterioration	C. McEvoy K. McCarthy
24	Development and Evaluation of Candidate Wood Preservatives with Improved Environmental Acceptability	C. McEvoy K. McCarthy
25	Inspection Techniques for Detecting Ground-Line Defects in Wooden Poles	C. McEvoy K. McCarthy
27	Assessment of Percent Wood Failure Using the Video Image Processor	W. Atyeo
28	Young Eucalypt Program: Sawn Timber Production	A. Rozsa
29	Assessment of Fire Damage in Regrowth Forests using Remote Sensing Techniques	R. Smith P. Woodgate

EXIT

THE POSTER SESSION WAS

WELL ATTENDED


ASSESSMENT OF WOOD QUALITY
THROUGH THE USE OF
X-RAY DENSITOMETRY
1

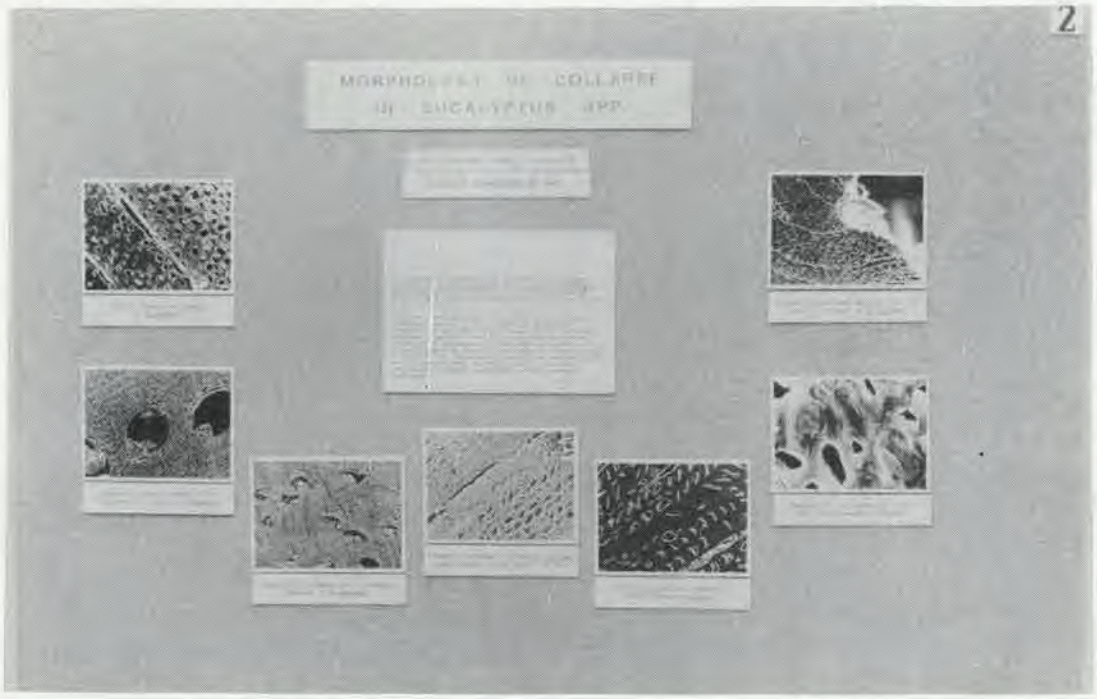
POSTERS/011286

POSTER NO. 1

ASSESSMENT OF WOOD QUALITY THROUGH THE USE OF X-RAY DENSITOMETRY

J. Ilic

A continuous scanning x-ray densitometer has been developed to enable the assessment of microdensity variations of wood from 2 mm thick wood cores machined from standard 5 mm increment cores. Some ideas are presented for the application of these techniques for the study of wood quality in hardwoods. These include earlywood/latewood relationships, and the distribution of moisture. Typical examples of density traces are shown for several species.


2

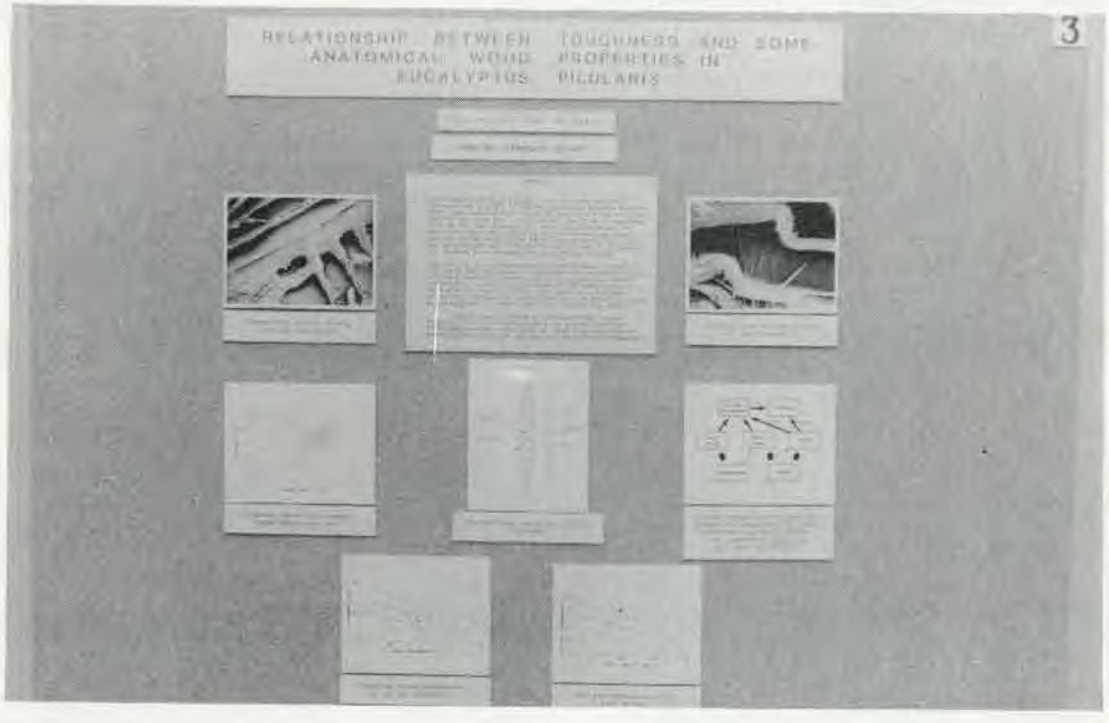
POSTER NO. 2

THE MORPHOLOGY OF COLLAPSE IN *EUCALYPTUS* SPP.

A.P. Wilkins and J.F. Wilkes

The anatomy of collapse was examined in Eucalyptus bancroftii, E. macrorhyncha, E. nitens, E. oreades and E. pilularis. Dry wood blocks were satisfactorily prepared for scanning electron microscopy using a steel microtome knife.

Collapse appeared to be restricted to fibres and to occur principally in the tangential direction. Proximity to ray parenchyma or vessels may influence both the propensity of a fibre to collapse and the direction of collapse. Collapse did not result in obvious damage to the wall structure of either fibres or other cells, (vasicentric tracheids, vessels, axial and ray parenchyma), although other cells were sometimes distorted in response to the stresses developed.


RELATIONSHIP BETWEEN TOUGHNESS AND SOME ANATOMICAL WOOD PROPERTIES OF EUCALYPTUS PICOLARIS
3

POSTER NO. 3

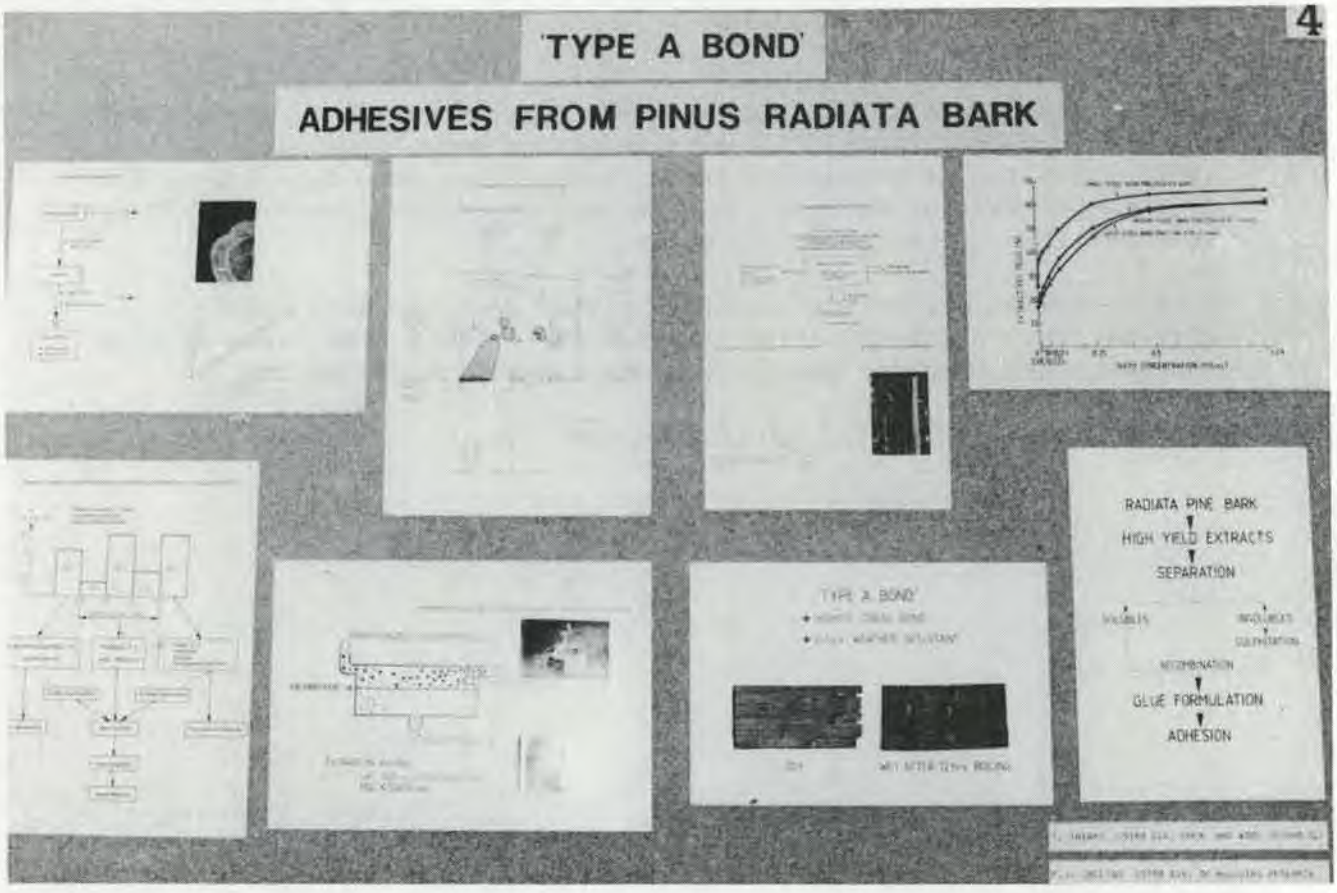
RELATIONSHIP BETWEEN TOUGHNESS AND SOME WOOD ANATOMICAL PROPERTIES IN *EUCALYPTUS PILULARIS*

A.P. Wilkins and M. Ghali

Wood samples of *E. pilularis* were divided into two experimental groups. Group one contained sixteen samples which were removed from three 55 year old trees. Group two consisted of 450 samples taken from five trees from each of the age classes: 25, 40 55 and 70 years. In group one the number of cell wall deformations (slip planes) in the wood fibre cell walls adjacent to rays was recorded at ray cell positions 1, 2 and 3. Toughness and density were measured in both group one and group two samples.

Significant interrelationships exist between toughness, cell wall deformations inn the fibre wall adjacent to the marginal ray cell and density in *E. pilularis*. Closer correlations were found between all of these variables in individual trees, rather than when data from all trees was combined. No relationships were found in fibre walls adjacent to other than the marginal ray cells.

Wood toughness may be influenced by either density, cell wall deformations or a combination of these two factors. The level of wood toughness may be under genetic control and influenced by the environment.


4
'TYPE A BOND'
ADHESIVES FROM PINUS RADIATA BARK
RADIATA PINE BARK
HIGH YIELD EXTRACTS
SEPARATION
GLUE FORMULATION
ADHESION

POSTER NO. 4

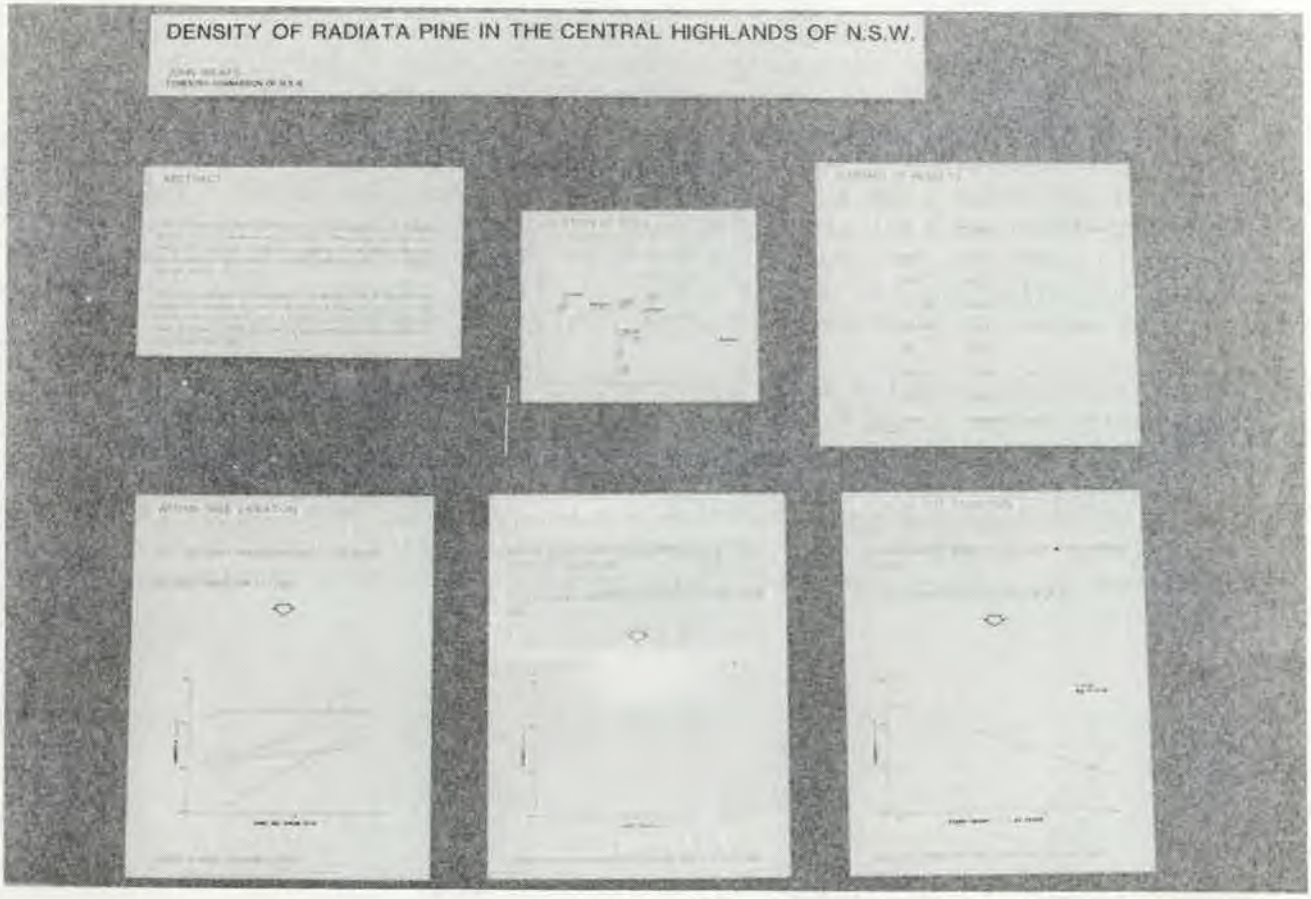
'TYPE A BOND' ADHESIVES FROM *PINUS RADIATA* BARK

Y. Yazaki and P.J. Collins

Due to increasing timber demand and the diminishing of large-diameter logs of high quality, the manufacture of reconstituted wood products offers a viable and more efficient alternative for the utilization of forest resources. This requires adhesives for such products as particleboard, plywood and so on. At present, the Australian reconstituted wood industry is paying approximnately $30 million per annum for the adhesives which are derived from non-renewable resources.

Radiata pine (*Pinus radiata* D. Don), the most important softwood in Australia, generates increasingly larger quantities of bark residues. This bark contains significant amounts of polyphenols useful as a basis for water-proof and durable adhesives. The amount of bark available could provide more than twice the amount of adhesives presently being used in the Australian reconstituted wood industry. Two factors which prevent the industrial use of bark extracts as adhesives are excessive viscosity and variability of the extracts. To overcome these problems, ultrafiltration methods were initially developed. However, high costs are the major disadvantage of the methods at present.

A recent study revealed that approximately 20-25% of extracts are not soluble in water at pH 6 and that the insoluble components are highly polymerized procyanidins. These insolubles are equivalent to the highest molecular size fraction obtained by the ultrafiltration methods. Based on these findings, simple processes for producing extracts which have an acceptable viscosity and which provide high and uniform quality adhesives have been developed. These processes have been provisionally patented.


DENSITY OF RADIATA PINE IN THE CENTRAL HIGHLANDS OF N.S.W.

POSTER NO. 5

DENSITY OF RADIATA PINE IN THE CENTRAL HIGHLANDS OF NSW

J. Wilkes

As part of a broader assessment of the wood properties of *Pinus radiata* in NSW, an analysis of variation in density in the Bathurst Region is presented. From 10 mature trees on each of 8 sites covering a wide range of soil types and climate, a diametral strip was taken at stump height. Extracted wood density was determined at 2 positions - inner wood (rings 1 - 4, 5 - 8), and outer wood (rings 20 -24, 25-28).

The centrifugal increase in density from juvenile to mature wood of pine was confirmed. More noteworthy were the between-tree (genetic) and between-site (geographic) effects, often >20%. These variations appear to relate in part to differences in rate of growth. No clear effect of climate was apparent. A fuller analysis will be possible when results become available for other sites across the state.

DEVELOPING TERMITE BAITS FOR THE PROTECTION OF TIMBER IN SERVICE

Decay in dovetail joints

WOOD PRESERVATION IN THE AUSTRALIAN BEEKEEPING INDUSTRY

Hot wax bath

A section from a super with severe decay

POSTER NO. 6A

DEVELOPING TERMITE BAITS FOR THE PROTECTION OF TIMBER IN SERVICE

J.R.J. French and P.J. Robinson

Research continues in order to refine effective and more environmentally safer substitutes for organochlorines and arsenicals against subterranean termites in protecting timber in service. Baiting natural termite colonies of *Coptotermes lacteus* in the Boola Boola State Forest in central Gippsland, and then modifying these procedures for in and around buildings has led to the present state of development. The main objective is to offer the pest controller and building-owner an alternative control method against subterranean termites. This is crucial, particuarly where residents in buildings require an almost insecticide-free environment.

Concurrent experimentation in the field and built-environment are deemed essential in this protection service.

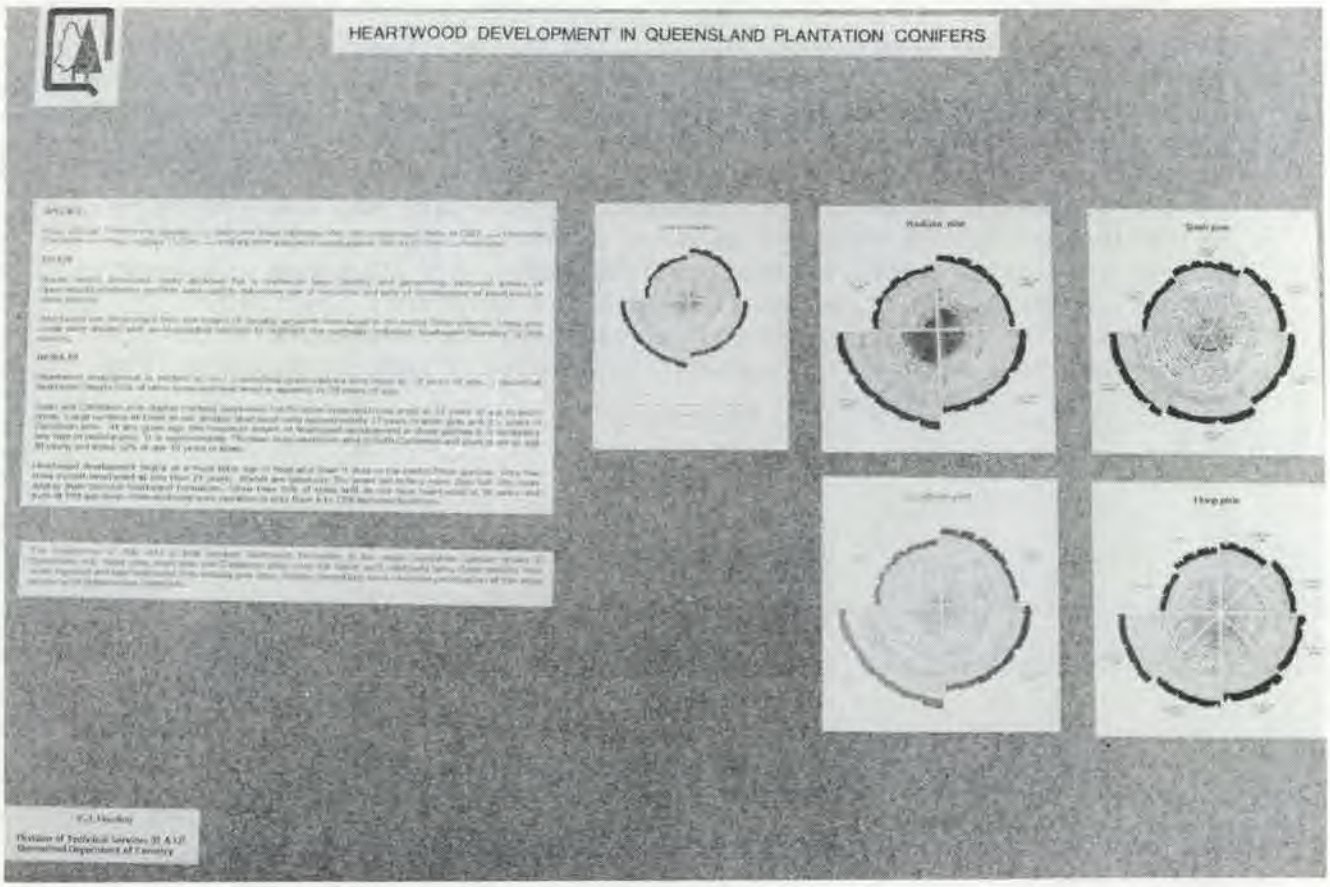
POSTER NO. 6B

WOOD PRESERVATION IN THE AUSTRALIAN BEE KEEPING INDUSTRY SURVEY JUNE/JULY 1985

P. Robinson and J. French

Australian apiarists produce, on average, between 30 - 40,000 tonnes of honey per year, of which, approximately half is exported. Export earnings in 1984-5 are estimated to be approximately US$12 million - 2 to 6 per cent of the world honey trade. Other bee products, pollen, beeswax and queen bees provide additional income to apiarists. The indirect benefit of bees to rural and farming industries from crop pollination has been conservatively estimated at $400 million.

In Australia, there are approximately 600,000 bee hives, most of which are constructed from softwood, particuarly radiata pine. A variety of 'do-it-yourself' wood preservative systems are used, including various paints, oils, waxes and stains. In response to requests from several Victorian apiarists for information on suitable bee box wood preservatives, a survey of 947 commercial apiarists was undertaken by CSIRO primarily to obtain information on the wood preservatives and paints used, their application, and the prevalence of decay and termite damage. Apiarists working 200 or more hives were sent a survey questionnaire. This group (7%) on average own approximately 70 per cent of Australian bee hives. Subsequently, completed returns numbered 386 (44%).


HEARTWOOD DEVELOPMENT IN QUEENSLAND PLANTATION CONIFERS

POSTER NO. 7

HEARTWOOD DEVELOPMENT IN QUEENSLAND PLANTATION CONIFERS

K.J. Harding

SPECIES

Pinus elliottii Engelm var. *elliottii* ..... slash pine; *Pinus caribaea* Mor. var. *hondurensis* Barr. et Golf. ..... Honduras Caribbean pine; *Pinus radiata* D. Don ..... radiata pine; *Araucaria cunninghamii* Ait. ex D. Don ..... hoop pine.

STUDY

Breast height increment cores obtained for a statewide basic density and percentage latewood survey of Queensland's plantation conifers were used to determine age of initiation and rate of development of heartwood in these species.

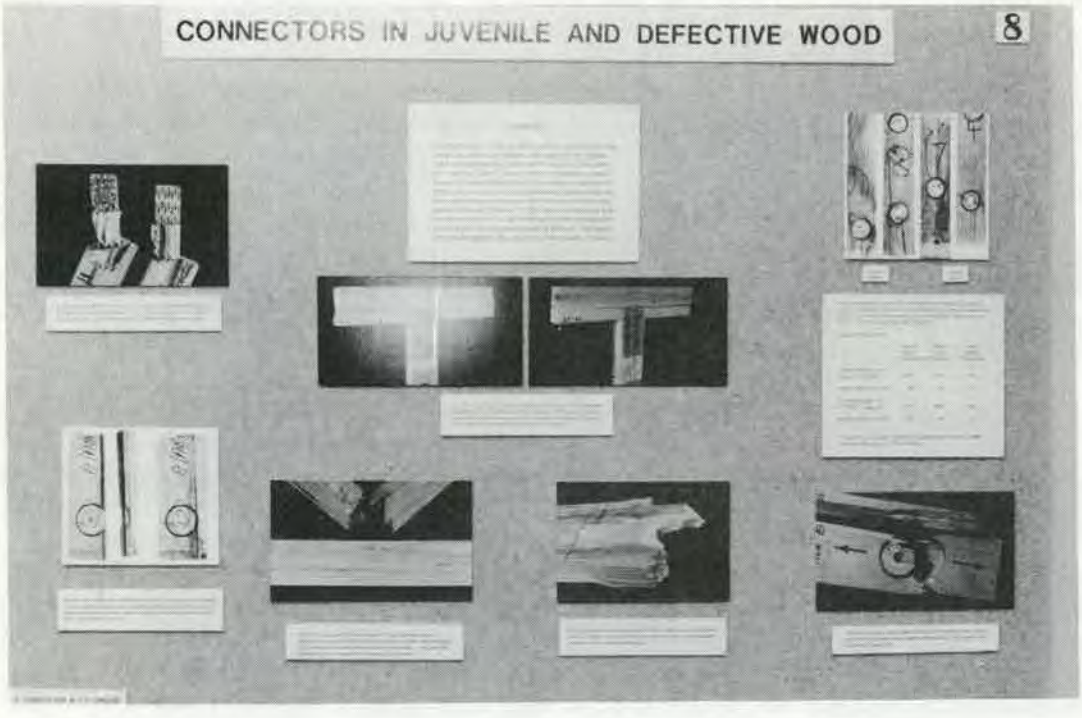
Heartwood was determined from the extent of visually apparent heartwood in the exotic *Pinus* species. Hoop pine cores were stained with an O-anisidine solution to highlight the normally indistinct heartwood boundary in this species.

RESULTS

Heatwood development is evident in most Queensland grown radiata pine trees by 12 years of age. Substantial heartwood (nearly 20% of stem cross-sectional area) is apparent by 30 years of age.

Slash and Caribbean pine display minimal heartwood (<0.5% stem cross-sectional area) at 12 years of age in some trees. Large numbers of trees do not develop heartwood until approximately 17 years in slash pine and 20+ years in Caribbean pine. At any given age, the maximum extent of heartwood development in these species is considerably less than in radiata pine. It is approximately 7% mean cross-sectional area in both Caribbean and slash pines at age 30 years, and about 12% at age 50 years in slash.

Heartwood development begins at a much later age in hoop pine than it does in the exotic *Pinus* species. Very few trees exhibit heartwood at less than 25 years. Stands are generally 30+ years old before more than half the trees display even minimal heartwood formation. More than 10% of trees still do not have heartwood at 48 years and even at this age mean cross-sectional area variation is only from 6 to 12% between localities.


CONNECTORS IN JUVENILE AND DEFECTIVE WOOD
8

POSTER NO. 8

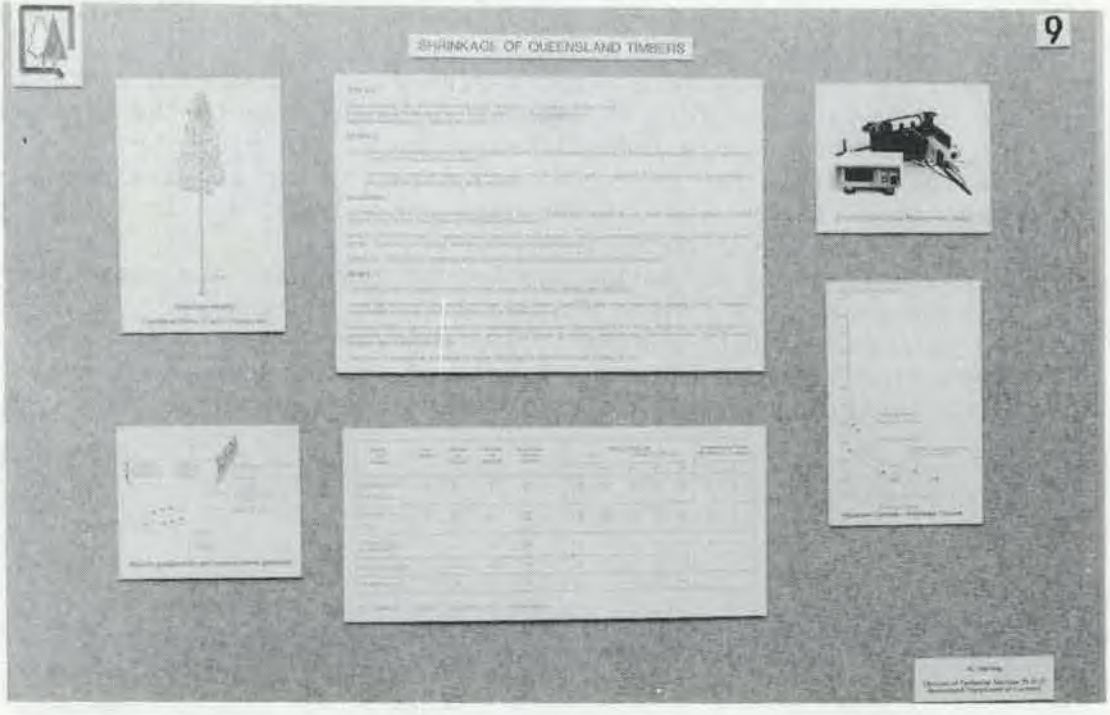
CONNECTORS IN JUVENILE AND DEFECTIVE WOOD

E.P. Lhuede and S. Towstoless

Connector loads in wood are determined by standard tests using defect free timber of a density range typical of the species. These pre-requisites may not be met in practice or even under test conditions where a careful selection of material is made; load capacities are generally reduced, with non-typical failure modes.

A series of photographs and tables will describe some of these failures as listed below:

1. Juvenile radiata pine, can be machine stress graded to an acceptable (F5) structural grade, but its density is low and non-typical failures of tooth plate connectors have been encountered on the pith included face.
2. Low density softwoods (e.g. Spruce-Pine-Fir) joined with tooth plate connectors may fail in tension perpendicular to the grain at loads below the tooth withdrawal capacity of the plate.
3. Hardwoods cut from the centre of relatively young trees where heart degrade (i.e. decay) has not advanced can exhibit non-typical, tensile failures near connectors.
4. Internal defects in hardwoods may not be apparent, and connectors used near these (e.g. shear plates) fail at low loads.
5. Tests with 67 mm shear plates in low density (non-pith-included) radiata pine showed a high percentage of failures due to a non-typical tensile fractures at relatively low loads.


SHRINKAGE OF QUEENSLAND TIMBERS
9

POSTER NO. 9

SHRINKAGE OF QUEENSLAND TIMBERS

K.J. Harding

SPECIES
Pinus caribaea Mor. var. *hondurensis* Barr. et Golf ..... Honduras Caribbean pine; *Callitris glauca* R. Br. ex R. Baker & H.G. Smith ..... white cypress pine; *Neorites kevediana* ..... fishtail silky oak.

MATERIAL
CARIBBEAN PINE - representative 17 and 23 year old stands were sampled at two major plantation area: Byfield (Rockhampton) and Tuan/Toolara (Maryborough/Gympie).

WHITE CYPRESS PINE - mature wood specimens were obtained from representative sample trees pooled from three areas: Barakula (Chinchilla), Western Creek (Millmerran) and Inglewood.

FISHTAIL SILKY OAK - samples were obtained from the Atherton region of North Queensland.

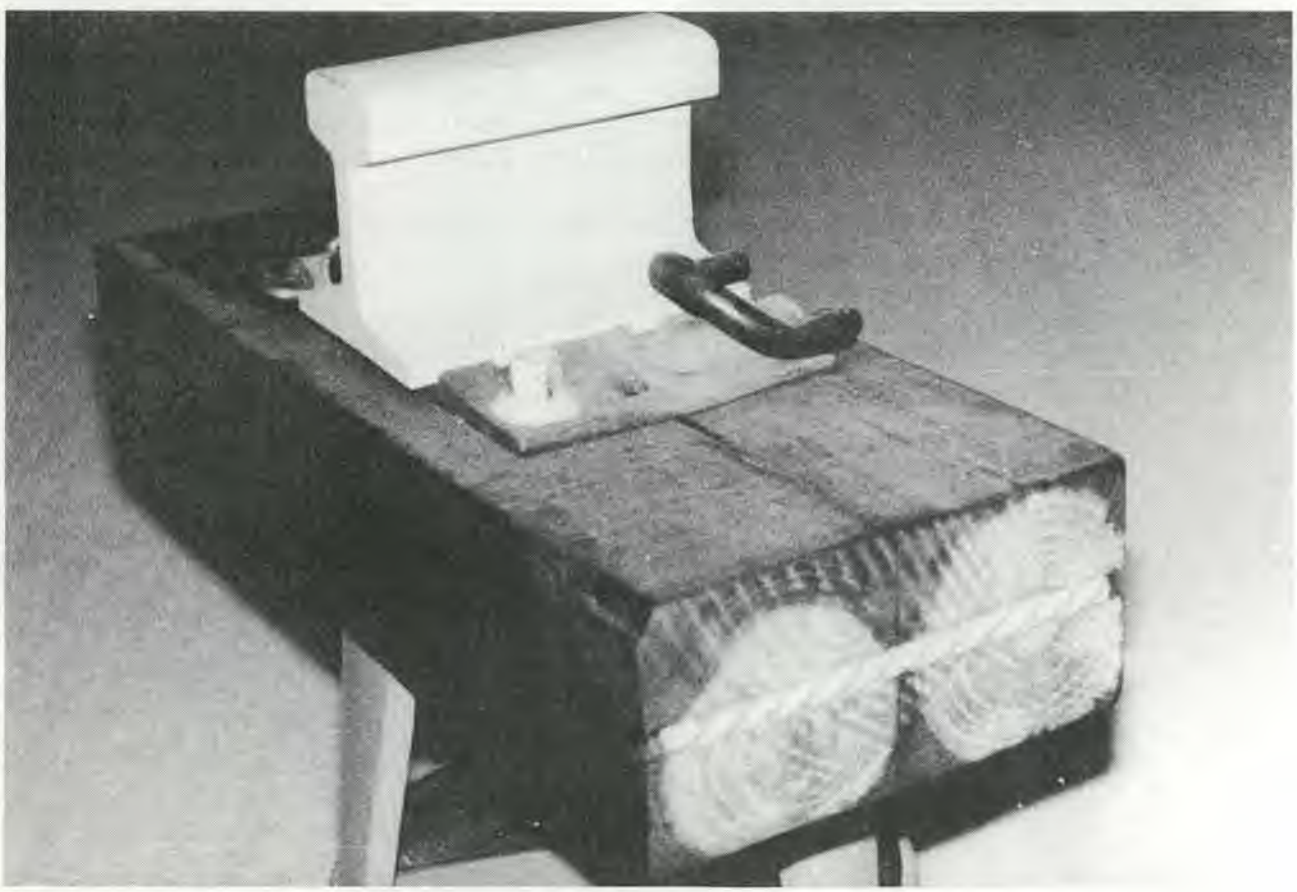
RESULTS
Caribbean pine shrinkage is similar to that of slash pine (*Pinus elliottii* var. *elliottii*).

Values for radial and tangential shrinkage of the juvenile wood are less than those for mature wood. However, longitudinal shrinnkage close to the pith is 2 to 3 times greater.

Previous CSIRO results, published for Queensland grown white cypress pine (DFP Tech. Paper No. 13, 1961), are for immature wood. Shrinkage in mature wood of this species is smaller. Interestingly, the intersection point for white cypress pine is quite low (21%).

The ratio of tangential shrinkage to radial shrinkage in fishtail silky oak is high at 4:1.

DEVELOPMENT OF TWO PIECE SOFTWOOD SLEEPERS



POSTER NO. 10

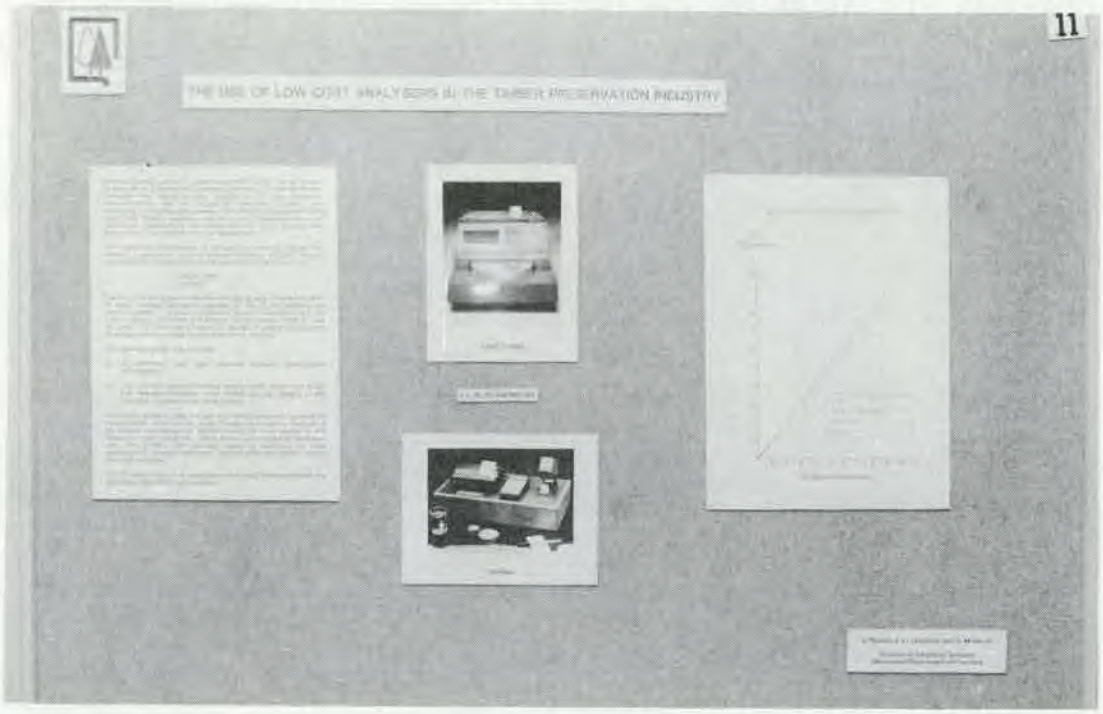
TWO PIECE SOFTWOOD RAIL SLEEPER

P. Shedley and J. Syers

In conjunction with the W.A. Department of Conservation & Land Management and the Timber Industry, Westrail has been active over the past years developing a two piece softwood sleeper.

The concept has been used previusly in other parts of the world, but the work in Western Australia is relatively new, using juvenile heart-in softwood (P. pinaster and P. radiata) case logs. These logs vary between 15 and 20 years of age.

Although only in the preliminary stage, the work has developed techniques which produce a technically acceptable sleeper. On going field trials will establish the useful life and serviceability in the operating environment.


11

POSTER NO. 11

THE USE OF LOW COST ANALYZERS IN THE TIMBER PRESERVATION INDUSTRY

J. Norton, L.E. Leightley and D. McIntosh

Internal quality control in timber treatment plants can be pursued by analysis of preservative treatment solutions and treated timber. However, the initial capital investment for the necessary instrumentation and its complexity dissuades treaters from practising in house quality control. The treater must proceed with costly and lengthy analyses through analytical laboratories. An alternative approach for the timber treater, is to use low cost analyzers (L.C.A.'s) based on X-ray fluorescence.

The Queensland Department of Forestry has recently carried out detailed comparitive studies between standard methods (Atomic Absorption Spectrophotometry) and two commercial L.C.A.'s viz

LABEX 2000
ASOMA

The L.C.A.'s are simple to operate and only require a moderate level of skill. Sample preparation consists of drying and grinding the treated timber. The ground material is placed in the instrument and a full copper, chromium and arsenic determination made in five minutes. Full turn around time from receipt of sample to provision of analytical result would be less than thirty minutes.

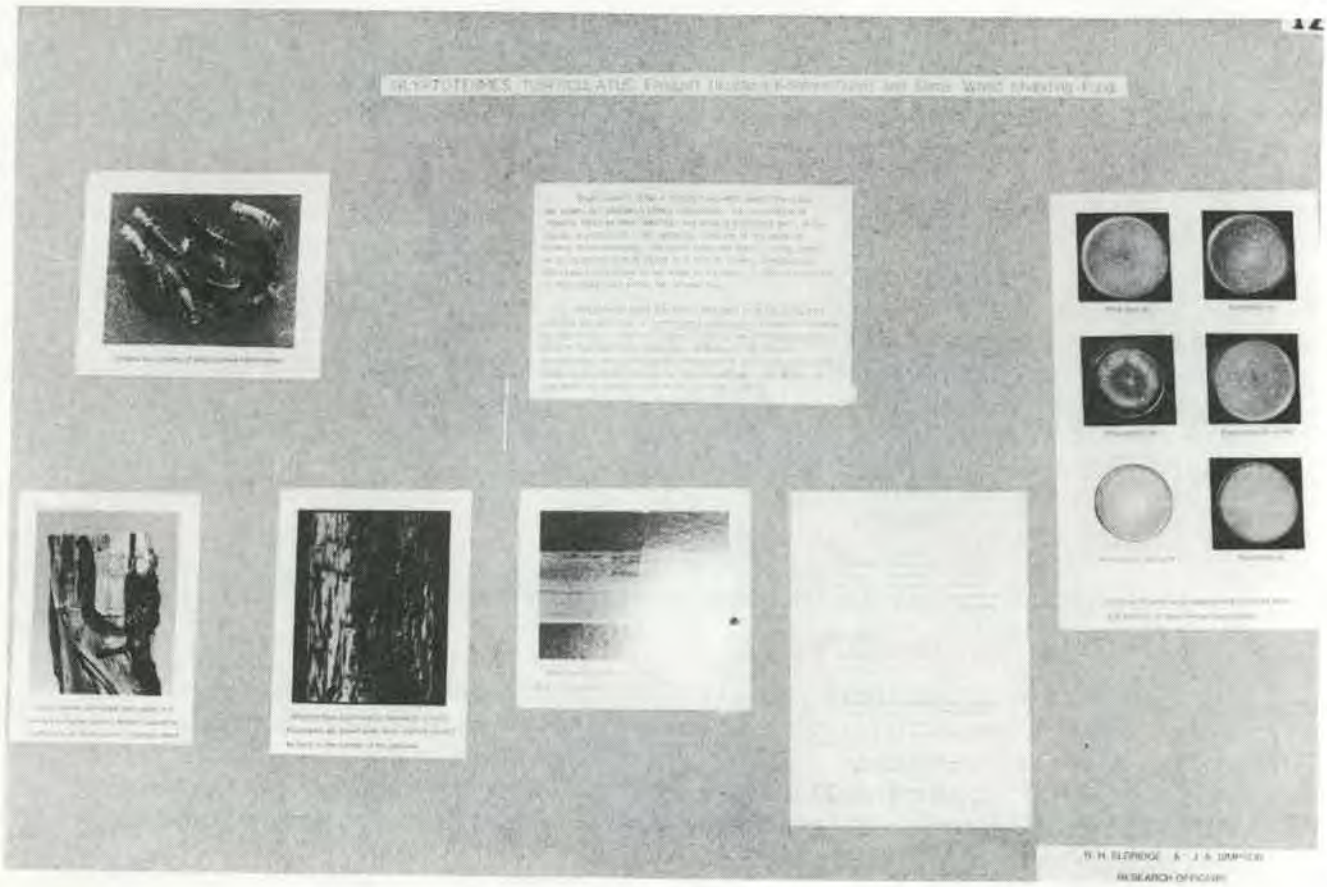
The following points may be made:

(a) No difference was found between different preservative formulations.

(b) The L.C.A.'s provided results more consistent (lower Relative Standard Deviations) than those generated by standard methods.

(c) The L.C.A.'s provided average results both higher and lower than standard methods. This finding may be related to the retention of preservative being tested.

The results found to date indicate that both instruments promise to be extremely useful to the timber treatment industry.



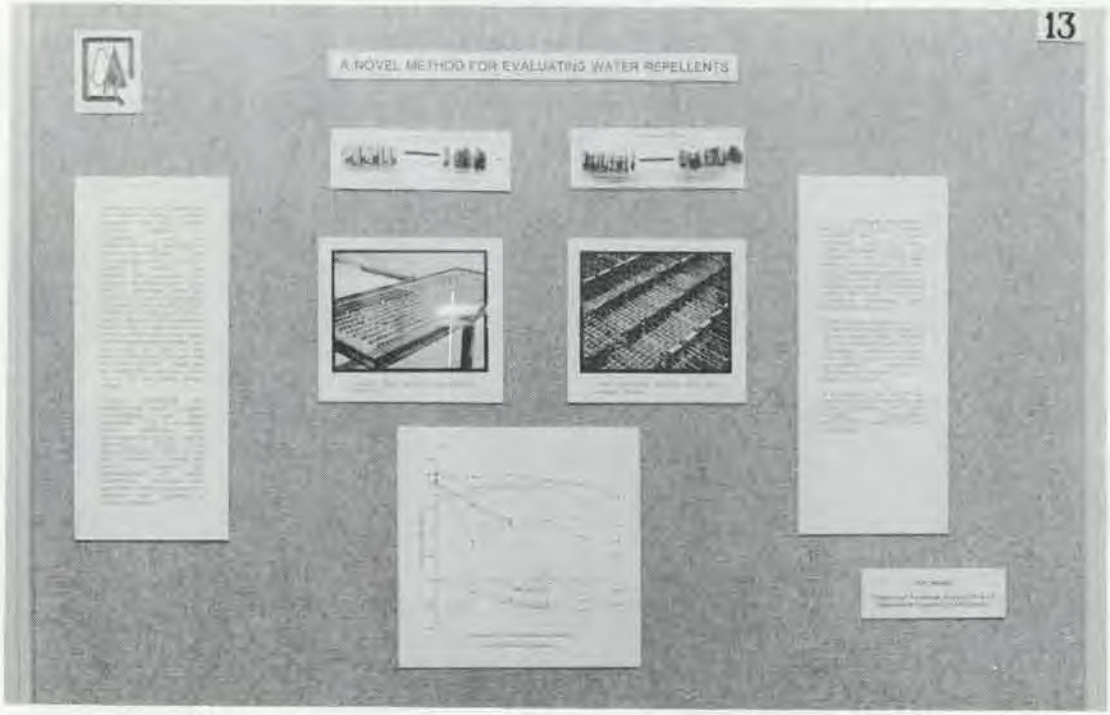
POSTER NO. 12

GLYPTOTERMES TUBERCULATUS FROGGATT (ISOPTERA:KALOTERMITIDAE AND SOME ASSOCIATED WOOD INHABITING FUNGI

R.H. Eldridge and J.A. Simpson

Relationships between termites and wood inhabiting fungi are known, but generally poorly understood. The infestation of standing trees by many termites, including *Glyptotermes* spp., often follows a succession - tree wounding, invasion of the wound by pioneer micro-organisms, (bacteria, fungi and yeast), establishment of an incipient termite colony by a pair of primary reproductives, and finally overgrowth of the wound by the tree. A complex ecosystem is thus established within the growing tree.

Isolation of fungi and yeasts were made from the guts, body surfaces and galleries of *Glyptotermes tuberculatus* Froggatt (Isoptera:Kalotermitidae). Organisms isolated included saprophytes, potential softrot fungi and fungi potentially antagonistic to termites. Observations, choice feeding and pathogenicity tests were carried out, revealing affinities between the termites and some fungi as well as confirming the pathogenicity of at least one organism.


13
A NOVEL METHOD FOR EVALUATING WATER REPELLENTS

POSTER NO. 13

A NOVEL METHOD FOR EVALUATING WATER REPELLENT PRESERVATIVES

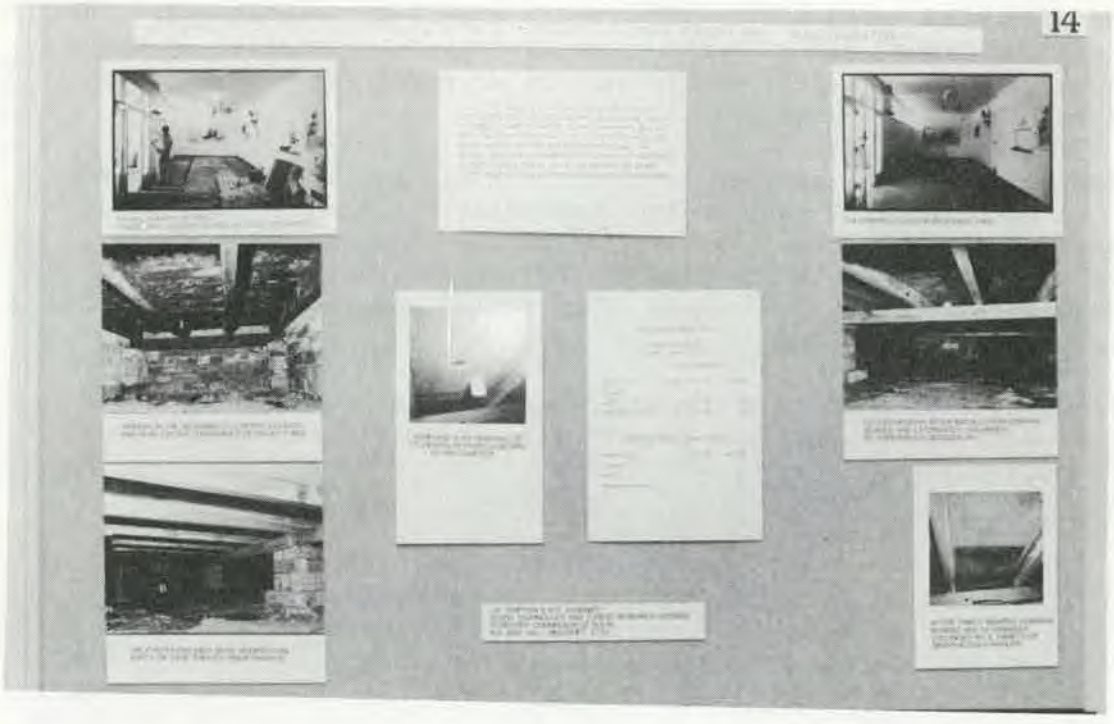
A.R. Moffat

Application of water repellent preservatives to timber surfaces offers protection from the weather, reducing degrade and movement. A novel test method has been developed to evaluate the efficacy of such formulations, when samples are exposed to weather. The method uses sapstain free sapwood of Radiata Pine. The size of specimens used was 25 mm x 25 mm x 6 mm along the grain. The specimens were exposed on a wire grid within a timber frame. Each specimen faced North so that the 25 mm x 25 mm side faced east west.

Several commercial water repellent preservative formulations have been evaluated. Prior to exposure water repellency was determined using the method described in AS 1607 - 1974, Water Repellent Solutions for the Treatment of Timber and Joinery - Appendix B6, Determination of Water Repellancy. Replicate test specimens were prepared for exposure and sampling at regular intervals.

The test exposure was sampled at 0, 3, 6, 9, 12 and 15 months exposure time. At each sampling, replicates were Water Repellent tested and evaluated for mould/fungal attack and removed from the test. Blank pieces were installed in the grid to provide constant exposure conditions during the test. A set of untreated specimens were included for reference.

In conjunction with AS 1607 the method offers a system for the rapid evaluation of water repellent preservative formulations, under field test conditions.


14

POSTER NO. 14

PERFORMANCE OF PARTICLEBOARD FLOORING IN A MOIST ENVIRONMENT: STRUCTURAL STABILITY AND BIODETERIORATION

J.A. Simpson and W.D. Gardner

The behaviour of two commercial types of radiata pine particleboard bonded with phenol-formaldehyde resin, one type with the commercial wood preservative Xyligen| incorporated into the resin, was studied in an inservice trial in a situation of high ambient humidity caused by poor subfloor ventilation. The Xyligen| treated particleboard was significantly less susceptible to colonisation by moulds, took up less moisture, and showed significantly less loss of strength than untreated particleboard.

15

CHEMICAL DIFFERENTIATION OF HEARTWOOD AND SAPWOOD IN ARAUCARIA CUNNINGHAMII

POSTER NO. 15

CHEMICAL DIFFERENTIATION OF HEARTWOOD AND SAPWOOD IN ARAUCARIA CUNNINGHAMII

L.E. Leightley and R.I. Davis

The heartwood of nearly all timbers is impermeable to preservatives. The presence of such heartwood, especially when low durability, is undesirable if preservative treated timber is destined for high hazard end uses. In many timbers the dark coloured heartwood is easily visually distinguishable from the lighter coloured sapwood. However, with some species this differentiation is far from clear.

Hoop pine (*Araucaria cunninghamii*) is an important plantation softwood species in Queensland. The heartwood and sapwood in sawn hoop are not easily differentiated. The increasing utilization of this species in the sawn form and its treatment with CCA have necessitated the development of a satisfactory chemical spot test to differentiate non-treatable heartwood from treatable sapwood.

Several spot test chemicals were examined for use in differentiating sapwood and heartwood in plantation hoop pine. Most of the colour reactions are based on the formation of addition compounds with the stilbene pinosylvins present in conifer heartwood.

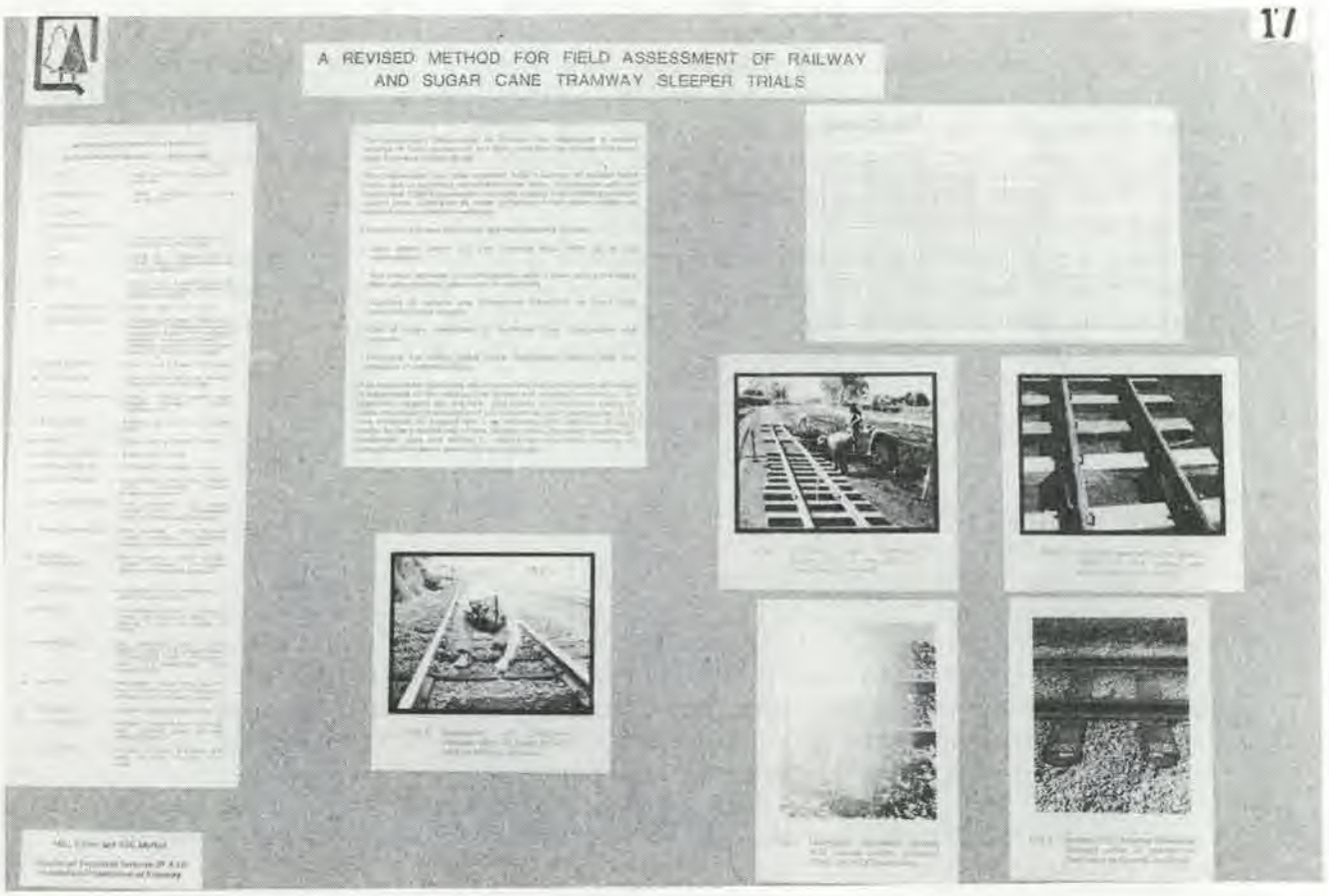
Chemicals providing colour change were:-

PANDA
Benzidine
O-anisidine
Aniline sulphate/sodium nitrite

The least effective was PANDA. Whilst Benzidine and O-anisidine provided distinct coloration to heartwood and sapwood, their known carcinogenicity would preclude their use at a sawmill. The aniline sulphate/sodium nitrite has low toxicity and renders sapwood a pale brown in contrast to a bright yellow heartwood.

Commercial in mill use of the aniline sulphate/sodium nitrite has been very successful.

A REVISED METHOD FOR FIELD ASSESSMENT OF RAILWAY AND SUGAR CANE TRAMWAY SLEEPER TRIALS



A REVISED METHOD FOR FIELD ASSESSMENT OF RAILWAY AND SUGAR CANE TRAMWAY SLEEPER TRIALS

M.L. Cause and A.R. Moffat

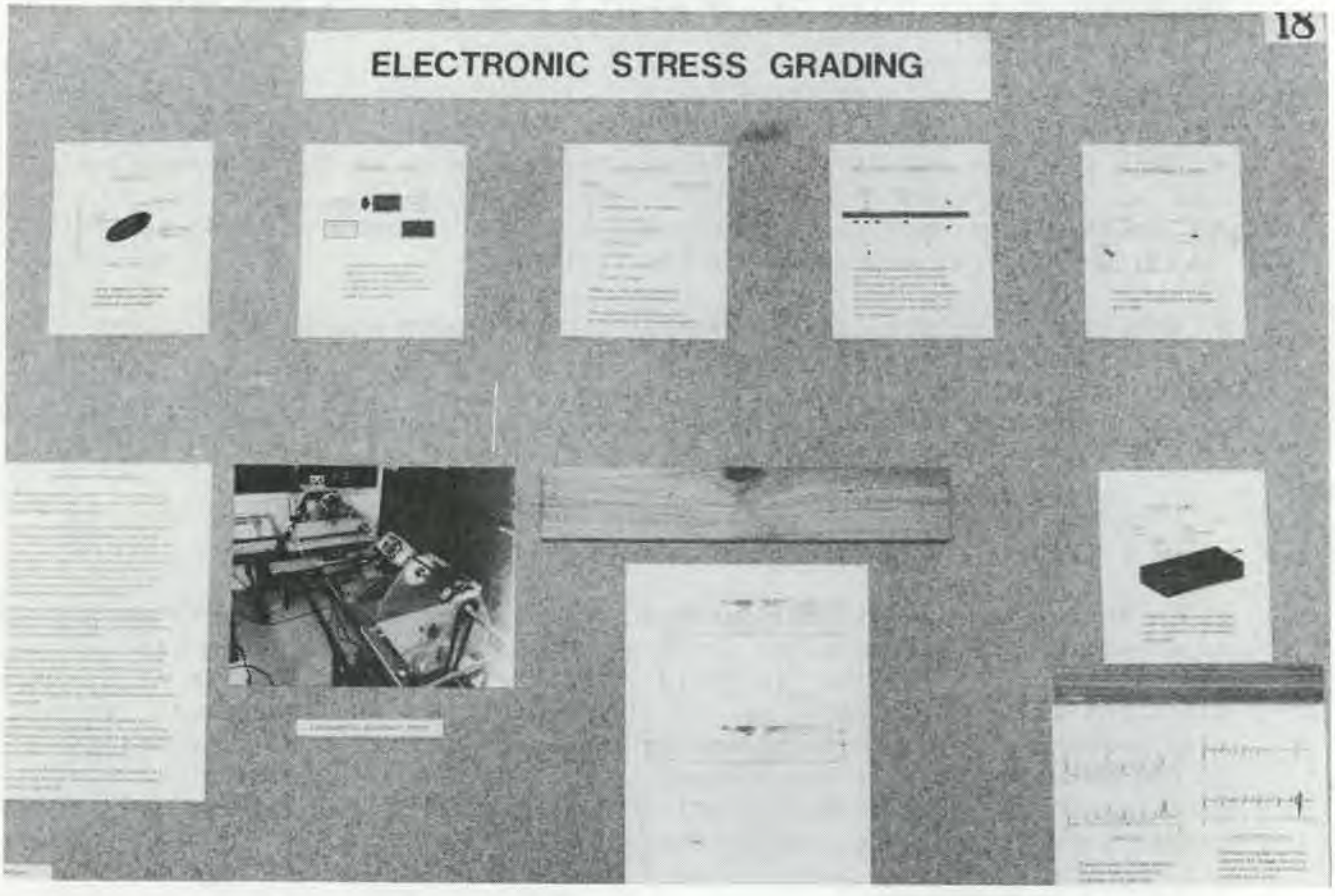
The Queensland Department of Forestry has developed a revised method of field assessment and data recording for railway and sugar can tramway sleeper trials.

The Department has been involved with a number of sleeper field trials, and is currently establishing new ones. Experience with the traditional CSIRO assessment methods suggest that advantages could accrue from collection of more definitive information capable of analysis using computer methods.

Features of the new data sheet and recording key include:

- Each sheet caters for two sleepers only, with up to ten assessments;
- The sheets attempt to be ergonomic, with a flow across the sheet that suits practical assessment in the field;
- Addition of several new assessment categories to assist with interpretation of results;
- Use of codes throughout to facilitate data manipulation and analysis; and
- Provision for notes about track engineering history over the duration of research trials.

It is anticipated additional information now being collected will assist in assessment of the relative performance of species/treatments. An important support for the new field sheets is the routine taking of black and white photographs of all sleepers at each assessment. It is also essential to support the new methods with attention to good design in the establishment of new sleeper trials, including provision of derailment gaps and ability to validly use statistical analysis in comparisons between species/treatments/sites.


18
ELECTRONIC STRESS GRADING

ELECTRONIC STRESS GRADING

P.J. Moglia

Machine stress grading, a procedure for sorting timber into structural grades, has been a major concern of the Division of Building Research for several years.

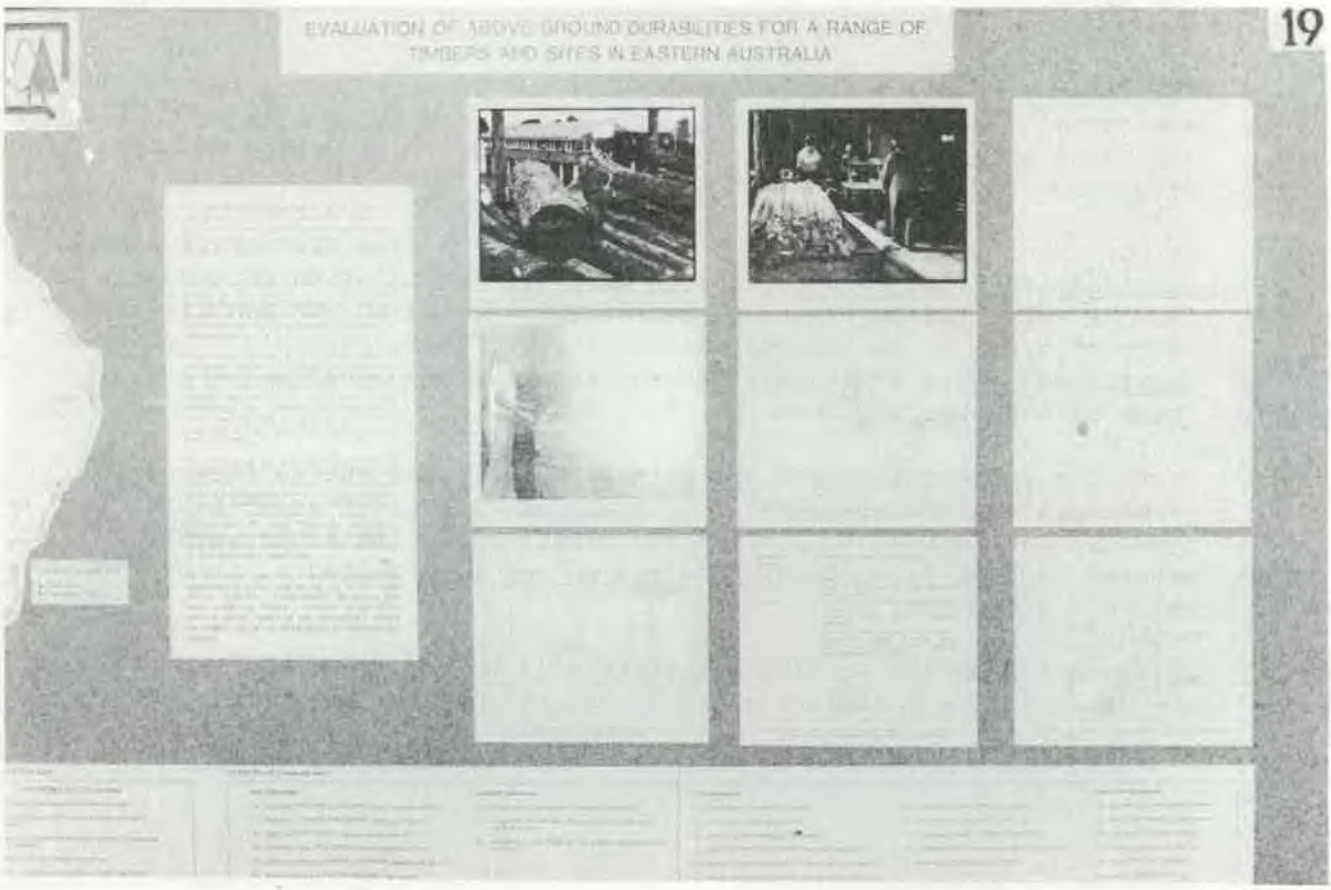
One problem with mechanical stress grading methods is that of maintaining the calibration of the machine in the rugged environment of a sawmill. Another is the very high cost of the machine, bearing in mind that modern high-speed planers can easily exceed the capacity of many stress graders. Accordingly, the concept of an electronic non-contacting grader which, apart from the conveying system, contains no moving parts and which can be sealed in a 'black box' so that it cannot be accidently altered is an attractive proposition.

Preliminary studies using microwaves as the primary detector of anatomical features that have an effect on strength have shown that such a grading machine is at least feasible, and may turn out to be relatively inexpensive.

On our experimental microwave bench we can determine the relative size and location of major defects such as knots and holes to an accuracy that is only limited by the number of detectors used. We can measure slope of grain to an accuracy of one degree. It is possible to measure density and moisture content. We envisage that we could measure all these parameters continuously.

Where the information from one detecting system is not sufficient to identify a feature absolutely, information from a different system (or systems) can be used to provide additional clues. In other words, several sets of 'low-grade' information can be combined to provide a reliable diagnosis.

The output from the various detectors will be analysed by a computer and the grade of the piece indicated by whatever method is appropriate.


EVALUATION OF ABOVE GROUND DURABILITIES FOR A RANGE OF TIMBERS AND SITES IN EASTERN AUSTRALIA
19

POSTER NO. 19

THE EVALUATION OF ABOVE GROUND DURABILITIES FOR A RANGE OF TIMBERS AND SITES IN EASTERN AUSTRALIA

M.L. Cause

The Queensland Department of Forestry is establishing a comprehensive trial to determine the 'above-ground' durability of forty-two (42) local and imported timber species at eleven (11) sites throughout eastern Australia.

This study employs simulated joinery units (mortise and tenon L-joints exposed above ground in the weather in a rack frame) deliberately designed to restrict air movement and provide high decay hazard similar to the more extreme actual ecological condition of external joinery.

Organisation of the trail involves nine (9) reference species (providing a range of durabilities from poor to very good) exposed at all sites, with a further thirty-three (33) species exposed at a main site. Two treatments (i.e. painted and unpainted L-joints) are included in the trial, and each L-joint test at each site is replicated twenty-four (24) times.

All L-joints in the trial have material characterised for basic density and other relevant factors. L-joint positions in the exposure racks are completely randomised for each site, and eight (8) assessments will be undertaken over the next twenty-five 925) years. A combination of visual field and destructive laboratory assessments will be undertaken, with the latter requiring pathology assistance in Basidiomycete isolations.

In all some 6 1/2 thousand painted and unpainted L-joints will be set out in the field during 1986/87. Additionally, provision has been made for future work with a second batch of the reference L-joints to be set out at all sites after an appropriate period.

POSTER NO. 20

CSIRO CONTINUOUS FEED TIMBER KILN

F.J. Christensen and R.L. Northway

A fully detailed set of design drawings of the CSIRO continuous feed timber kiln has been commissioned from Integrated Engineering of Coffs Harbour NSW.

This set of drawings will be made available to licensees of the kiln.

Estimates of construction costs indicate that the kiln will be comparable in cost to the high temperature kilns used currently by the industry for drying softwoods.

The potential for eliminating problems with distortion and the savings expected in operating costs merit serious consideration by the industry.

POSTER NO. 21

WOOD FIBRES IN PLASTER

R.S.P. Coutts

Australia has a long history relating to the use of organic-fibre reinforced plaster. The earliest plaster sheets at the start of the century were in the form of panels reinforced with hessian and wooden laths; later New Zealand flax was used and finally sisal fibre replaced flax as the reinforcement. More recently boards have been made with improved mechanical properties by using glass fibres as reinforcement in the plaster matrix.

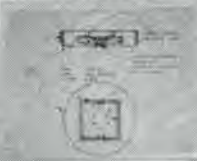
In Australia the current cost of sisal and glass fibres have aroused the need to study alternative reinforcing fibres. This has resulted in the present study of wood pulp fibre which is a readily available, cheap source of reinforcement. The use of wood pulp fibres as a replacement for asbestos fibres has been successfully demonstrated in the $200 - 300 M Australian fibre-cement industry and was reported at the 1981 Forest Products Conference.

Plaster products containing 8-10% by mass of wood pulp fibres and values of flexural strength of approximately 28 MPa, fracture toughness of 2-3 kJ/m^2 and density of approximately 1.5 gm/cm^3. These properties are superior to those of current commercial fibre-plaster sheet products and Australian industry is showing considerable interest in this system.

DEVELOPMENT AND COMMERCIAL APPLICATION OF MAINTENANCE PROCEDURES FOR THE PROTECTION OF WOODEN POLES FROM BIOLOGICAL DETERIORATION

THE PROBLEM

DEVELOPING THE SOLUTION



APPLICATION

C McEVOY K McCARTHY
CSIRO DCWT

POSTER NO. 23

DEVELOPMENT AND COMMERCIAL APPLICATION OF MAINTENANCE PROCEDURES FOR THE PROTECTION OF WOODEN POLES FROM BIOLOGICAL DETERIORATION

C. McEvoy and K. McCarthy

Wooden poles may be subjected to a number of deteriorating factors in service. Probably the most important of these are decay and termites.

Decay can proceed from the outside of a pole inwards - softrot - or from the inside outwards - centre rot. Both types of decay, which are cause by quite different types of fungi, will reduce service lives substantially if not attended to.

The most effective means of preventing further deterioration at the ground line of old poles is to apply a sterilizing chemical. For new poles, treated or otherwise, and where no deterioration is present, this should be applied for the first time after 6-8 years. After extensive research and in-service testing we believe that the most efficient means of controlling soft rot is to apply a preservative containing bandages. These have been arrived at by detailed laboratory work, and as with the CSIRO bandage, by service testing. Chemicals for controlling centre rots and termites must be able to diffuse from the site of application. The best configuration for the application of such chemicals appears to be via three or four holes bored abaxially at or about groundline.

In addition to some commercial products marketed for the control of centre rot, CSIRO in collaboration with the SECV have formulated a number of diffusion pastes specifically designed for the control of centre rot and termites. One of these products is currently under trial in 100 SECV transmission poles.

DEVELOPMENT AND EVALUATION OF CANDIDATE WOOD PRESERVATIVES WITH IMPROVED ENVIROMENTAL ACCEPTABLITY

OIL - BORNE EMULSIONS

DEVELOPMENT

EVALUATION

SELECTED RESULTS

LIGHT ORGANIC SOLVENT PRESERVATIVES

WATER-BORNE FORMULATIONS

C McEVOY K McCART
CSIRO DCWT

DEVELOPMENT AND EVALUATION OF CANDIDATE WOOD PRESERVATIVES WITH IMPROVED ENVIRONMENTAL ACCEPTABILITY

C. McEvoy and K. McCarthy

Over the last few years CSIRO has increased its research effort towards the development of new wood preservatives - the so-called third generation preservatives - and the evaluation of experimental commercial formulations. It is hoped to develop preservatives which will provide treated wood with an adequate service life and, most importantly, will be environmentally acceptable. Research effort has been directed at the three main categories of preservatives:

1. Oil-based formulations - work on these type of preservatives has concentrated on finding a 'cleaner' alternative to high temperature creosote (HTC). The solution to this problem seems to be overcome with the development of a number of formulations based on pigment emulsified creosote (PEC). In addition it is envisaged that a light oil-CCA emulsion developed by CSIRO and undergoing pilot plant scale treatment could have improved weathering and in-service performance over CCA-treated timber. Research involving this group of preservatives has progressed from laboratory type testing through to pilot plant testing and, in the case of PEC, full scale commercial treatment;

2. Light organic solvent preservatives (LOSPs) CSIRO has an on-going programme of assessing current and potential LOSP formulations. This involves the determination of both efficacy and threshold values of a number of LOSPs which are either currently used or have recently been developed by industry. In addition a number of experimental formulations developed by CSIRO have also been tested;

3. Water-borne formulations; stakes treated with experimental water-borne formulations both of CSIRO and industry origin are continually being assessed in ground contact with CSIRO's accelerated field simulator (AFS). The performance of variously treated stakes is monitored against the yardstick of stakes treated with CCA. The CSIRO experimental formulations based on metal soaps such as copper ethanolamine (CEN) show promise, particularly in radiata pine.

INSPECTION TECHNIQUES FOR DETECTING GROUNDLINE DEFECTS IN WOODEN POLES

K McCARTHY C McEVOY
CSIRO DCWT

POSTER NO. 25

INSPECTION TECHNIQUES FOR DETECTING GROUND-LINE DEFECTS IN WOODEN POLES

C. McEvoy and K. McCarthy

Inspection procedures must accurately detect the extent of deteriration and, equally significant, detect the defect in very early stages so that preventative measures can be taken to inhibit serious strength losses. Detection of internal decay has long been a major problem for those responsible for wood pole maintenance. Badly deteriorated ppoles may be relatively easy to detect, but poles in early stages pose a more difficult yet challenging problem.

In Australia the internal condition of most wood poles is determined by the traditional sounding (hammer) and boring inspection methods. Sounding and boring techniques have frequently been proved unsatisfactory as they are unable to quantify the defect and their ability to detect defects relies solely on the experience and judgment of the pole inspector. Due to limitations of traditional pole inspection techniques, various instrumental techniques have been developed to improve the accuracy and reliability of pole inspection.

A survey was conducted to evaluate the ability of three commercial and one experimental devices to detect internal decay in SECV transmission poles. The results obtained from these instruments were compared with the traditional sounding and boring techniques used by a pole inspector.

POSTER NO. 27

ASSESSMENT OF PERCENT WOOD FAILURE USING THE VIDEO IMAGE PROCESSOR

W. Atyeo

Following the Ash Wednesday fire of February, 1983, the Woods and Forests Department of South Australia began a major salvage and storage operation to recover some 1.8 million M3 of burnt sawlog.

In 1983, a research project was initiated to monitor the 1.0 million M3 of sawlog under water storage in the South-east of the State. The following properties were assessed at six monthly intervals:

- mechanical properties
- seasoning
- preservation
- gluability

Gluability included the following properties:
- Finger joint bending strength and percent wood failure (%WF)
- Wet cleavage test
- Block shear strength and %WF

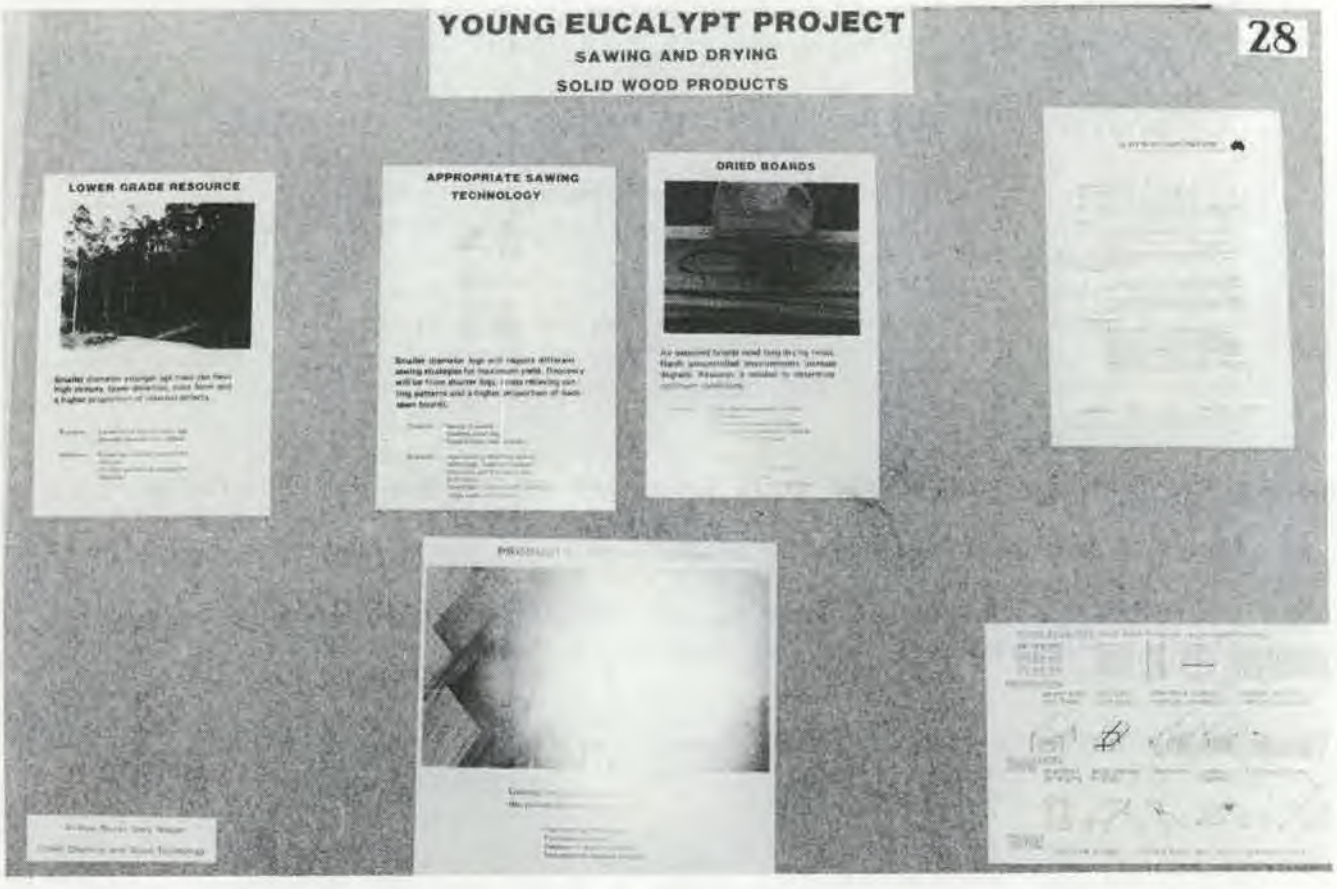
Both a phenolic adhesive and a PVA adhesive were tested.

Manual assessment of %WF for this project was found to be unsatisfactory.

The Video Image Processor (VIP) developed by the Wood Science Group, Division of Chemical and Wood Technology, CSIRO can be used to provide a completely objective estimate of %WF.

The technique has been successful on radiata pine specimens glued with phenolic adhesives. It may not work if the glue/wood contrast is less distinct.

The trends with time of shear strength and %WF of glued stored timber are shown in the accompanying graphs.


YOUNG EUCALYPT PROJECT
SAWING AND DRYING
SOLID WOOD PRODUCTS
LOWER GRADE RESOURCE
APPROPRIATE SAWING TECHNOLOGY
DRIED BOARDS

POSTER NO. 28

YOUNG EUACLYPT PROGRAM: SAWN TIMBER PRODUCTION

A. Rozsa

This project is part of a larger cooperative program of research into the growth, harvesting, and use of intensively managed eucalypts.

The aim of the project is to determine methods of producing the best return of highest quality end product from the available resource. The investigation will determine the range of variability that can be expected in the forest resource, log forms and sizes, minimum practical log diameters, best possible sawing techniques, most efficient drying methods, physical properties and grade quality of finished boards. Implicit in the study is the need to assess the marketing prospect of timber in light of the differences between this material and what maybe currently available.

At present we are concentrating on an assessment of regrowth and plantation material in Tasmania, sawing trials have been carried out on a range of tree sizes from a single even age stand of regrowth *eucalyptus regnans*. The work is now being extended to cover a range of species, sites and management techniques.

The poster illustrates some of the differences between fast grown and mature timbers, explains the difficulties encountered in conversion and demonstrates some of the techniques used for researching the problems and proposes some potential solutions for maximising recovery from what can be a refractory material.

POSTER NO. 29

ASSESSMENT OF FIRE DAMAGE IN REGROWTH MOUNTAIN FORESTS USING REMOTE SENSING TECHNIQUES

R. Smith and P. Woodgate

The poster describes the various remote sensing techniques used to locate, map and schedule the salvage of fire damaged timber following a wildfire in Victoria's Central Highlands.

About 12 000 ha of mountain ash forests, predominantly 1939 regrowth, were fire damaged. Given the likelihood of wildfires occurring in future in Victoria's extensive ash regrowth resource, it is important that salvage planning be based on the best possible resource data.

CHAIRMAN'S SUMMARY:

SESSION 1: Biodegradation and Chemical Treatments

by Dr. Harry Greaves

We found in our session that the conference organisers had put together a well-balanced program covering five pertinent topics within the preservation sphere.

In the first paper 'Recent Advances in Oil-based Preservative Emulsions in Australia' Chen Woo Chin discussed the work we have been doing over the past few years in collaboration with Koppers Australia Pty Ltd and one or two of the major users notably SECV. It was particularly appropriate that he talk about PEC preservatives especially in the light of the need to develop more environmentally acceptable formulations and also in view of the fact that emulsion technology, particularly in North America and Europe, is receiving a lot of attention. He discussed the ultra-stability we have achieved with PEC and its family members which, of course, is the key feature in using that particular preservative in a modern environment where the product is constantly being recirculated from treatment cylinder, back to work tank, back to storage tank, through top-up, back into work tank again. He also presented the difficult area of what role the pigments play in preventing migration of the creosote components to the surface of the

wood and thereby, of course, reducing the handling difficulties.

Finally he gave a brief appraisal of what we see as our new emulsion - an emulsion of oil and CCA which we are calling PROTAN and which, it seems to me, has a much bigger potential even than PEC because it was developed to counter the problems of treating softwoods with emulsions but may also be used to treat hardwoods. In addition it may be pigmented in various fashions to treat joinery timbers.

The second paper by David Gardner 'Current Fire Retardant Research and Future Markets' was again most appropriate particuarly in view of the fact that David has first returned from a tour of North America, sponsored by ATRI, to examine the potential of fire retardants in the building scene. His paper covered a number of areas notably the use of fire retardants in this country based on the review made by Karl Schmalzl. He also presented data on current research for fire retardants, the future research needs and those activities in the building sector that might affect the ultimate scope or employment of fire retardants in Australia. He placed a great deal of emphasis on codes and building industry attitudes to the use of fire retardant treated timber. On the other hand he also said that he did not think that we were geared to develop or formulate new fire retardants and that this should be left to the big industrial companies using the technology available to them. I take a contrary view and feel we are appropriately

structured to develop fire retardants of our own. I do not think we should simply be resolved in this country to test imports for their efficacy as fire retardants and their efficiency as bioretardant agents. However that is something David is not here to defend so I will not press the point any further.

The third paper 'Research and Development for the Preservation of Panel Products' presented by Gary Johnson stressed the difficulty of developing appropriate bioassay procedures. He discussed at some length Jim Creffield's efforts to develop realistic termite bioassay systems and concluded his paper by referring to the cocktail, BAC/permethrin, we have developed at CSIRO during the last 3-4 years with the close co-operation of PAA and Wellcome Australia Ltd. This particular cocktail looks like providing an extension of markets worth, at least, $35 m per annum in an area that is already valued at approximately $130 m per annum. In other words a significant increase in the marketability of plywood for what I believe is a fairly insignificant cost in R and D.

The fourth paper 'The Potential for the Expanded Use of Treated Softwood Poles' was given by Liam Leightley. Essentially the presentation hinged on the framework of supply and demand based largely on the projected figures by Mason for the electricity industry but he also touched on the requirements for pole-frame construction including housing. Clearly the demand for the most common size, i.e.

11.0 m to 12.5 m in length, may well not be met by the present supply of hardwoods. Equally it is clear there is likely to be a good supply of softwoods in that particular length class that could pick up the shortfall and indeed take over some of the market. The trials, so far, of CCA treated poles and CCA treated house poles look most encouraging for the future supply position.

The final paper 'Performance of Wood Rail Sleepers in Australia and Their Potential' was presented by John Costolleo with copious illustrations of the 'do's and dont's' of wood sleepers. Particularly he emphasised the point that you only get what you pay for. In other words you need to put good quality wood into the track if you want good service. He discussed the value of adding wood preservatives to wooden sleepers, particularly to more durable species that are already giving good service life but which can be extended by the judicious use, notably, of oil-borne formulations. He also stressed the decreasing availability of the durable hardwood resource and that is something we must face up to if we wish to retain the sleeper industry as a market for timber. On the other hand as Bruce Rumball has pointed out the rail sleeper market is not a high value yielding area for timber compared with the sawn timber market, the panel products market, etc.

Finally a comment on the FPRC committees. As I see it the WPC and JWPC committees have struck a reasonably good balance of industry and research input into their

operations. They have also arrived at an extremely good balance of influence within the preservation market, at least within this country and probably also New Zealand. With the inclusion of Fiji to the closed session hopefully they have some influence within that country too.

I believe in terms of FPRC that the WPC could proceed independently. However I fervently hope the WPC and JWPC will continue and while they do they will obviously feed-back information to the conference every two years and accept comment and input on future directions.

CHAIRMAN'S SUMMARY - SESSION 2 STRUCTURAL APPLICATIONS

by R.H. LEICESTER

It is probably of some significance that of the six papers in the Session on 'Structural Applications', only two papers were concerned with research in the conventional sense of the term, and of these one was in fact a revue paper. The two research papers were the one on timber connectors by Ted Lhuede and the one on timber structures and fire by Bob Leicester.

In the paper on connectors, Lhuede focussed on aspects of current research such as the effects of splitting, creep and juvenile wood. it was pointed out that connectors are the achilles heel of timber construction and with this complex action the necessity for research in this area is likely to be with us indefinitely. New construction with roof trusses amounts to something like $40 m a year and accordingly correct information on connector behaviour is of economic significance.

The paper on fire resistance of timber structures by Leicester indicated that the current state of the art is adequate for formulating workable rational methods for building design both with respect to the early fire hazard and to the structural performance of timber construction. For effectiveness, the next move would appear to be not more research, but rather to introduce a coordinated effort to have the Australian Building Code modified to accept performance criteria for fire resistant design. Other industry groups, such as those of the steel and plastics industries are currently promoting this approach and accordingly it would appear to be an optimum time for the timber industry to do likewise.

The two papers by Ron Beckett and Bryan Walford concerned the practical application of timber to building structures. Beckett focussed on the Australian situation where there is still a problem with the general acceptance of timber as an engineering material, notwithstanding the facts that timber production is increasing and that our per capita

useage is only half that of New Zealand's. Beckett's thesis is that this is largely due to the fact that the timber industry has failed to promote timber as a technically sound structural material. He mentioned the fact that the Darling Harbour Authority in Sydney stated that to use timber for the construction of a prestige building was to 'place reliance upon an unproven technology'. Certainly it is true that in drafting timber engineering standards there is always a compromise on quality control matters because most structural timber is used for house framing; some method must be introduced for ensuring the additional quality required for engineered construction.

Walford described the success story of engineered timber construction in New Zealand where it is commonly used for industrial buildings and other low-rise construction. Large structures up to 50 m span were described. It would appear that once having overcome the initial hurdle of acceptance of timber as a structural engineering material, the success of timber construction was due more to engineering rather than research. For example reasons cited for success included detailing of joint connections, erection procedures and the consideration of total construction costs (rather than just the cost of the structural material required).

The two final papers by Colin McKenzie and Greg Reardon concerned one of the outstanding success stories of timber engineering in Australia, namely the major role played by timber in cyclone resistant construction. McKenzie described in detail the evolution of the building regulations in this regard in Queensland. Two key points emerged; the first was the necessity of testing composite structural elements such as shear walls and trusses; the second was the necessity of preparing useable design manuals.

Reardon described the technique and the use of testing total houses, a very expensive type of test and possibly unique in the world. This type of test was found to be useful in revealing several aspects of structural behaviour that were not predicted by simple engineering analyses; two examples were the unexpected load path through shear wall

systems and the significant strengthening effects of non-structural components such as ridge capping. In addition the tests revealed that of the five standard houses tested to date, all have had an unanticipated weakness that reduced their load carrying capacities to about half the expected values; these weaknesses were usually associated with components not normally used in the construction of engineered structures.

In summary, the papers and related discussion have highlighted two aspects of the structural application of timber. The first is that we have an urgent problem in gaining the acceptance of timber as a proven structural material, and that this is not strictly a research matter. The second is that research should be increasingly focussed on composite elements (such as a complete shear walls) rather than on single elements (such as nails).

CHAIRMAN'S SUMMARY - SESSION 3: PRIMARY CONVERSION AND DRYING

by

F.J. Christensen

In my opinion, the new presentation format at least partly achieved the added depth of treatment anticipated by the change and I would recommend its retention. At the same time, it is important to made a careful selection of topics for the papers in order to sustain the interest of a fairly diverse audience and fewer subject matter specialists both working in the timber conversion area and attending the conference on this occasion.

The six papers presented at this session gave a reasonably wide representation of current research activities and developments in the timber conversion area. They ranged from resource considerations and mathematical modelling through to primary conversion and secondary processing.

A common theme linking most of the papers was the implicit or implied reference to the need to add value to sawn hardwood timber, a means of increasing productivity and cash flow through product improvement in the face of decreasing resource availability. This aspect was considered in relation to the inherent quality of the timber and the scope for upgrading as well as the means available for doing so.

The reported increase in commercial drying facilities in Australia and the relative increase in the percentage of wood being seasoned show that some timber processors are value-adding by this simple strategy. The advent of the CSIRO progressive kiln has provided the smaller hardwood producer with a relatively cheap and effective means of drying. This development was cited as a good illustration of the technology transfer to industry that Ian Bevege in his Keynote Address rightfully noted was often lacking in forest products research. While commercially developed dehumidifiers can and are being used for predrying hardwoods, they are a less attractive alternative than the progressive kiln. The recent adoption by industry of high temperature drying for hardwoods below fibre saturation point and the consequent marked decrease in drying times have greatly increased commercial drying capacity with virtually no capital expenditure. This is another recent success story with technology transfer.

It was reported that the first licence for the CSIRO continuous-feed kiln is expected to be signed shortly now that a detailed design had been prepared. Attention was drawn to the fact that the almost identical drying times for green softwoods and hardwoods below fibre saturation point extend the potential application of this drier.

The paper on basic research into the development of a mathematical drying model oriented towards reducing drying degrade in sawn eucalypt timber reported confirmation of the onset of surface checking predicted from realistic values of stresses and strains assigned to the one-dimensional computer model. A spin-off has been a "video game" that has proved to be a valuable training aid for kiln operators.

The utilization of increasing proportions of small, young and possibly fast-grown eucalypt regrowth logs, even in the short term, is an event that will affect the operations of sawmills around most of Australia. While we already have some knowledge of the conversion characteristics of this material there is urgent need for further research and development on resource evaluation, sawing and drying techniques, and grading studies. A start has been made, as reported in three of the papers presented at Session 3, with investigations on both sawing systems and species evaluation. Research in this area is being helped through funding being provided by the Australian Timber Research Institute, the Commonwealth sponsored Public Interest Project in Western Australia and the Young Eucalypt Project Consortium. There is also the prospect of funding through the Victorian Government's timber industry strategy. This raises the question of whether this diverse effort or a more co-ordinated one would be more effective?.

Mention was made of the exciting developments taking place in primary wood conversion including the extensive use of computerized scanning, sawing, materials handling and grading systems. These are being used to an increasing degree in Australian sawmills. Apart from productivity considerations, the use of such systems can ensure that the best possible use is made of every log processed. While the present application of this rapidly developing technology has been mainly in the softwood area, research into means of detecting defect in logs in time

with production tempos is showing promise for the programmed sawing of hardwood logs containing natural defect. The innovation at this session of having a paper presented on electronics in the forest products industries by a manufacturer and supplier of such equipment is acclaimed.

I have been asked to comment on whether the Joint Timber Seasoning Committee should continue in its present form, be changed or disbanded. I consider it should continue to function along the same general lines that it has been following as I believe it has served a useful function both for researchers working in the field and for the interchange of ideas and information it provides with industry. The Committee now has balanced and able representation from the different sectors belonging to the JTSC.

The session highlighted the interest in and benefits of timber conversion activities and, I consider, the need for their continuation at an even higher level of investigation. This approach is essential to safeguard research and development capabilities in a cost-effective and productive research area of demonstrated and potential value to timber based industries.

CHAIRMAN'S SUMMARY

SESSION 4 - Preparation for use as a Reconstituted (Wood) Product

by Kevin Lyngcoln

I would like to again thank Bob Cowan, John Carson, Mike O'Halloran, Barry McCombe and Rupert Palmer for their contribution to this session.

The perceived clear messages which I believe surfaced in Session 4 are:

1. The need for development of 'Performance Standards' based on end use applications. These standards must have sound scientific base. The development of this type of standard as against the traditional conforamnce approach will allow
   (a) optimisation of existing products in existing applications;
   (b) the more ready acceptance of new structural use products such as OSB, waferboard, structural particle board, LVL, PSL and Scrimber into existing markets.
   (c) the optimised utilization of new and traditional reconstituted structural use products into new applications.

2. The extension of the above message was that to be accepted in the market place, reconstituted wood based structural use products must be manufactured on a sound scientific base that will ensure
   (a) structural reliability;
   (b) bond durability;
   (c) durability for end use via building practice or preservation.

There appeared to be a viewpoint that in order to meet these objectives, research bodies will need to develop a new generation of performance based tests which allow innovation, thereby the smooth transfer of new products, adhesives, and preservative treatments from the development phase to the market place.

3. With the recognized reduction in wood quality, size and length, there will be a continuing trend towards the development of a new generation of structural use reconstituted products such as LVL, PSL and Scrimber to provide

(a) improved mechanical properties;

(b) structural reliability, i.e. improved CV; and

(c) physical characteristics of large section size and long length.

There may be a need, therefore to shift research emphasis to cover these developments from the viewpoints of processing technology, physical and mechanical property determination and application technology for these new generation products. Certainly this situation again re-emphasises the need to develop performance based standards.

4. Similarly, with the reduction in wood resource diameter and form, continued research effort must continue in veneer recovery practices. Optimised practices in veneer recovery assume greater importance in the light that veneer becomes the raw material not only for plywood but also for LVL, PSL and composite products.

Assessment of overseas practices, together with field studies and trials within Australia and the transfer of technology to industry are essential parts of research effort.

5. Existing timber adhesives technology, particularly in the field of durability, is based on formulations of formaldehyde adhesives namely phenol, melamine urea and urea formaldehyde that have been available since the mid 1950's. The durability of these adhesives has often been based on their use to bond plywood and a great deal of the research effort and conclusions was carried out by researchers such as R.A.G. Knight and N. Perkins in the UK and USA. They have provided a 'bench mark', abliet conservative, for what has become accepted as a durable, structural timber adhesive. Test procedures are many and varied and are restrictive as they tend to deny the reconstituted wood industry room for innovation in using new adhesive formulations and types. There was a strong feeling, during the session, that research bodies should actively pursue the development of short-term performance tests to evaluate the long-term durability of adhesives.

CHAIRMANS SUMMARY - Session 5: GROWTH FOR END USE

A.G. Brown

Major changes are occurring in the nature of the raw material supplied to the forest products industries. The inevitability of the move from old-growth indigenous forests to regrowth and plantations has long been recognised, but the opportunities to manipulate both regrowth and plantation forests to influence wood quality, and the consequences of a range of factors already acting on established plantations are less well appreciated. Research already undertaken has given clear indications as to how further investment could most rapidly influence crop characteristics. This, together with industry tends to shorter rotations, provides more opportunities than have existed for collaboration between forest scientists, forest products scientists and industry. These opportunities are being vigorously followed up in at least some countries which are potential international competitors. In regrowth forests, a potentially-valuable resource in several southern States, a collaborative research program (Paper 5/5) involving industry, State forest services and CSIRO is successfully addressing a wide range of issues important to the future of industries looiking forward to the use of young eucalypts (e.g. Paper 5/2). Much of this research is also relevant to plantations of eucalypts, which are of rapidly-increasing importance.

A key to the success of plantation ventures is the correct choice of planting material. A number of basic studies of eucalypts undertaken over the last 25 years are now at the point at which collaboration by forest products scientists and industry is essential if the best material is to be used in plantations (Paper 5/L). Sufficient preliminary work has been undertaken to provide methodologies (e.g.

Paper 5/1) and indications that economically and technically important opportunities do exist (e.g. Matheson et al., Appita 38, 205-12).

Radiata pine has been grown in Australia for more than 100 years, but the nature of the wood cut is probably changing more rapidly now than at any other time. In a number of regions the supply of 'old-crop' (pre-1940) logs is being replaced by much younger material. This replacement is accompanied by significant changes (generally adverse) in log quality, due primarily to the overwhelming importance of age as a determinant of wood density. Density is probably the most important single parameter of wood quality, being an essential component of forest yield (together with volume), closely related to a number of mechanical properties, and correlated with several pulping characteristics. The effect of the reduced rotation length on logs may not be at first apparent, since much more intensive site preparation, fertilization, wider spacing and breeding have combined to raise growth rates appreciably. Thus the 'new crop' logs may not look much smaller than those previously available, but their quality is certain to differ. Another factor affecting density to a significant extent is the environment at the forest site - differences of the order of 20% may occur between different areas (Poster by J. Wilkes; Turvey and Smethhurst, Aust. For. Res. 15, 43-9). Thus there should be no complacency about the quality of radiata pine wood - the gains available from breeding (Paper 5/3) and vegetative reproduction (Paper 5/4) may be essential simply to lessen the departure from the status quo.

SESSION.6

CHAIRMANS SUMMARY _

SESSION 6: Fibre and Chemicals from Wood

by Dr A.F.A. Wallis

The session was comprised of a lead paper by the chairman, and contributions on pulping developments (Dr P.J. Nelson), development of rayon fibres (Mr A.A. Sioumis), eucalyptus oils (Mr P. Abbott) and two papers on carbon from wood (Dr K.J. Harrington and Dr P. Fung).

In the lead paper, Dr Wallis discussed the trends in the supply and manufacture of fibres and chemicals in Australia. He noted that Australia was about 70% self sufficient in paper and board production, and this is likely to increase as more printing papers are manufactured here. Into the future, printing and writing and tissue grades are likely to increase their share of output at the expense of packaging grades. There will be an increasing demand for bleached chemical pulp, although in Australia, mechanical pulps are likely to remain prominent due to low energy costs and the suitability of wood species for the processes. For supply of chemicals, petroleum is likely to remain the preferred feedstock for bulk chemicals for a long period, and wood will only be a source of chemicals when advantage is taken of the chemical structures inherent in the wood i.e. from the wood extractives or wood polymers.

The chemicals cellulose industry has been losing market share to synthetic polymers, but with improved technology some of this lost

ground could be retrieved.

Dr Nelson gave an account of the developments in pulping over the last 5 years. In chemical pulping, advances have mainly been in organic solvent pulping, although the strengths of these pulps are generally lower than those of typical kraft pulps. The major developments have been in mechanical pulping, particularly in CTMP manufacture and bleaching.

Mr Sioumis outlined the commercial development of rayon fibres. The problems associated with the present technology were highlighted, and research directions to overcome these problems were discussed. Although rayon fibres have lost market share to synthetics, they have desirable water absorption properties and with improved technology for manufacture they could become more prominent in the future.

Mr P. Abbott gave a stimulating account of the eucalyptus oil industry in Australia. Once the sole world supplier of eucalyptus oil, Australia now accounts for only a minor quantity of the world production. Through research programs such as tissue culture breeding of suitable eucalypts, the industry in this country could be more competitive with the major oil-producing countries, China, South Africa, Spain and Portugal.

The session concluded with two papers on wood-derived carbon. Dr K.J. Harrington's presentation outlined the factors critical to the performance of activated carbons in applications such as gold recovery. His talk was illustrated by excellent photomicrographs. Dr P. Fung summarized the carbon in pulp method of gold extraction, and gave promising results on the development of suitable carbons from jarrah wood for the purpose.

The session was not well attended by industry personnel due to the competing parallel session 3.

22nd FOREST PRODUCTS RESEARCH CONFERENCE

LIST OF DELEGATES

Peter ABBOTT	Invited Speaker
B.S. ASWATHANARAYANA	Indian Plywood Industries Res. Institute
Bill ATYEO	S A Woods & Forests Dept
Neil BAKER	S A Woods & Forests Dept
Ron BECKETT	N S W Institute of Technology
Harold BREITINGER	C S I R O D B R
Alan BROWN	C S I R O D F R
Paul BOWDITCH	C S I R O D B R
John BUTCHER	Forest Research Inst. (NZ)
John CARSON	A T R I
Myron CAUSE	Qld Department of Forestry
Sam CHAFE	C S I R O D C W T
Chen Wood CHIN	C S I R O D C W T
Frank CHRISTENSEN	C S I R O D C W T
John COLEMAN	C S I R O D C W T
Peter COLLINS	C S I R O D B R
Bob COUTTS	C S I R O D C W T
John COSTOLLOE	C S I R O D C W T
Laurie COOKSON	C S I R O D C W T
Bob COWAN	S A Woods & Forests Department
Peter CRAMMOND	Aust Particle Board Manufacturers Assoc.
Jim CREFFIELD	C S I R O D C W T
Christine DEAN	C S I R O D F R
Bob DEKKER	C S I R O D C W T
Ed DOUGAL	University of Melbourne
Paul EDWARDS	F A F P I C
Phillip EVANS	A N U
Rob EVANS	C S I R O D C W T

Alan FARRINGTON	A P P I T A
John FRENCH	C S I R O D C W T
Paul FUNG	C S I R O D C W T
David GARDNER	Forestry Commission of N S W
Geoff GARTSIDE	C S I R O D C W T
Harry GREAVES	C S I R O D C W T
Mark GREENACRE	T P A A
David GOUGH	Qld Department of Forestry
Denis GRANT	Forestry Commission of N S W
Alan HALLIGAN	Aust Particle Board Research Inst
Denis HANLEY	Capricornia Inst of Advanced Education
Kevin HARRINGTON	C S I R O D C W T
Tony HASLETT	Forest Research Inst (NZ)
Warren HEWERTSON	C S I R O D C W T
Doug HOWICK	C S I R O D C W T
Hugo ILIC	C S I R O D C W T
K. IILYAMA	C S I R O D C W T
Murray JESSOP	Tasmanian Forestry Commission
Gary JOHNSON	C S I R O D C W T
Peter JUNIPER	Timber Promotion Council
Bill KEATING	C S I R O D C W T
Alex KRILOV	Forestry Commission of N S W
John KEITH	T D A (NSW)
Kevin LYNGCOLN	Plywood Association of Australia
Bob LEICESTER	C S I R O D B R
Liam LEIGHTLEY	Qld Department of Forestry
Ted LHUEDE	C S I R O D B R
Andrew MARTIN	C S I R O D C W T
David McARTHUR	C S I R O D C W T
Ean McARTHUR	C S I R O D C W T

Barry McCOMBE	C S I R O D C W T
Dan McCARTHY	C S I R O D C W T
Wal McCULLOCK	Invited Speaker
Kevin McCARTHY	C S I R O D C W T
Chirs McEVOY	C S I R O D C W T
Mick McDOWALL	Capricornia Inst Advanced Education
Colin McKENZIE	T R A D A C
Bob McKIMM	Dept. of Conservation, Forests & Lands
Greg MEACHEM	Forest Products Assoc. (WA)
E. MIREKU	A N U
Bob MILNER	Chisholm Institute of Technology
John MILLER	Aust. Particle Board Manufacturers Assoc.
Bob McNAMARA	C S I R O D B R
Robert MILLS	Tas. Timber Promotion Board
G. MILLER	S A Wood and Forests
Tony MICHELL	C S I R O D C W T
Peter MOGLIA	C S I R O D B R
Simon MURPHY	Dept. of Conservation Forests & Lands
S.K. NATH	Indian Plywood Industries Res. Institute
Peter NELSON	C S I R O D C W T
Peter NELSON	A P P I T A
John NICHOLAS	C S I R O D B R
Richard NORTHWAY	C S I R O D C W T
Mike O'HALLORAN	American Plywood Association
Prof. A. OLIVER	University of Tasmania
Barbara OZARSKA	University of Melbourne
Rupert PALMER	C S I R O D B R
Frank PHILLIPS	C S I R O D C W T
Dennis PONTIN	Telecom
D.M. RAGHUNATH RAO	Indian Plywood Industries Res. Institute
Ken RALPH	Tasmanian Timber Promotion Board
Bill RAWLINS	C S I R O D C W T
Greg REARDON	James Cook University

Peter ROBINSON	C S I R O D C W T
Andrew ROZSA	C S I R O D C W T
Bruce RUMBALL	R P R I
Bruce SANDIE	Swinburne Institute of Technology
Karl SCHMALZL	C S I R O D C W T
Pam SHADBOLT	Chisholm Institute of Technology
Phil SHEDLEY	Conservation and Land Management (WA)
K. SHYAMASUNDAR	Indian Plywood Industries Res. Institute
Graeme SIEMON	Conservation and Land Management (WA)
David SPENCER	C S I R O D F R
Tony SIOUMIS	C S I R O D C W T
Tom SYERS	C S I R O D C W T
John THORNTON	C S I R O D C W T
Dietmar TORNER	Aust. Particleboard Manufacturers Assoc.
Sergei TOWSTOLESS	C S I R O D B R
Adrian WALLIS	C S I R O D C W T
Gary WAUGH	C S I R O D C W T
Peter WELLS	Chisholm Institute of Technology
John WILKES	Forestry Commission N S W
Yoshi YAZAKI	C S I R O D C W T

THE ENGINEERING USE OF TIMBER IN LARGE INDUSTRIAL BUILDINGS

G.B. Walford

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ABSTRACT

Three recent examples of large industrial timber buildings are described: A factory extension using glulam columns and plywood box rafters and purlins; A mill building using tapered glulam columns and rafters with nailed steel gusset plates at the joints; The Econobarn system of mechanically laminated timber arches. These show that, to be economically competitive, timber design must be innovative with as much attention paid to erection procedures as to the design calculations.

INTRODUCTION

The timber construction scene in New Zealand is particularly vigorous. Innovative engineers are willing to implement the latest technology and building controls are flexible enough to permit the erection of buildings of novel design. Light industrial single storey buildings are a growth area for timber construction, competing successfully against steel and concrete. On the other hand some ground has been lost to competing materials in house construction, e.g., cement-fibreboard weatherboards, concrete ground floors, and aluminium joinery.

An important ingredient in the New Zealand scene is the realistic use of radiata pine, a timber that does not have exceptionally high structural properties but it is easy to machine, glue, nail, treat with preservatives, and is readily available. Another important ingredient is confidence among designers and clients. This confidence grows with experience and the continued

construction in timber of large industrial buildings is proof of that but it must be backed up by good quality control, easy-to-use design codes and manuals, and continued research and development.

This paper describes some of the design features of recently-constructed industrial buildings in New Zealand.

HENDERSON AND POLLARD LTD FACTORY

An extension of 7800 m^2 to an existing factory was designed by John Little and Associates and was built in early 1985, for the processing and storage of wood panel components. The completed cost of the building shell, excluding services and the sprinkler system, was \$197/m^2 which Little (1985) describes as very cost competitive. Alternative designs were not done, however, because the group of companies owning the building manufacture plywood, sawn timber, glulam and other wood products. Nevertheless, an estimated cost for an equivalent design in steel at that time was \$215/m^2.

Figure 1 shows a typical cross section of the building during construction. The structure consists of:

1. Box section rafters spanning 26 m at 10 m centres, connected to glulam columns by nailed plywood gussets.
2. Box section purlins spanning 10 m at 2.5 m centres.
3. Plywood double stressed skin prefabricated wall panels.
4. Plywood roof bracing panels.
5. A plywood shear wall along the central line of columns.

This choice of elements gave a building that is free of dust-collecting ledges, an important consideration for fire risk in a wood processing plant.

The box section rafters and purlins were made 1200 and 400 mm deep respectively to make efficient use of standard size plywood sheets. The chords of the purlins were finger jointed 90 x 45 mm Engineering grade radiata. By finger jointing, the required length of 10 m and the required grade was easily

obtained from lower grade stock. The chords of the rafters were 230 x 135 mm glulam with the laminations arranged vertically. A feasible alternative was nail-glued 250 x 50s with the gluelines horizontally arranged and butt joints strategically staggered but the industry was better equipped to produce the glulam. The webs and chords of these box section members were assembled with a rigid adhesive using nail pressure. The same method was used in the 44 m span box beams erected at the Epsom Showgrounds in 1984 (Hill and Harris, 1985). Although nail pressure assembly does not give as high a glueline strength as obtained by mechanical clamping, it is adequate because the web-to-chord shear stress is low, being limited by the allowable rolling shear in the plywood.

A very neat purlin/rafter connection was used, consisting of a wooden block nailed to the side of the rafter. As shown in Figure 2 the bottom chord of the purlin is shorter than the top so that the purlin slides downwards over the block which bears on the top chord. The connection is completed by nailing the plywood webs to the block and fastening a steel strap across the top to give some moment resistance to the joint.

By using nailed only plywood gussets at the rafter/column joints, rigid connections are formed which provide the lateral wind/seismic force resistance. For erection, one gusset plate was pre-fixed to the column, the other plate being site-fixed after the rafter was seated on top of the column. The design of these joints has been described by several authors (Batchelar and Cavanagh, 1984; Lowe and Edwards, 1985) and research is continuing (Boult, 1986). Compared to steel gusset plates, plywood plates have an advantage in that predrilling is not necessary and the several hundred fasteners needed in each joint can be rapidly and accurately placed using a pneumatic nail- or staple-gun. This extensive use of nails is a common feature in recently-constructed timber industrial buildings. The reason is that in terms of allowable load per fastener per dollar in-place cost, nails are more economical than bolts or bolts plus split ring contectors (Gale and Green, 1984).

In the factory extension described the only places bolts were used were in the connection between the rafters and the existing factory, and in the column base fixing. In these situations bolts were useful for lining-up during erection of the columns and moment resistance was not required.

NORTHERN PULP LTD TRIBOARD MILL AT KAITAIA

Triboard is a new product developed jointly between a NZ and a West German company. It is a three layer wood fibre and/or particle board which can be made with a high density surface and low density core in thicknesses ranging from 5 to 100 mm. Production will start in 1987. The heart of the process is a steam injection continuous press built by Seimplekamp Ltd.

The main building, due for completion in September 1986, covers 10,000 m^2 and was designed by M.L. Batchelar. It was originally designed in steel portal frames by the principal consultants but a last minute enquiry to McIntosh Timber Laminates Ltd produced an alternative design in timber that turned out to be 10 to 15% cheaper.

The structural framework consists of portal frames as shown in Figure 3, where tapered glulam members are joined with nailed steel gusset plates. A firm called Timbertek Systems Ltd of Taradale, NZ, specialises in this type of construction and was responsible for the new sawmill building erected earlier this year (1986) for the Fiji Pine Commission in Fiji. Because the joints are easily site-fixed by carpenters and builders labourers, transport of the straight glulam components presents few problems and the use of specialised labour, i.e., welders, is avoided. Many other buildings; warehouses, coolstores, churches and factories have been built using glulam and nailed steel plates so it can be considered commonplace in NZ.

Figure 4 shows a closeup view of the eaves joint and box gutter attachment. Note that only nails are used in the joint, to fix the box gutter, to attach purlins and to fasten the strap metal bracing. About 1900 nails are used in each joint. This is similar to the number used in a plywood gusset joint for

members of this size. There is little to choose between plywood or steel for the gusset plates; the steel gives a more compact design without projecting beyond the edges of the glulam members while the plywood gives a saving in on-site labour.

The glulam was specified as No. 1 framing which is equivalent to F5 in Australian terminology. Design and manufacturing standards provide for higher grades of timber for glulam but because of difficulties of supply and quality control in the higher grades, it is more realistic to specify the lower grades. Because of lower design properties for the lower grades, this means that quantity is substituted for quality in the production of members of the required strength properties. In the case of a four story office building erected for Odlins Ltd in 1981 the specification of lower rather than higher grades led to cost savings. Smith (1982) reported the following percentage savings in material costs:

Use of untreated timber in lieu of boron or similar C8	6%
Use of melamine urea glue in lieu of recorcinol	8%
Use of No. 2 framing grade in lieu of No. 1 framing	25%
Use of No. 1 framing grade in lieu of engineering	20%

Designers usually tend to specify the highest grade in order to minimise member sizes but they should be aware that specifying a low grade may yield a more economical design, especially if stiffness rather than strength governs.

The tapered rafter members of the Triboard mill were first made as rectangular pieces which were sawn lengthwise at the required angle to yield pairs of tapered rafters. This technique minimises wastage but does not allow the usual arrangement of two or more grades of laminations with the high grade on the outside and the lower inside.

An important consideration is the erection procedure. Figure 5 shows two-bay sections of roof measuring 30 x 12 m assembled at ground level ready for hoisting into place as a complete unit. It is faster, safer and cheaper

to do this work close to the ground than 15 m or more above it. In one case, an entire roof measuring 20 x 50 m was assembled complete with wiring at ground level and hoisted as a unit onto 10 pole columns (Stacey, 1984).

ECONOBARN OR GANGLAM ARCH CONSTRUCTION

A development that is continuing to win prizes from the NZ Timber Industry Federation for its innovative value is the Econobarn structures system. This is based on the Ganglam arch which is made from laminations of green timber (usually radiata), that are fastened together by nailplates (Gang-Nails) applied to the wide face of the arch.

Very low costs are claimed (Anon, 1986) for construction by this system - about $\$50/m^2$ for the shell only (no floor), and standard designs are available for spans of 8 to 45 m. Figure 6 shows one of the first examples, an haybarn of 8 m span with arches at 2 m centres. The arches are made from 8 laminations of dressed 23 x 45 mm green radiata. 180 x 30 mm GN1 plates at about 750 mm centres on both sides of the arch provide the only means of shear transfer between the laminations. End joints in the laminations are simple butt joints with a nail plate applied to the outer face (tension side) only. No grading rules are necessary for the timber in these arches because by bending them to the required curvature they are effectively proof tested. Figure 7 shows an artists sketch of a 27 m arch-supported building built in 1985 and used as a factory. With the concrete floor, services and associated office/entrance structure, this building cost about $\$150/m^2$. The imagination of the designers of this system know no limits and have put forward proposals for a 70 m span structure to be used as a hangar for B747 aircraft.

The design theory and its application are described by Gale and Kroonenburg (1984) and proof testing has been done on arches up to 27 m span. The theory has some anomalies and untested assumptions. For example, stresses are calculated assuming a solid section (like glulam) but shear transfer between laminations is provided solely by the nailplates which are at 700 to 900 mm centres. However,

Local authorities have accepted the design calculations and evidence from proof testing and issued permits for these buildings. While most of the buildings have been for agricultural and horticultural purposes with little risk to human life, the consequences of a building collapsing around a B747 are certainly serious. A study of the theory was made by Parker (1985) and further work is proposed at the Forest Research Institute. Areas of concern in the design theory are:

- actual stress distribution,
- effects of shear deformation,
- effects of plate/timber slip,
- effects of creep and drying deformation.

As a final comment, this development shows that the timber engineering scene in NZ is innovative and the building controls are flexible enough to accommodate it.

CONCLUSIONS

1. The economic viability of large industrial buildings in timber is probably more dependent on the speed and ease of construction than on the finesse of the engineering calculations.

2. Economical design solutions may be found by substituting quantity for quality in some cases.

3. Confidence in timber for industrial buildings in NZ is increasing as their numbers increase and depends on the use of clever erection techniques, the realistic use of readily available timber, imaginative designers, and building controls that are flexible enough to allow innovation yet maintain safety.

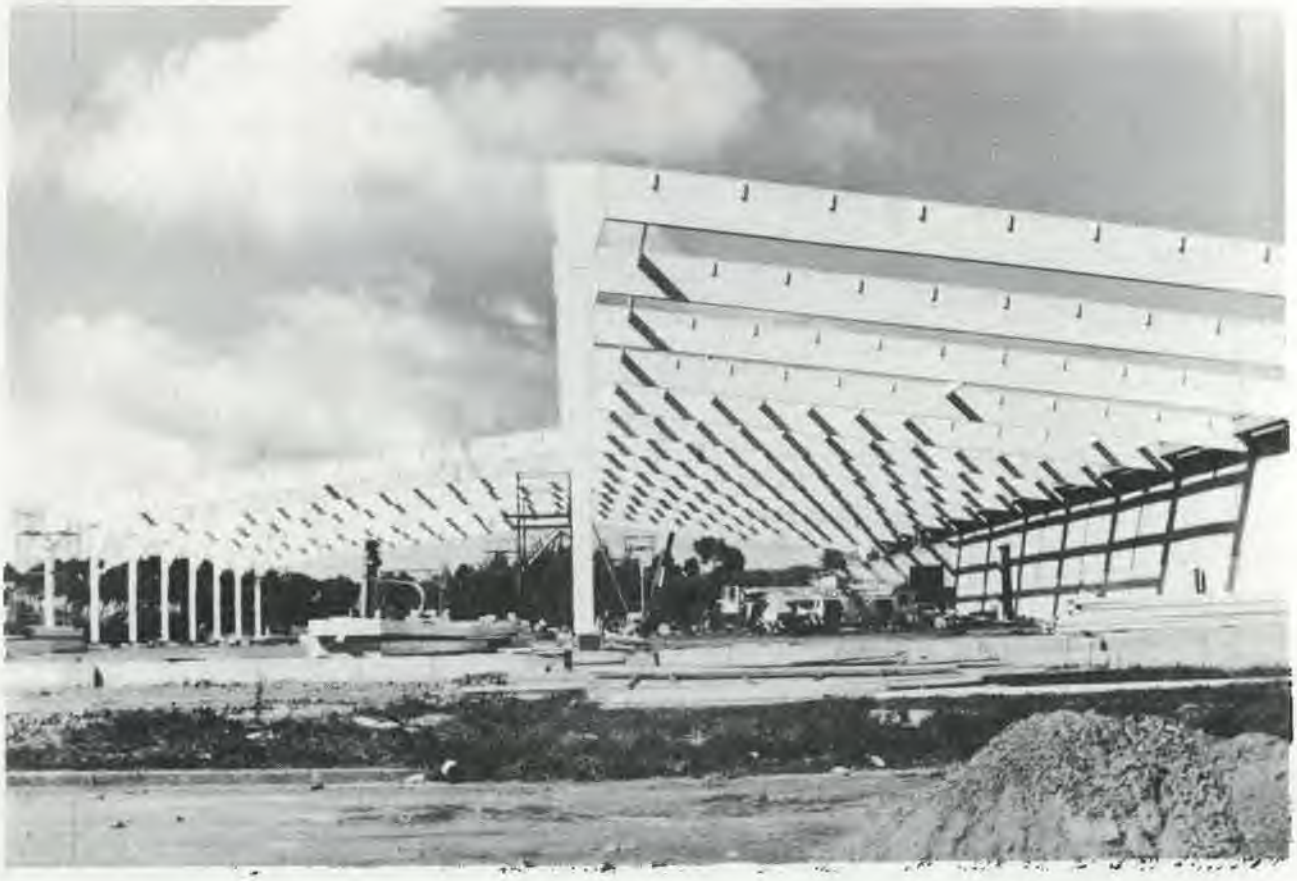

FIGURE 1 - Structural framework of glulam columns and plywood boxbeams for a warehouse/factory extension

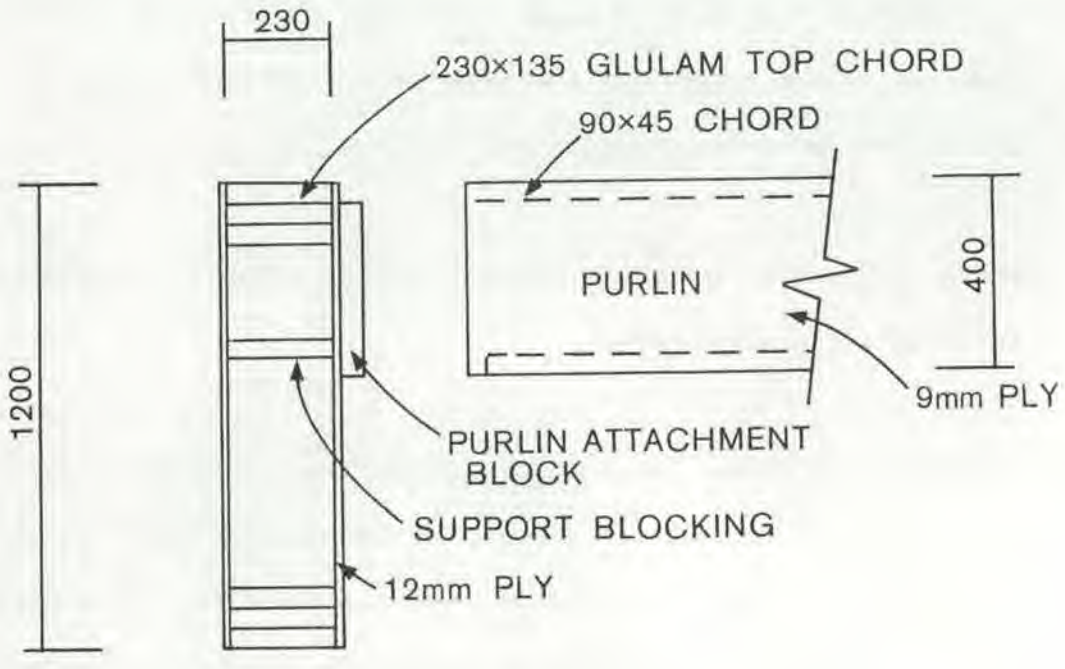

FIGURE 2 - Detail of the rafter/purlin connection used in the building shown in Figure 1

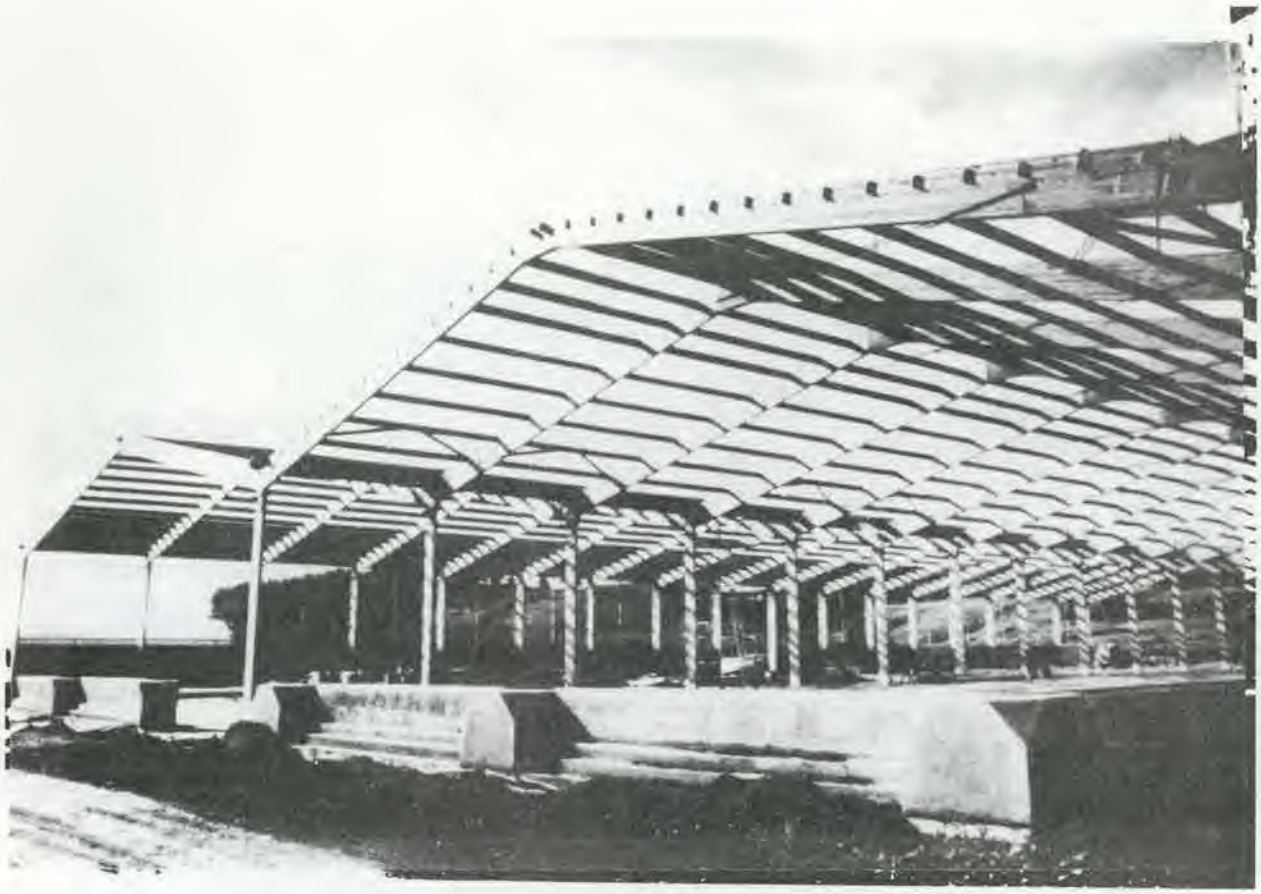

FIGURE 3 - Structural framework of the Triboard mill using glulam and nailed steel gussets

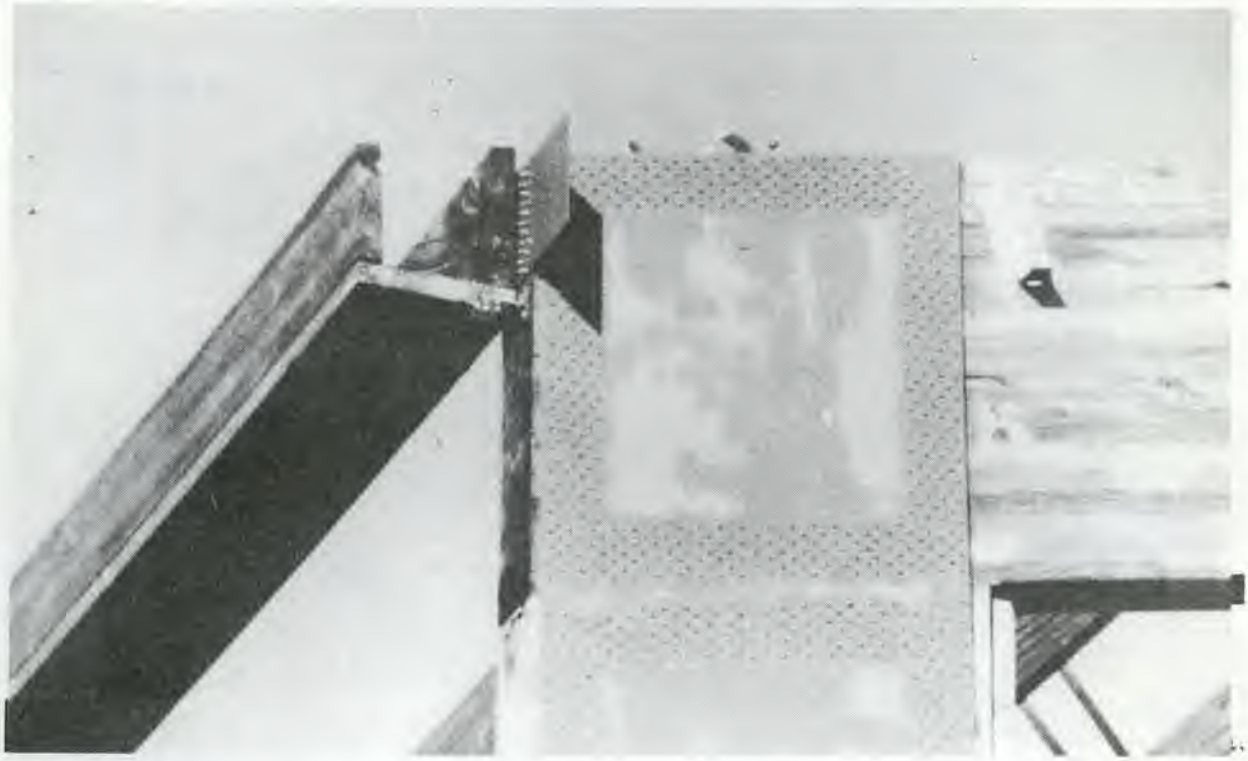

FIGURE 4 - Close up of the eaves joint and box gutter attachment showing the use of nailed steel plates

FIGURE 5 - Two bay sections of roof assembled ready for hoisting as units into place

FIGURE 6 - One of the first examples of construction using ganglam arches - a haybarn of 8 m span

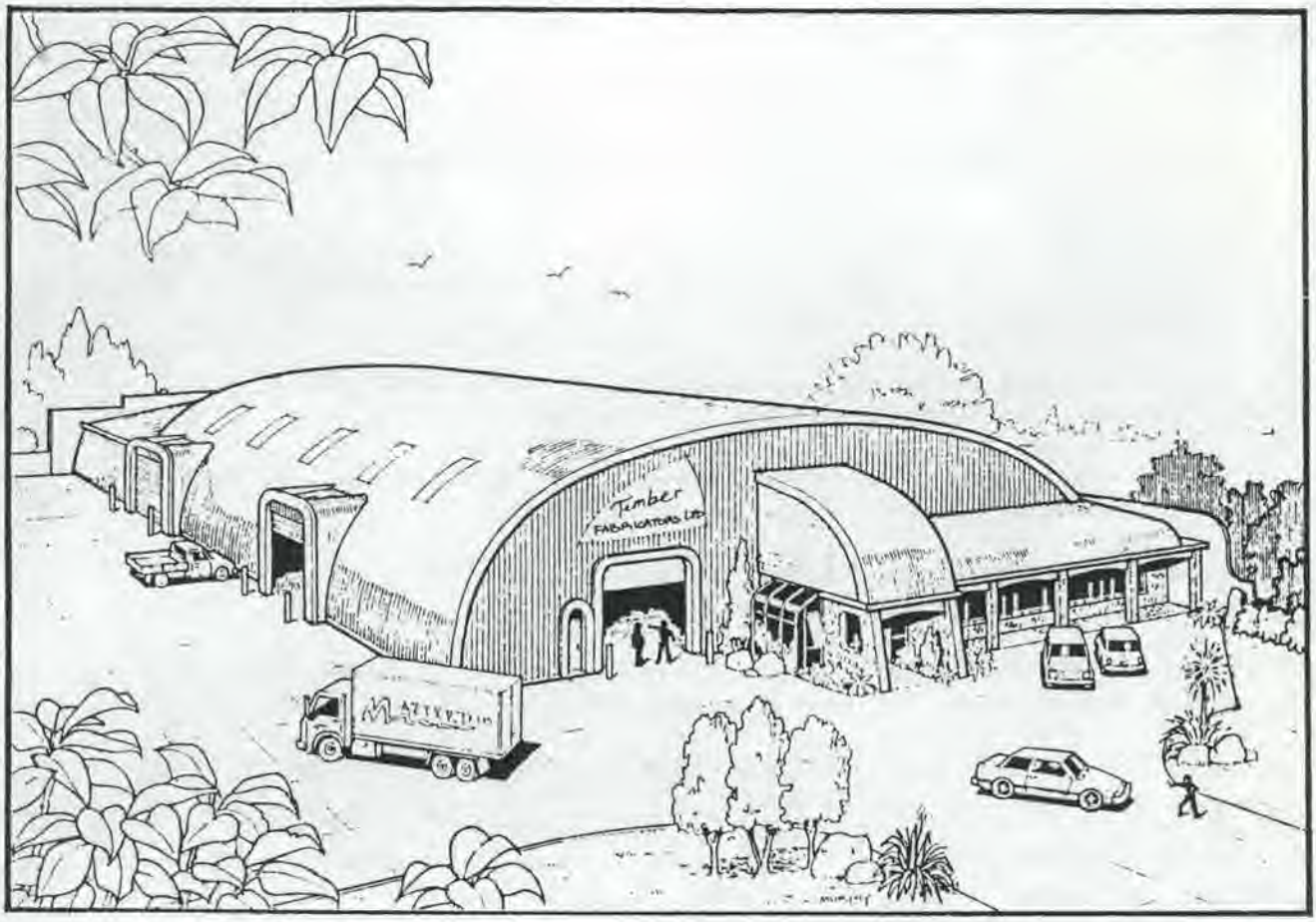

FIGURE 7 - A recent example of Econobarn construction - a factory with 27 m span arches

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CONTINUOUS PRODUCTION AND TECHNOLOGICAL TRENDS IN TIMBER CONVERSION

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ABSTRACT

Economic, environmental and resource considerations are forcing the Australian timber conversion industry to become more productive and efficient in relation to usage of labour and materials. The realization of these objectives is closely influenced by the attitude of management to the adoption of appropriate existing technology to handle the changing nature of the resource and to maximize profitability.

The basic elements needed for optimal performance by a timber processing complex include: effective utilization of raw materials; the right combination of vertically and horizontally integrated operations for processing these materials, particularly to high value-added products; appropriate machinery and operator training to convert these materials efficiently and to achieve high productivity levels; and the planned incorporation of flexibility at each stage of processing to enable a realistic range of profitable products to be manufactured at short notice to meet market demands.

This paper considers a range of modern primary and secondary processing technologies that is appropriate for converting the changing hardwood resource, and others that have been introduced by progressive softwood producers to increase the degree of automation employed.

The increasing trend to the use of computers in all phases of timber conversion operations is helping to increase recovery of sawn timber, decrease labour costs and improve conditions for operators by eliminating some tasks low in job satisfaction, by drastically reducing their numbers in high risk areas on the mill floor and by minimizing the mental stress induced by a high rate of decision making. While completely automated sawing of softwood timber is already a practical reality, this practice is unlikely to be feasible in the near future for Australian hardwoods because of the need to grade-saw them to eliminate unacceptable natural defect occurring in most logs now being processed.

The adoption by sawmillers of relatively simple technologies, such as the upgrading of defective and otherwise unusable timber by finger jointing or the development of rationalized grading rules to ensure a realistic correspondence between timber quality and end-use requirements, has the potential to provide effective cost benefits. Likewise, a realization of both the need and means for drying timber as rapidly as possible to optimize drying costs and minimize drying degrade should be recognized by the timber industry.

INTRODUCTION

This paper is about trends in timber conversion. So while the main emphasis is on current trends, clearly emerging future trends are also included.

In wood processing, there are a number of interacting factors that should determine the most effective and profitable processing and product combinations for each and every sawlog put through a mill but with due regard to market forces. This entails: firstly, the making of crucial measurements on each log to enable well-informed decisions to be made on how it should be sawn or peeled; secondly, deciding on how each piece of sawn timber or veneer should be processed or manufactured to achieve maximum value and marketability; and thirdly, using largely automatically sequenced and controlled machines to carry out the actual mechanical processing, conveying and storage operations in the primary conversion of the wood. Obviously, such processing involves a large measure of computer control to provide a workable system: but already, some conversion plants in Australia do use on-line computers *e.g.* for sawing, sorting, planing and grading functions. The last link in the chain of operations is effective utilization of all residues generated, either as horizontally or vertically integrated operations. Computer controlled rationalization of all individual processing operations in sawmills and plywood mills is a future objective but one towards which wood conversion industries in Australia are very definitely moving.

THE CHANGING TIMBER RESOURCE BASE

Since the resource base has a direct influence on optimal processing techniques and technologies, it is appropriate to briefly consider present realities and future possibilities in this area.

The long predicted change in the both the size and composition of the resource base (1) is now a practical reality of direct concern to both producers and processors of wood. That its consequences are engaging the minds of Government is demonstrated by the development of appropriate strategies (*e.g.* (2)) to deal with what is now a serious problem throughout Australia in the hardwood area. It was predicted in (1) that there would be a 33 percent reduction in sawlog availability from native broadleaved forests between 1975 and 2000: from 6.9 million m^3/y to 4.6 million m^3/y. For too long, a professed commitment to the philosophy of sustained yield was achieved at the expense of a significant shift in the age distribution of forests to the young end, a disaster in the case of species such as *Eucalyptus marginata* with a natural regeneration cycle of 250 years or so. This general problem has been recognized and positive but drastic steps are being taken by State Governments to rectify the position in the long term. Meanwhile, hardwood sawmillers have had to accept both cuts in their log quotas and a much higher proportion of smaller regrowth logs for processing. At the same time, they are being urged to maximize value-added components of products as ways of making best use of a valuable but scarce resource and of restoring cash flows lost through reduced production levels (e.g. the Victorian Government's value adding utilization system - VUAS). The sawmillers' job is made more difficult by high levels of growth stress and increased proportions of knotty corewood in small and comparatively young regrowth logs. The supply and quality of hardwood logs will improve in the medium-to-long term in response to the reduced log quotas imposed and with a significant extension in the rate of establishment of hardwood plantations. To cope with existing and future realities, there must be further rationalization of hardwood operations to ensure that plants are of such a size that turnover is adequate to finance the cost of expensive, but labour saving, high efficiency technology.

At the other end of the resource spectrum, there is a rapid increase in the availability of softwood sawlogs: from 1.3 million m^3/y in 1975 to 9.1 million m^3/y in 2000 (1). A significant part of it is thinnings which are disposed to processing problems largely due to proportionately higher volumes of juvenile or core wood in prescribed thinnings and extreme variations in growth rate of delayed thinnings. Both types of wood have a high potential to distort during drying but can usually be handled satisfactorily with recommended high temperature drying techniques, although primary conversion strategies obviously affect the

outcome too. The problem is compounded by the generally small diameter of the thinnings resource. Typically, 40-45 percent of second and third thinnings have small end diameters (SED) in the range 15-25 cm (3). The current log size position will not improve in the short-to-medium term.

PRIMARY CONVERSION OF WOOD

Sawmilling and its attendant operations can be regarded as a continuous production process even though there may be buffer storage zones to temporarily hold timber passing from one machine to another. The modern trend is to programmed or computer controlled sawing to increase production and recovery, improve sawing accuracy and productivity, and optimize product value and marketability. While the ideal wood conversion system would be an integrated operation under the control of a mini or mainframe computer, there are still very definite advantages in having one or more component parts of a system under computer control, *e.g.* log scanner, headrig, multisaw edger, resaw and docker. An overview of electronic scanning and computer process control in sawmills is given in (4). With such systems, the level of decision-making needed at each stage of processing is inversely proportional to the degree of computerised automation of sawing that can be introduced. The solution or compromise reached is very much determined by the characteristics of the raw material being processed.

1. Softwoods

Because softwoods, particularly larger logs, are comparatively straightforward to handle, they are most amenable to automated conversion processes. This favorable situation is partly due to the fact that natural defect such as knots does not have to be excised, as is the norm for much of appearance grade hardwood products, but is accepted as an integral characteristic of the sawn timber. Already, the sawing of softwood logs can be computer controlled from start to finish, with operators having a monitoring role until something goes wrong and they assume control. The operator of one such system is located in a central control room through which the logs may pass on a conveyor for psychological reasons, *i.e.* so that the close proximity of the logs and their odour help him to retain a sense of reality with his working environment. Automated systems of different kinds are employed in Australia.

For example, at one Australian softwood conversion plant, a chipper/edger combination is used for the programmed sawing of 18-26 year-old thinnings with an average SED of 190 mm (5). Each log is electronically scanned to measure its diameter at 100 mm intervals along its length. That information is fed into a computer which selects a particular cutting pattern intended to maximize the value of the timber sawn from the log, which then passes through a canter/horizontal edger. This produces a squared cant and up to two wane-on-edge boards. Still under computer control, the centre cant is then optimally resawn by a multi-saw vertical edger while the wane-on-edge boards pass through a chipping edger. Only two operators are needed for the primary conversion from log to sawn timber of 60 m^3 (dry, dressed basis)/7.5 h shift from some 2600 logs in mainly 4.8 m lengths.

At another Australian plant (6), optimized width cants produced by twin log breaking-down bandsaws are scanned by infrared beams while being conveyed. Electrical signals from photoelectric detectors are used by a computer to calculate the exact shape and size of each cant. This information is matched against programmed sawing patterns that provide for conversion optimization based on volume or order priority. The computer then controls the setting of the following chipping heads and twin reducer bandsaw which produce the optimum quantity of chips and number of side boards from the previously unsawn edges of the cant. The squared flitch is then resawn manually on a quad bandmill with very limited options for the operator. This partly computer programmed sawing system evolved from successive changes made to increase productivity and improve product quality as mill log input increased, but it was subject to constraints which limited the degree of optimization attainable.

In addition to improving productivity, these two systems described also have the advantage of improved sawing accuracy which improves downstream operations. Reducing the variation in thickness between green sawn boards benefits both the uniformity of drying and the surface finish after moulding.

2. Hardwoods

The hardwood resource, particularly regrowth, has inherent characteristics that make programmed sawing a difficult goal to attain

although probably worthwhile striving for in terms of perceived benefits. Among these wood characteristics are: high growth stress levels and gradients, log sweep and other irregularities of form, tension wood, large knotty core, brittle heart, defective overgrown branch stubs and kino veins. It is a serious deterrent to optimal conversion that the presence of most of these characteristics cannot readily be reliably located until after the first sawcut is put into a log. In addition, many logs are likely to be small in diameter, which severely limits the yield, size and range of potential products although not necessarily the value of the dried sawn timber (7). In spite of these numerous difficulties, sawmillers are able to recover products capable of upgrading to higher value-added ones. Use of the grade-sawing process, which enables much of the defect to be sawn out of individual pieces of timber, achieves that end. But it does play havoc with recovery and productivity, particularly when face straightening cuts are needed to overcome distortion produced during the sawing of logs with high growth stress gradients.

Grade-sawing involves eliminating or limiting the size and location of natural defects in boards by selective cutting. The degree to which logs need to be grade-sawn is determined by the extent and position of defects in the log. These defects only becomes apparent as newly sawn faces are exposed by fresh cuts, which may also introduce longitudinal distortion from high growth stress gradients. Thus, the sawing of hardwoods is an interactive process that requires *inter alia* continuous and rapid electronic scanning to locate and size defects to put it completely under computer control. Herein lies the crux of the problem which is discussed below.

In many Australian hardwood sawmills, particularly those producing green scantling, there has been little change over the years in the sawing systems used. Even such a development as the Australian designed pony carriage/linebar combination, which was first introduced almost twenty years ago, is still not widely used. An important factor contributing to this delay in adopting improved sawing technology is the comparatively small size of many hardwood mills in Australia and the lack of turnover to service the level of capital investment required for the purpose. Even in the largest hardwood mills the basic conversion technology used also remains virtually unchanged although mechanization of materials handling has been substantially upgraded. The changes made,

however, have improved productivity and, in some cases, the accuracy of sawing. This is illustrated by the computer controlled sawbenches (8) installed by one large Australian sawmiller for flitch resawing which subsequently minimize the amount of wood removed by their planing machines.

The considerable difficulties involved in the sawing of small logs with a range of natural defects highlight the need for two vital elements in the development of computer programmed sawing technologies: (a) a high degree of flexibility in the operational capabilities of sawing equipment and, consequently, the range of marketable products that can be produced at any time; and (b) the provision of intelligent and rapid decision-making capabilities. Hardwood logs that are comparatively straight and free of defect could now be programmed sawn on computer controlled equipment. Size and shape information derived from an electronic log scanner would be processed by the computer controlling the carriage, setworks, saws and chippers cutting according to optimally selected sawing patterns. Specific equipment options available will not be considered in this paper. For logs with hidden defect, it could be a reasonable compromise to provide the operator with overriding manual control of the computer selected sawing patterns, so that he can grade-saw according to wood quality where required. While such a system could be expected to reduce the operator's mental workload, both machine productivity and product optimization could be seriously disturbed by his intervention. Obviously, the application of rapid electronic scanning to defect detection would be the preferred option. Some solutions to this important adjunct to programmed sawing of hardwoods have already been obtained (9,10,11,12).

Two essential and differing tasks need to be performed by an automated defect detection system for grade sawing logs into boards: (a) the detection of hidden defect and (b) discrimination of different types of defect. For both tasks, there is need to classify and measure the size and relative position of all relevant defects. In addition, there are a number of performance requirements that automatic image analysis equipment would need to meet. Options for defect detection methods include optical, ultrasonic, microwave, x-ray, neutron and photon devices. Since none of these sensing methods is capable of detecting both surface and internal defects, a comprehensive defect detection system would require a combination of optical with internal detection

methods. Promising test results were obtained with computer assisted photon tomography (using an Iridium 192 gamma ray source) for the detection and location of knots, although still somewhat too slow for practical use in a sawmill. In another study (13), industrial tomography proved to be an accurate method of locating knots, growth rings, surface cracks, borer holes, decay and preservative within poles.

While an automated defect detection system for use with programmed grade sawing of logs is still not a practical reality, electronic scanners in conjunction with computer controlled saws are being used commercially for detecting and cutting out surface defects in boards to produce clears, particularly for furniture components. In Scandinavia, where grading rules relate largely to knots, grade scanners that detect and measure knots as well as sizing boards are used at the front end of edger optimizers, dockers and sorters, all under computer control (14).

3. Grading, sorting, handling and stacking

These operations are a major production cost for sawn timber. The cost can be substantially reduced by the installation of modern materials handling systems such as the automatic and semi-automatic computer assisted sorters and stackers used by the softwood industry. Two factors mitigating against their introduction into the hardwood industry are the smaller scale of operations in most mills and the larger number of sorts for size needed although the latter could be rationalized to a great extent. Green chains and circular sorting tables are the equipment generally used by the hardwood industry for sorting and stacking sawn timber. The work associated with such operations is heavy and is performed with little or no protection from the weather.

At a number of Australian softwood sawmills, as part of the continuous production process, computer controlled drop-sorters are used at the sawn timber outfeed from the mill. As each board on the outfeed conveyor passes the grading operator, he enters its grade into a computer which stores the information and relates it to subsequent measurement of the dimensions of the relevant board. The combination of grade and dimensions determines which compartment bin of the dropper-sorter a particular board is placed in and stored until ready to be strip stacked. At the appropriate time, bins are emptied and the timber conveyed to an automatic stacker for stickering into kiln charges. The

computer maintains a continually updated tally of timber in the individual bins.

This development has greatly increased productivity and eliminated the heavy physical work often performed in the open under extremes of climatic conditions. For example, at one plant where fourteen stackers had toiled unprotected from the weather during long hot, dry summers and cold, wet winters, installation of a drop-sorter/automatic stacker combination resulted in the need for only three operators performing light physical duties under cover to handle an increased volume of timber. It also eliminated production problems arising from the continuing need to recruit stackers and to cope with their high rates of absenteeism.

SECONDARY PROCESSING OF WOOD

An assured supply of processed timber - of adequate strength, appearance and quality - is essential to the continuing viability of the construction, furniture and other wood-using industries in Australia. In both the short and long term, much of the demand for sawn timber must be met from local resources processed by our own timber industry - partly on account of diminishing world timber resources and partly on account of an escalating, adverse trade balance. It is a realistic objective for Australia to become a net exporter of timber in the medium term.

Provided an operation is large enough to service the capital investment needed to establish secondary wood processing facilities, then profits can be maximized by increasing the value-added component as much as the grade and quality of the timber will permit. The additional processing cost involved may represent only a small fraction of the added value of the timber. For example, first quality timber sold as green scantling might yield \$350/m^3 or a net profit of \$50/m^3. If sold as dried structural or truss timber at \$650/m^3, the net profit could rise to \$250/m^3. If sold as furniture timber at \$1000/m^3, the net profit might be \$550/m^3. If suitable for conversion to mouldings, a net profit in excess of \$2000/m^3 would not be an unreasonable expectation. This illustrates that the volume of turnover alone does not determine the profitability of a wood processing operation. At the same time, it must be recognized that only a certain percentage of sawn hardwood timber can be upgraded although this may be increased by further processing such as cutting out defect and finger jointing.

Drying and possibly planing facilities are the principal ones generally needed to increase the intrinsic value of timber. The widespread adoption by the Australian timber industry of seasoning kilns and schedules resulting from research and development activities, principally by CSIRO, has provided industry with a world-class infrastructure. It also illustrates good technology transfer.

There is no need to review in this paper the excellent drying facilities enjoyed by the softwood industry, although I will refer later to the continuous-feed kiln. While the position is less attractive for the hardwood industry, it is still possible to dry most hardwoods relatively quickly and economically with existing kilns and schedules. The position is likely to improve with the increased interest being shown in hardwood drying research in Australia.

A great deal of damage is inflicted on hardwoods dried in the open air without protection. It can also be an expensive operation, especially for thicker timber, when interest charges on stock and drying degrade are taken into account. Therefore, the predrier developed in the early 1950s and still used today should be seriously considered by all medium-to-large hardwood producers throughout Australia as essential equipment. Even where natural air drying conditions are considered to be generally good, they may be excessively slow or fast for much of the year. It makes good economic sense to dry 50 mm thick hardwood in a predrier in 6-8 weeks under controlled conditions than for 2 years in the open subject to the vagaries of the weather. While predriers are still a viable proposition, their cost places them outside the consideration of many smaller timber producers for whom the CSIRO progressive kiln is of special significance.

1. CSIRO progressive kiln

This kiln, which was developed in the mid-seventies (15), provides a cost-effective and multi-task means of drying to all timber producers, irrespective of size of operation. Conceptually, it is a brilliant design for which full credit should go to Leo Brennan, formerly of CSIRO. It is simple and cheap with particular application to the drying of ash-type eucalypts for which it can provide the right drying conditions when the timber is green-off-saw as well as progressively more severe conditions that are suitable for such timber as it dries to

fibre saturation point and below. The first commercial unit was constructed in 1978 (16) and extensively tested before others were built for such diverse tasks as the drying of hardwood squares for rake and tool handles, blackwood boards for wine casks, and radiata pine rounds before preservative treatment. A detailed review of its design, application and use is given in (17).

The biggest installation of the CSIRO progressive kiln in Australia (18) is in Tasmania where eight two-stack wide units have now been constructed and are used mainly for drying 50 mm thick eucalypt timber. They have a combined holding capacity of 1300 m^3 and an annual throughput of some 8000 m^3 from green to just below fibre saturation point. After reconditioning, the timber can be dried at high temperature (19) to 12-15% moisture content on a 24-hour duty cycle, provided no part of any piece of timber is above about 25% moisture content. If it is, there is a high risk of internal checking occurring during the high temperature drying. In conclusion, it can be predicted with some confidence that the CSIRO progressive kiln will be adopted for a wide range of drying tasks in Australia in line with the trend to increase the value-added component of sawn hardwood timber.

2. CSIRO Continuous-feed kiln

It can be predicted with even more confidence that construction of the first CSIRO continuous-feed kiln will commence early in 1987. Further information will be released when the licensing agreement is signed.

This is good news, particularly for the three of us who have been involved in its development since the concept was first proposed almost fifteen years ago (20,21). An overview of high temperature drying research on softwoods in Australia and its relation to the evolution of the CSIRO continuous-feed kiln is given in (22).

The concept and design of continuous-feed driers for sawn timber evolved from successful research at CSIRO on the rapid drying of distortion-prone wood from plantation conifers. The original horizontal prototype dried green softwood timber evenly and rapidly (4-6 times faster than high temperature drying in batch kilns) but not without excessive distortion in 35-50 mm thick corewood. An apt solution to the inherent problem of inadequate restraint of the timber during drying was

found in a vertical design of the continuous-feed kiln. In this unit, timber in a stack is moved downwards, row-by-row or pack-by-pack, through the successive processing zones of drying, cooling, steaming and final cooling. This arrangement progressively counteracts the timber's tendency to distort as it dries. Studies simulating these conditions (23) have demonstrated that corewood up to 50 mm thick dries with low levels of distortion if sawn uniformly to thickness.

A number of general principles, which should preferably be included in any major departure from conventional timber drying kilns, were enunciated in (20) for a continuous-feed kiln. These were:

- Emphasis should be placed on minimizing the labour content in the seasoning operation while maintaining a total capital cost comparable to that of existing systems on a basis of comparable output.
- Heat for drying should be provided from the incineration of wood residues but the use of steam for heating should be avoided to reduce both capital and operating costs.
- Automatic control of temperature, air velocity and cycle time should be inexpensive, and changes from one thickness of timber to another should be simple.
- The equipment should be designed for in-factory construction on a production basis followed by simple on-site assembly, and be capable of extension to give increased drying capacity without major reconstruction.

These criteria, apart from the expansionary feature, and others are incorporated in the latest design consisting of a set of detailed drawings of the continuous-feed kiln. These were prepared under contract and CSIRO supervision by a commercial equipment manufacturer. A complete set of drawings will be made available to licensees of the kiln.

The continuous-feed kiln has many operational and economic advantages for commercial applications. It is self-contained and designed to perform the complete seasoning process in the one unit, virtually without operator intervention. It eliminates manual stacking of timber, the use of concrete restraining weights, and the need for intermediate handling operations and facilities. Direct firing is an option for the drying of green timber. Although originally intended for the drying of softwoods, the recent work on the high temperature drying of hardwoods

from below fibre saturation point (19) clearly indicates its application for this purpose which would require virtually the same drying times as green softwoods of equal thickness up to 50mm.

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THE CURRENT POSITION (SEPTEMBER 1986) OF THE DEVELOPMENT OF SCRIMBER

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ABSTRACT

The current developments in the commercial production of Scrimber are discussed. A production plant is planned for the South-east of South Australia and will be operational in 1988.

1. INTRODUCTION

1.1 The principles of Scrimber were defined by Mr. J.D. Coleman of CSIRO and a provisional patent application made in 1976. Full patent was applied for in 1977 and granted in Australia and USA in 1980. Patents have also been applied for or granted to cover the product elsewhere.

Towards the end of 1977, Repco was granted a 2-year option to undertake collaborative engineering and commercial development. The Repco Board recognized that it was likely to take 10 years to achieve a commercial return.

1.2 The collaboration continued during 1978 and 1979 involving the building of development machinery and various process trials, producing a clearer picture of the likely production process. Various raw materials were tried but Pinus radiata was settled on because of the volume of first thinning material available from commercial plantations throughout south-east Australia. Drying and press curing were also examined and various resin systems considered. Because of the volume of work to be done, the 2-year option was extended through 1980. During this period, product 4 metres long was being produced on a specially built hot platten press and some specialized machinery was built.

1.3 The necessity of using a water-proof resin was recognized and two systems, tannin-formaldehyde and water emulsifiable isocyanate, were identified as likely to be suitable. It was also realized that the thick sections intended for this product were best cured by dielectric (RF) heating and a unit was purchased for this development.

1.4 Repco having developed the Scrimber process saw that it had potential, and decided to discuss commercial development with companies in the timber industry. To this end, an experimental plant was establishment in Dandenong adjacent to the main Repco Research site. As a result of the internal re-structuring of Repco and of the motor vehicle industry in general, its Board decided to licence Scrimber. Following negotiation, SATCO assumed responsibility for the establishment of a manufacturing plant. Subsequent to the licencing of SATCO, Repco has progressively divested itself of its manufacturing companies. The licencing of Scrimber was a natural outcome of this policy.

1.5 SATCO's Licence to Manufacture

CSIRO and Repco have granted to SATCO a 3-year licence to use their Scrimber know-how and patents. The licence is exclusive in the Geographic Territory, i.e. Australia and the ASEAN rim. SATCO purchased the experimental plant from Repco and are now the only group able to manufacture Scrimber. SATCO has agreed to construct and commission a Scrimber production plant having a capacity of 10 000 cubic metres per shift year. CSIRO and Repco are required to grant to SATCO the exclusive right to manufacture Scrimber in the Geographic Territory.

2. PRODUCT

2.1 Properties and Performance

Scrimber is presently manufactured to a density of 650 kilograms per cubic metre, slightly lower than dry Victorian hardwood or European or American oak and substantially lower than blackbutt, jarrah and European beech.

The bending strength of Scrimber is around that of high quality, clear dry softwood. Prolonged loading over periods of 12 months has shown that the allowances required for creep and strength under continuous loads are the same as for Pinus radiata. Scrimber exceeds the durability requirements of AS. 1859 for Structural Particleboard. The adhesive used is classified as suitable for structural applications in AS. 2754.1-1985 Adhesives for Plywood Manufacture. Unlike natural timber, Scrimber is very stable and does not bow, spring or twist.

Scrimber can be easily worked with standard wood-working machines and tools and will accept normal fastening. Scrimber's surface can be painted, stained or polished like natural timber and does not need any special preparation.

2.2 Product Development

The 'recipe' for 'Stage 1' Standard Scrimber has been decided. It will be produced from Pinus radiata first thinnings. The adhesive will be tannin-formaldehyde, and the product density 650 kilograms per cubic metre. Scrimber produced by this recipe achieves the requirement for the F11 timber grade in Australia.

3. MANUFACTURING PLANT

3.1 Process Development

(1) Log Sorting and Input - Relates to a simple log yard and is not difficult.

(2) Scrimming - Considerable developments have occurred in this area in order to present a uniform mat to the driers. The process has been patented, and drawings are ready for manufacturing of the production plant.

(3) Mat Preparation - Considerable work has been done to develop an even thickness, even density mat to ensure both consistent drying and a uniform density product. A new system has been perfected.

(4) Drying - Will be based around a modified veneer drier.

(5) Resin - Application of tannin-formaldehyde has been perfected with minimum water uptake by the dry scrim mat.

(6) Lay-up - Will be using the thatch method.

(7) Pre-pressing and Pressing - Will be done in a large press. The size of Scrimber flitch produced will be around 10 m x 1 m x 100 mm.

(8) Curing - Will be by RF.

3.2 Development Period

SATCO assumed responsibility for Scrimber on 16th December, 1985, and since then considerable progress has been made towards the establishment of a manufacturing plant. The plant will be built in two stages -

- 'Stage 1' Capacity 10 000 cubic metres per shift year, to be operational during early 1988
- 'Stage 2' Capacity 20 000 cubic metres per shift year, to be operational two years after the first stage

The 'Stage 1' manufacturing plant will contain some equipment capable of operating at the ultimate plant throughput. These items are -

- Log yard
- Crushing mills
- Pre-press
- Glue kitchen
- Press and dielectric heating unit

In these areas, we are confident of the final design and the effect of scale on capital cost does not justify introduction of lower capacity equipment.

All other equipment will be designed to operate with 'Stage 1' throughput and duplicated or modified when the plant is upscaled to full capacity.

As 75% of the total capital will be spent in establishing 'Stage 1', profitability will be increased dramatically once 'Stage 2' manufacture is achieved. Two-stage development also allows the market to be developed in a rational manner, plant output being increased at a rate matched to market acceptance.

The experimental plant is still located at Dandenong, Melbourne, where the Product, Process and Manufacturing Plants are being developed.

3.3 Development Status

A flow sheet and manual for the manufacturing plant have been developed by Scrimber staff. A number of items of equipment have been defined and specifications are being forwarded to potential suppliers, e.g. -

- Press and dielectric heating unit
- Drier
- Glue kitchen

Equipment unique to the Scrimber process will be designed by SATCO and put out to tender for manufacture. Design of the crushing and scrimming mills has commenced.

To expedite development, a critical patch analysis has been constructed for the manufacturing plant.

4. MARKETING

4.1 SATCO's objective is to market the total production volume of Scrimber through existing selected timber merchants and stockists throughout Australia. The product will be marketed toward residential and commercial construction for rafters, ridge beams, hanging beams, strutting beams, lintels and floor joists over long spans.

Two hundred and fifty beams produced in the Experimental Plant, 4 m x 300 x 50 need to be subjected to testing for Absac approval.

The process of allocation of strength grade is of considerable concern to SATCO.

4.2 Grade for Conventional Timber

Grade is allocated to a timber species which is not able to be modified by an industrial process by -

- Testing clear specimens;
- Allocating a grade to the species;
- 'Correcting' by a series of factors to allow for long term load, creep etc
- (If machine stress graded), a further 'correction' factor is allowed because correlation between 'e' and 'r' is only around 70%;
- Reducing this 'corrected' grade by 80%
  65%
  50%
  40%

  to allow for strength reducing factors like knots, sloping grain etc. to arrive at lower grades.

This method of grade allocation is coming under increasing criticism around the world because in-grade testing shows that by the time all the factors are applied, the lower grades merge into one another, and the strength differences are not found in practice.

Seems to us that two grades, based on 'e' not 'r', are much more logical and R.P.R.I. will be working towards that end.

4.3 Grade for Industrially Processed Wood

Industrially processed wood has far less variability than timber. To proceed through the process of determining e and r as for timber, then to apply 'correction' factors the same as timber without questioning seems to SATCO to be very conservative and penalizes the manufactured product.

A preferable approach would seem to be to test a number of pieces and allocate an actual grade to the material based upon its own characteristics. Then span and load tables should be calculated based upon the results achieved, rather than based upon the nearest lower F rating.

5. EXPERIMENTAL PLANT

This will be re-located in the South-east of South Australia together with the production unit, so that work can continue on further Scrimber developments - preservation, moulded shapes, etc.

GLUED STRUCTURAL TIMBER PRODUCTS

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ABSTRACT

Man's future shelter needs can be met through the developments of reconstituted or composite wood based products. These products will provide new opportunities to expand the use of wood as a building material and allow better utilisation of our forest resources.

INTRODUCTION

I would like to begin by asking the question, "What are man's basic needs?"

This is a simple question, but one which we all too often take for granted, particularly those of us who live in complex industrial societies.

Of course these basic needs are:-

food
clothing and
shelter

I believe that we should always remind ourselves of these basic needs, if it only serves to remind us to ask the question, "what is our business?" We should never lose sight of this simple question.

Our early ancestors were hunter-gatherers who sought shelter in caves. As man evolved he learnt to construct shelters out of rocks, stones, clay and, of course, timber in the form of branches, bark and logs. No doubt, our ancestors when selecting their building materials selected those most readily available and workable within their surrounding environs to satisfy their shelter needs.

Minerals, metals and wood resources have served man over the centuries. These materials still provide the primary resource for the manufacture of building products needed by man to erect his shelters, be they humble cottages or multi storey buildings. These materials can be used singularly or in combination to complement and enhance their intrinsic qualities. Wood is but one of these materials available to man to erect his shelters.

Today, the choice of a building material to meet a particular application will, inter alia, depend upon its ability to meet specified performance requirements and supply needs such as its fitness for purpose, its cost and support service.

We should not perceive traditional usage of a resource as conferring exclusiveness of choice. In fact, if I may be so bold as to say, tradition is often the cause of myopic thinking and the stumbling block of innovation. A new product will quickly replace an existing one if it better meets performance requirements and supply needs.

Let me refer to my earlier question "what is our business?" Clearly, we are in the shelter business through the supply of wood based products to meet the needs and demands of the building and construction industry.

If we see ourselves in the timber business then our thinking is channelised and narrowly focussed. If one is in the wood business instead of the shelter business he is likely to react with some kind of defensive program to protect wood rather than looking at new and innovative ways of integrating this excellent resource "wood" into his shelter business.

RECONSTITUTED AND/OR COMPOSITE WOOD BASED PRODUCTS

I see reconstituted or composite wood based products falling within the preceding context, expanding the use of our resource into a variety of innovative building materials to meet one of man's most basic needs "shelter" in either an industrialised or a developing country.

I include in building materials both structural and non structural in the form of framing, sheathing and panel products respectively.

The following comments are directed at framing materials for both light framed structures and heavy industrial/commercial buildings. Other papers in this session will more than adequately cover panel and sheet products.

CHANGING RESOURCE

We are all accutely aware that our resource base is rapidly changing from mature virgin forests to natural regrowth and plantation forests. Such change brings with it faster grown wood, more variable wood properties and smaller diameter logs to process. Large defect-free logs which were so desired in the past for peeling and sawing operations to provide traditional structural products, have all by and large been harvested and utilised.

Evidence of supply problems with large solid sawn timber (SST) structural products is now emerging within the building industry. Basically, it comes down to a simple question of log geometry. A sawlog will yield only so much square and rectangular SST.

The answer to these supply problems lies within the broad group of wood based materials known as reconstituted or composite products.

Wood is biological in origin, its internal structure being fixed by nature. We have in the past assumed that the manipulation of wood properties was beyond our control. This is no longer true. Materials engineering of wood begins with growing the trees and extends throughout the whole manufacturing operations to produce reconstituted wood based structural products.

The solution then to the supply of SST is to take our raw wood material, break it down into smaller elements, fibres, strands, veneers or smaller dimensioned SST, add adhesive, press or blend into a reconstituted or composite product as long, thick and wide as you need to achieve some specific performance requirement.

The resultant product is no longer wood, it is infinitely better. The density, anisotropy, dimensional, physical and mechanical properties can all be controlled to produce a wood based product whose properties in many ways resemble SST but for one and that is SST's inherent variability.

EXISTING, NEW AND FUTURE RECONSTITUTED STRUCTURAL PRODUCTS

Let me now discuss some examples of reconstituted structural products which have or will replace SST framing members.

Glued Laminated Structural Timber (Existing)

Glued laminated structural timber (GLST) represents the oldest form of reconstituted structural product. It is composed of small dimensioned SST sections, face glued to make up large structural timber sections. In fact early laminated beams did not use adhesive to bond the lamination faces together but employed bolted assemblies often in connection with shear blocks inserted between the lamination faces. The concept of laminating small timber sections to produce larger members is therefore quite an old one.

GLST allows the utilisation of small diameter logs to be converted into larger SST sections which would not otherwise be attainable from the sawlog. However, in Australia, GLST has often been produced as a recovery line item or operation to utilise sawmill shorts, these shorts being end jointed using finger joints or scarf joints. Adhesives include caseins, melamines and phenolics. Phenolic type adhesives predominate because of their known ability to meet long term durability performance requirements.

Production of GLST

Production of glued laminated timber, at least in Australia, is not highly mechanised, being labour intensive and requiring manual lay-ups and finishing operations. Presses for laying up the members can be either mechanically (screw jacks) or hydraulically operated. End jointed laminations are passed manually through a glue spreader and layed up in the press. Heat is applied to the presses to ensure good bonding of the adhesive. Radio frequency

pressing and drying can be used because it speeds up the drying time, but should only be contemplated where continuous production of constant end sections are intended. This equipment is not suited to jobbing operations.

GLST produced in Australia is laminated from both hardwoods and softwoods. Hardwoods include, jarrah, ash type eucalypts and brush box. Softwoods include radiata pine and slash pine. Oregon GLST is also imported into Austrlia.

Production size of GLST range in size from 200mm to 1000mm in depth. The average member depth is probably around 350mm with 85% or thereabouts of production being less than 500mm deep.

Application of GLST

GLST is used in utilitarian structural applications however I believe the bulk of production is consumed in architectural applications where appearance and finish are prerequisite requirements. The configuration of most GLST used in buildings is straight or moderately cambered. Members are used in post and beam type construction or as chord members of large timber trusses.

The application of curved members, whether in portal framed buildings, pedestrian bridges, or in the more exotic architectural styles has been extremely limited.

Properties of GLST

The stiffness of GLST as expressed in terms of coefficient of variation is far superior compared to SST. Unfortunately, the same cannot be said of its strength. While the laminating of small timber sections distributes and disperses the strength reducing effects of material defects (knots, sloping grain etc.), the primary cause of strength reduction in GLST can be attributed to end jointing of laminations with finger joints. The saving grace being that most GLST members are sized on stiffness to meet serviceability criteria, where the bending stresses may be less than 50% of the outer lamination grade. However if the joint does not have long term structural integrity and durability it will perform in the same manner as a butt jointed lamination in which case collapse or failure of the member may ultimately eventuate.

Research is needed to determine the mechanism of failure and the bonding process in finger joints and the development of optimum profiles and adhesives systems to achieve joint strengths better than No. 2 structural grade (60%).

Consumption of GLST

Despite having been in existence for a considerable period of time GLST has not found wide usage in Australia. My guess is that current consumption probably stands at around 20,000m^3 per annum (give or take) out of a total of around 4,000,000m^3 per annum of sawn timber.

I suggest the bulk of GLST produced is consumed in light framed domestic structures, with the remainder being consumed in commercial buildings (shopping centres etc.), assembly and institutional buildings (churches, schools, public halls etc.) and industrial buildings (warehouses etc.).

GLST has suffered ups and downs having come into disrepute at times due essentially to lack of proper quality control procedures within each of the production processes of its manufacture. The main cause of the problem was delamination of the interfaces of the laminations caused through inadequate adhesive bonding.

The reasons for this low consumption are many and varied:-

Attitudes to Production

The production of GLST is, as I have said often a recovery line item to utilise sawmill shorts. The cost and supply of shorts is low. To use larger length SST framing or board products, which commands a higher price in the market place, would be to increase the cost of manufacture and hence price of GLST. It comes down to a question of supply and demand and return on investment.

Education and Information

Engineers in general have little, if any, education in timber engineering design. In fact, timber is often perceived by engineers as a temporary material to be used during construction rather than one which can provide permanence for industrial and commercial buildings. Lack of familiarity of design procedures and the availability of design aids works against the use of GLST and for that matter timber per se.

Generally it has been my experience that architects are very sympathetic to the use of GLST. The engineer, quantity surveyor and builder obviously influence choice of material.

Fabrication

The timber industry in Australia does not provide fabrication facilities for the use of GLST in industrial and commercial building. These facilities are readily available in the steel construction industry. I have had the occasion to talk with large building construction companies, and their major complaint is detailing on site of GLST rather than being able to place a subcontract for the supply of fully fabricated assemblies.

Supply and Service

In the past inability to supply GLST on time has left nasty tastes in the mouths of architects and builders, particularly when the builder is subject to liquidated damages for late completion. To compete one has to provide service to the consumer.

Building Regulations

In respect of light framed timber construction, domestic housing, the regulations in general do not have any restrictions which might limit the use of GLST and/or SST. In commercial and industrial buildings, the fire performance requirements of the building regulations need to be closely examined to determine their influence and whether or not they impose undue restrictions on the use of GLST and all wood based building products be they SST or reconstituted.

New Reconstituted Products

A new product which has come into the Australian market is laminated veneer lumber L.V.L. Kevin Lyngcoln's keynote address has admirably covered this product in his lead paper, suffice for me to say that I consider this product has great potential as a reconstituted wood based product.

Scrimber is another example of a reconstituted wood based product still under development. The utilisation of early thinnings is ideally suited to this product for upgrading the resource into value added products. Obviously more development is necessary to evaluate the viability of this product.

Another recent reconstituted product developed in the USA is parallel strand lumber which it is understood is going into commercial production. Solid cross sections can be produced in continuous lengths using long strands (30 to 60 mins) derived from veneer being compactly pressed and bonded together. The advantages are unlimited sizes and lengths, consistent properties and high mechanical properties.

Future Reconstituted Products

As our resource changes trees will get smaller, growth rates will get faster, therefore sawn products from them will not be as high in quality as sawn products from older larger trees of the past. It is only logical then that reconstituted and manufactured parts will become much more numerous than in the past. This is heralding a new era in forest products research and development. If these new wood based reconstituted products are to compete with such uniform materials as steel or aluminium it will be necessary that they have properties which ensure durability, reliability, predictability and reproducibility.

Future Challenges and Research Needs

I have already alluded to these needs in my preceding comments.

Data for reconstituted products will need to be developed not only for basic engineering design properties, bending shear and M of E etc. but we will also have to address fastener performance, fire resistance, duration of load effects, moisture effects, dimensional properties, tensile and shear effects parallel and perpendicular to the orientation of the wood elements.

It will be necessary to develop a wide profile of data which characterises the properties of reconstituted products. I suspect many of these properties have never been characterised for SST simple because they have been around for eons. All this information will be necessary if reconstituted wood based products are to gain acceptance in the building industry in demonstrating that they have the properties necessary to meet performance requirements for durability, reliability, predictability and reproducibility.

The current generic grading procedures will also need to be addressed as these rules were developed for SST sections. If we are to maximise the properites of reconstituted products we should not tie ourselves into a system which never perceived such products. Obviously this will mean a new method of presentation of design data of appraisal and accreditation if it is to be accepted by end users.

Adhesives technology will play an even greater role in reconstituted and composite wood based products. Research will need to be undertaken into developing efficient and effective adhesives, evaluating life cycle effectiveness of new formulations in respect of long term durability, identification of environmental problems that might occur with new systems etc.

Technology transfer will be a major activity associated with reconstituted products. Information will need to be transfer through all levels from researcher, engineer, architect and builder. It must be a two way activity to ensure feedback of experiences so that new needs can be identified.

Finally, reconstituted and composite wood based products through multidisciplinary effort from researchers to marketers afford new an exciting opportunities for expanding the wood based industry. I am however compelled to add a cautionary note, we must be pragmatic in our endeavours at all times, and not succumb to the euphoria of woods good mentality. Yes, I agree, trees are a renewable resource and future store house of chemicals and fibre which can benefit man. In my opinion this does not matter one iota, if we cannot meet the performance requirements of other materials, we will be out of the shelter business.

RECENT DEVELOPMENTS IN THE AUSTRALIAN PLYWOOD INDUSTRY AND THEIR LIKELY INFLUENCES ON FUTURE RAW MATERIAL NEEDS

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INTRODUCTION

Plywood, the nineteenth century prototype wood-based panel, prompted the development of rival sheet materials made variously from wood fibres, chips, wafers and oriented strands of wood. Each of the new materials gained acceptance by providing minimum cost solutions for particular end-uses.

To maintain its viability against such competition, the local plywood industry had to resort to a variety of tactics, the most fruitful being to exploit plywood's inherently superior strength properties. Today, panel constructions are often custom-designed to suit loading conditions and machine stress-grading is being widely used so that the strength advantage can be fully utilised.

Eucalypts, which tend to be troublesome in production, had only limited value as peeler material for furniture grade 3-ply in the past, but now are being appreciated for their good bending strength and hardness, especially when used for face veneers.

The manufacture of laminated veneer lumber (LVL) in Australia will put the industry's product in competition with glulams and perhaps imported Douglas fir timber. Here, again, eucalypts' good strength properties could be used to advantage.

When in competition with plywood, the rival panel materials often have a price advantage due to a lower unit raw material cost and a higher recovery of product from logs. However, new technology in veneer manufacture, in the form of the 'spindleless' lathe, powered back-up rolls and second generation computerised billet centering is expected to boost recovery significantly and, hence, reduce the rival panel materials price advantage. This new technology will at the same time allow smaller diameter raw materials to be utilized.

CURRENT DEMAND FOR PEELER MATERIAL

About 75% of the peeler logs consumed in the local industry is pine (*Pinus spp.*) with radiata pine (*Pinus radiata*) the main species. A typical pine peeler log is around 40 cm in diameter and not much different from a sawlog, other than having a larger average diameter. Pine is being used mainly for the manufacture of structural and utility grades of plywood in accordance with the Australian structural plywood Standard AS 2269-1979. Information on the rationale of grading for structural plywood and end uses for the product can be found elsewhere (1).

When assessing the suitability of pine peeler material for plywood,consideration is usually given first to average diameter, since this will have considerable bearing on recovery (2) and then to the yield of C-grade veneer, i.e. veneer that is free from open defect and loose knots. C-grade veneer is used as face veneer in structural plywood and as underlay to face in some non-structural plywoods. Any shortfall in this grade will have to be made up by up-grading lower grade veneer in labour-intensive patching and salvage operations.

Pine is often combined with other species usually as an economical 'fill', for example, in relatively thick panels intended for high finish applications.

Structural plywood is also made entirely from eucalypts and from pine and eucalypts in combination, with eucalypts as outer veneers. Consumption of eucalypts, although not great, is increasing due to their acceptance as rainforest substitutes in NSW and because of their good performance in structural applications.

About 50% of the Australian industry's production, including some structural products, is intended for high finish applications and must have one or two high quality face veneers, high quality in this context meaning uniform in texture and without knots or open defect. Products in this category include concrete formwork, marine plywood and paintgrade plywood. The rainforests in Queensland and Northern NSW have been the industry's traditional source of high quality face veneer but cessation or drastic curtailment of rainforest logging in those States is forcing the industry to look elsewhere for face veneer and today much

face veneer of mixed dipterocarp species is being obtained from South East Asia, although this supply, too, is showing signs of faltering.

DEVELOPMENTS IN VENEER MANUFACTURING EQUIPMENT

There have been two streams of development in veneer manufacturing equipment, one catering mainly for the processing of small diameter softwoods, and the other, not so important today, for relatively large diameter hardwood logs.

Most of the development in small diameter log equipment has, until quite recently, been aimed at increasing production capability and substantial progress in this regard has been made over the past 30 years. A notable landmark in that period was the Coe Manufacturing Company's "one billet per minute" peeling line as advertised in trade journals in the late 'fifties. Today, the most advanced peeling lines in the USA have four billets per minute and greater capability, and can process around 360 m^3 of 2.6 m long billets in an 8-hour shift.

Much of the improvement in veneer lathe performance was achieved by mechanising billet pre-centering and loading. Nevertheless, from Australian experience, mechanisation of these functions introduced centering accuracy and so the gain in productivity was achieved at the expense of recovery. For example, CSIRO research has shown that when a typical radiata pine peeler billet is manually centred it has a form index of close to 0.8 (1), indicating that after rounding it up in a lathe, 80% of its original volume would be left. However, when precentering and loading are mechanised, billets of the same form quality have a significantly inferior form index, in this comparison, around 0.75. Ronan et al (2) came to similar conclusions about the performance of mechanical lathe changers. Centering inaccuracy of mechanical chargers does not necessarily reflect faulty design or machine malfunction, but rather the difficulty of the task of locating, within seconds, the optimum centering axis of an often bumpy peeler billet. For example (3), for the relatively simple geometric shape of a billet of circular cross-section with taper and sweep and for the special case of:

$$\text{sweep (s)} = \text{taper} = \text{billet diameter}/20$$

the optimum centering axis is located by marking the dogging point at

the butt and top ends at distances 9S/8 and S/8 respectively from the geometric centre in the plane of the sweep and in a direction away from the concave side of the billet. Understandably, for ten years or so, high-speed centering has been recognised as a task for sophisticated surface scanning gear and a computer, but progress in developing such a system has been slow. In the writer's opinion there is little doubt that an effective system will ultimately be developed and it may even be available in second generation centering systems currently being advertised in trade journals. With accurate centering of pine billets, form indices of 0.83 should be achievable. With this improvement significant reduction in round-up waste will result.

Ever since dual telescopic spindles were perfected in the late 'fifties and until the recent development of powered back-up rolls, minimum peeler core diameter for peeling 2.6m billets into 3.2mm veneer has remained at close to 125mm. The now proven powered back-up roll has allowed peeling of 2.6m long peeler cores down to a diameter of 75mm while a radical development of it, the so-called spindleless lathe, promises a minimum core diameter of 50mm. In its present state of development, the spindleless lathe has some notable confirmed or potential limitations:

1. Billets must be 20cm or less in diameter and, furthermore, be of good form, otherwise they have to be pre-rounded in another spindleless lathe.

2. Much of the product from the juvenile core of the tree would be of low strength and perhaps unacceptable for structural plywood.

3. Peeled quality of 3.2mm veneer, especially of hardwoods, would suffer as a result of the extreme curvature of the cutting arc when the diameter is reduced below 70mm.

The development of the veneer manufacturing equipment described will serve first to reduce the cost of making plywood but at the same time allow smaller diameter logs to be used. Spindleless lathe production, should its promise be realised, could be based on logs of an unprecedented 15cm average diameter. The recovery versus diameter curves for 2.6m conversion given in Figure 1 illustrate the recovery potentials for the two peeling systems. The curves are for:

(a) A conventional small log lathe with dual telescopic spindles and mechanical pre-centering and loading.

(b) A lathe fitted with a powered back-up roll and second generation computerised centering.

(c) A spindleless lathe with gravity feed (no charger).

The graphs are based on a relationship between recovery and raw material and production parameters which was derived in earlier research (1,4). They are intended to show the recovery potential of the systems rather than recovery actually being achieved, since little is known of their performance in industry.

LAMINATED VENEER LUMBER (LVL)

Information on the method of manufacture and the properties of LVL as made in Australia can be found in the lead paper to this section of the Conference. As pointed out in that paper, veneer quality requirements with regard to knots and open defects are not demanding and, indeed, seem to have minimal influence on LVL's properties. Therefore, peeler material as normally used for the production of structural plywood according to the Australian Standard AS2269, should be acceptable. For mainly aesthetic reasons, veneer without open defect, i.e. C-grade or better, is used for face veneers, but since LVL has fifteen or more laminations, meeting this requirement should not be difficult. Variation in density within a raw material is likely to have more influence on LVL's strength properties than the presence of knot and open defect in veneer,and therefore may have to be closely monitored.

Unlike the local plywood product, LVL currently made in Australia is based on 1.25m long veneers and therefore the veneer can be produced on a core lathe at a significantly higher recovery rate than can be obtained than for 2.6m conversion as normally used for plywood. The better recovery is due to being able to peel down to a smaller core diameter (75mm c.f. 125mm) and to effectively better form quality (1). It follows that smaller diameter raw material can be used for LVL than for plywood, although the use of small diameter logs incurs the penalty of an increase in the proportion of low-strength juvenile wood in production. Nevertheless, if necessary, the affected veneer, which can readily be detected can be set aside for use in plywood for non-structural use.

FUTURE SUPPLY OF FACE VENEER

A dwindling supply of peeler logs from local rainforests has made the industry increasingly dependent on imported face veneer. Much of the latter is used for concrete formwork. The face veneer supply situation today might have been worse but for the foresight of the Queensland Forestry Department when it started establishing plantations of hoop pine (*Araucaria cunninghamii*) some fifty years ago. The trees have been intensively pruned and will become an increasingly important source of high quality veneer for use as faces on marine plywood and concrete formwork.

In the early post-war years, the use of eucalypt face veneer in high finish applications was well established in Victoria and Tasmania. The raw material at that time was selected logs from large diameter forest grown trees. Today the only eucalypt available for peeling in Victoria and NSW is young regrowth, but very little of it is being used for high quality face veneer although its good potential in this regard is starting to be recognized.

With the sponsorship of the Plywood Association of Australia (PAA) and the NSW Forest Products Association, CSIRO has been active in developing appropriate technology for manufacturing face veneer from regrowth eucalypts. In field studies it has been established that the wood quality of selected logs of blackbutt (*Eucalyptus pilularis*), Rose gum (*E. grandis*) and spotted gum (*E. maculata*) from even-aged regrowth stands is good enough for face veneer production. The average diameter of the materials studied was around 40cm. In just completed manufacturing trials of selected logs of rose gum, in which specially developed processing techniques were used, good yields for a veneer and a satisfactory recovery were obtained. It is expected that eucalypts will become an increasingly important source of face veneer, especially for high finish structural applications as well as structural backs and faces for structural plywood.

Pruned slash pine (*Pinus elliottii*), Loblolly pine (*P. taeda*) and Caribbean pine (*P. caribeae*) will be available from Queensland plantations and no doubt will be exploited for clear veneer. Pronounced growth rings in these species rule out their use as face veneer for the more demanding face veneer applications, e.g. paint grade plywood and the better grades of concrete formwork.

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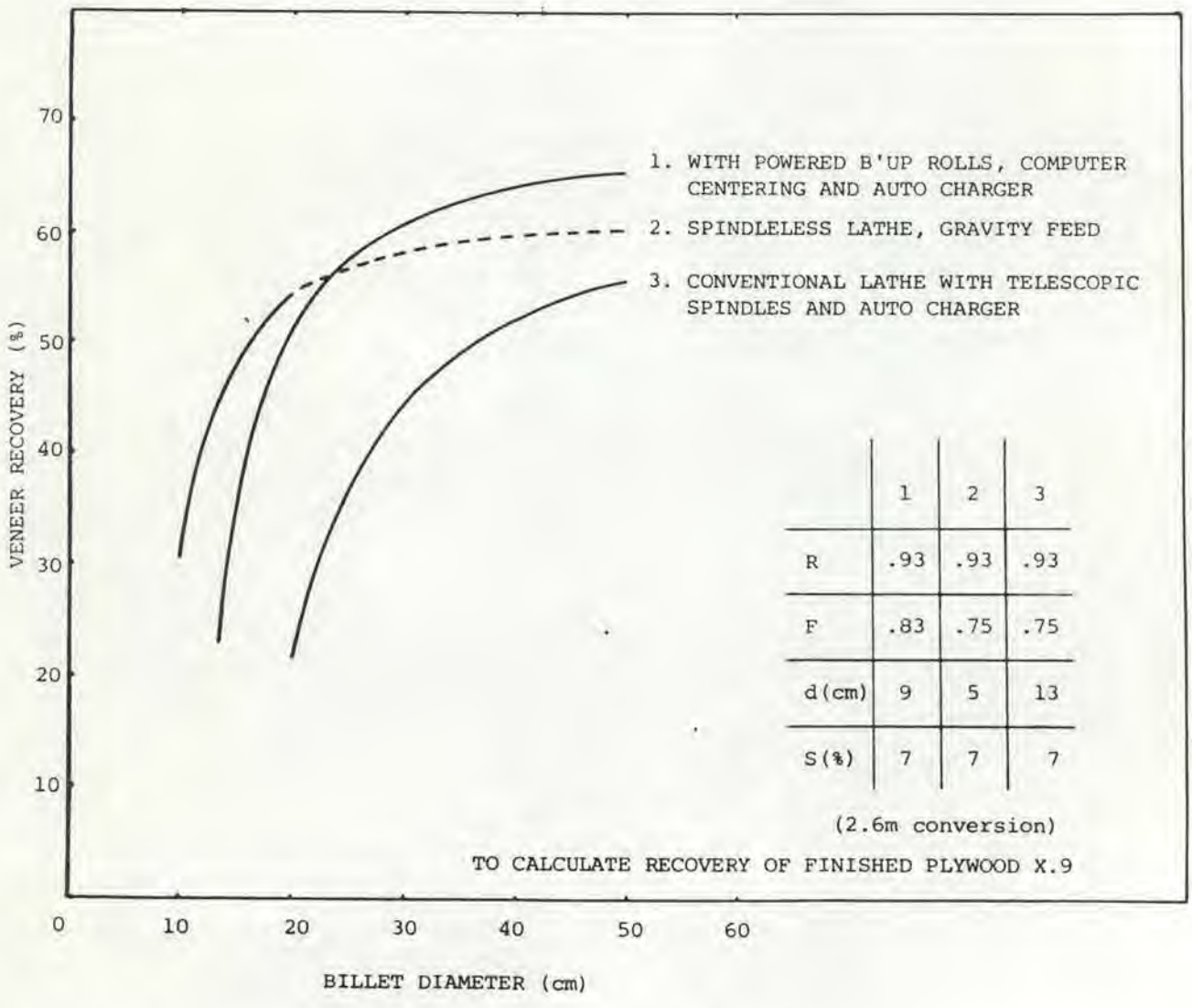

Figure 1. Estimated recovery versus diameter relationships for 'state of the art' peeling equipment for converting Pinus into D-grade and better structural veneer. The raw material and production parameters, R,the index of relative freedom from internal defect; F, the form index; S, % volumetric shrinkage in drying; and d, the average peeler core diameter, are shown.

THE DURABILITY OF BONDED WOOD STRUCTURAL COMPONENTS

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ABSTRACT

This paper briefly examines the question of the life expectancy of buildings, the durability of the components upon which the structural integrity of buildings depend and the methodology of assessing and predicting the durability of building materials. These concepts are applied to the problems associated with the assessment of new adhesive systems and bonded wood products for use in structural applications. The durabilities of plywood and glulam are discussed as examples of bonded wood products that have become accepted for structural use. Some systems of assessing and approving new materials in other countries are examined which could provide possible guidelines for the establishment of such a system in Australia.

INTRODUCTION

It is rarely possible to discuss adhesive performance without giving some consideration to the performance of the adherend. Wood is certainly no exception in this respect. Thus rather than attempt the mammoth task of writing a general overview of the durability of wood adhesives only the most critical of applications in which wood adhesives are used will be discussed, namely, in the manufacture of materials used as structural elements in buildings.

LIFE EXPECTANCY OF BUILDINGS

Carruthers (1) defined a structural element as one which, if removed, could cause partial or total collapse of the building. He went on, 'It follows that the replacement of a structural element is rarely practical at an economic cost. --- the designer must ensure that an adequate level of safety is maintained throughout the expected life of the building. --- Buildings tend to continue in use as long as they remain safe, their maintenance costs do not rise to unacceptable levels, there are no outside pressures to redevelop the site ---, and for as long as they can be adapted or renovated to meet any change in the needs of the occupants. In practice therefore --- it is suggested that for most

buildings the designer has little choice. He must design for a long life, that is, for the 'greater than 100 years' quoted in British Standard Code of Practice CP3 Chapter IX (1950)'. While this approach to life expectancy is the one accepted in this paper it must be acknowledged that there will be other approaches depending upon whose expectations are under consideration. The views of the owner, the builder, the materials supplier and the lending authority would all be expected to differ.

DURABILITY

Farhi (2) describes the durability of a building material as the attribute of being able to maintain a performance level above some threshold that is regarded as acceptable. In the case of structural elements performance is described in terms of a level of mechanical properties which must be maintained over the life of the building. A vast body of observation and experience has accumulated on the types and magnitudes of changes that occur during the ageing of traditional materials used in traditional methods of construction so that design criteria can be established on the basis of known behaviour. Where no such body of information exists for new materials or methods of construction it is necessary as part of the development process to carry out investigations upon which some prediction of long term durability can be based. This type of investigation involves identifying the changes that occur during the natural ageing process as well as the environmental agents that bring about these changes and then establishing a relationship between cause and effect. The ageing factors can then be applied to the material under investigation in such a way as to accelerate the ageing process but keeping within the limits of severity determined by the environment to which the material will be exposed in service. The validity of the prediction can only be established by comparison with data accumulated from natural ageing trials that were laid down at the outset of the development program. It would seem that there are difficulties in putting this fairly simple philosophy into practice. Materials manufacturers tend to stumble across these considerations after numerous complaints from consumers. From an investigational stand point the pitfalls lie in correctly identifying and applying the environmental agents and in correlating these with the changes observed during both natural and accelerated ageing.

Some characteristic types of ageing behaviour of building materials are depicted in Fig. 1.

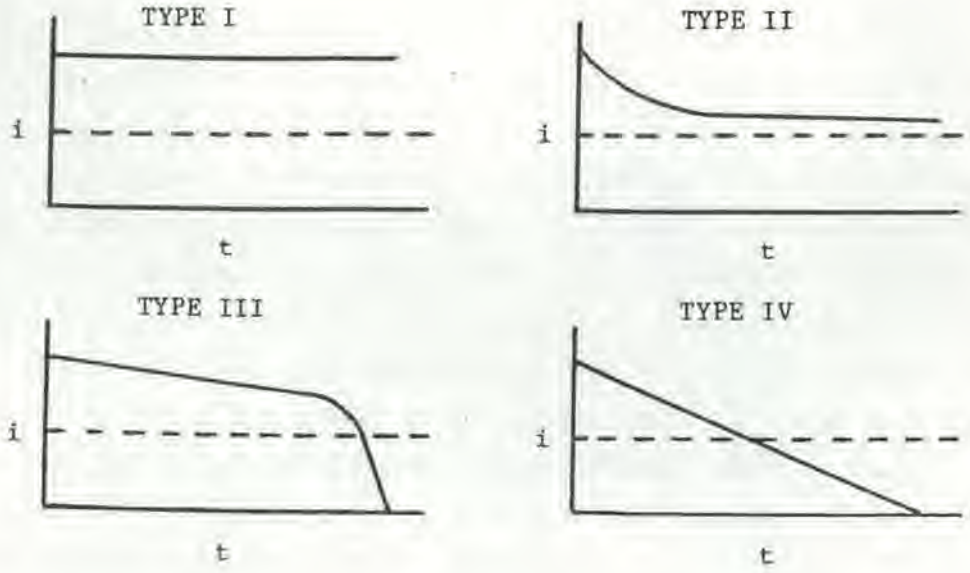


Fig. 1 Some typical ageing characteristics of building materials showing the indicator of ageing (i) as a function of the time factor (t). Broken line represents the acceptable threshold of performance. Farhi.

Type I corresponds to the pull-off strength of a cement based adhesive over a series of wetting and drying cycles. Type II corresponds to the effect of heat on extension at rupture of certain waterproofing membranes. Type III corresponds to the effect of UV radiation on tensile-impact strength of rigid PVC and Type IV to the effect of heat on the dehydrochlorination index of rigid PVC. The PVC examples point up the importance of knowing which of the ageing factors will be critical in service and whether the particular ageing factor is being applied at an appropriate level. The use of, say, temperature above some level which may be critical to performance could produce misleading results. From a structural viewpoint it is necessary to be able to show that the ageing behaviour of the material in service is of Type I or II. Type III or IV behaviour would only be acceptable where a finite life of the structure is accepted and adhered to. This would be a special case which does not generally apply to structural aspects of construction.

THE AGEING OF WOOD

Few timber species can withstand full weather exposure for the periods of time envisaged in most building design. Wooden structural members are generally protected from sun and rain either by a surface coating or more usually by virtue of the design of the building. The life expectancy of

wooden structural members can be regarded as indefinite provided that appropriate measures have been taken to prevent biological attack and that due allowance has been made for the type of loading to which the member will be subjected. Of importance in this context is the time dependent increase in deflection of members loaded particularly in bending above a certain proportion of ultimate. The long term load factors currently in use in the timber engineering code are known to be adequate on the basis of experience with some experimental backing from what is known as the Madison curve which relates ultimate strength to time under load. In structural design the frequently quoted 50 year service life is based on elapsed time under load which is expressed as a proportion of basic working stress. Thus actual life would be expected to be well in excess of 50 years. A large international research effort is currently underway to gain a better understanding of the phenomenon. Three moisture content regimes are being used, high, low and cyclic, the last being of greatest interest because of the closer approximation to actual service conditions where mechano-sorptive effects would be expected to play an important part.

THE AGEING OF PLYWOOD AND GLULAM

In 1950 Perkins (3) described a relationship between wood failure in lap shear plywood specimens after a boil-dry regime and resistance to delamination of matched material under full weather exposure over a period of eight years. This relationship is depicted in Fig. 2 which shows the rate at which exposure specimens, grouped according to an initial property level, i.e. bond quality, reach a given endpoint in the ageing process, namely, delamination. The work was based on phenolic adhesives under one set of exposure conditions which were harsher than the protected exterior conditions usual for structural elements.

This plot of incidence of delamination should not be confused with the type of relationship depicted in Fig. 1 in which the level of some particular property is plotted against either real time under natural ageing or elapsed time under artificial ageing conditions.

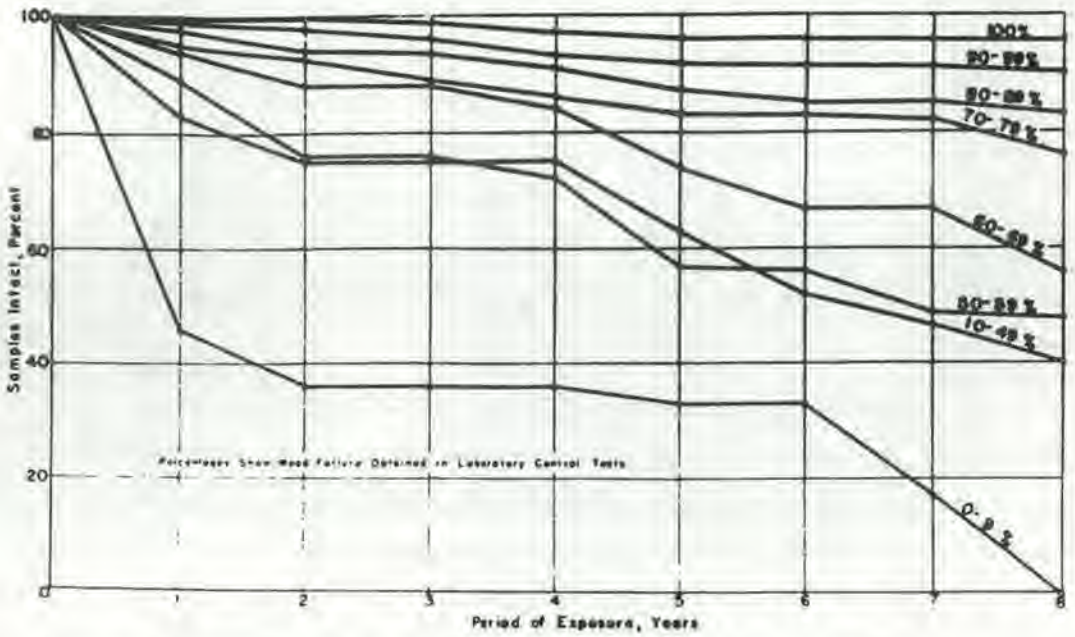


Fig. 2 Performance of plywood on exposure fence. Perkins.

Knight's (4) major report of 25 years of exposure trials using a range of adhesive and specimen types and exposure conditions indicated a clear relationship between durability, exposure conditions and the chemical type of the adhesive. His results are summarised in Table 1.

Again the data are expressed as time to reach an endpoint. In plywood samples a bond quality of 4 (40% wood failure) was described as efficient, 3 as marginal and 2 or below as a failure. Bonds in laminated timber specimens were regarded as having failed when 25% of glueline area had separated.

TABLE 1
Efficiency of Various Types of Adhesives for Wood
in Terms of Environment of Use and the Actual or Estimated Life

Chemical Type of Adhesive	Exposure and Performance		
	Full Exterior	Semi-Exterior and Damp Interior	Dry Interior
PF, RF and Combinations	Expected life of 25 years	Indefinite	Indefinite
MF and MF:UF	Fail in 5 to 10 years	Estimated life of 10 to 20 years	Indefinite
UF	Fail in 2 to 5 years	Fail in 5 to 10 years	Indefinite
Casein	Fail in 1 to 2 years	Fail in 2 to 5 years	Indefinite
Animal	Fail in a few months	Fail in a year	Indefinte

P - phenol R - resorcinol M - melamine U - urea F - formaldehyde

The results of Knight and Perkins combined with accumulated experience have led to the long standing situation where only phenolic based adhesives are used in plywood and glulam for general structural applications. Casein adhesives are accepted in glulam where interior conditions can be guaranteed. The only change to this situation has been the recent acceptance by the American Institute of Timber Construction of an emulsion polymerised isocyanate as an alternative to resorcinol in laminating.

Raknes (5) attempted to demonstrate direct relationships between bond deterioration and environment using casein, urea, resorcinol and acid setting phenolic adhesives exposed to interior, protected exterior and outdoor conditions. These results are summarised in Fig. 3.

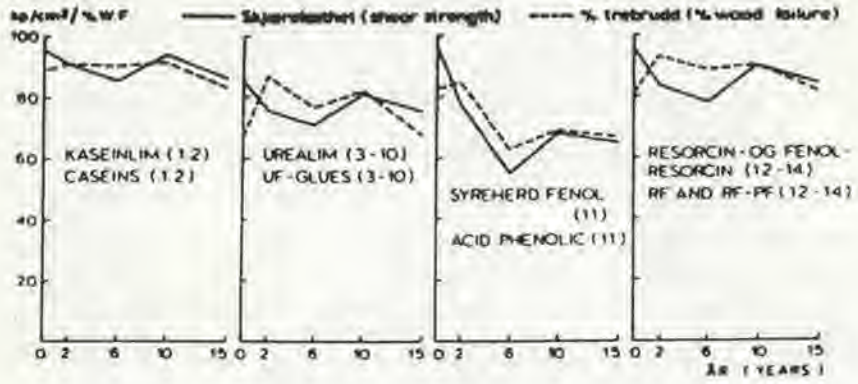


Fig. 3 Block shear strength/% wood failure Averages for various adhesive types under interior and protected exterior exposure. Raknes.

All adhesive types exhibited a peak in wood failure at two years and a trough in shear strength at six years followed by a more steady decline between 10 and 15 years of interior and protected exterior exposure. The deterioration in properties after 15 years is not nearly as great as one might have predicted on the basis of the results after six years and on a knowledge of Knight's work. The difference between these and Knight's results would appear to reflect the differences between the climates of Norway and England and Nigeria where Knight's exposure trials were carried out. Results of exterior exposures were poorly reported but appeared to be rather similar to those of Knight.

On the basis of rather patchy evidence it would seem that phenolic bonds, samples of which produce high wood failure on rupture, exhibit Type II ageing behaviour where shear strength is the indicator of ageing

under protected exterior exposure. Bonds prepared using non-durable adhesives and poor quality phenolic bonds would be expected to exhibit type III behaviour with respect to shear in protected exterior. Bending strength and stiffness are then likely to exhibit type IV behaviour since these would not be greatly affected until shear strength falls to a level below which shear forces arising out of the bending load are sufficient to cause bond breakage.

RECONSTITUTED WOOD PRODUCTS

Plywood, LVL and glulam are not included in this category because essentially they behave as solid wood bonded into a particular configuration. The properties of reconstituted wood products are determined largely by the degree of subdivision and the adhesive system used in the reconstitution process. Table 2 lists the various raw materials used and the extent to which each has retained fibre orientation and cross tensile strength, i.e. those factors upon which wood strength depends. Solid wood and veneer are included for comparison.

TABLE 2
Extent of Retention of Solid Wood Characteristics by Raw Materials for Various Reconstituted Wood Products

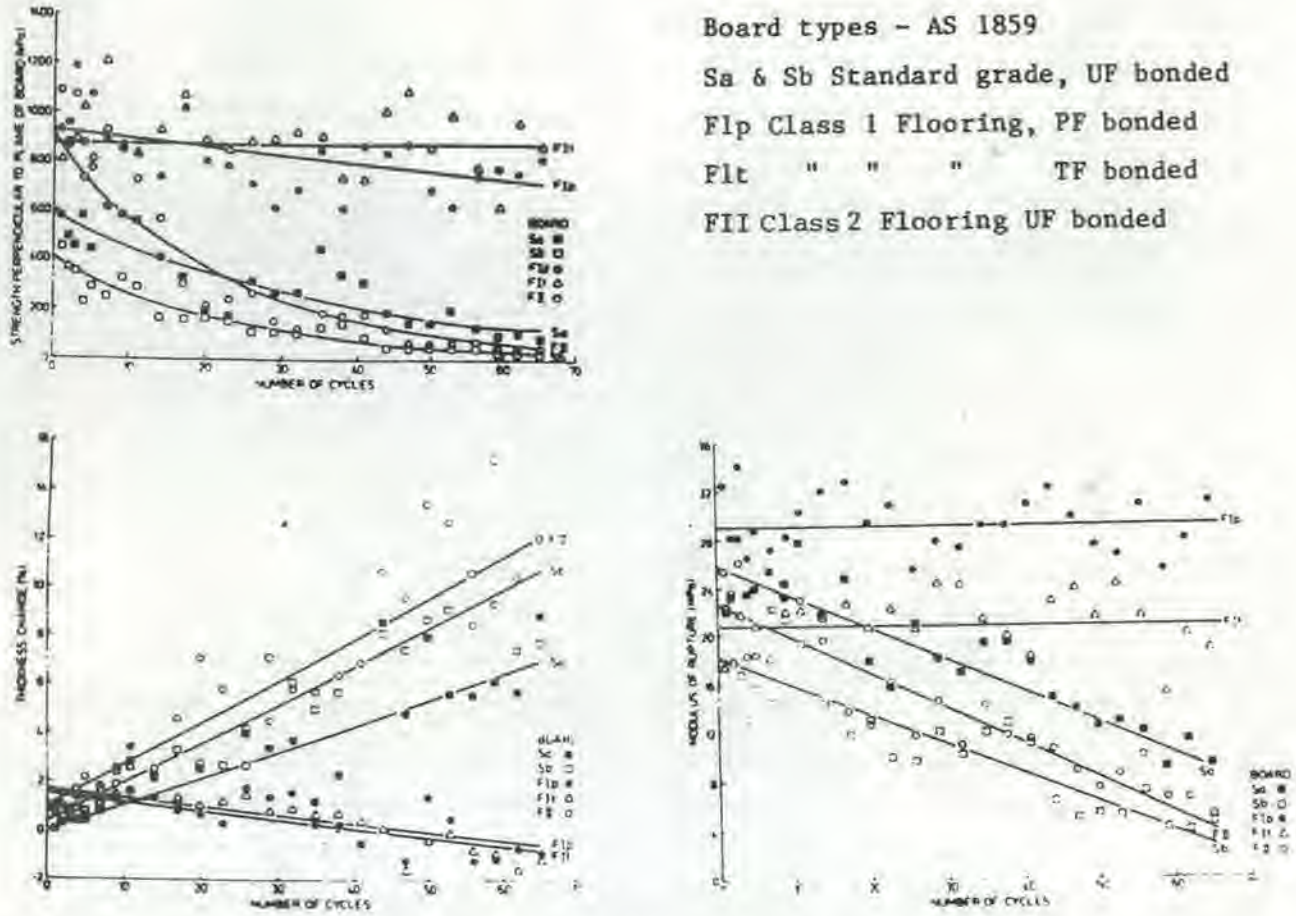
Raw Material	Retention of Fibre Orientation	Retention of Cross Tensile Strength	Product
Solid wood	+	+	Glulam
Veneer	+	Partial	Plywood LVL Parallam
Reconstituted wood products			
Scrim	+	Minimal	Scrimber*
Wafers and Strands	Over length of particle	–	Wafer board* OSB*
Flakes		–	Particle board*
Core flakes	"		
Surface fines	Minimal		
Pulp	–	–	Fibreboard Insulation board MDF Hardboard*

* Denotes possible use in structural applications

LVL – Laminated veneer lumber
OSB – Oriented strand board
MDF – Medium density fibreboard

With the exception of glulam all are bonded at elevated temperatures. The pressing conditions for plywood and LVL lead to a slight increase in density of the product over that of the parent wood. The magnitude of the increase will be determined by wood species, pressing time, temperature and pressure and also the moisture content of the assembly. Most of the compression is mechano-sorptive deformation arising out of moisture content changes taking place during pressing and is therefore largely irreversible. While the same phenomenon occurs in the pressing of particle and fibre-boards a much greater level of densification is imposed in order to achieve a required level of strength properties. For example, radiata pine with a density of 500-600 kg/m^3 is used to make particleboard or MDF with a density of 650-700 kg/m^3 or hardboard with a density of 900-1000 kg/m^3. The thickness swelling of these materials, either when exposed to high humidity conditions or when fully saturated with water, i.e. generally greater than the maximum swelling achievable in the parent wood. The phenomenon has been reviewed by Halligan (6). Not all this swelling is recoverable on reconditioning to ex-press moisture content, the residual increase being termed springback. These changes are accompanied by a deterioration in mechanical properties. Repeated wetting and drying cycles can induce a progressive increase in thickness swell and springback as well as loss in strength, possibly leading to the total destruction of materials manufactured with non-durable adhesives.

While thickness swell, springback and strength loss are the almost universally used indicators of ageing there is a lack of consensus on what constitutes an appropriate ageing environment, either natural or accelerated. Palmer and Stashevski (7) showed that property changes could be induced in a variety of commercially available Australian boards by cycling them between humidities of 25 and 85% RH both at 38 deg C. Fig. 4 shows that rapid degradation occurred in all three UF bonded boards, a slight loss of internal bond in a PF bonded board and no change in the properties of a tannin-formaldehyde (TF) bonded board. These results also serve to demonstrate the difficulties in identifying trends in property changes in such a variable material. Christensen (8) showed strength losses in MF/UF/PF bonded Class 1 flooring under the same conditions which were chosen to simulate the annual major moisture content cycles undergone by wood based materials in protected exterior environments. In this work no natural ageing trials of matched materials were laid down for comparison.



Board types - AS 1859
Sa & Sb Standard grade, UF bonded
Flp Class 1 Flooring, PF bonded
Flt " " " TF bonded
FII Class 2 Flooring UF bonded

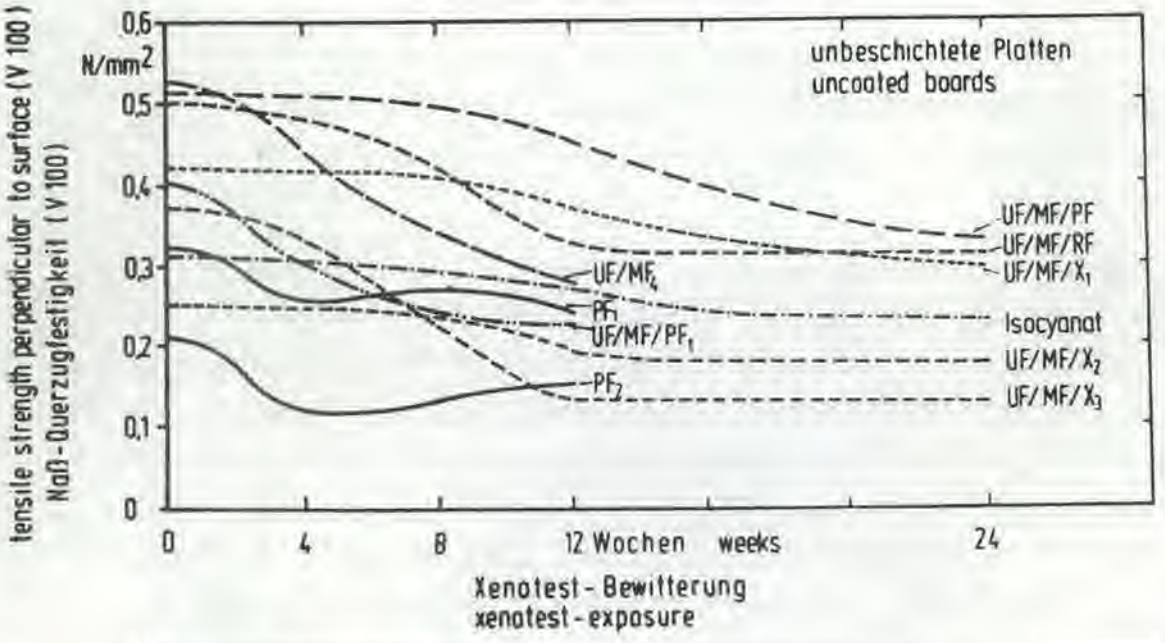
Fig. 4 The effect of humidity cycling (1 week 40 degC/25% RH, 1 week 40 degC/85% RH) on internal bond, thickness and bending strength of various particleboards. Palmer and Stashevski.

Regardless of the intended use of material under investigation, most workers choose full weather exposure as a reference natural ageing environment because of its severity and because the changes in protected exterior environments take place so slowly. It would seem likely that the changes taking place in protected exterior environments would be of a different kind and would be masked by the changes brought about by thermal and UV effects of solar radiation and frequent wetting and drying associated with full weather exposure. Thus little information is being collected that would enable comparisons to be made between laboratory and naturally aged material, say, in a wall cavity.

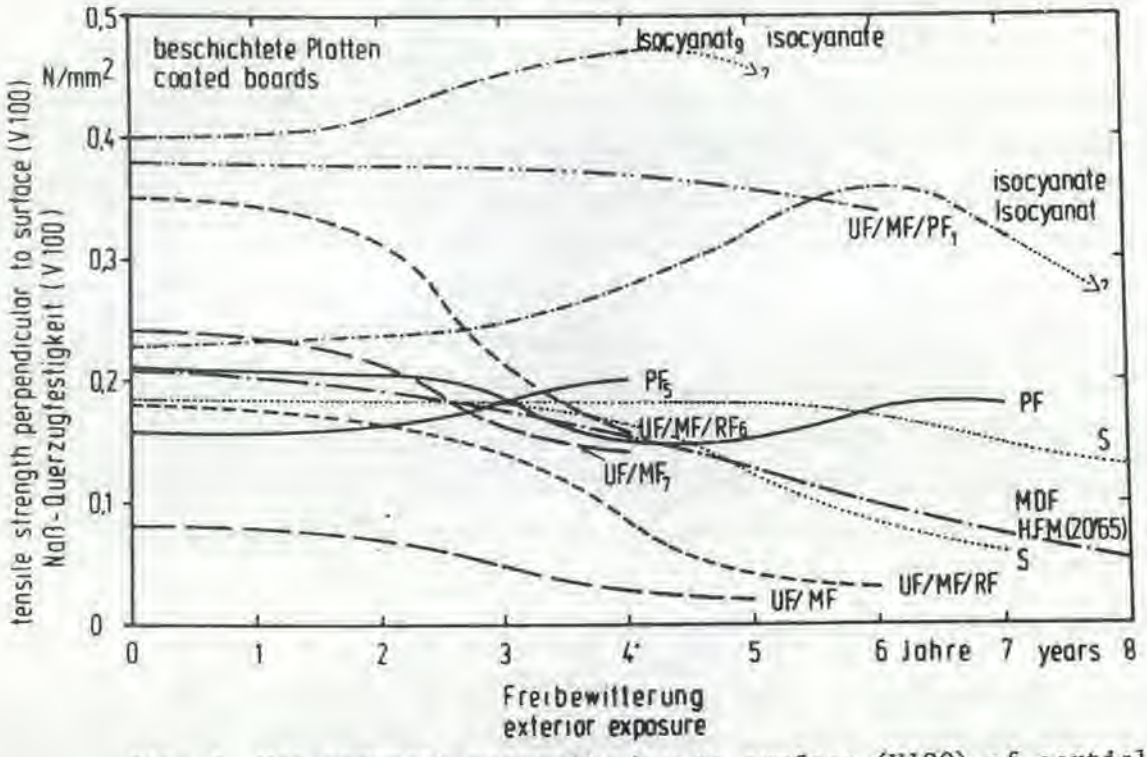
Laboratory ageing procedures range from the simulated full weather exposure approach of Deppe (9) through cyclic soaking, freezing, and drying regimes to a single water soak at some particular temperature. It is hardly surprising that Deppe provides the most satisfactory correlation between natural and laboratory ageing and even this provides predictions of

behaviour in full weather exposure only in central Europe. Other correlations tend to be valid for a given property, board type, adhesive system or period of exposure. This is to be expected when attempting to compare the results of a particular test on a variety of board types with differing ageing characteristics. As pointed out by Carrol (10) attempts are made to use cyclic torture tests as both a predictor of the ageing behaviour of well made boards and as a means of detecting boards with manufacturing faults. The confusion appears to have arisen out of following the plywood precedent in which there is the unusual situation where the boil test serves both as a quality control test and as a durability predictor.

Clearly then there is no universal touchstone for durability and various countries and manufacturing groups tackle the problem in their own way. In Germany, early structural boards bonded with 30:70 MF/UF adhesive systems were exhibiting failures in situations of high humidity. This led to the use of liquid phenolics although there were initial problems associated with the highly hygroscopic nature of boards being made using resins with high levels of alkali. The enthusiasm of manufacturers to use newly developed resin systems such as RF modified MF/UFs, sulphite liquors and isocyanates provided the stimulus fo the development of the Xenotest method as a rapid means of assessing the durability of these systems. The Xenotest apparatus is an exposure chamber with conditions carefully chosen to simulate outdoor exposure conditions prevailing in central Europe. It is claimed by Deppe that by deleting periods of normal climate (daytime temperatures of 15-25 deg C, cloudy sky and no precipitation) natural weathering can be accelerated by a factor of about twelve. Specimens are subjected to six to twelve months Xenotest exposure and then tested wet for internal bond after a two hour boil. A comparison of natural and Xenotest exposures is given in Fig. 5. This is part of the testing carried out by the Federal Research Institute of Testing Materials, Berlin, (BAM), in approving boards for structural applications. Other tests include strength, creep and fatigue tests as well as loadings and resistance to hydrolysis of the resin system. BAM also operate a quality assurance scheme to ensure that manufacturers continue to maintain the property requirements established in the approval process.



5a



5b

Fig. 5 Wet strength perpendicular to surface (V100) of particleboards glued with different resins after 24 weeks of Xenotest exposure (5a) and 8 years of exterior exposure (5b). Deppe.

In the USA the main contenders in the structural market are waferboard and OSB which are bonded with powdered PFs at a 2-3% loading. The American Plywood Association (11) is accepted as the major approving body and their approach is to afford plywood the status of a traditional material, to evaluate the particular properties that have contributed to its successful performance in the particular application and to ensure that these property levels can be matched and maintained by any other material regarded as a

candidate for the same application. Mill output is then subject to monitoring through the APA quality assurance program. By keeping to phenolics the process of approval of adhesive systems is greatly simplified.

In the UK natural weathering at the Princes Risborough Laboratory (12) is taken as the reference ageing environment and the V313 exposure conditions contained in the French Standard NFB51 263 as the 'accelerated ageing' regime. This has been adopted on the basis of correlation coefficients for strength and swelling properties after the V313 exposure and 7 years natural weathering. The V313 exposure consists of a 3 day water soak at 20 degC, 1 day at -12 deg C and 3 days drying at 70 deg C. The board is tested after three such treatments. No property levels have as yet been laid down for structural applications but it is likely that acceptance will be based on a combination of swelling and strength loss requirements after V313 exposure with a possible trade off between the two. This would allow both particle boards and water/oriented strand boards to come within a common set of requirements. These will be incorporated in the particleboard standard which is currently under revision. In the meantime the British Board of Agrement has published a method of assessment and testing (MOAT No. 26:1983) to provide manufacturers with guidelines on the kind of information that would be required in an application for Agrement Board certification. The Institution of Structural Engineers (13) has published a report on the derivation of basic working stresses but this is of limited usefulness since it is based on Scandanavian data.

IMPLICATIONS FOR AUSTRALIAN MANUFACTURERS

Materials that are to be used in structural applications must be capable of maintaining certain strength levels for an indefinite period in the wide range of protected exterior environments that exist in this country. The strength requirements can be determined either by evaluating the properties of traditional materials that have been known to perform satisfactorily in the particular situation or by going through the much larger exercise of establishing basic working stresses so that the material can be used in general structural applications. The prediction of indefinite life can be based either on using traditional adhesive systems or by evaluating the durability of newly developed systems. In order to do this it is necessary to establish an appropriate methodology for doing so. Overseas experience is of limited help in this area. In the USA where the range of climates is similar to that of Australia the problem has been

avoided by insisting on PFs in structural applications. The European experience is largely irrelevant because of their lack of hot/wet and/or hot/dry climatic conditions. A prerequisite for such an assessment would be an investigation into the range of conditions existing in wall cavities and roof spaces. Having set property requirements it is then necessary to see that manufacturers can produce materials that meet these requirements and that their output continues to meet the requirements. The only satisfactory product approval and quality assurance scheme operating in the bonded wood structural component area in Australia is that of the Plywood Association. The role of ABSAC will necessarily be limited because of lack of a quality control arm. The situation in some states where only the manufacturers recommendation is needed for the product to be accepted is a formula for disaster. There is a good case for the establishment of an Australian Institute of Timber Construction that would oversee the approval and quality control aspects of bonded wood structural wood components.

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WOOD QUALITY VS. QUANTITY: A DILEMMA FACING TREE BREEDERS

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INTRODUCTION

In this presentation I wish to address a question which I know has probably been keeping you awake all night. That question is this – "What happens to wood quality when we breed trees for fast growth?" Almost all of the breeding programs of exotic pines in Australia have placed major emphasis on increasing growth rate. Little, or in many cases, no selection pressure has been applied to wood quality. It was probably reasonable to devote the first generation of selection to "cleaning up" these pine species by improving major production traits like growth and form. These particular traits have the practical advantage of being easy to measure and are obviously important.

However, the time has probably come, on entering the second generation of selection, for breeders to begin to pay much more attention to the quality of the timber being produced. It is important not to leave it too long before getting serious about selection for wood quality. If we are not careful we could easily end up facing the sort of crisis breeders of dairy cattle met in the 1960's when an increasingly health conscious western world learned about the dangers of high cholesterol. Up until then the dairy breeders had, for many generations, been selecting for high butterfat content. Then, almost overnight, they had to do a complete about face and begin selecting for low butterfat. Not a nice prospect for any breeder. We don't want our "high growth" breeds of radiata or caribbean pine to become the "high fat" lines of forestry. We must avoid at all cost any chance of waking up one morning to find our

high growth breeds are producing unacceptable timber qualities. Those cattle breeders at least had a chance to redeem themselves. They could get through a few generations fairly quickly. With forest trees you don't have that luxury! The long generation interval is a very real barrier to quickly changing the direction of selection.

Maybe I am exaggerating a little, but the tale of woe in dairy cattle serves as a useful reminder to breeders not to become excessive in selection for a particular trait. It also highlights the importance of trying to anticipate shifts in market requirements.

WOOD QUALITY VS. QUANTITY: A DILEMMA

The title of this address is: "Wood quality versus quantity: a dilemma facing tree breeders". In talking about wood quantity I am meaning growth. In talking about wood quality I can only tell you a little about wood density. The dilemma to which I refer is the well known and consistent negative genetic association between growth rate and wood density in many conifers.

This adverse genetic relationship has been well quantified for radiata pine in Australia - the work of Alan Brown [1,2], Jack Nicholls [2,3] and Leon Pederick [4] being prime examples. The same adverse genetic relationship has been found in New Zealand and documented by such workers as Jack Harris [5], David Cown [6] and Rowland Burdon [7]. In breeding terms this negative association means that if you select very intensively for one of these traits then there will almost certainly be a corresponding decline in the other. Let me take an example from work I have been involved in for radiata pine in Gippsland with John Cameron from APM Forests and my colleague in CSIRO, Paul Cotterill [8].

EXAMPLE IN RADIATA PINE

Using the method of index selection we attempted to simultaneously improve these adversely associated traits in one breeding population. We

found that, for selection of second generation plus trees, we could place unlimited emphasis on growth at around 10 years and expect to improve this trait by about 35% but the consequences of so doing would be a decline of about 4% in wood density (Table 1). On the other hand, by placing greater selection pressure on density we found we could expect to improve that trait by about 11% each generation, but would suffer a 23% decline in growth (Table 1). As you might imagine, neither of these scenarios was acceptable to a forest grower. We were facing the dilemma of the quantity versus quality.

THE TRADE-OFF

This adverse genetic association between growth and density of radiata pine appears to be strong enough to make it impossible to substantially, and I repeat, substantially, improve both traits at the same time in one population. The compromise finally decided upon was to accept less gain in growth whilst attempting to hold density at its present level [8]. This option seems sensible because the present density of radiata pine appears to be acceptable for most end uses.

It is possible that in future advanced generations APM will decide to attempt to achieve at least some improvement in density (maybe a 1 or 2% gain) even if it means accepting still less improvement in growth. Such a decision will depend on closer economic analyses of the influence of volume and density on pulp yield.

OTHER POSSIBILITIES FOR BREEDING

So far I have spoken about continued selection in one population. In another project with APM we are presently investigating the possibilities of developing multiple populations of trees which are selected on one or other of adversely associated traits.

(1) DEVELOP MULTIPLE LINES

For the moment we are attempting to develop two populations or "lines". One line is selected for high growth (and of course form

TABLE 1:

EXAMPLE FOR RADIATA PINE IN GIPPSLAND

SELECTION EMPHASIS	EXPECTED GAINS	
	GROWTH	DENSITY
SINGLE TRAIT SELECTION –		
fast growth only	35%	−4%
high wood density only	− 23%	11%
MULTIPLE TRAIT INDEX SELECTION –		
improve growth/ density constant	18%	zero

traits), while the other line is selected for high density. Crosses might be made between these two lines in the hope that the offspring produced would exhibit both good growth and good density. It's also possible, of course, that such crosses may produce offspring which revert to the parental types, that is, are good for either one trait or the other, but not both.

(2) INTRODUCE OUTSIDE MATERIAL

Another possible solution to the dilemma involves introducing genes for high wood density from outside the current breeding population. This would mean forming a hybrid - probably with material from the natural Guadalupe Island population of radiata pine. Research in New Zealand has clearly shown this Guadalupe material to have slightly slower growth than local improved material but some 10% more dense wood. It is possible that a hybrid between these two populations would retain some of the rapid growth of the improved material whilst incorporating some better density from the Guadalupe material. Based on the 10% figure quoted above you could expect around five percent (mid parent) increase in wood density from such a scheme and sacrifice only one to two percent in growth. This sort of 'happy marriage' of the best features of two populations is not uncommon in tree breeding. It has been observed for growth and other production traits in hybrids of tropical pine species in Queensland and, of course, eucalypts around the world!

HYBRIDISATION AND MASS PROPAGATION

Hybridising, that is, crossing of different populations may be a particularly powerful tool when used in combination with mass vegetative propagation. The crossing of say high growth with high density lines, or maybe current improved stock with Guadalupe material, should maximise the possibility of generating at least a few families which are outstanding performers for both growth and density, as well as having acceptable form.

If these few families can then be mass propagated by first producing substantial quantities of controlled-cross seed and then multiplying this seed by mass vegetative propagation we really will be able to make progress. These techniques of mass propagation are no pipe dream. They are with us right now and companies like APM, APPM in Tasmania and the N.Z. FRI have gone a long way towards putting them into practice. There are, of course, also the additional benefits to be gained at the sawmill from the use of cuttings - as will be seen in the next paper in this session [9].

DEVELOPING APPROPRIATE BREEDING STRATEGIES

So, what about these wood traits anyway. It's certainly not a simple or straightforward matter to evaluate density and other wood quality traits - as I'm sure you're all very much aware. To properly assess wood quality traits trees have to be sampled and laborious laboratory studies undertaken. There are a great number of wood characteristics that can be assessed and related to all manner of parameters like strength, working properties, wearing properties, pulp yield, preservation retention and so on. But, in general, very little is known about the genetic relationship between growth and wood quality traits. It's really staggering. Even more frustrating is the lack of information on the relative economic importance of growth versus wood traits and how this relative importance changes with differing end uses such as sawn timber, reconstituted wood products and so on. I hope that over the next few years tree breeders will make every effort to reliably estimate genetic associations between growth and important wood traits and investigate breeding strategies which can give acceptable progress in both wood quantity and quality. Industry must also play its part by helping us decide the economic importance of wood traits.

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