

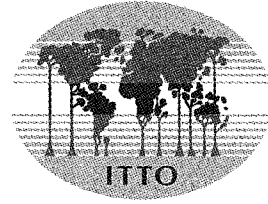


Plantation Eucalyptus: Challenge in Product Development

Proceedings of the International Conference on Plantation Eucalyptus
Zhanjiang, Guangdong, China, November 28 - December 1, 2005




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Silvicultural Management of Eucalypt Plantations for Solid Wood and Engineered Wood Products – Experience from Tasmania, Australia

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ABSTRACT

The silvicultural management of eucalypt plantations has been developed and refined in Tasmania, Australia for production of clear wood (i.e. high-quality pruned logs) for sawn timber and veneer production. The species most suited for these plantations in the Tasmanian environment are *Eucalyptus globulus* and *E. nitens*. This paper reviews the research on pruning and thinning of these plantations, mix of products and economic comparison of various regimes.

1 INTRODUCTION

Tasmania is an island state in southern Australia with rich natural and planted forest resources in a cool temperate climate. Eucalypt timber is supplied from old-growth and regrowth native forest resources for a variety of processing industries including sawn timber, veneer and paper. In the past 25 years eucalypt plantations have been developed, predominantly aimed at supplying high quality pulpwood for the pulp and paper industry (Tab.1). Due to increasing reservation of native forests for conservation and recreational activities, a need developed for the exploration of silvicultural techniques in eucalypt plantations to provide timber (structural and appearance grades) and other wood products such as laminated veneer lumber, appearance grade veneers and other engineered wood products.

Tab.1 Area of hardwood plantations (hectares) in the State of Tasmania and Commonwealth of Australia (including Tasmania) at December 2004 (National Forest Inventory, 2005). Plantations are predominantly eucalypt species

| | Ownership | | | Total |
|-----------|-----------|---------|--------|---------|
| | Public | Private | Joint | |
| Tasmania | 22,331 | 120,411 | 8,530 | 151,272 |
| Australia | 75,146 | 617,070 | 23,315 | 715,531 |

Forestry Tasmania, a Tasmanian Government Business Enterprise, has been engaged in research to produce clear wood from plantation grown eucalypts since 1990 (Gerrand *et al.*, 1997a). Silvicultural

research has been undertaken on pruning and thinning regimes to produce suitable dimension logs for processing in conventional sawmills and veneer mills. Silvicultural thinning of young natural regrowth forests has also been undertaken to accelerate production of suitable dimension logs (Cunningham, 1997; Brown, 1997; Gerrand *et al.*, 1997b).

There are potentially a number of regimes that could be used for management of eucalypt plantations. Gerrand *et al.* (1997b) identified constraints on the development of regimes producing high quality timber in a reasonable time. These include limited species selection; necessary spacing limitations based on establishment costs, merchantability and windthrow; low recovery of select grade timber from unpruned stands; the variable nature of occlusion of branch stubs and kino problems; risk of decay entry through damage associated with pruning and thinning.

Pruning of live branches is undertaken to produce clearwood by removing the possibility of defects associated with knots in timber products (Gerrand *et al.*, 1997a; 1997b). Pruning research has demonstrated the physiological response of trees to various levels of crown removal (Pinkard and Beadle, 1998; Pinkard *et al.*, 2004). Pruning also presents opportunities for wood decay fungi to enter the tree and prescriptions have been developed to minimise the risk of infection (Barry, 2005; Neilsen and Gerrand, 1999).

Thinning is a silvicultural technique that is used to maximise growth of trees retained after the thinning operation. Thinning does not increase the maximum volume production of a forest stand, but may be used to redistribute volume into fewer stems. Usually these larger stems have a much higher market value due to their ability to be processed into a wider range of products, some of which attract higher prices in the market (eg. appearance grade veneer and timber). Thinning research has been aimed at finding the optimum timing and number of retained stems to maximise production of clear wood in the pruned trees. Attempts to reduce the need for thinning, by planting a lower number of stems per hectare, result in log degrade due to increased number and size of branches (Neilsen and Gerrand, 1999; Medhurst *et al.*, 2001). It is important to have high initial tree stocking for early control of branch development and then utilise thinning to accelerate growth of the lower log on selected retained stems.

Recent results from Australia (Washusen, 2004) and Spain (Nutto and Touza, 2004), with *Eucalyptus globulus* plantation sawing studies, suggest that trees grown under less competition through early thinning to low residual stocking tend to have reduced growth stresses in the logs produced. This may have implications for silvicultural regimes adopted to produce timber that is fit for purpose in the market.

2 EUCALYPT PLANTATION SILVICULTURE-RESEARCH RESULTS FROM TASMANIA

The majority of the eucalypt plantations established in Australia have been aimed at producing fibre for pulp in domestic or export markets such as Japan, Korea, China and Indonesia. *Eucalyptus globulus*, which is a native tree in Tasmania, is regarded as the premium source of fibre for bleached kraft pulp production. Most of the plantations in Australia are of *E. globulus*. This species is also widely planted in South America, south western China, Africa and the Iberian Peninsula. There has been extensive research on silviculture and breeding to improve the fibre quality of this species for pulp production.

The cool temperate climate in Tasmania results in a limitation on sites suitable for planting with *E. globulus* primarily because of the species' susceptibility to frost damage. *E. nitens* is more resistant to frost and has become the preferred species for establishment of plantations in frost prone areas. The consequence is that *E. nitens* is the predominant species used in plantations in Tasmania.

The research program undertaken by Forestry Tasmania into eucalypt plantation silviculture has been aimed at production of a pruned bottom log of the tree, typically to a height of 6.4 metres. The aim is to produce a log with a large end diameter between 50 and 60 cm under bark with a knotty core of 15cm diameter (Tab. 2). This type of log would be suitable for sawing or rotary peeling. In addition, unpruned logs will also be produced above the pruned section and may also be suited to sawing and peeling depending on the degrade tolerances of processing industries. Degrade is typically in the form of defects such as knots, decay, encased bark and kino.

Tab. 2 Log grades and specifications used for analysis of eucalypt plantation regimes in Tasmania, Australia. Values in Australian dollars (A\$) are stumpage prices for comparison purposes and are not actual prices as markets for eucalypt plantation peeler and saw logs are not well established

| Log grade | Code | Log diameter under bark (cm) | | Log length (m) | | Value (A\$ · m ⁻³) |
|---------------------------|------|------------------------------|----------|----------------|---------|--------------------------------|
| | | Minimum | Maximum | Minimum | Maximum | |
| Pruned peeler or sawlog | PP | 30.0 | no limit | 2.6 | 6.4 | 90 |
| Unpruned peeler or sawlog | PU | 25.0 | no limit | 2.6 | 11.0 | 50 |
| Small sawlog (unpruned) | SS | 15.0 | 32.0 | 2.5 | 11.0 | 35 |
| Pulp | P | 10.0 | no limit | 2.5 | 11.0 | 20 |
| Waste | X | | | | | 0 |

2.1 Pruning

The objective of pruning is to allow the production of timber or veneer sheets which are free of knots, knot holes and other defects associated with branches such as encased bark, decay and kino. Many eucalypts are capable of shedding branches naturally and produce an occlusion zone behind the dead branch stub. However, when grown in plantations, species such as *E. globulus* and *E. nitens* do not shed branches in a satisfactory manner and produce many defects which make the logs unsuitable for defect-free timber or veneer production (Montagu *et al.*, 2003). It has also been demonstrated that pruning of dead branches is not satisfactory because the dead branch stub is retained in the tree and can be pushed out with the bark as the tree grows, leaving behind a kino pocket or initiating decay in the intended clear wood zone (Gerrand *et al.*, 1997b; Barry, 2005).

There are three aspects of pruning which are essential to producing clear wood and maintaining adequate growth of pruned trees. These are

- 1) Pruning branches while they are still alive.
- 2) Pruning trees with small branches.
- 3) Limiting the amount of the green crown which is removed in any pruning event to maintain the growth of the pruned trees.

The appropriate level of pruning for *E. globulus* and *E. nitens* appears to be in the order of 30% to 50% of green crown removal (Pinkard and Beadle, 1998; Pinkard *et al.*, 2004) at the time of canopy closure. Early foliage removal prior to canopy closure can be combined with solid wood production in *E. globulus*, provided no more than 20% is removed, or up to 40% on high productivity sites (Pinkard, 2003).

These restrictions on pruning add cost to the operation. Experience in Tasmania has shown that to maintain a knotty core diameter over stubs (DOS) of 15 cm or less there must be several visits to a tree to ensure only green branches are removed and green crown removal is within the parameters mentioned above. We have found that this requirement is dependent not only on site productivity but also nutritional status of

the stands. Plantations located on soils with low inherent fertility require remedial fertiliser addition to maintain green branches in the lower portion of the canopy for pruning.

The current prescription is to visit the tree on at least two to three occasions to remove approximately two to three metres of live crown in any one lift. The limitations of converting research into practice indicate the prescription must vary with site quality and logistical constraints.

The market for peeler logs for veneer products such as laminated veneer lumber (LVL), requires a log of 2.6 metres length to allow for trimming to the final sheet width of 2.4 metres. The height of pruning adopted by growers in Tasmania varies between 5.2 metres and 7.2 metres, with Forestry Tasmania adopting a standard pruned height of 6.4 metres. This gives flexibility in the production of pruned peeler logs and sawlogs from the plantations. It allows for variations in stump height and trimming of logs to remove defect prior to processing. In South America pruned heights up to 11 metres have been implemented.

2.2 Thinning

The aim of thinning the eucalypt plantations is to maximise the growth of retained stems to increase the production of pruned logs (i.e. clearwood) from the plantations, where pruning has been undertaken. Indirectly this aim is to maximise the financial return from the plantation.

Thinning research has been directed at determining the best time and residual stocking to maximise the production of clearwood from pruned stands and achieves positive commercial returns over a range of site qualities.

Trials have been established over a number of sites to test non-commercial thinning (i.e. early thinning before removed stems have reached a saleable size) and commercial thinning (i.e. thinning when the majority of removed stems can be sold).

In Tasmania the constraint for commercial thinning is currently that at least 100 tonnes per hectare of saleable wood needs to be available for removal in the thinning operation to make it a viable commercial operation for the harvesting contractor. The dimensions for saleable wood are given in Tab. 2.

Results from commercial and non-commercial thinning regimes with residual stocking of between 100 and 400 stems per hectare, have been compared with those from unthinned stands.

2.3 Log yields and financial analysis of regime options

Growth models for Tasmanian *E. nitens* plantations are contained in the Farm Forestry Toolbox (Private Forests Tasmania, 2004). The Toolbox was used to project yields of various log classes (Tab. 2) from *Eucalyptus nitens* plantations in Tasmania. Financial analysis only considered establishment, direct growing costs and log prices on the stump. Land, harvesting and transport costs were not included. Site index is defined as the mean dominant height of the tallest 50 trees per hectare at age 15 years. Two site qualities used in the following analyses reflect treatments in existing trials, now 20 years old, which will be harvested in the next few years to verify the suitability of logs for various products and to modify growth and taper functions associated with the regimes.

The log yields for a high quality site (site index = 28) are given in Fig. 1. It can be seen that over a 30 year rotation there is little difference in the total yield of the plantation under an unthinned or single commercial thinning scenario. However, the commercial thinning at age nine combined with pruning of the retained trees (CT09 to 250 sph), where nearly half the standing volume is removed at age 9 gives a much

higher yield of both pruned (PP) and unpruned sawlogs (UP). Small sawlogs (SS) may be utilised as pulp logs depending on price and availability of processing facilities.

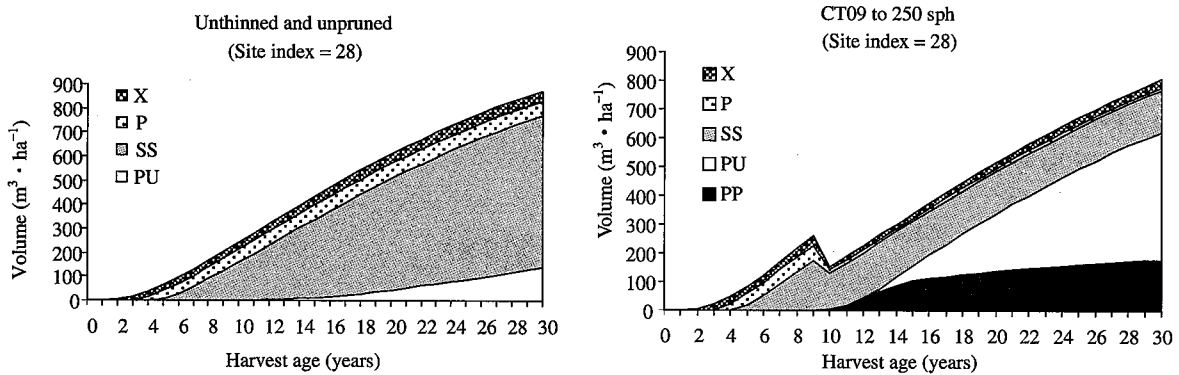


Fig. 1 Estimated yield of logs from two regimes for *Eucalyptus nitens* plantations on a high quality site (Site Index = 28) in Tasmania. CT09 = Commercial thinning at age 9 years with pruning in three lifts to 6.4 metres. The number of retained stems per hectare (sph) after thinning is 250 and the harvested volume at thinning is about 100 tonnes per hectare. Stands were planted with 1,100 sph. Log grade set and prices are described in Tab. 2

Financial analysis of the two regimes using estimated Net Present Value (NPV) as the indicator of optimum financial return indicates that better returns can be achieved from the pruned and thinned regime compared with an unthinned, unpruned regime (Fig. 2).

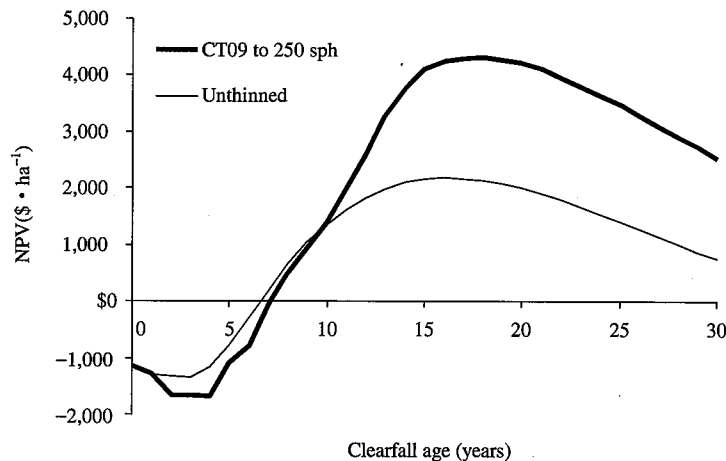


Fig. 2 Estimated Net Present Value (NPV) of two regimes for *Eucalyptus nitens* plantations on a high quality site (Site Index = 28) in Tasmania. CT09 = Commercial thinning at age 9 years with pruning in three lifts to 6.4 metres. The number of retained stems per hectare (sph) after thinning is 250. Interest rate used in NPV calculation = 9%. Log grade set and prices are described in Tab. 2

In both cases the maximum NPV is achieved at a harvest age 15 to 20 years for this site. Fig. 1 shows that the yield of pruned logs approaches a maximum at about this time and the increase in volume growth is mostly in unpruned logs. Returns from the unthinned regime would be substantially reduced if there was no market for small sawlogs as these logs would then be placed in the pulpwood market.

We also examined a low-quality site and applied three possible alternative silvicultural regimes for producing solid wood according to the log grade set in Tab. 2:

- 1) Early non-commercial thinning at age 6 years to 250 sph (NCT06 250 sph).

- 2) Commercial thinning at age 12 years to 250 sph (CT12 250 sph).
- 3) Commercial thinning at age 12 years to 400 sph (CT12 400 sph).

This was done for a low quality site (site index 23) (Fig. 3). It should be noted that the Toolbox program predicts production of a proportion of unpruned peeler or sawlogs in the NCT06 regime. However, our observation is that the branch size above the pruned section is quite large and these logs may actually only be suitable as pulp. To account for this we have allocated the PU log class the same price as P in the financial analysis for NCT06 regime.

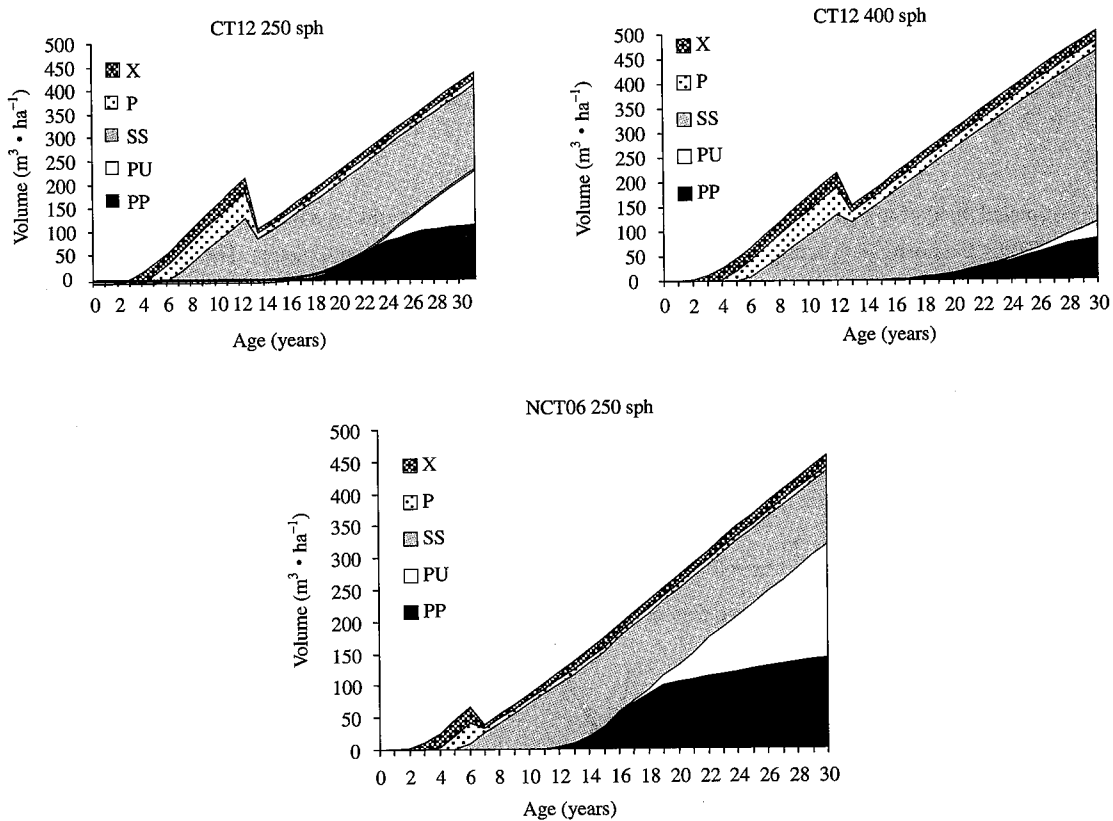


Fig. 3 Estimated volume by log category (Tab. 2) with stand age for three solid wood silvicultural regimes for *Eucalyptus nitens* in Tasmania (site index = 23) where trees are pruned to 6.4 metres

Fig. 3 demonstrates that the early-non-commercial-thin option (NCT06 250 sph) produces the greatest volume of pruned logs. As recovery of clearwood varies with log size we estimated the expected volume of clearwood for each silvicultural regime by assuming a cylindrical knotty core (15cm diameter), and then predicted volume of clearwood produced with clearfall harvest age for each regime (Fig. 4). Clearwood volumes reflect the expected yield of pruned logs, but differences in log volumes are exaggerated by expected differences in clearfall pruned log size: NCT06 produces the biggest logs at a given clearfall age whilst CT12 to 400 sph produces the smallest pruned logs. If the objective of maximising production of pruned logs is refined to be maximising the production of pruned clearwood, the objective is achieved at age 18 for NCT06 (MAI of clearwood production = $3.5 \text{ m}^3 \cdot \text{ha}^{-1} \cdot \text{yr}^{-1}$) and age 25 for CT12 to 250 sph (MAI = $2.5 \text{ m}^3 \cdot \text{ha}^{-1} \cdot \text{yr}^{-1}$). CT12 to 400 sph shows relatively low estimated clearwood productivity even at rotation age of 30 years.

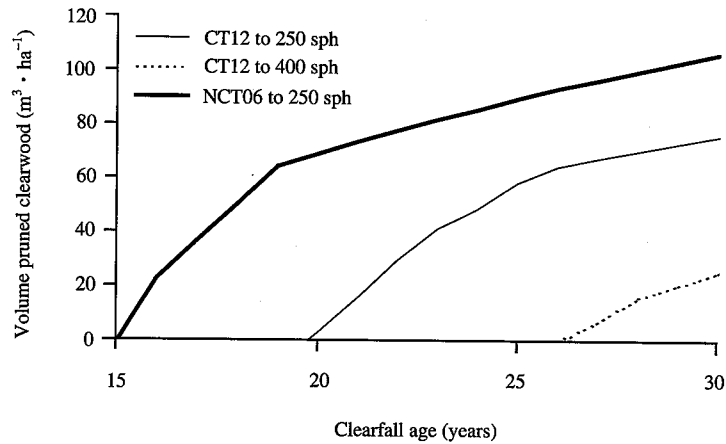


Fig. 4 Clearwood volume produced in three regimes up to age 30 years from three regimes for *Eucalyptus nitens* in Tasmania (site index = 23) according to log grade set in Tab. 2 and trees are pruned to 6.4 metres

If the MAI of total log value is examined to determine the optimum regime for a plantation at site index = 23 using the log grade set in Tab. 2 and yields shown in Fig. 3 then the result reveals that NCT06 yields an optimum MAI of value around age 18 years while commercial thinning regimes do not attain a maximum until 30 years or beyond (Fig. 5).

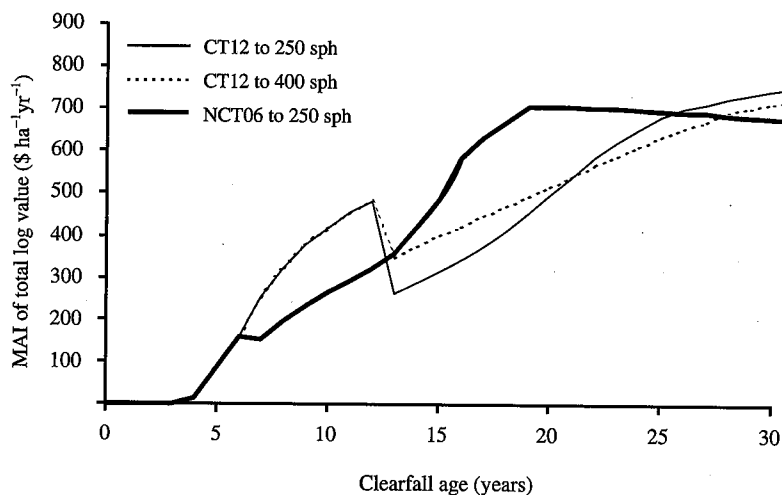


Fig. 5 Mean annual increment (MAI) of total log value from three regimes shown in Fig. 3 of *Eucalyptus nitens* plantations in Tasmania (site index = 23)

Estimated Net Present Value (NPV) for different clearfall ages can be compared for the three regimes for this low quality site (site index = 23) (Fig. 6). NPV is maximised with CT12 to 250 sph and clearfall harvest age is 23 to 25 years. NCT06 still gives a positive NPV at age 18 years, but the window of opportunity for harvest to maximise financial return is very small. This is borne out in Fig. 6 where the MAI of total log value remains relatively unchanged after age 18 for this regime.

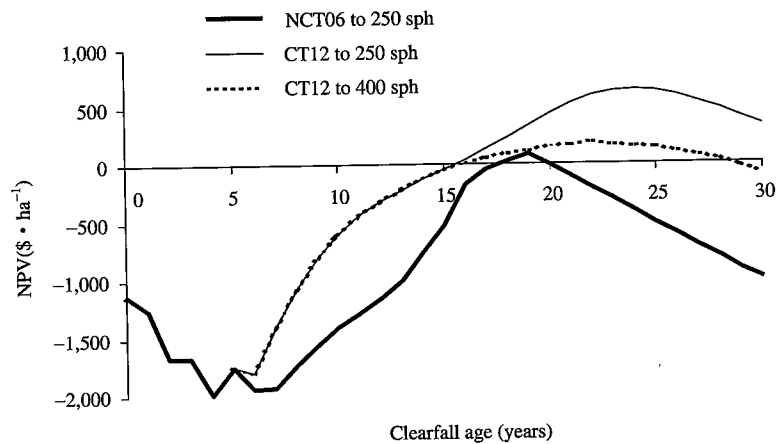


Fig. 6 Estimated Net Present Value (NPV) of three regimes for *Eucalyptus nitens* in Tasmania where trees are pruned to 6.4 metres. Site Index = 23. NCT06 = Non-commercial thinning at age 6 years, CT12 = Commercial thinning at age 12 years. The number of retained stems per hectare (sph) after thinning is indicated. Interest rate used in calculation of NPV is 9.0%

3 CONCLUSIONS

The impact of site quality has an influence, as expected, on the financial return of the commercial thinning regime to 250 sph. On the high quality site (site index = 28), commercial thinning was scheduled at age 9 (CT09, Fig. 1) and maximum NPV in excess of \$4,000 per ha was achieved at about age 17 (Fig. 2). This compares with commercial thinning scheduled at age 12 years on the lower quality site (Site index = 23) (CT12 to 250 sph, Fig. 3) and maximum NPV of about \$600 per hectare achieved at 24 years age (Fig. 6). A contributor to reduced NPV at the lower quality site is not only the reduced volume and longer rotation time, but also higher costs associated with fertiliser addition in the first 6 years.

The decision for a forest grower is usually a balance between financial return for the regime adopted and the ability to produce enough quantity of a resource with certain characteristics that are suitable for market. Larger industrial or Government owned growers often adopt regimes which produce raw materials suitable for existing or proposed processing industries. In these cases the financial gain is made in value-adding during processing of the timber, not necessarily in the sale of produce from the forest.

This study has shown that non-commercial thinning at a young age to a stocking of approximately 250 stems per hectare, combined with pruning of the retained trees yields the highest volume of clearwood. At low site quality this regime is financially viable, but the window of opportunity for final harvest is quite narrow for maximising financial returns to the grower. In contrast, commercial thinning regimes produce a reduced quantity of clearwood per hectare and take longer to do, but the overall financial return of the regime is greater. If there is substantial improvement in the recovery of high value products from sawn timber from early thinning regimes (Washusen, 2004; Nutto and Touza, 2004) then the desirability of such regimes is increased.

4 FURTHER OBSERVATIONS

Breeding objectives have been developed for pulp yield but are yet to be determined for solid wood or engineered wood products. Traits to be measured and their relationship with performance of processed products need to be considered in the development of these breeding objectives. The consequences of

pursuing an inappropriate breeding objective can diminish the economic value and marketability of plantation grown timber.

Issues of wood quality of fast grown plantation timber are of major concern to solid wood and veneer processing industries in Australia (Nolan, 2005). These processors have developed sawing and drying systems to process large dimension and relatively slow grown eucalypt logs from native forests. The wood quality of plantation grown eucalypts is not well understood and new processing systems will need to be developed to handle this new resource.

Products from eucalypt plantations will compete with existing products sourced from softwood plantations. Therefore hardwood products will need to demonstrate advantages in utility or appearance to differentiate in the market place.

REFERENCES

- Barry K M, Hall M F, Mohammed C L. 2005. The effect of time and site on incidence and spread of pruning-related decay in plantation grown *Eucalyptus nitens*. *Can J For Res*, 35: 495-502
- Brown G. 1997. Growth responses to thinning in eucalypt regrowth forests. *Tasforests*, 9: 105-122
- Cunningham J. 1997. Development of operational techniques for thinning eucalypt regeneration. *Tasforests*, 85-104
- Gerrand A M, Medhurst J L, Neilsen W A. 1997a. Thinning and pruning eucalypt plantations for sawlog production in Tasmania. *Tasforests*, 9: 15-34
- Gerrand A M, Medhurst J L, Neilsen W A. 1997b. Research results for thinning and pruning eucalypt plantations for sawlog production in Tasmania. *Forestry Tasmania*, 210
- Medhurst J L, Beadle C L, Neilsen W A. 2001. Early-age and later-age thinning affects growth, dominance, and intraspecific competition in *Eucalyptus nitens* plantations. *Can J For Res*, 31: 187-197
- Montagu K D, Kearney D E, Smith R G B. 2003. The biology and silviculture of pruning planted eucalypts for clear wood production-a review. *For Ecol Man*, 179: 1-13
- National Forest Inventory. 2005. National forest industry 2005 update. Canberra: Bureau of Rural Sciences (www.affa.gov.au/nfi)
- Neilsen W A, Gerrand A M. 1999. Growth and branching habit of *Eucalyptus nitens* at different spacing and the effect on final crop selection, *For Ecol Man*, 123: 217-229
- Nolan G, Greaves B, Washusen R, Parsons M, Jennings S. 2005. Eucalypt plantations for solid wood products in Australia – a review. Forest and Wood Products Research and Development Corporation Report (Project no: PN04.3002):130
- Nutto L, Touza V M C. 2004. High quality *Eucalyptus* sawlog production. In: *Eucalyptus in a Changing World*. Proceedings of IUFRO Conference, Aveiro, 11-15 October (RAIZ, Instituto, Investigacao da Floresta e Papel, Portugal): 658-666
- Pinkard E A, Beadle C L. 1998. Above ground biomass partitioning and crown architecture of *Eucalyptus nitens* following green pruning. *Can J For Res*, 28: 1419-1428
- Pinkard E A. 2003. Physiological and growth responses related to pattern and severity of green pruning in young *Eucalyptus globulus*. *For Ecol Man*, 182: 231-245
- Pinkard E A, Mohammed C, Beadle C L, Hall M F, Worledge D, Mollon A. 2004. Growth responses, physiology and decay associated with pruning plantation-grown *Eucalyptus globulus* Labill. and *E. nitens* (Deane and Maiden) Maiden. *For Ecol Man*, 200: 263-277
- Private Forests Tasmania. 2004. Farm Forestry Toolbox Version 4 CD ROM. (www.privateforests.tas.gov.au)
- Washusen R. 2004. Wood quality and sawn product value using conventional processing strategies in plantation grown *Eucalyptus globulus* managed for sawlog production. In: *Integrating Forestry into Farms Communities and Catchments*. Proceedings of Australian Forest Growers Biennial Conference, Ballarat, 3-5 May (AFG): 96-101

Towards the Prediction and Management of Windthrow in *Eucalyptus* Plantations Across Tasmania, Australia

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ABSTRACT

Tasmania, Australia, lies between latitudes 40° and 44°, where strong winds and heavy rainfall are common. Much of the plantation estate is located in exposed areas at altitudes of up to 1,000 m above sea level, and often surrounded by mountainous terrain. Intensive silvicultural regimes are used to produce high value sawn timber and veneer products, principally of *Eucalyptus globulus* and *E. nitens*. Notably, these regimes include a single heavy thinning, an operation known to promote tree instability. As a result, there is concern regarding the risk of windthrow.

The factors proven to directly influence the risk of windthrow in other tree species are well known. These include; wind speed, rainfall, elevation, topography, soil properties (physical and hydrological), root development, stand attributes (edge orientation, forest structure), tree characteristics (crown and stem morphology) and silvicultural operations (notably cultivation and thinning). However, far less is known of the influence of these factors on windthrow in *Eucalyptus* plantations.

In response, a qualitative windthrow hazard assessment procedure has been developed for Tasmania - WindRISK, based upon a broad review of the literature. In practice, a range of biotic and abiotic variables are assessed and each given a score based on their potential influence on the risk of windthrow (1 = low, 2 = medium and 3 = high). The total score then defines the overall risk of windthrow as low, medium or high. Thinning at a mean dominant height (MDH) > 20 m or height : diameter (h : d) ratio > 1.0 is considered over-riding irrespective of the total score, and the risk of windthrow is described as 'high'.

This paper offers a summary of WindRISK with examples of recent applications, a program of future research is presented.

1 INTRODUCTION

1.1 Windthrow

Wind damage in forest plantations may be catastrophic or endemic (Miller, 1985; Quine, 1995). The

former is related to rare climatic (wind) events, often resulting in windsnap - above ground stem breakage (Mitchell, 1998). The latter is a function of (normal) climatic (wind) events; topographical, site and silvicultural factors, typically resulting in windthrow - uprooting and toppling of individual trees (Mayer, 1989).

Financial losses due to windthrow in particular can be considerable (Savill, 1983; Grayson, 1989; Quine, 1991; Mitchell, 1995a; Somerville, 1995). In addition to lost timber revenue, windthrow can damage residual trees, affect wildlife populations, lead to pest and disease problems, increase fuel loadings and limit recreational activities (Savill, 1983). Furthermore, salvage operations can be dangerous and expensive (Mitchell, 1995b).

1.2 Tasmania

Located between 40°S and 43.5°S, Tasmania, Australia, is characterised by mountainous regions occurring throughout the western, central and northeastern areas, with flat to rolling terrain throughout the remaining areas (Davies, 1965). Median rainfall varies markedly, typically from 500 mm · yr⁻¹ in the sheltered east and southeast to 3,200 mm · yr⁻¹ in the west (Bureau of Meteorology, 1993). Winds vary from northwest to southwest following the easterly passage of low and high pressure systems. Gusts in excess of 100 km · hr⁻¹ are common, the strongest and most persistent winds occur during late winter and early spring, with gale force winds (10 minute mean in excess of 63 km · hr⁻¹) originating from the west (Bureau of Meteorology, 1993).

In Tasmania, intensive silvicultural regimes have been developed to provide logs for sawn and veneer products from hardwood plantations, principally of *Eucalyptus globulus* and *E. nitens*. These regimes include a single heavy thinning, typically from 1, 100 stems · ha⁻¹ to a final stocking of 300 stems · ha⁻¹ (Medhurst *et al.*, 2001; Ronggui *et al.*, 2003), an operation known to promote forest instability and the risk of windthrow (Cremer *et al.*, 1982; Quine *et al.*, 1995; Ruel, 1995). The plantation estate managed by Forestry Tasmania under 'solid wood' regimes is summarised in Fig. 1.



Fig. 1 Forestry Tasmania plantation estate managed under 'solid wood' regimes

It is worth noting that of the 25,000 ha currently planted (Fig. 1), only 5% of this has been thinned, and there have already been several major windthrow events in thinned stands, each affecting in excess of 5-10 ha.

Despite environmental and silvicultural conditions pertinent to windthrow, the overall risk in Tasmania remains unknown. Further uncertainty has arisen for a number of reasons. These include: (i) the anticipated

expansion of the 'solid wood' plantation estate, in some cases into potentially higher risk areas, (ii) the timing and intensity of silvicultural operations known to promote instability, notably thinning, and (iii) the effects of predicted climate changes on weather patterns.

1.3 Risk assessment

Early strategies for assessing the risk of windthrow in countries such as Canada, the United States of America and United Kingdom, were deterministic in approach and criticised for not including a measure of probability (Moore and Somerville, 1998; Moore and Quine, 2000; Ni Dhubhain *et al.*, 2001). Furthermore, their application was limited to the local attributes on which they were based (Mitchell, 1995b).

Subsequently, probabilistic approaches have been designed, for example the quantitative wind risk model ForestGALES developed in the UK (Gardiner *et al.*, 2004). However, simple diagnostic models (Harris, 1989; Strathers *et al.*, 1994; Mitchell, 1995b) in which the key factors related to windthrow can be assessed in the field and tallied, remain a sound basis for silvicultural decision making at a stand level. To the author's knowledge, no such schemes exist in Australia.

2 METHODS

A qualitative windthrow hazard assessment procedure has been developed, The WindRISK model, based upon a review of the widely documented relationships between climate, site, soil and silviculture, and windthrow. The procedure, following minor revisions, is described below.

2.1 WindRISK

In practice, each of the four key factors affecting the risk of windthrow; climate, site, soil and silviculture, are assessed using a number of variables (Tab. 1 and Tab. 2).

Tab. 1 Summary of climate, site and soil variables used in WindRISK

| | Variable | Effect on risk of windthrow | Classification (low, medium or high) |
|---------|---|--|--|
| Climate | Wind speed ($\text{km} \cdot \text{hr}^{-1}$) | Increases with increasing wind speed | Based on range in mean annual wind speed |
| | Rainfall ($\text{mm} \cdot \text{yr}^{-1}$) | Increases with increasing rainfall | Based on range in mean annual rainfall |
| Site | Elevation (m \cdot ASL) | Increases with increasing altitude | Based on State wide range of key species |
| | Topography | Increases with increasing slope and/or presence of key terrain attributes - crests, saddles, valleys and valley heads | Based on field observations |
| | Location and orientation | Increases if located on upper slopes, ridges or plateaus and/or edges orientated perpendicular to the prevailing wind and/or recently cut blocks | Based on field observations |
| Soil | Depth (m) | Increases with decreasing soil depth | Based on range in soil depth for key soils |
| | Drainage class | Increases with decreasing drainage | Based on drainage classification for key soils |
| | Stoniness (%) | Increases with increasing stoniness | Based on range in soil stoniness for key soils |

The influence of each variable on the risk of windthrow is assessed as low, medium or high and given a score of 1, 2 or 3 respectively. To protect intellectual property, specific boundaries used in practice are not included in Tab. 1 and Tab. 2. The feature resulting in the highest score defines the score for each variable. For example, a stand might be located on relatively sheltered lower slopes (score 1) though major edges may be orientated perpendicular to the prevailing wind direction or downwind of a recent cut-block (score 3), hence the score for this variable would be 3 (see *location and edge orientation*, Tab. 1).

Tab. 2 Summary of silviculture variables used in WindRISK

| Silviculture | Variable | Effect on risk of windthrow | Classification (low, medium or high) |
|--------------|---|--|---|
| | Root morphology | Increases with decreasing root symmetry | Based on nature and extent of cultivation and/or drainage works |
| | Stand density (stems · ha ⁻¹) | Increases during 3-5 year period after thinning | Based on time since thinning |
| | Stem morphology | Increases with increasing MDH and/or h:d ratio | Based on values reported in the literature |
| | Canopy structure | Increases with increasing number and/or size of gaps in the canopy | Based on forest health surveillance and/or time since thinning |
| | Crown drag coefficient | Increases with crown 'sail area' and/or stiffness | Based on values reported in the literature |

For any coupe, thinning at a mean dominant height (MDH) > 20 m or height : diameter ratio (h : d) > 1.0, is considered over-riding irrespective of the total score for the coupe, and the risk of windthrow is described as 'high'.

2.1.1 Climate variables

Wind speed defines the typical wind forces that can be expected for an area, though there is considerable debate regarding the overall importance of mean and maximum wind speed and also, duration (Cremer *et al.*, 1982; Savill, 1983; Strathers *et al.*, 1994). Rainfall provides an indication of the potential for periodic water logging of the soil and associated losses in soil mechanical strength, root growth and tree anchorage (see below).

To develop risk classes, meteorological data for Tasmania were obtained from the Australian Bureau of Meteorology, this included mean annual wind speeds (km · hr⁻¹, 10 minute mean at 0900 hrs and 1, 500 hrs, n = 104 sites) and mean annual rainfall (mm · yr⁻¹, n = 670 sites). Data were subject to quality control by the Australian Bureau of Meteorology such that (i) monthly data were provided only for those months where observations were collected on at least 21 days and (ii) where based on multiple daily readings, only days where at least six observations were made were used. The extent of each record is not reported here, though it is acknowledged that a few sites have an unbroken record of meteorological data due to closure, reopening, maintenance and upgrading, and relocation (to within 1 mile). These data are summarised in Tab. 3.

Tab. 3 Summary of wind speed and rainfall in Tasmania

| | | Mean | Stdev | Min | Max | N |
|-------------------------------------|-------------------------|-------|-------|------|-------|-----|
| Wind speed (km · hr ⁻¹) | Mean annual (0900 hrs) | 13.90 | 6.99 | 3.60 | 32.90 | 104 |
| | Mean annual (1,500 hrs) | 18.15 | 6.66 | 7.00 | 35.70 | 104 |
| Rainfall (mm) | Mean annual total | 980 | 470 | 401 | 3,587 | 670 |

Source: Australian Bureau of Meteorology.

Mean annual wind speeds at 1,500 hrs were consistently higher than those for 0900 hrs, the former were used in the final analysis. Mean annual wind speed (1,500 hrs) and mean annual rainfall were divided equally into three broad bands, the lower and upper extent defined by the minimum and maximum values in Tab. 3.

2.1.2 Site variables

Elevation provides a surrogate indicator of the return period of extreme wind and/or rainfall events. Topography accounts for the topographical enhancement or 'amplification' of wind speeds (Moore, 1977;

Robertson, 1986; Moore and Somerville, 1998), and also the occurrence of turbulent air flows or 'gustiness' within the landscape (Robertson, 1987). Location and edge orientation provide an indication of overall exposure (Somerville, 1980; De Walle, 1983; Laiho, 1987; Lohmander and Helles, 1987; Ruel *et al.*, 2000), which includes the location of the stand within the landscape (i.e. in the leeward shelter of a hill or on an exposed ridge) and also, of major forest edges relative to the prevailing wind.

Classification of elevation, topography, forest location and edge orientation in WindRISK is arbitrary. Elevation is based on the current range of key plantation species, whilst topography, forest location and edge orientation are more subjective and based on maps and field observations.

2.1.3 Soil variables

Soil depth, drainage and stoniness are derived from field assessments. Soil depth provides an indication of effective rooting depth and vertical anchorage (Somerville, 1979; Boyd and Webb, 1981; Quine *et al.*, 1995). Drainage class describes any reduction in root depth and soil mechanical strength due to water logging (Busby, 1965; Kennedy, 1974; Savill, 1976; Moore, 1977; Cremer *et al.*, 1977; Turvey, 1980; Smith *et al.*, 1987). Stoniness defines the total soil volume available for root growth, or potential shearing effect on roots of coarse fragments during prolonged wind loading (Stone, 1977).

Classification of soil depth and stoniness in WindRISK is based on conditions commonly reported for plantation sites in Tasmania, while drainage classes are based on those currently defined by Grant *et al.* (1995).

2.1.4 Silviculture variables

Root morphology allows for the effects of cultivation and/or drainage works on root symmetry (Zehetmayr, 1954; Booth, 1974; Savill, 1976; Somerville, 1979), providing an indication of horizontal anchorage.

Stand density describes the mutual support provided by trees grown at high stockings and any loss of this support through thinning (Mayhead *et al.*, 1975; Savill, 1976; Cremer *et al.*, 1977; Cremer *et al.*, 1982; Savill, 1983; Quine *et al.*, 1995). Stem morphology relates to stand indices strongly correlated with tree stability, notably mean dominant height (MDH) and height : diameter (h : d) ratio (Faber and Sissingh, 1975; Kramer and Bjerg, 1978; Cremer *et al.*, 1982; Savill, 1983). Classification of these features in WindRISK is based on thresholds reported in the literature; typically fast growing plantations are unstable during the period 3-5 years immediately after thinning (Cremer *et al.*, 1977; Petersen and Borough, 1999) or when they are thinned at an MDH >20m or h : d >1.0 (Cremer *et al.*, 1982).

Canopy cover is a measure of the potential for turbulent air flow both over and within the forest (Quine *et al.*, 1995), typically associated with tree mortality, poor and/or variable tree growth or existing windthrow. Crown drag coefficient defines the wind force acting on the crown relative to the 'sail' area and stiffness of the crown.

2.2 Interpretation of output from WindRISK

The total score, based on the sum of the scores for each variable, defines the overall risk of windthrow and any action to be taken (Tab. 4).

Tab. 4 Interpretation of WindRISK output

| Assessment type | Risk and score | | |
|--|--|--|---|
| | Low | Medium | High |
| <i>Site selection</i> - using climate, site and soil variables | 8 | 9-16 | 17-24 |
| <i>Plantation</i> - using climate, site, soil and silviculture variables | 13 | 14-26 | 27-39 |
| Description of risk | Low - resisting forces (will/currently) dominate | Medium-applied and resisting forces in balance | High - assumes applied forces (will/currently) dominate |
| Action | None | Seek advice | Seek advice |

Where WindRISK is used during a site selection procedure only climate, site and soil variables are used. For an assessment of an existing plantation, for example during the prioritisation of thinning operations, silviculture variables are also included. Depending on the output, field staff may seek advice on operational issues including; establishment techniques (plantation design and location, cultivation and fertiliser application), plantation edge firming treatments, and the timing and intensity of thinning or harvesting operations, including those in adjacent stands.

3 DISCUSSION

3.1 Key site attributes and WindRISK output

In the absence of long-term silvicultural records against which to validate WindRISK, the model was applied retrospectively to examine three recent windthrow events. In each case, 5-10 ha were affected in the period immediately after commercial thinning, from 1,100 stems · ha⁻¹ to a final stocking of approximately 300 stems · ha⁻¹, at ages 10-11 years. Key site attributes and WindRISK output for each event are summarised in Tab. 5.

Tab. 5 Site attributes of recent windthrow events and WindRISK output

| Variable | Site attributes and WindRISK score | | | | | | |
|-------------------|--|-----------------|---------|-----------------|---------|-----------------|---|
| | AR 022D | Score | UR 024C | Score | LI 151B | Score | |
| Climate | Wind speed (km · hr ⁻¹) | <20 | 1 | <20 | 1 | <20 | 1 |
| | Rainfall (mm · yr ⁻¹) | 1,487 | 2 | 1,309 | 2 | 1,360 | 2 |
| Site | Elevation (m · ASL) | 300 | 2 | 350 | 2 | 350 | 2 |
| | Topography | Steep | 3 | Moderate | 2 | Steep | 3 |
| | Location and orientation | Exposed | 3 | Moderate | 2 | Exposed | 3 |
| Soil | Depth (cm) | 80 | 2 | 50 | 2 | 50 | 2 |
| | Drainage class | Good | 1 | Good | 1 | Good | 1 |
| | Stoniness (%) | <30 | 1 | <30 | 1 | <30 | 1 |
| Silviculture | Cultivation and root morphology | Mound plough | 2 | Spot rip/mound | 2 | Line rip/mound | 3 |
| | Stand density (stems · ha ⁻¹)* | 250-300 | 3 | 250-300 | 3 | 250-300 | 3 |
| | Stem morphology | MDH (m) >20 | 3 | MDH (m) > 20 | 3 | MDH (m) >20 | 3 |
| | Canopy cover | Highly variable | 3 | Highly variable | 3 | Highly variable | 3 |
| | Crown drag coefficient | Low | 1 | Low | 1 | Low | 1 |
| Total | | 27 | | 25 | | 28 | |
| Risk (adjusted)** | | High (high) | | Med (high) | | High (high) | |

* Thinned stocking for period <3-5 years since thinning.

** Adjustment based on thinning at MDH >20 m.

Windthrow at UR014C and LI151B was ascribed to late thinning (MDH > 20 m). At UR014C, windthrow was frequently observed in poorly drained areas where root depth and tree anchorage would have been limited. At LI151B, windthrow was concentrated in areas exposed to the prevailing westerly winds, preferential rooting along continuous rip lines may have reduced stability further still. A routine assessment early in the life of these two plantations using WindRISK would have indicated the need to ensure that thinning operations were applied on time - UR014C would have scored 24, at the high end of the 'medium' risk classification, whilst LI151B would have scored 27 indicating a 'high' risk.

3.2 Future development of WindRISK

Future development of WindRISK will focus on quantification and weighting of each variable.

3.2.1 Application of geographical information systems

Digital Terrain Models (DTM) stored as layers in Geographical Information Systems (GIS) have been used successfully to map topographical exposure and predict wind speed (Quine and White, 1998; Ruel *et al.*, 2002). In practice, and for a given location, the minimum and maximum altitude of features along a transect of fixed distance are derived, and the angle to these features calculated (Fig. 2).

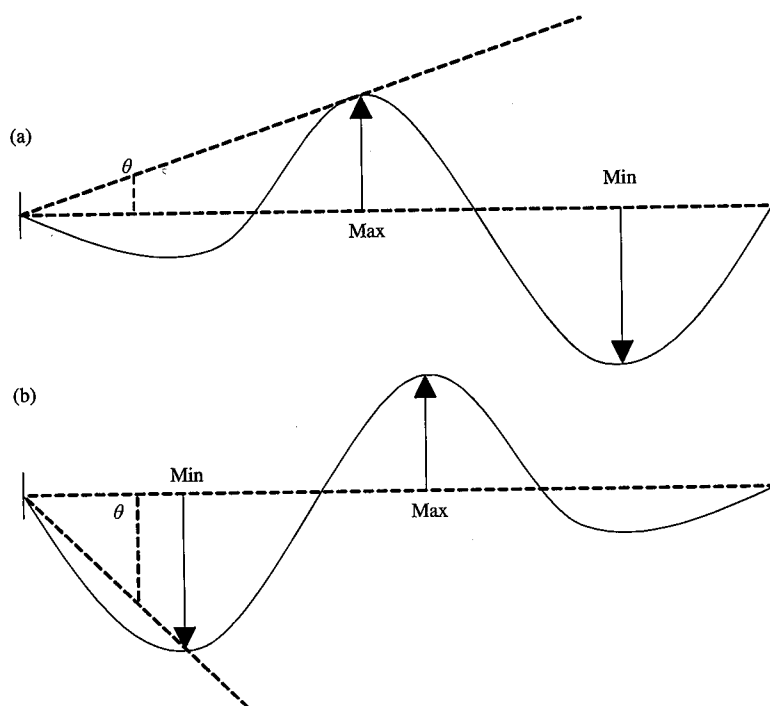
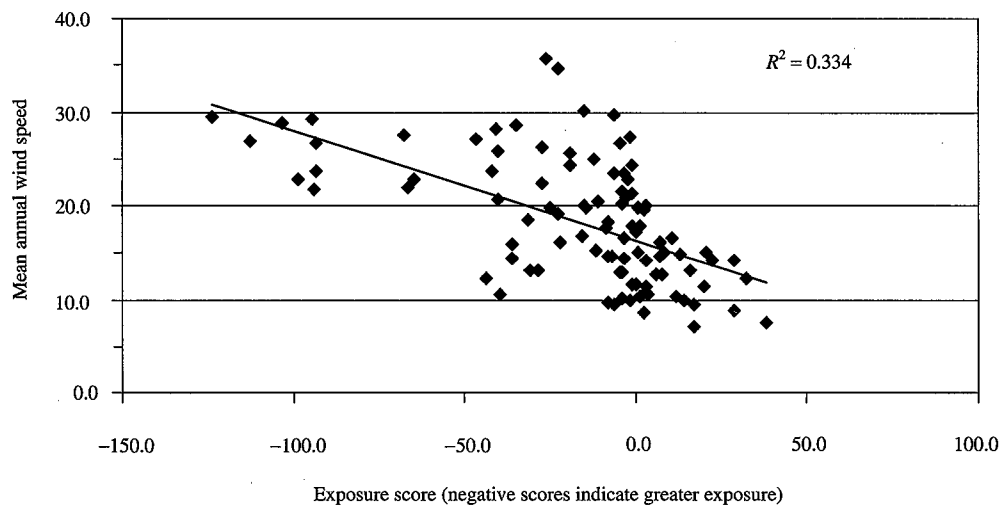


Fig. 2 Calculation of topographical exposure

If the maximum altitude is reached before the minimum altitude, the angle to the former is used (Fig. 2a)-a hill near the site is considered to have more influence on exposure than a deep valley located beyond that hill. This is repeated for the eight cardinal points of the compass at a user defined spatial resolution. The sum of all eight angles defines the level of exposure, lower scores are indicative of greater exposure.

Grid resolutions of 50 m and distance limits of between 0.5 and 1 km have performed well (respectively Quine and White, 1998; Ruel *et al.*, 2002). The application of exposure mapping is now being tested in Tasmania, Fig. 3 illustrate the relationship between exposure and wind speed for 98 sites across the State.

(a) 1 km transect



(b) 3 km transect

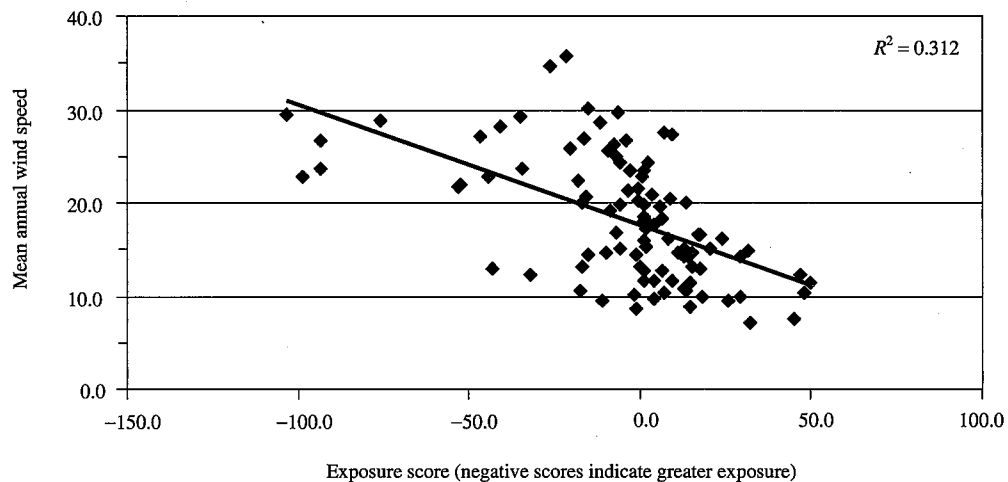


Fig. 3 The relationship between exposure and wind speed

In each case, a 50 m² grid resolution was used, and lower scores (increasing exposure) were indicative of increased wind speeds, though the relationships were weak. Further refinements and field testing of this technique will allow for the confounding effects of elevation, proximity to the coast and prevailing wind direction.

In use, exposure mapping will provide valuable information when selecting new plantation sites, and also, the appropriate thinning regime. In native forests, the increasing emphasis on retention systems carries the potential risk of windthrow (Neyland, 2004). Exposure mapping will allow forest aggregates to be designed and located to improve their overall stability.

3.2.2 Field studies

Field studies will be carried out to determine empirically climate-site-soil-silviculture relationships for key economic species in Tasmania, and also, the portability of existing windthrow risk models. These include:

- 1) Tree pulling studies to determine critical turning moments under a range of conditions.
- 2) Quantifying growth responses to key silvicultural operations, notably thinning, and their effect on tree stability through analysis of stem form.
- 3) Desktop photo-interpretation of historic windthrow events across Tasmania and the development of a database/GIS layer relating windthrow to climate, site, soil and silvicultural attributes.

Additional studies will focus on the effects of wind stresses on wood quality, the development of low-risk regimes for sites where windthrow is likely, and also, the potential economic impacts of windthrow.

4 CONCLUSIONS

Currently, WindRISK does not provide information on the *probability* or *timing* of a windthrow event. Instead, the risk of windthrow at some stage in the life of a plantation is determined to be low, medium or high, as defined by a range of biotic and abiotic variables.

In its present form, the procedure allows more informed decision making in terms of site and regime selection, in particular, the timing and intensity of thinning operations. This is critical given the high levels of capital investment and potential returns associated with 'solid wood' regimes currently used in Tasmania.

Validation and quantification will extend the operational range of WindRISK to additional plantation regimes not discussed here, different tree species, and, native forest silviculture.

REFERENCES

- Booth T C. 1974. Silviculture and management of high-risk forests in Great Britain. *Irish Forestry*, 21, 145-153
- Boyd D M, Webb T H. 1981. The influence of the soil factor on tree stability in Balmoral Forest, Canterbury, during the gale of August 1975. *New Zealand Journal of Forestry*, 26 (1), 96-102
- Bureau of Meteorology. 1993. *Climate of Tasmania*. Victorian Printing Pty Ltd.
- Busby J A. 1965. Studies on the stability of conifer stands. *Scottish Forestry*, 19, 86-102
- Cremer K W, Myers B J, Duys F van der, Craig I E. 1977. Silvicultural lessons from the 1974 windthrow in Radiata pine plantations near Canberra. *Australian Forestry*, 40 (4): 274-292
- Cremer K W, Borough C J, McKinnell F H, Carter P R. 1982. Effects of stocking and thinning on wind damage in plantations. *New Zealand Journal of Forestry Science*, 12 (2): 244-268
- Davies J L. 1965. *Atlas of Tasmania*. Lands and Survey Department, Hobart
- De Walle D R. 1983. Wind damage around clearcuts in the Ridge and Valley Province of Pennsylvania. *Journal of Forestry*, 81, 158-172
- Faber P J, Sissingh G. 1975. Stability of stands to wind. II. The practical viewpoint. *Nederlands Bosbouw Tijdschrift*, 47 (7/8): 179-193
- Gardiner B, Suarez J, Achim A, Hale S, Nicoll B. 2004. *ForestGALES - a PC-based wind risk model for British forests. v.2.0*. United Kingdom: Forestry Commission
- Grant J C, Laffan M D, Hill R B, Neilsen W A. 1995. *Forest soils of Tasmania. A handbook for identification and management*. Forestry Tasmania
- Grayson A J. 1989. *The storm of October 1997: impact and response*. Forestry Commission Bulletin 87. HMSO, London. 46
- Harris A S. 1989. *Wind in the forests of southeast Alaska and guides for reducing damage*. USDA Forest Service PNW-GTR-244, 63
- Kennedy M J. 1974. *Windthrow and windsnap in forest plantations, Northern Ireland*. Mich. Geogr. Publ. 11, Department of Geography, University of Michigan, Ann Arbor, 164.
- Kramer H, Bjerg N. 1978. *Biological aspects of tending young stands of Norway spruce*. Forestry Faculty, University of Göttingen, West Germany, No. 55. 121
- Laiho O. 1987. Susceptibility of forest stands to windthrow in Southern Finland. *Folia Forestalia*, 706, 23-24
- Lohmander P, Helles F. 1987. Windthrow probability as a function of stand characteristics and shelter. *Scandinavian Journal of Forest Research*, 2, 227-237
- Mayer H. 1989. *Windthrow*. Philosophical Transactions of the Royal Society of London. 324, 267-281
- Mayhead G J, Gardiner J B, Durrant D W. 1975. *A report on the physical properties of conifers in relation to plantation stability*. U. K. Forestry Commission, Research and Development Division Report. 39
- Medhurst J L, Beadle C L, Neilsen W A. 2001. Early-age and later-age thinning effects growth, dominance and intra-specific competition in *Eucalyptus nitens* plantations. *Canadian Journal of Forest Research*, 31, 187-197

- Miller K F. 1985. Windthrow Hazard Classification. Forestry Commission Leaflet No. 85. Forestry Commission Great Britain
- Mitchell S J. 1995a. A synopsis of windthrow in British Columbia: occurrence, implications, assessment and management. In: Coutts M P, Grace J. Eds. 1995. Wind and trees. Cambridge University Press, 448-459
- Mitchell S J. 1995b. The windthrow triangle: a relative windthrow hazard assessment procedure for forest managers. The Forestry Chronicle, 71 (4): 446-450
- Mitchell S J. 1998. A diagnostic framework for windthrow risk estimation. The Forestry Chronicle, 74 (1): 100-105
- Moore M K. 1977. Factors contributing to blowdown in streamside leave strips on Vancouver Island. B. C. Min For Land Manage Rep, 3, 34
- Moore J R, Somerville A R. 1998. Assessing the risk of wind damage to plantation forests in New Zealand. New Zealand Forestry 431, 25-29
- Moore J, Quine C P. 2000. A comparison of the relative risk of wind damage to planted forests in Border Forest Park, Great Britain, and the Central North Island, New Zealand. Forest Ecology and Management, 135, 345-353
- Neyland M G. 2004. Selection, harvesting damage, burning damage and persistence of retained trees following dispersed retention harvesting in the WARRA silvicultural systems trial in Tasmania. Tasforests, 15, 55-66
- Ni Dhubbain A, Walshe J, Bulfin M, Keane M, Mills P. 2001. The initial development of a windthrow risk model for Sitka spruce in Ireland. Forestry, 74 (2): 161-170
- Petersen L, Borough C. 1999. Windthrow - blowing away your profits. Australian Forest Grower. Special Liftout Section. No. 47. Autumn 1999. 22 (1): 5
- Quine C P. 1991. Recent storm damage to trees and woodlands in southern Britain. In: Hodge S. J. Ed. Research for practical arboriculture. Forestry Commission Bulletin 97. HMSO, London. 83-89
- Quine C. 1995. Assessing the risk of wind damage to forests. In: Coutts M P, Grace J. Eds. Wind and trees. Cambridge University Press. 379-403
- Quine C P, Coutts M P, Gardiner B A, Pyatt D G. 1995. Forests and wind: management to minimise damage. Forestry Commission Bulletin 114. HMSO, London. 27
- Quine C P, White I M S. 1998. The potential of distance-limited topex in the prediction of windiness. Forestry, 71 (4): 325-332
- Robertson A. 1986. Estimating mean windflow in hilly terrain from tamarak [*Larix laricina* (Du Roi) K. Koch] deformation. International Journal of Biometeorology, 30, 333-349
- Robertson A. 1987. The use of trees to study wind. Arboricultural Journal, 11, 127-143
- Ronggui Z, Baker T, Neilsen W. 2003. Growth responses to thinning in young Eucalyptus plantations in China and Australia. In: Turnbull J W. Ed. Eucalypts in Asia. Proceedings of an International Conference held in Zhanjiang, Guangdong Province of China, 7-11 April 2003. ACIAR Proceedings No. 111. 169-173
- Ruel J C. 1995. Understanding windthrow: silvicultural implications. The Forestry Chronicle, 71 (4): 434-445
- Ruel J C, Quine C P, Meunier S, Suarez J. 2000. Estimating windthrow risk in balsam fir stands with the ForestGales model. The Forestry Chronicle, 76 (2): 329-337
- Ruel J C, Mitchell S J, Dornier M. 2002. A GIS based approach to map wind exposure for windthrow hazard rating. Northern Journal of Applied Forestry. 19 (4): 183-187
- Savill P. 1976. The effects of drainage and ploughing of surface water gleys on rooting and windthrow of Sitka spruce in Northern Ireland. Forestry, 49 (2): 133-141
- Savill P S. 1983. Silviculture in windy climates. Forestry Abstracts. Review Article, 44 (8): 473-488
- Smith V G, Watts M, James D F. 1987. Mechanical stability of black spruce in the clay belt region of northern Ontario. Canadian Journal of Forest Research, 17, 1080-1091
- Somerville A. 1979. Root anchorage and root morphology of *Pinus radiata* on a range of ripping treatments. New Zealand Journal of Forestry Science, 9 (3): 294-315
- Somerville A. 1980. Wind stability: forest layout and silviculture. New Zealand Journal of Forestry Science, 10 (3): 476-501
- Somerville A R. 1995. Wind damage to New Zealand State forest plantations. In: Coutts M P, Grace J. Eds. Wind and Trees. Cambridge: Cambridge University Press 460-467
- Strathers R J, Rollerson T P, Mitchell S J. 1994. Windthrow handbook for British Columbia forests. BC Min For. Research Branch Working Paper 9401, Victoria, BC. 34
- Stone E L. 1977. Abrasion of tree roots by rock during wind stress. Forest Science, 23 (3): 333-336
- Turvey N D. 1980. A forest survey. II: The application of soil survey information to forestry operations. Australian Forestry, 43, 172-177
- Zehetmayr J W L. 1954. Experiments in tree planting on peat. Forestry Commission Bulletin, London. 22, 110

The Implications of Cellulose Crystallite Width for Solid Wood Processing and its Manipulation by Thinning and Fertilizer Application

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ABSTRACT

SilviScan technology and a non-destructive core-sampling protocol designed to detect tension wood in *Eucalyptus globulus*, were applied to an *E. globulus* silvicultural trial. These procedures were to test the interaction of thinning and fertilizer application, to assess the effect that thinning had on tension wood formation. In addition, 35 trees were harvested to assess the implications of cellulose crystallite width (an indicator of tension wood severity) in the core-samples on solid wood processing performance.

The results indicated that heavy thinning of trees at eight years of age contributed to the development of severe tension wood and that this effect was mitigated where fertilizer was applied. These findings support the commonly held belief that tension wood in straight vertical trees is formed as a response to bending stresses that develop from wind in stands destabilised by thinning. However, tension wood severity only increased in treatments where there had been a poor growth response. This is probably because in fertilized stands where there has been a significant growth response, increased stem bulk overcame internal bending stresses.

There was an increase in board distortion during sawing and development of defects during drying as cellulose crystallite width increased in associated core samples. The results indicate that the core sampling strategy was effective in identifying trees with significant volumes of tension wood and could be used in tree improvement programs to select trees with improved processing performance.

Processing performance deteriorated where the maximum crystallite width in the cores exceeded 3.4–3.5 nm. This level was about the mean crystallite width in the most heavily thinned, unfertilized treatments.

1 INTRODUCTION

Cellulose crystallite width can be used to indicate tension wood presence in hardwoods (Hanna, 1973; Hanna and Coté, 1974; Blaho *et al.*, 1994; Washusen and Evans, 2001). Recently it has been demonstrated that x-ray diffraction analysis applied by the SilviScan technology can be used to obtain measurements of cellulose crystallite width, and that this measurement can be used to identify regions of tension wood within a number of eucalypts and other hardwoods (Hillis *et al.*, 2004; Washusen *et al.*, 2005a).

Application of this technology in field trials testing silvicultural treatments and genetic variates may now be a useful way of understanding tension wood formation in species where tension wood commonly

forms. One such species is *Eucalyptus globulus*, where in southern Australia tension wood is known to be very common in stands managed for pulpwood production (Washusen, 2000; 2002). However, when thinning is applied to improve growth of individual trees it appears that tension wood volumes may be minimised and processing performance of solid wood improved dramatically because of reduced growth stress levels at the log periphery and improved drying performance of sawn timber (Washusen *et al.*, 2004; Waugh, 2004). To the contrary Waugh (1972) found that thinning of *Populus* led to higher growth stresses and similarly, Hamilton *et al.* (1985) found that oaks produced tension wood following thinning. This is possibly linked to destabilisation of stands following thinning (Kubler, 1988).

To clarify the role that thinning had on tension wood formation and to assess the value of the experimental cellulose crystallite width measurement, the SilviScan technology and a core-sampling protocol designed to detect tension wood in *Eucalyptus globulus* in southern Australia was applied to a field trial. This trial tested the interaction of thinning and fertilizer treatments to: (i) assess the effect of thinning on tension wood formation and (ii) assess the implications of crystallite width in the core samples on wood processing performance of the sampled log.

2 METHODS

2.1 The plantation and thinning treatments

The plantation used in the experiments is described by Washusen *et al.* (2005b). It was located in south-eastern Australia and was a thinning \times fertilizer trial established in 1991 with Otway Waitawhile Track provenance *E. globulus* subsp. *globulus*. The plantation was located adjacent to a species/provenance trial used in earlier research to investigate tension wood occurrence. Based on this previous research it was believed that tension wood was a significant problem in trees >8 years of age at this location.

Experimental plots were thinned in 1999 (at 8 years) to 200 and 400 trees \cdot ha⁻¹ with unthinned control plots retained at 1,000 trees \cdot ha⁻¹. At thinning, fertilizer was applied to half of the plots at a rate of 200 kg \cdot ha⁻¹, 62.5 kg \cdot ha⁻¹, 62.5 kg \cdot ha⁻¹ and 6 kg \cdot ha⁻¹ for N, P, K and S respectively to produce six treatments (in three replicates) of; 200, 400 and 1,000 with and without fertilizer. Baker^① (pers comm.) indicated that there was a significant growth response to the fertilizer treatment following thinning.

2.2 Core sampling and SilviScan analysis

Core sampling was undertaken in October 2003 when the trees were 12.5 years old (4.5 years after thinning). Twenty-five trees were randomly selected from each treatment to determine differences between treatments, and a number of additional large diameter trees were cored to ensure sufficient large diameter trees were available for subsequent processing trials. Selection was structured to ensure that trees selected from each treatment were distributed across the plantation. Before core sampling the selected trees were inspected to ensure they were straight and vertical. Where a tree was discarded it was replaced with a tree of similar diameter.

The core sampling strategy was designed to detect tension wood. The strategy was developed from research in plantation-grown *E. globulus* grown in southern Australia and has been used to segregate trees

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containing tension wood volumes that may be detrimental to processing performance.

Two bark to pith, 12 mm diameter increment cores were extracted from the southwest side of the stem at 1.0 m and 0.6 m above ground level using a CSIRO Trecor. The cores were prepared by standard procedures for SilviScan analysis. Air-dry density at 8% moisture content was measured at 50 μm intervals and cellulose crystallite width averaged over consecutive 5 mm intervals. From the data output traces, information was extracted from the outer 4.5 growth rings to obtain average and maximum values over this defined spatial period. The outer 4.5 growth rings represented the wood produced after the time of thinning at 8 years. To isolate these data, a single ring boundary was allocated using microdensity traces at the 5th peak from the end of each sample. If there was a doubt about where this peak occurred the peak closer to the cambium was selected to eliminate wood that had formed prior to the time of thinning. The data extracted included mean and maximum cellulose crystallite width (the highest measurement recorded). ANOVA was conducted using GenStat to test for significant sources of variation attributed to thinning intensity, fertilizer application, sample height and the relevant interactions. The blocking structure for ANOVA was defined as replicates, plots within replicates and trees within plots (Williams *et al.*, 2002). Where significant sources of variation were found, least significant difference tests based on residual degrees of freedom and standard error of the difference between treatment means (Williams *et al.*, 2002) were conducted to test for significant differences.

2.3 Tree selection for processing trials

From the full length SilviScan traces, the mean data for the two cores and the percentage of core sample length with cellulose crystallite width ranges of < 3.3 nm, 3.3-3.5 nm and > 3.5 nm were determined for trees of suitable diameter for sawing (25-34 cm DBHOB). In total 35 trees were selected for harvest that represented the range in crystallite width. A stratification and accrual method was applied to ensure that trees with low and uniform crystallite width had the same diameter range as trees with greater crystallite width.

Examples of the ranges in crystallite width for the two cores for selected trees are given in Fig. 1. Fig. 1a shows low and relatively uniform crystallite width in both cores; Fig. 1b high and variable crystallite width in both cores; Fig. 1c a gradient from low to high crystallite width in both cores; Fig. 1d high crystallite width only in the core at 0.6 m; and Fig. 1e high crystallite width only in the core at 1.0 m.

Fig. 1d and Fig. 1e demonstrate the reason why a two-core sampling strategy was used to diagnose tension wood presence within stems. While many trees have consistent trends in both cores (e.g. Fig. 1a- Fig. 1c), several trees produce contrasting trends. While the location of the zone in which tension wood forms is predictable in straight vertical *E. globulus* (Washusen, 2002), tension wood at times forms sporadically and often a single core at 1.0 m or 0.6 m will miss isolated tension wood zones at or near breast height in a tree.

The selected trees were harvested in March 2004 when they were approximately 13 years old (5 years after thinning). From the harvested trees a single 3.0 m long log was taken from the lower stem. The logs were sawn to produce a 106 mm wide centre cant that was resawn to produce four to six 28 mm thick backsawn boards. The boards were numbered from 1 to 6 starting from the outer board on the southwest side of the cant and sequentially numbered across the cant. At the conclusion of sawing all boards were measured for spring and bow, wrapped in plastic and transported to CSIRO at Clayton for drying.

The boards were randomized and stacked for drying in a pilot scale kiln and reconditioned prior to board assessment. The schedule used dried the boards from green to 12% moisture content in 32 days. This is about one third of the time taken to dry *E. globulus* wood in recent industry trials conducted by Washusen

et al. (2004). At the conclusion of drying, the boards were measured for spring, cupping, surface checking, internal checking and unrecovered collapse. During this assessment, growth ring orientation was examined on the board ends and mid length and the boards were categorized as perfectly backsawn or partially quartersawn (mixed growth ring orientation).

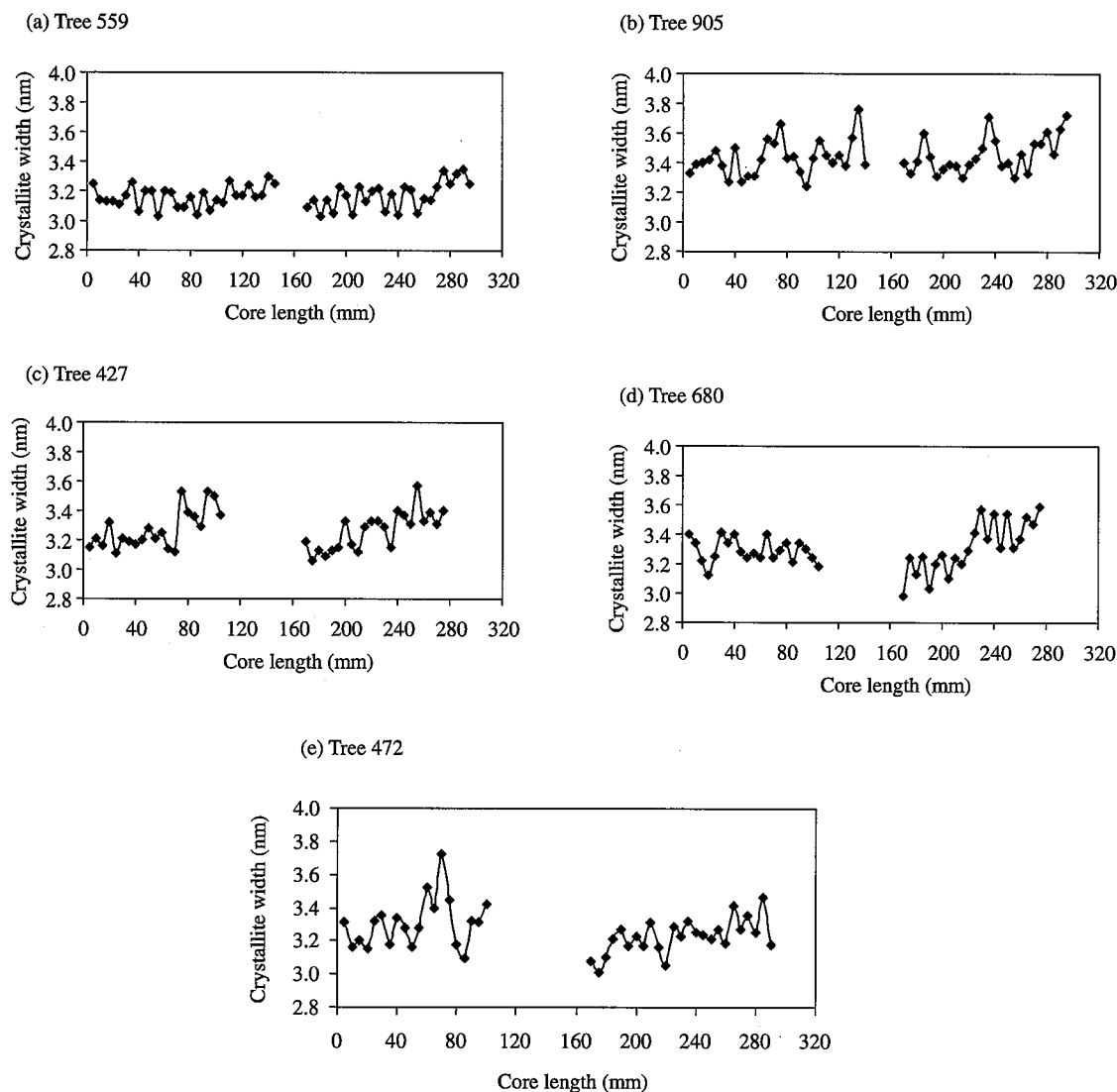


Fig. 1 Examples of cellulose crystallite width traces for the 2 cores (the left trace is for the 1.0 m core and the right trace for the 0.6 m core) taken from trees selected for processing

2.4 Statistical analysis and methods of comparison

Before analysis, boards were allocated into two groups: (i) backsawn (growth rings tangential to the wide face of the board) or; (ii) mixed orientation (growth rings at an oblique angle to the wide face in at least one location - i.e. either end or the centre of the board length).

Pearson and Spearman Correlations were calculated to determine significant correlations between mean and maximum cellulose crystallite width and board sawing and drying defects, taking into consideration growth ring orientation. ANOVA and Mann-Whiney U tests were also calculated for boards allocated into groups based on the cellulose crystallite width in the cores.

3 RESULTS AND DISCUSSION

3.1 Comparisons of crystallite width between silvicultural treatments

ANOVAs were calculated with cellulose crystallite width and the maximum cellulose crystallite width as dependant variables and spacing, fertilizer treatment, replicate \times plot and sampling height as categorical predictors. This analysis is reported in full in Washusen *et al.* (2005a).

There was no interaction between the thinning and fertilizer treatments and sample height. However, there were significant differences between the two sample heights for mean cellulose crystallite width and the maximum cellulose crystallite width, and the interactions between fertilizer and spacing were significant for cellulose crystallite width ($p < .05$) and maximum cellulose crystallite width ($p < .01$). The results can be best summarized by the means for fertilizer \times spacing for cellulose crystallite width and maximum cellulose crystallite width in Fig. 2.

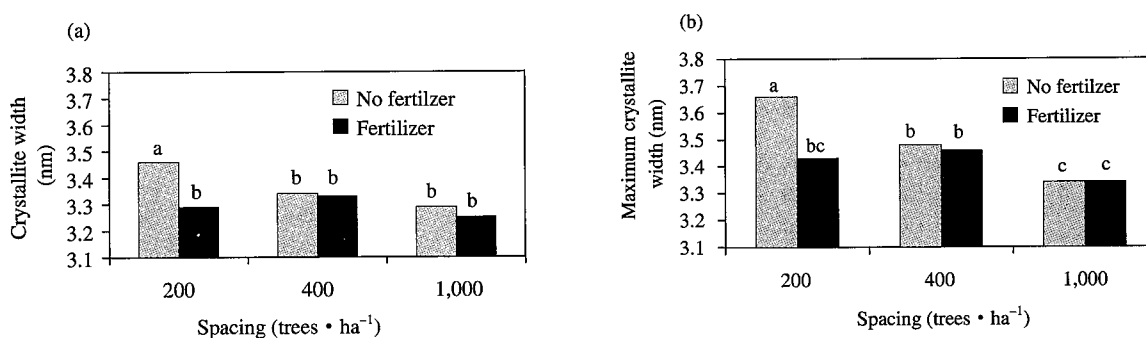


Fig. 2 Plots of mean cellulose crystallite width (Fig. 2a); maximum cellulose crystallite width (Fig. 2b) for the spacing and fertilizer treatments ('a' is significantly different to 'b', 'bc' and 'c'; 'b' is significantly different to 'c' at $p < .05$) (Washusen *et al.*, 2005a)

While there was a trend of increasing maximum crystallite width with thinning intensity the most important finding is the significant difference between the two 200 tree \cdot ha $^{-1}$ thinning treatments in both mean crystallite width and maximum crystallite width (Fig. 2b). Given that high crystallite width indicates tension wood, these results support the commonly held belief that thinning will contribute to the formation of tension wood possibly through greater exposure of individual retained trees to wind following thinning. Also given that there was a growth response to the fertilizer application (Baker *pers comm*), rapid growth may mitigate against tension wood formation where the thinning intensity is high because increased girth contributes to greater stability of the trees.

3.2 The implications of crystallite width for green processing characteristics

Mean and maximum cellulose crystallite width from the outer 4.5 growth rings in the two cores was used as the wood microstructure data in the analyses of green boards.

In green boards, Spearman and Pearson Correlations indicated that maximum crystallite width was significantly correlated with spring and bow for backsawn and mixed orientation boards as a single group, with similar correlations as separate groups. Bow represents only a minor defect because it can be minimised during drying in appropriately weighted drying stacks. However, spring is a much more serious defect. The

only method of eliminating spring is by ripping or moulding boards on a 'four-sider' following drying to the next smaller marketable size (in width) resulting in considerable loss of volume and reduced board length.

For subsequent analysis of variance the boards were grouped into three equal groups based on the maximum crystallite width from the two cores. The groups were <3.46 nm, 3.46-3.60 nm and >3.60 nm. The results are summarised in Fig. 3. Analysis of variance confirmed that spring was significantly less in boards grouped on crystallite width < 3.46 nm and the two other groups with a trend of increasing spring as maximum crystallite width increased.

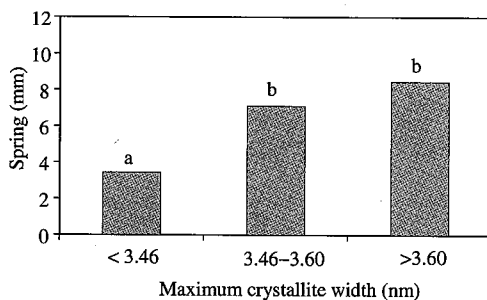


Fig. 3 Spring in 3.0 m long green back-sawn boards immediately after sawing
'a' is significantly different to 'b'

The results show that with crystallite width < 3.46 nm in the cores, board distortion could be reasonably contained. Even this magnitude of crystallite width may indicate that gelatinous fibres characteristic of tension wood (IAWA, 1964) may still be found in the wood (Washusen and Evans, 2001; Washusen *et al.*, 2005a), so it is likely that further reductions in crystallite width would see even greater improvements in processing performance.

3.3 The implications of crystallite width for dry board defects

The wood microstructure data used in these analyses was the same as for the green boards. However, only boards numbered 1 and 2 were used because the outer boards from the northeast side of the logs (opposite side of the log to where the cores were extracted) were eliminated as they were used to monitor drying and had been cut into three short lengths. Boards containing the pith were also discarded to eliminate drying degrade associated with the pith from the analysis.

The measured board data included spring, bow, cup, length of unrecovered collapse (undersizing), surface check severity and internal check area at the mid length of the boards. Spearman Correlations indicated that crystallite width was not significantly correlated with either surface or internal checking. The reason for this may be attributed to the relatively rapid drying schedule. However, there were significant correlations between maximum crystallite width and spring in all boards (positive), cupping in backsawn boards (positive) and undersizing in mixed orientation boards (positive). There were significant but weaker correlations with mean crystallite width.

The differences in drying defects between backsawn and mixed orientation boards are due to the orientation of the growth rings. The unrecovered collapse led to undersizing only in mixed orientation boards due to excessive tangential shrinkage in tension wood bands, which tended to be aligned across the thickness of the boards at an oblique angle to the board face. Where tension wood bands occurred in perfectly backsawn boards they were aligned with the growth rings and therefore approximately tangential to the board face (and back). This alignment can produce variation in tangential shrinkage between the face and

backs of boards resulting in excessive cupping during drying.

The correlations were recalculated after inclusion of all boards (other than those used to monitor drying) to examine relationships on a whole log basis. The results of the correlations on the whole board group generally indicated similar correlations. Given that the larger sample was heavily weighted to the boards closest to the pith this indicated that the core microstructure could give a good indication of potential board drying defects on a whole log basis.

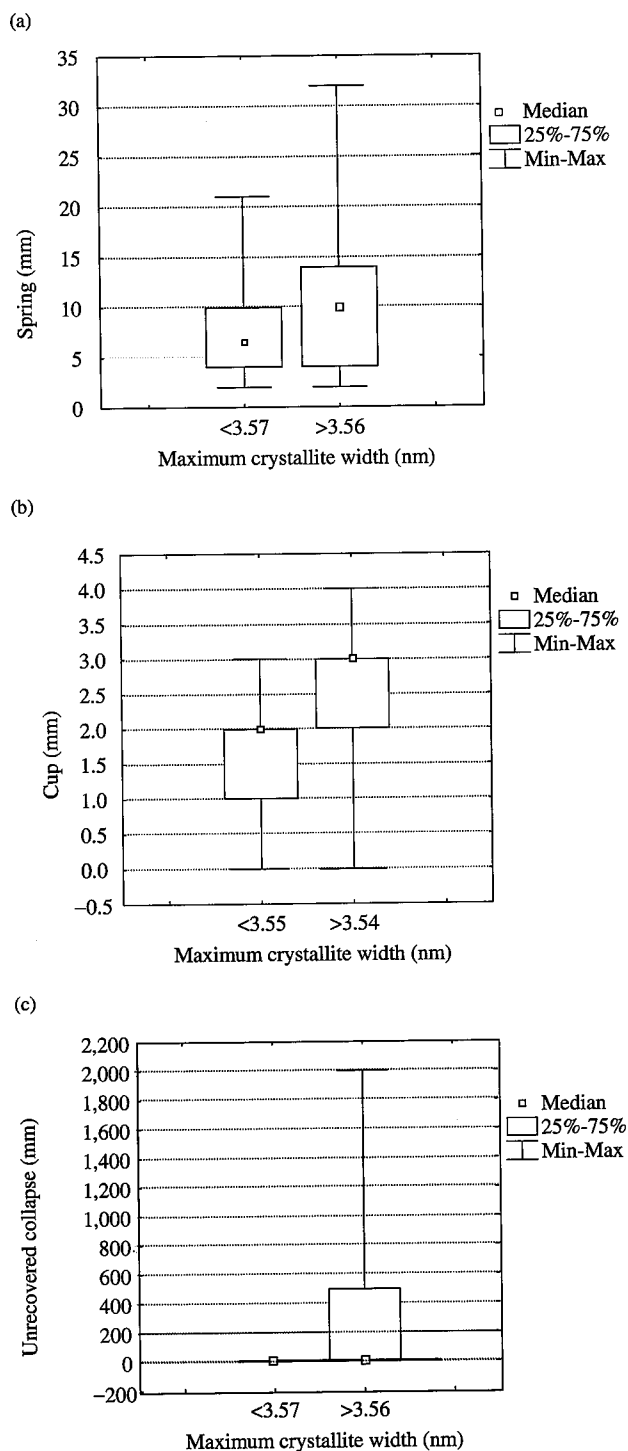


Fig. 4 Defects after drying in boards grouped on maximum crystallite width in cores

(a) Spring in back-sawn and mixed orientation boards; (b) Cupping in backsawn boards; (c) Unrecovered collapse in mixed orientation boards

The most important correlations for further analysis were maximum crystallite width and spring in all boards, cup in backsawn boards and undersizing in mixed orientation boards. The following analysis was conducted on boards in two groups using the median value of maximum crystallite width. ANOVA and Mann-Whitney U tests were applied where appropriate. Significant differences were found for spring and cupping and all boards with unrecovered collapse (undersizing) were found only in the high crystallite width group. The data are summarised in Fig. 4, which show the distribution of the data in each group. Notably there was some excessive spring and cupping in the low crystallite width groups. However, as discussed above, there is likely to be some tension wood in this group and a further reduction in crystallite width may see improvements in results.

3.4 Tension wood severity and the effectiveness of the two-core sampling strategy

In general, the results show that where either of the two core samples had a maximum crystallite width above 3.4-3.6 nm, boards exhibited a tendency to greater processing defect. Given that less severe tension wood is likely to be found below this magnitude and that severe tension wood may also be located elsewhere in the boards because of the sporadic nature of tension wood distribution, the results are encouraging. They indicate that crystallite width measurements in the two cores could give a good indication of processing performance in the butt log in this plantation. Where crystallite width is lower than reported here there may even be a further improvement in processing performance.

In addition, tension wood in straight vertical trees forms initially near the base of the stem and extending to about 30% tree height as severity worsens (Washusen, 2002), which suggests that processing performance would only improve further up the stem. Because of this the two-core strategy is effective at detecting trees where processing performance may deteriorate and sampling higher in the stem is not warranted.

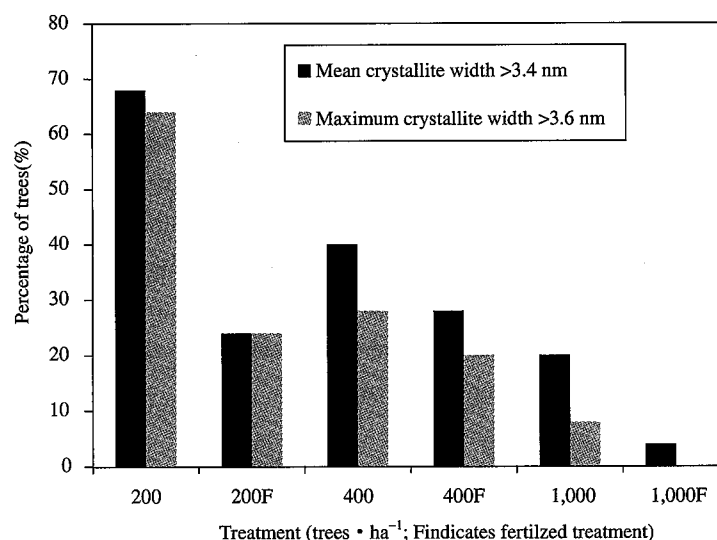


Fig. 5 Plot of the percentage of trees from each treatment with at least one core sample that had mean cellulose crystallite width >3.4 nm and maximum cellulose crystallite width >3.6 nm (adapted from Washusen *et al.*, 2005b)

The prevalence of tension wood with a severity that affected processing performance in this trial is shown in Fig. 5. This shows the percentage of trees in each treatment where mean crystallite width and maximum crystallite width in the outer 4.5 growth rings exceeded 3.4 nm and 3.6 nm respectively. In the

most adversely affected treatment almost 70% of trees had crystallite width of this magnitude declining to less than 5% in the unthinned/fertilized treatment. Clearly, if tension wood prevalence is to be reduced in plantations managed to produce large diameter sawlogs then further work is essential to refine thinning strategies. This further work needs to utilise the non-destructive sampling protocols used here. However, the analysis of sample height suggests that only one core is needed to assess differences between silvicultural treatments and either height is equally effective. The only time that a two-core strategy is needed is when attempts are made to select trees for processing.

4 CONCLUSIONS

The results indicate that heavy thinning of trees at age eight years can contribute to tension wood formation, however this can be mitigated where fertilizer is applied. This finding supports the commonly held belief that tension wood in straight vertical trees is formed as a response to increased destabilisation of the stand following thinning. However, increased tension wood formation only occurs in trees where there has been a poor growth response. Presumably this is because in fertilized stands where there has been a growth response, increased stem bulk overcomes internal bending stresses without the need for tension wood formation.

The implications for wood processing performance are an increase in board distortion off the saw and an increase in the development of drying defects during drying as crystallite width increase. A threshold level of about 3.4-3.6 nm is indicated, above which processing performance deteriorates. This level was common in the most heavily thinned unfertilized stands in the trial.

SilviScan technology and a modified sampling protocol (single core) can now be applied on a broad scale to develop optimum tending practices for *E. globulus* to produce high quality sawlogs, and has potential to be applied in other hardwoods given validation that crystallite width can be universally applied in eucalypts and validation of sampling protocols.

5 ACKNOWLEDGEMENTS

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REFERENCES

- Blaho J, Vozar M, Sindler J. 1994. Some properties of reaction wood and normal wood of beech (*Fagus sylvatica* L.). Zbornik Vedeckych Prac Drevarskej Fakulty Technickej Univerzity vo Zvolene, 297-306
- Hamilton J R, Thomas C K, Carvel K L. 1985. Tension wood formation following release of upland oak advance reproduction. Wood and Fiber Science, 17: 382-390
- Hanna R B. 1973. Cellulose Sub-elementary Fibrils. Ph.D. Thesis. New York: SUNY College of Environmental Science and Forestry, Syracuse
- Hanna R B, Cote W A. 1974. The sub-elementary fibril of plant cell wall cellulose. Cytobiologie 10(1): 102-116
- Hillis W E, Evans R, Washusen R. 2004. An Unusual Formation of Tension Wood in a Natural Forest *Acacia* sp. Holzforschung, 58(3): 241-245
- IAWA. 1964. Multilingual glossary of terms used in wood anatomy. Verlagsanstalt, Buchdruckerei, Konkordia, Winterthur, 185

- Kubler H. 1988. Silvicultural control of mechanical stresses in trees. *Canadian J of Forest Research*, 18(10): 1215-1225
- Washusen R K. 2000. The occurrence and characteristics of tension wood and associated wood properties in *Eucalyptus globulus* Labill. Ph.D. thesis. Department of Forestry, The University of Melbourne
- Washusen R. 2002. Tension wood occurrence in *Eucalyptus globulus* Labill. 2. Spatial distribution of tension wood in 10 trees and its relationship with tree form. *Australian Forestry*, 65(2): 127-134
- Washusen R, Evans R. 2001. The association between cellulose crystallite width and tension wood occurrence in *Eucalyptus globulus* Labill. *IAWA J*, 22(3): 235-243
- Washusen R, Reeves K, Hingston R, Davis S, Menz D, Morrow A. 2004. Processing pruned and un-pruned *Eucalyptus globulus* managed for sawlog production to produce high value products. Report PN03.1315. Melbourne, Australia: The Forest and Products Research and Development Corporation, 27
- Washusen R, Evans R, Southerton S. 2005a. A study of *Eucalyptus grandis* and *Eucalyptus globulus* branch wood microstructure. *IAWA Journal*, 26(2): 203-210
- Washusen R, Baker T, Menz D, Morrow A. 2005b. Effect of thinning and fertilizer on the cellulose crystallite width of *Eucalyptus globulus* *Wood Science and Technology* (accepted)
- Waugh G. 1972. Growth stresses in poplar. A preliminary study. Bachelor degree dissertation. University of Melbourne. 49
- Waugh G .2004. Growing *Eucalyptus globulus* for high-quality sawn products. *Eucalyptus in a changing world - international IUFRO Conference of the WP2.08.03 on Silviculture and Improvement of Eucalypts, Portugal*
- Williams E R, Matheson A C, Harwood C E. 2002. *Experimental Design and Analysis for Tree Improvement*, Second Edition. CSIRO

Growth Response to Thinning in a Productive *Eucalyptus globulus* Plantation in Victoria, Australia

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ABSTRACT

The production of high-value clear-wood sawlogs from *Eucalyptus* plantations requires early selection and pruning of the sawlog crop trees to produce knot-free wood and thinning to reduce competition and enhance growth rates. The trade-off in production of sawlogs and pulpwood was examined in two contrasting thinning treatments applied to a productive *E. globulus* plantation at Werribee, Victoria, Australia: Sawlog regime, Sawlog and Pulpwood regime. Higher density Pulpwood and Biomass regimes were used to measure potential site productivity. In the Sawlog and Sawlog and Pulpwood regimes, sawlog crop trees (220 trees · ha⁻¹) were selected and pruned to 6 m height at age 4 years. The plantation was irrigated with nutrient-rich wastewater during summer.

Mean annual increment at age 11 years was about 33 m³ · ha⁻¹ in the Biomass regime. Standing volume in the Sawlog and Sawlog and Pulpwood regimes at age 11 years was approximately 41% and 90% respectively that in the Biomass regime. There was no difference in volume of the sawlog crop trees between the Sawlog and Sawlog and Pulpwood regimes, indicating that the dominant trees were not subject to significantly more competition in the stand at a density of about 600-700 trees · ha⁻¹ than at about 220 trees · ha⁻¹. Following commercial thinning at age 11 years, growth of the sawlog trees in the Sawlog and Sawlog and Pulpwood regimes was similar. The results suggest that at least where water and nutrient supply are relatively abundant, *E. globulus* can be managed under a commercial thinning regime (in this study yielding over 100 m³ · ha⁻¹ pulpwood at age 11 years) without significantly compromising the growth of the sawlog crop trees.

1 INTRODUCTION

A decline in the availability of sawlogs from native forests and a rapid increase in the area of eucalypt plantations during the last decade (Ferguson *et al.*, 2003) has prompted an interest in the silviculture of eucalypt plantations grown for high value timber production (Gerrand *et al.*, 1997; Medhurst *et al.*, 2001; Pinkard *et al.*, 2004). The necessity to plant at high densities to allow for the selection of well formed sawlog crop trees, pruning of these to produce knot-free timber, and the financial requirement to shorten rotation lengths means that thinning is a necessary component of sawlog production regimes (Nolan *et al.*, 2005).

Early thinning to a final density of about 200 or 300 trees · ha⁻¹ from around 1,000 to 1,500 trees · ha⁻¹ can maximise growth of the sawlog crop trees but can also significantly reduce total stand production (Medhurst *et*

al., 2001). Later thinning can result in a commercial yield of pulpwood to increase the financial return (Gerrand *et al.*, 1993; Candy and Gerrand, 1997). However, the pulpwood crop trees can compete with, and reduce the growth of the sawlog crop trees. Therefore there is a trade off between maximising the growth of the sawlog crop trees and obtaining an early financial return from a pulpwood crop. Several thinning regimes have been examined, for a range of eucalypt species, that involve a single early thinning, a single later age thinning, or multiple thinnings (Schönau and Coetzee, 1989; Gerrand *et al.*, 1997; Medhurst *et al.*, 2001; Ronggui *et al.*, 2003), and the growth responses have been found to vary with site quality, tree age, thinning intensity and species. Optimising the trade off between pulpwood and sawlog production requires long term growth data for a range of these factors. This study examines the growth response to alternative silvicultural regimes applied in a productive *Eucalyptus globulus* plantation at Werribee, Victoria, Australia.

2 MATERIALS AND METHODS

2.1 Site characteristics

The trial was established on irrigated farmland at Werribee (37°54'S, 144°40'E) 35 km south west of Melbourne, Victoria, Australia. Werribee receives an average annual rainfall of 520 mm, with a slight spring maximum, and has a mean annual pan evaporation of 1,350 mm with a maximum in January. Mean daily minimum and maximum temperatures are 13 and 25°C respectively in January and 5 and 13°C respectively in July. Prior to trial establishment, the site was improved pasture. The soil, formed from Quaternary basalt, has a brown light clay surface soil over a red-brown clay subsoil and yellow-grey calcareous clay (Red Duplex Soil; Northcote, 1971). On average the plantation was flood irrigated seven times each year between October and April with nutrient-rich municipal wastewater (electrical conductivity of 2 dS · m⁻¹) totalling about 700 mm · yr⁻¹.

2.2 Experimental design

Eucalyptus globulus was planted in March 1990 to provide comparisons of four silvicultural treatment regimes, commencing with a range of initial stockings (Benyon and Stewart, 1993). The treatments subsequently implemented were:

Sawlog regime: stocking 1,330 trees · ha⁻¹, non-commercially thinned to 220 trees · ha⁻¹ at age four years

Sawlog and Pulpwood regime: stocking 1,330 trees · ha⁻¹; non-commercially thinned to 670 trees · ha⁻¹ at age four years, commercially thinned to 220 trees · ha⁻¹ at age 11 years

Pulpwood regime: stocking 2,500 trees · ha⁻¹, unthinned

Biomass regime: stocking 4,440 trees · ha⁻¹, non-commercially thinned to 2,220 trees · ha⁻¹ at age four years.

The treatments were established in 0.32 ha plots with three replicates in a randomised block design. Within the Sawlog and Sawlog and Pulpwood regimes, 220 sawlog crop trees · ha⁻¹ were selected (using stem straightness, diameter, and spacing criteria) and pruned to 6-7 m height at age four years. For comparative purposes, equivalent sets of trees were selected in the Pulpwood and Biomass regimes. Following selection of the sawlog crop trees (or equivalent) the additional trees to be retained at thinning were selected primarily on the basis of diameter. That is, thinning was from below. In this paper, the Pulpwood and Biomass regimes are primarily used for growth comparisons with the sawlog regimes, rather than representing current practicable silvicultural regimes.

2.3 Growth measurements

Tree survival, height (H; m), and diameter over bark at 1.3 m (D; cm) were measured to age 15 years (Sawlog and Sawlog and Pulpwood regimes) or 11 years (Pulpwood and Biomass regimes). Individual tree volume, underbark to a small-end diameter of 2 cm (V; m³), was estimated using a model developed for *E. globulus* by Wong *et al.* (1999):

$$V = 2.8737 \times 10^{-5} D^2 H + 4.0837 \times 10^{-4} D \text{ (Adj. } R^2 = 0.997)$$

Stand density, dominant height (mean height of the 100 largest diameter trees · ha⁻¹), basal area and volume were calculated from individual tree measurements. Basal area, volume and mean diameter were also calculated for the largest diameter 200 trees · ha⁻¹ of the selected sawlog (or equivalent) crop trees.

Between ages 11 and 15 years, windthrow occurred in the Sawlog and Pulpwood and Biomass regimes (trees in the Sawlog regime were relatively stable; the Pulpwood regime had been clearfelled at age 11 years). Stand growth data presented here for age 15 years includes the windthrow component (see later). To assess crown sizes and epicormic growth (which had resulted from thinning at age 11 years), height to the green crown and the length of the stem with epicormic branches were also measured at age 15 years.

2.4 Statistical analysis

Differences between silvicultural regimes were tested using an Analysis of Variance (ANOVA) or Residual Maximum Likelihood analysis (REML) in Genstat™ (VSN International Ltd., Hemel Hemstead, U.K.). REML was used for some analyses where it was necessary to exclude data from one plot (Pulpwood regime in Replicate 2) because of poor survival. Treatment effects in the REML analysis were assessed by Wald statistics, which are distributed as Chi squared. The Standard Errors of Difference (S.E.D) for comparison of treatment means are provided.

3 RESULTS

3.1 Initial spacing and early thinning responses - growth to 11 years of age

Prior to any thinning, total stand basal area and volume to age four years increased with stand density (Fig. 1a, Fig. 1c and Fig. 1e), with some of the increase in volume attributable to greater height growth in the higher density Pulpwood and Biomass regimes (Fig. 1b). However there was no significant stand density effect on basal area (and therefore average tree diameter) or volume of the sawlog crop trees (Fig. 1d and Fig. 1f). The non-commercial thinning at age four years accentuated the differences in stand density (Fig. 1a) and hence stand basal area and volume increments. By age eight years, four years after thinning, diameters, basal areas and volumes of the sawlog crop trees were significantly greater in the two sawlog regimes than in the Pulpwood or Biomass regimes (Fig. 1d, Fig. 1f and Fig. 2). These differences were then maintained, or increased, with time.

By age eight years, dominant height was significantly less in the Sawlog regime (density between 200-250 trees · ha⁻¹) than the other regimes (670 to 2,220 trees · ha⁻¹), between which, differences in height were insignificant (Fig. 1b).

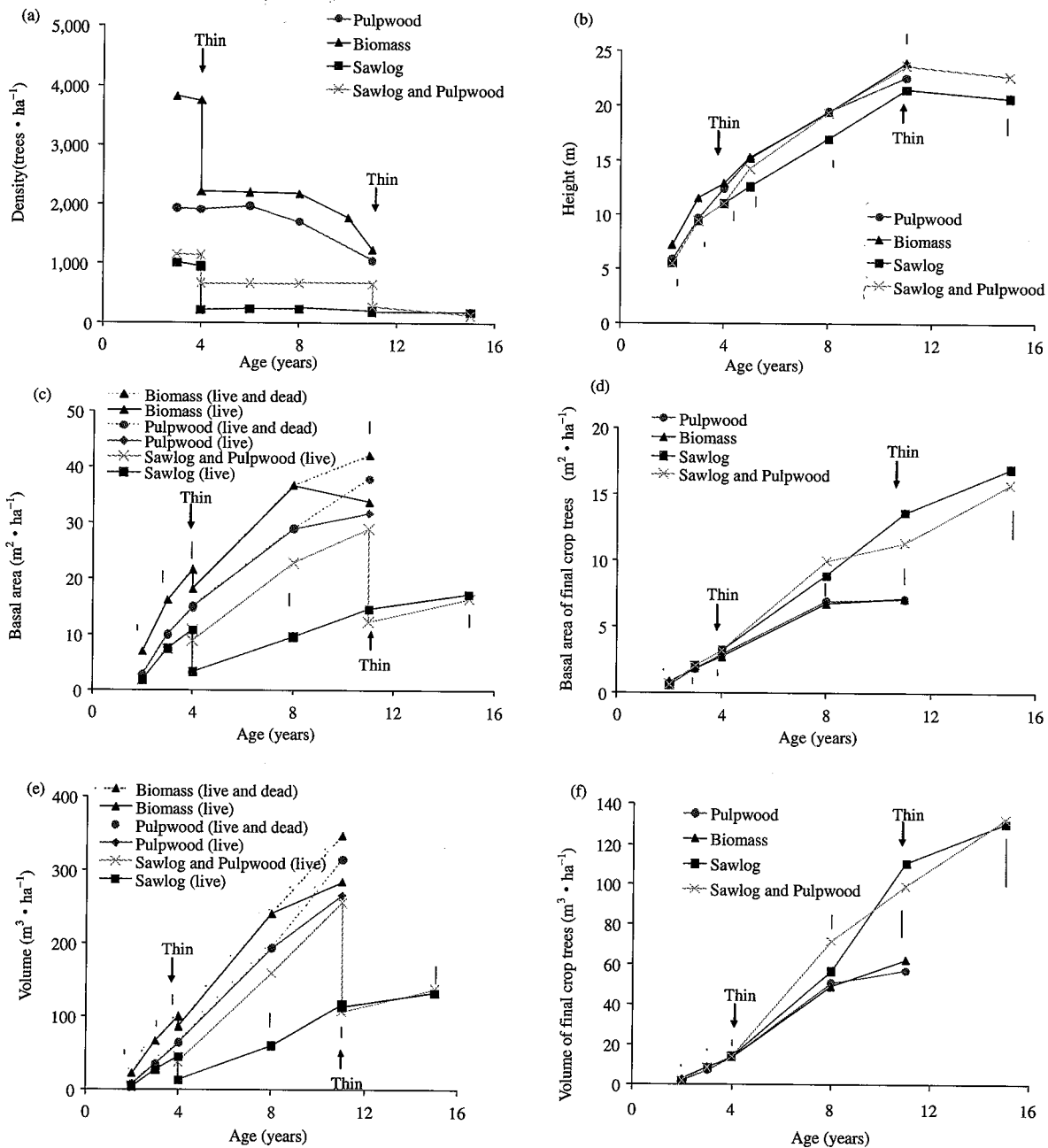


Fig. 1 Stand growth parameters for the four silvicultural regimes: tree density (a), dominant height (b), total basal area (including live and dead trees in Biomass and Pulpwood regimes at age 15 years) (c), basal area of sawlog crop trees (d), total stand volume (including live and dead trees in Biomass and Pulpwood regimes) (e), and volume of sawlog crop trees (f). Bars are Standard Errors of Difference between means

Mortality was generally low (less than 20% in all regimes) until about age eight years (Fig. 1a). Between ages eight and 11 years mortality in the Pulpwood and Biomass regimes (1,800 and 2,300 trees \cdot ha $^{-1}$ at eight years) increased sharply to about 50%. This significant mortality occurred at stand basal areas of 30-35 m 2 \cdot ha $^{-1}$ and about 16% and 20% of the total basal area growth in the Pulpwood and the Biomass regimes was dead at age 11 years (Fig. 1c and Fig. 1e).

Tree diameter (a surrogate for dominance ranking within regimes) was significantly correlated with increment. Volume increment was greatest for the largest 200 trees \cdot ha $^{-1}$ and declined with each diameter

class (Fig. 3). The volume increments of smallest trees (400-600 trees · ha⁻¹) were not significantly different across all regimes. The size of the response was also influenced by the regime. In the Sawlog and the Sawlog and Pulpwood regimes the largest 200 trees · ha⁻¹ grew about 14 m³ · ha⁻¹ · yr⁻¹ between ages four and 11 years, while those in the Pulpwood or Biomass regimes grew about 9 m³ · ha⁻¹ · yr⁻¹. Trees that died were generally the suppressed trees from the smaller diameter classes (Fig. 4).

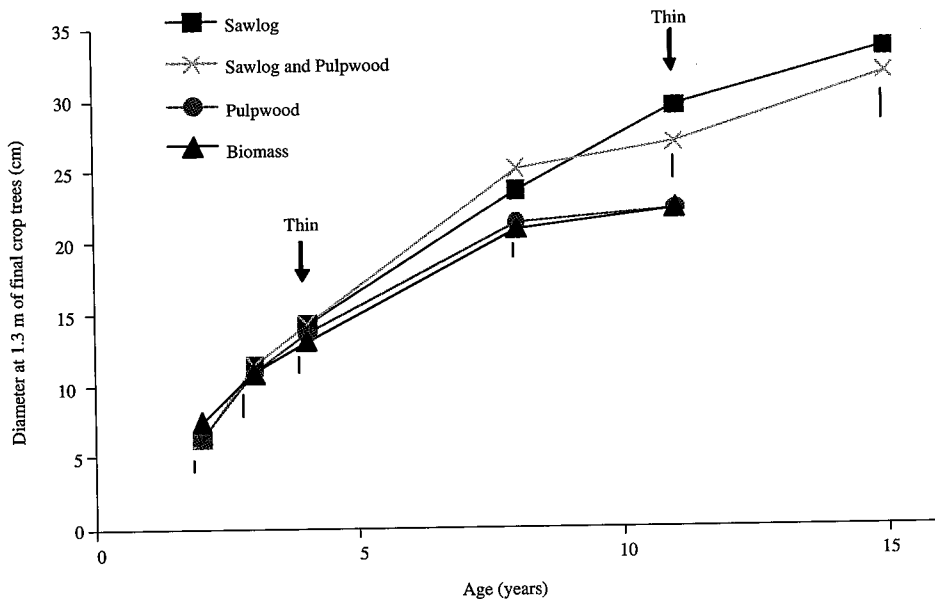


Fig. 2 Mean diameters of the sawlog crop trees in the four silvicultural regimes to age 15 years
Bars are standard errors of difference between means

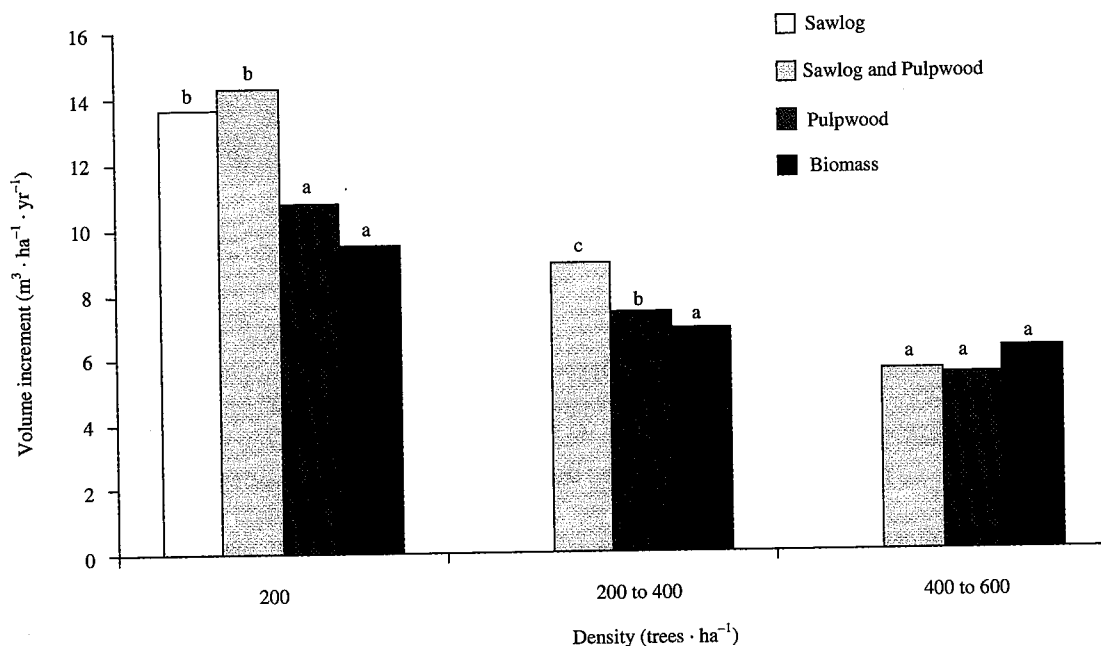


Fig. 3 Periodic annual volume increments (age 4 to 11 years) of groups of trees (largest diameter 200, 200-400 and 400-600 trees · ha⁻¹) in each silvicultural regime. Values for a given diameter class sharing the same letter are not significantly different ($P < 0.05$)

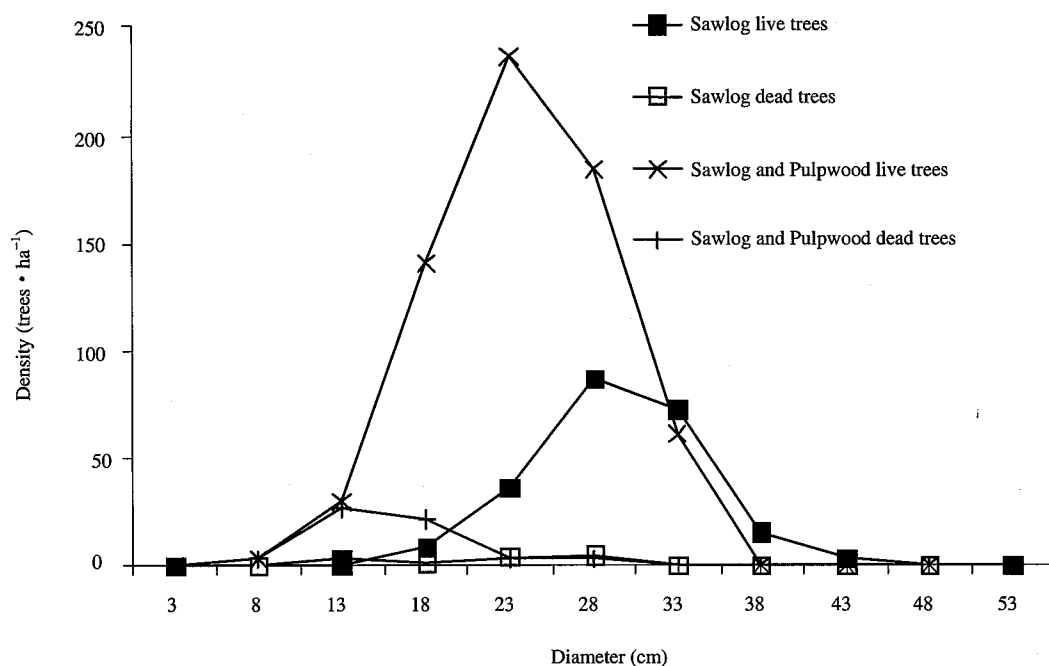


Fig. 4 Diameter distributions of live and dead trees in the Sawlog and the Sawlog and Pulpwood regimes at age 11 years

3.2 Later age thinning responses - growth to 15 years of age

About 8% and 21% of total stand basal area was windthrown in the Sawlog and the Sawlog and Pulpwood regimes respectively between ages 11 and 15 years. Windthrow affected trees from all diameter classes, and consequently contributed to the apparent decline in dominant height over this period (Fig. 1b). Basal area, volume growth and mean diameter of the sawlog crop trees continued to be similar (Fig. 1d, Fig. 1f and Fig. 2).

At age 15 years, green crown heights of the sawlog crop trees were about 7 m and 12 m in the Sawlog and the Sawlog & Pulpwood regimes respectively (Tab. 1). The green crown height in the Sawlog regime resulted from pruning to about 6 to 7 m at age 4 years and there has been negligible subsequent rise in the green crown height. While pruning also occurred in the Sawlog and Pulpwood regime, the green crown rose significantly between ages 4 and 11 years because of the higher stand density. The relatively intense thinning that more than halved basal area at 11 years in the Sawlog and Pulpwood regime resulted in vigorous epicormic

Tab. 1 Mean tree heights, green crown heights and epicormic growth for the sawlog crop trees

| Items | Sawlog and Pulplog | Sawlog | S.E.D. |
|--|--------------------|--------|--------|
| Tree height (m) | 22.5a | 20.4a | 1.28 |
| Height to green crown (m) | 11.8b | 7.3a | 0.45 |
| Length of tree stem with epicormic branches (m) | 7.2b | 0.7a | 0.58 |
| Length of pruned bole (lower 6 m) with epicormic branches (m) | 2.2b | 0.6a | 0.37 |
| Percent of tree stem with epicormic branches | 32.2b | 3.5a | 3.19 |
| Percent of length of pruned bole (lower 6 m) with epicormic branches | 37.3b | 10.3a | 6.24 |

S.E.D. Note: standard error of difference between means. Values in the same row sharing the same letter are not significantly different ($P < 0.05$).

growth on the sawlog crop trees. At least 32% of the total tree height contained epicormic branches, and at least 37% of the lower 6 m of the tree stems (the pruned section of the tree) also had epicormic branches. In contrast, in the Sawlog treatment only about 10% of the lower 6 m of the tree stems in the sawlog treatment contained epicormic branches, which had grown since earlier thinning at age 4 years.

4 DISCUSSION

The potential total productivity of the Werribee site (as measured by the growth of the Biomass regime) was $25 \text{ m}^3 \cdot \text{ha}^{-1} \cdot \text{yr}^{-1}$ at age 4 yrs, and about $33 \text{ m}^3 \cdot \text{ha}^{-1} \cdot \text{yr}^{-1}$ (allowing for early thinning and mortality) at age 11 years. The productivity is similar to that reported in other irrigated *E. globulus* studies in southern Australia (for example $25\text{-}30 \text{ m}^3 \cdot \text{ha}^{-1} \cdot \text{yr}^{-1}$ at age 11 years at Shepparton, Victoria; Baker *et al.*, 2005), and at sites receiving high rainfalls (Duncan *et al.*, 2000). Basal areas and volumes of the sawlog crop trees were the same in both the Sawlog and the Sawlog and Pulpwood regimes despite growing at different densities (220 and 670 trees $\cdot \text{ha}^{-1}$ respectively) following early thinning at age 4 years. Thus, it was possible to grow an additional 450 pulpwood trees $\cdot \text{ha}^{-1}$ in the Sawlog and Pulpwood regime, yielding $140 \text{ m}^3 \cdot \text{ha}^{-1}$ at age 11 years, without significantly reducing the growth rates of the 200 sawlog crop trees per ha (when compared to the Sawlog regime). After commercial thinning, basal areas and volumes were similar in the two sawlog regimes, and the subsequent growth of the sawlog crop trees was similar. That early thinning to only 670 trees $\cdot \text{ha}^{-1}$ did not compromise the growth of the pruned sawlog crop trees at Werribee contrasts with results from other studies in eucalypt plantations where thinning responses occurred below 600 trees $\cdot \text{ha}^{-1}$ (Medhurst *et al.*, 2001). For example, thinning from between 1,000 and 1,500 trees $\cdot \text{ha}^{-1}$ to between 100 and 400 trees $\cdot \text{ha}^{-1}$ at age six to nine years increased the growth of the largest 100 to 250 stems $\cdot \text{ha}^{-1}$ in three *E. nitens* plantations in Tasmania. Medhurst *et al.* (2001) found significant differences between the largest 200 trees $\cdot \text{ha}^{-1}$ in treatments thinned to 100 or 200 and 300 stems $\cdot \text{ha}^{-1}$. The lack of a growth response in our study (age 4 years when thinned, about one year after canopy closure) suggests that the trees had enough space to grow at densities of 670 trees $\cdot \text{ha}^{-1}$ let alone 222 trees $\cdot \text{ha}^{-1}$.

Retaining stand densities of about 670 trees $\cdot \text{ha}^{-1}$ until age 11 years resulted in trees with shorter (and narrower) live crowns than those in the Sawlog regime (200 trees $\cdot \text{ha}^{-1}$). The increased light availability after the later thinning in the Sawlog and Pulpwood regime resulted in epicormic branches rather than the expansion of existing canopies. While there was no significant impact on volume growth trajectory, the pruned sections of the boles in the Sawlog and Pulpwood regime could no longer produce clear wood without pruning the epicormics. The potential of *Eucalyptus* spp. to produce epicormic branches after thinning has been noted previously (Schönau and Coetzee, 1989; Montagu *et al.*, 2003). Generally on sites where trees have developed small crowns it may be wise to apply multiple light thinnings to reduce the likelihood of epicormic branching (Kerruish, 1978; Schönau and Coetzee, 1989) and windthrow.

The windthrow at Werribee is likely to have resulted from the combined effects of thinning, soil factors and irrigation. Wind damage has been observed in other eucalypt stands following intense thinning (from 100 to 1,000 trees $\cdot \text{ha}^{-1}$) (Medhurst *et al.*, 2001). Consequently, operational prescriptions for *E. nitens* in Tasmania require that commercial thinning be undertaken before the stand reaches a mean dominant height of 20 m (Forestry Tasmania, 1998). The commercial thinning at Werribee was undertaken at a dominant height of about 24 m. The irrigation may have resulted in shallow root systems and hence exacerbated the wind damage. Nevertheless, the irrigation facilitated high growth rates compared to those that might be expected on a site with an annual rainfall of only 520 mm (perhaps less than $10 \text{ m}^3 \cdot \text{ha}^{-1} \cdot \text{yr}^{-1}$; Duncan *et al.*, 2000).

This study has shown that silvicultural management of density as in the Sawlog and Pulpwood regime can provide for a pulpwood thinning and thus an additional source of income to that for sawlogs, without reducing the growth of the retained sawlog crop trees. However, it is important to consider the stability of the stand following thinning, and whether the canopies of the retained trees are large enough to respond to the increased light conditions without developing epicormic branches. To minimise these risks, commercial thinning should be done as soon as financially possible. On sites where trees have developed small crowns it may be wise to apply multiple light thinnings to reduce the likelihood of epicormic branching and wind damage. The contrasting results of this study compared to others show the importance of obtaining long term growth data from a range of sites, species and regimes that vary in the intensity and age of thinning. Furthermore, an understanding of the processes that lead to these growth outcomes could aid the development of models to explain and predict the responses and hence assist with the final economic decisions regarding regimes.

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REFERENCES

- Baker T, Duncan M, Stackpole D. 2005. Growth and silvicultural management of irrigated plantations. In: Nambiar S, Ferguson I. (Eds.) *New Forests: Wood Production and Environmental Services*. CSIRO Publishing, Melbourne, 105-126
- Benyon R, Stewart H. 1993. Sewage irrigated eucalypt plantations at Werribee, Victoria. Melbourne Water, Department of Conservation and Natural Resources Melbourne
- Candy S G, Gerrand A M. 1997. Comparison of financial returns from sawlog regimes for *Eucalyptus nitens* plantations in Tasmania. *Tasforests*, 9, 35-50
- Duncan M J, Baker T G, Appleton R, Stokes R C. 2000. Growth of eucalypt plantation species across twelve sites in Gippsland, Victoria. Report No 99/056, Centre for Forest Tree Technology, Department of Natural Resources and Environment Melbourne
- Ferguson I, Spencer R, Wood M, Fox J, Baker T, Stackpole D, Wild I. 2003. The potential availability of plantation roundwood. *Australian Forestry*, 66, 30-36
- Gerrand A M, Prydon R, Fenn G. 1993. A financial evaluation of eucalypt plantations in Tasmania. *Tasforests*, 5, 77-97
- Gerrand A M, Neilsen W A, Medhurst J L. 1997. Thinning and pruning eucalypt plantations for sawlog production in Tasmania. *Tasforests*, 9, 15-34
- Kerruish C M. 1978. Harvesting. In: Hillis W E, Brown A G. (Eds.), *Eucalypts for Wood Production*. CSIRO, Melbourne, 229-255
- Medhurst J L, Beadle C L, Neilsen W A. 2001. Early-age and later-age thinning affects growth, dominance, and intraspecific competition in *Eucalyptus nitens* plantations. *Canadian Journal of Forest Research*, 31, 187-197
- Montagu K D, Kearney D E, Smith R G B. 2003. The biology and silviculture of pruning planted eucalypts for clear wood production - a review. *Forest Ecology and Management*, 179, 1-13
- Nolan G, Greaves B, Washusen R, Parsons M, Jennings S. 2005. Eucalypt plantations for solid wood products in Australia - A review. Project No. PN04.3002. Melbourne: Forest and Wood Products Research and Development Corporation
- Northcote K H. 1971. A factual key for the recognition of Australian soils. Glenside: Rellim Technical Publications
- Pinkard E A, Mohammed C, Beadle C L, Hall M F, Worledge D, Mollon A. 2004. Growth responses, physiology and decay associated with pruning plantation-grown *Eucalyptus globulus* Labill. and *E. nitens* (Deane and Maiden) Maiden. *Forest Ecology and Management*, 200, 263-277
- Zhang R, Baker T, Neilsen W. 2003. Growth responses to thinning in young eucalyptus plantations in China and Australia. *Eucalypts in Asia*, ACIAR Proceedings No. 111, Zhanjiang, Guangdong, China. Australian Centre for International Agricultural Research, Canberra. 169-173
- Schönau A P G, Coetzee J. 1989. Initial spacing, stand density and thinning in eucalypt plantations. *Forest Ecology and Management*, 29, 245-266
- Forestry Tasmania. 1998. Prescriptions for pruning and thinning eucalypts in plantations for clearwood production. Division of Forest Research and Development, Forestry Tasmania, Hobart
- Wong J, Baker T G, Duncan M J, Stackpole D J, Stokes R C. 1999. Individual Tree Volume Functions for Plantation Eucalypts. Report No 99/037. Centre for Forest Tree Technology, Department of Natural Resources and Environment, Melbourne.

Tolerance of Eucalyptus Trees to the Action of Storms and Their Relationships with Wood Properties

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ABSTRACT

Summer storms have caused serious damage in *Eucalyptus* plantations at several regions in Brazil. The pattern of damage varies from a light bending of stems through to the tree breaking. At the Vale do Rio Doce region, Minas Gerais State, it appears that the tolerance of the trees to the storms depends on both the genetic material and the environment where they grow. It has also been reported that damage mostly occur when the trees are twenty-four-months-old. Thus, the objective of this work was to report the results of research on wood of *Eucalyptus* clones. Non-destructive and destructive assessments were carried out in the trees and wood. Up to this stage of the studies it has been found that trees cultivated on flat land are less tolerant to storms. These trees normally produce wood with higher values of fibre length, width, lumen diameter and wall thickness; small microfibril angles, small values of mechanical properties and low growth stresses. Analyses of regression revealed that the tolerance of clones to storms was better estimated by fibre width and by growth stresses.

1 INTRODUCTION

In the region of Vale do Rio Doce, Minas Gerais State, reports exist on the occurrence of storms causing damage such as uprooting, permanent bending and breaking in *Eucalyptus* clones trees, jeopardizing in different forms their development. Aspects and types of damage on the trees can be observed in Fig. 1. This phenomenon is caused by severe gusts of wind, which are characterized by descendent flow of air, which can be devastating. In this region, the damage registered represented losses of 55 ha in 1991, 62 ha in 1992, 224 ha in 1996, 144 ha in 1997, 125 ha in 1998, 40 ha in 1999, 300 ha in 2000 and 700 ha in 2001. Also, there are records of damage caused by storms in *Eucalyptus* plantations in several other regions in Brazil: Western and Northern areas of Minas Gerais State, Southern parts of Bahia State, Espírito Santo State and Western areas of São Paulo State, in addition to the already mentioned Rio Doce valley.

According to local observation and records, these storms occur during the summer, mainly November, December and January, acting on the trees when they are around 24-months-old. At this age, the trees average a total height around 16 metres height and 11 cm DBH. When they break, the rupture occurs around five meters of height in the stem.

Also, it has been observed that: (i) considering the same age and site, there are differences in the tolerance of different *Eucalyptus* clones to the action of the storms; (ii) the same clone is more tolerant to the storms, when planted on sloping land rather than on flat land. However, there were no studies on the causes

of these differences to support future choices of new genetic material to be planted.



Fig. 1 Aspects of the *Eucalyptus* plantation after a storm

It is known that factors such as slope of the land and climatological winds can influence the development of the tree and the woody tissue, causing the formation of reaction wood and thus promoting development of growth stresses in the stem.

The objective of this work was to evaluate the wood characteristics of four two-year-old *Eucalyptus* clones cultivated on two different topographies, to contribute to the explanation of the damage to the clones under the action of storms.

2 MATERIAL AND METHODS

2.1 Genetic Material

Four 24-months-old *Eucalyptus* clones (57, 68, 111 and 1213), planted on flat and sloping sites, were utilized in this work. The tree spacing was 3.00 m × 3.33 m. The total height and the average DBH of the trees are presented in Tab. 1.

Tab. 1 Average total height and diameter at breast height (DBH) of the *Eucalyptus* planted in flat and sloped land

| Clone | Topography | Total height | DBH |
|-------|------------|--------------|-------|
| 57 | Flat | 16.19 | 11.60 |
| 57 | Sloped | 16.91 | 11.05 |
| 68 | Flat | 17.10 | 12.57 |
| 68 | Sloped | 15.56 | 10.13 |
| 111 | Flat | 17.10 | 11.44 |
| 111 | Sloped | 15.01 | 9.94 |
| 1213 | Flat | 16.36 | 11.53 |
| 1213 | Sloped | 17.33 | 9.95 |

Four trees per clone on both flat and sloping sites were sampled. The trees were randomized amongst

erect, sound, without bifurcation and non-boundary trees. The DBHs were then measured. In the sampled trees the longitudinal residual strain (LRS) associated to the growth stresses were measured, using the Nicholson method modified by the Cirad Forêt (Lima *et al.*, 2004). The product of LRS by the modulus of elasticity in static bending gave an indication of the growth stress. After felling the trees, the total heights were measured. From each tree, the basal ten metre log was removed. The sampling for studies on the wood characteristics was carried out on core samples cut at each meter. Samples for fibre morphology measurement were prepared according to method used by Lima (1999); basic density was determined according to ASTM-D2395 (1997), using immersion in water. Mechanical properties determination followed the British Standard 373 (1957). From the second core sample representing the portion of the stem between 1.0 and 2.0 m, samples for microfibril angle determination were collected (Lima *et al.*, 2004).

2.2 Place of the experiment installation

The experiment was set in the forest farm of the Celulose Nipo-Brasileira S.A. - CENIBRA, in flat and sloping land at Rio Doce Valley region, Minas Gerais State, near to Belo Oriente City. The altitude of the sites varies from 230 m to 500 m, the latitude is 19°17'S and the longitude is 42°23'W. The climate, according to the classification by Köppen is Aw (tropical rainy of savanna) with annual average precipitation of 1,205 mm. The average temperature is around 25°, while the annual average relative humidity is 67.3%.

The flat lands are areas of alluvial soils, which occur along the bases of the valleys near streams and rivers. They represent those soils of colluvial-alluvial origin. These sites generally have a slope smaller than 4%. In the sloping areas the soils are predominantly latossol or cambissol with an inclination over 10%.

2.3 Tolerance of the clones to the storms

In this study the velocity of the wind was not determined. For the estimation of the level of tolerance of the trees to the storms, five technicians of Cenibra S.A., independently conferred grades from 50 to 100 to their performances, where 50 corresponds to the highest tolerance and 100 the lowest. The result of this evaluation is shown in Tab. 2. While Clone 129 listed in this Table was not included in this study, its behaviour to storm action is well known and served as a reference for high tolerance.

Tab. 2 Evaluation of the tolerance of the *Eucalyptus* clones, planted on flat land and on sloping land, to the action of storms

| Clone | topography | Technician Number Grades of tolerance | | | | | Average |
|-------|------------|---------------------------------------|----|-----|----|----|---------|
| | | 1 | 2 | 3 | 4 | 5 | |
| 129 | Sloped | 98 | 90 | 100 | 95 | 90 | 95 |
| 129 | Flat | 96 | 90 | 90 | 90 | 80 | 89 |
| 1213 | Sloped | 80 | 70 | 90 | 85 | 70 | 79 |
| 1213 | Flat | 75 | 80 | 80 | 80 | 60 | 75 |
| 111 | Sloped | 80 | 90 | 90 | 95 | 70 | 85 |
| 111 | Flat | 73 | 80 | 90 | 90 | 60 | 79 |
| 57 | Sloped | 68 | 60 | 80 | 70 | 70 | 70 |
| 57 | Flat | 60 | 70 | 60 | 65 | 60 | 63 |
| 68 | Sloped | 60 | 60 | 60 | 55 | 50 | 57 |
| 68 | Flat | 50 | 50 | 50 | 50 | 50 | 50 |

2.4 Analysis of regression

An analysis of regression was executed to verify the influence of the dimensions of the fibres, microfibril angles, basic density and mechanical properties and growth stresses of wood of *Eucalyptus* clones on the tolerance of the trees to the storms. This analysis was executed using MINITAB, version 11.11, Minitab Inc. Minitab for Windows (1996).

3 RESULTS AND DISCUSSION

3.1 Fibre morphology

Tab. 3 shows the fibre dimensions of the *Eucalyptus* wood per clone and topography. The fibre dimensions found in this work were similar to those found by various authors (Tomazello Filho, 1985; Lima, 1999; Silva, 2002; Mori, 2003), however, none of them examined wood from *Eucalyptus* as young as two year-old. Comparing the results found here with those obtained by Lima (1999) in the inner region of the log (formed when the tree was young) the values of the fibre dimensions are more similar. Only the fibre dimensions found by Silva (2002) were clearly larger than those found in this work.

Tab. 3 Fibre length (FL, mm), fibre width (FW, μm), lumen diameter (LD, μm), fibre wall thickness (FT, μm) of wood *Eucalyptus* clones planted on flat (F) and sloped land (S), accompanied by the average (Av)

| Clone | FL | | | FW | | | LD | | | FT | | |
|---------|------|------|------|-------|-------|-------|------|-------|-------|------|------|------|
| | F | S | Av | F | S | Av | F | S | Av | F | S | Av |
| 57 | 0.99 | 1.00 | 1.00 | 16.22 | 17.17 | 16.70 | 8.32 | 9.34 | 8.83 | 3.95 | 3.92 | 3.94 |
| 68 | 1.10 | 1.07 | 1.09 | 19.85 | 18.69 | 19.27 | 11.6 | 10.68 | 11.16 | 4.11 | 4.00 | 4.06 |
| 111 | 1.07 | 1.03 | 1.05 | 16.13 | 15.82 | 15.97 | 9.12 | 7.98 | 8.55 | 3.54 | 3.92 | 3.73 |
| 1213 | 1.07 | 1.05 | 1.06 | 15.80 | 16.49 | 16.14 | 7.26 | 8.81 | 8.03 | 4.25 | 3.80 | 4.02 |
| Average | 1.06 | 1.04 | 1.05 | 17.00 | 17.04 | 17.02 | 9.08 | 9.20 | 9.14 | 3.96 | 3.91 | 3.94 |

The average fibre length changed from 1.00 to 1.09 mm (Tab. 3). Tomazello Filho (1985), researching ten-year-old *Eucalyptus grandis*, sampled from pith to bark and obtained fibre lengths changing from 0.68 (inner wood) to 1.32 mm (outer wood), which are longer than those found here. The fibre length presented by Lima (1999), investigating the inner regions of logs of 11 eight-year-old *Eucalyptus* clones, changed from 0.91 to 0.98 mm — a smaller range (0.07 mm). For *Eucalyptus grandis* aged 24 years, Silva (2002) obtained average lengths of 1.13 mm, while Mori (2003) working with *Eucalyptus* clones aged between 7.5 and 13.5 years old found values between 0.88 and 1.09 mm, which are longer than the values found in this study.

Clone 68 had longer fibres in trees planted on flat land than in those on sloping land. It is important to remember that this clone presents the highest propensity to damage by storms (Tab. 2). The shorter fibres presented by clone 1213 in trees planted on sloping land showed highest resistance to the storms (Tab. 2).

The average fibre width changed from 15.97 to 19.27 μm (Tab. 3). These values are similar to those found by several authors working with *Eucalyptus* wood: Tomazello Filho (1985) [FW changing from 19.3 to 24.1 μm], Lima (1999) [FW changing from 16.68 to 19.28 μm], Silva (2002) [average FW equal to 18.73 μm] and Mori (2003) [FW changing from 14.1 to 19.6 μm].

The fibre lumen diameter (LD) changed from 8.03 to 11.16 μm (Tab. 3). Also for this characteristic,

these values are similar to those found by several authors working with *Eucalyptus* wood: Tomazello Filho (1985) [LD changing from 10.0 to 12.0 μm], Lima (1999) [LD changing from 9.8 to 12.4 μm], Silva (2002) [average LD equal to 10.37 μm] and Mori (2003) [LD changing from 7.9 to 10.2 μm].

The fibre wall thickness (FT) presented in Tab. 3 changed from 3.73 to 4.06 μm . These fibres are thinner than those studied by some authors working with *Eucalyptus* wood: Tomazello Filho (1985) [FT changing from 4.6 to 6.0 μm], Silva (2002) [average FT equal to 4.2 μm] and Mori (2003) [FT changing from 3.3 to 5.1 μm]. Differently, Lima (1999) [FT changing from 3.2 to 3.5 μm] found values of FT lower than those found in this work.

It can be observed in Tab. 3 that clone 68 presented the highest values of fibre length, fibre width, lumen diameter and fibre wall thickness. This clone is considered highly prone to the action of the storms. It is possible that the combination of the characteristics of these “big” fibres can be contributing to the lower resistance of the trees of clone 68 to the action of the storms. The relationship between fibre dimensions and wood strength was demonstrated by Lima (1999), working with *Eucalyptus* wood. Accordingly, the compression strength parallel to the grain increased when the fibre wall thickness increased, but reduced when the lumen diameter increased.

3.2 Relationship between fibre dimensions and tolerance of the clones to the storms

Tab. 4 presents the analysis of regression of the tolerance of the *Eucalyptus* clones to the storms as a function of the fibre dimensions. It can be observed in this table that the tolerance is reduced when the fibre dimensions increase. However, the relationship of the tolerance with both fibre length and fibre wall thickness was not statistically significant. On the other hand, the model can significantly explain the dependence from the fibre lumen diameter: [$T = 130.2005 - 6.61474LD$; $R^2 = 60.0\%$]. This means that 60.0% of the tolerance of the trees to the storms can be associated with fibre lumen diameter. This relationship is still higher (75.4 %) when the tolerance is calculated as a function of the fibre width [$T = 190.3912 - 7.08768 FW$; $R^2 = 75.4$]. It is important to mention that a few years ago, the company started to apply additional fertilization on the stands, obtaining higher growth rates. Possibly this practice has contributed to influence the fibre morphology, and consequently the mechanics of the trees.

Tab. 4 Analysis of regression of the level of the tolerance of the *Eucalyptus* clones to the storms (T) as a function of the fibre dimensions

| Equation | R^2 | F | $S_{y,x}$ |
|-----------------------------|-------|-----------|-----------|
| $T = 159.0197 - 85.2217 FL$ | 7.2 | 0.46 ns | 12.6213 |
| $T = 169.9756 - 25.4622 FT$ | 19.5 | 1.45 ns | 11.7557 |
| $T = 130.2005 - 6.61474 LD$ | 60.0 | 9.01 ** | 8.2812 |
| $T = 190.3912 - 7.08768 FW$ | 75.4 | 18.44 *** | 6.4907 |

Note: R^2 , coefficient of determination (%); $S_{y,x}$, standard error; ns: non significant; ** significant at 5% of probability; *** significant at 1% of probability.

3.3 Microfibril angle

Tab. 5 shows the values of microfibril angles (MFA) of the wood of *Eucalyptus* clones planted on flat land and on sloping land. The averages of these values are also shown in this table per clone.

Tab. 5 Average microfibril angles, in degrees, of wood of *Eucalyptus* clones planted on flat land and on sloping land

| Clone | Microfibril angles | | |
|---------|--------------------|--------------|---------|
| | Flat land | Sloping land | Average |
| 57 | 26.9 | 26.6 | 26.8 |
| 68 | 24.8 | 25.6 | 25.2 |
| 111 | 25.4 | 24.3 | 24.9 |
| 1213 | 27.2 | 26.5 | 26.9 |
| Average | 26.1 | 25.8 | 26.0 |

The average MFA was equal to 26° (Tab. 5). In general, the variation of the angles was small: 2° between the higher and the smaller angles. Also, the difference between the MFA of the clones planted on flat land and on sloping land was small (Tab. 5), changing from 24.3° to 27.2°. These values were similar to those obtained by various authors. For *Eucalyptus rubida* Yoshida *et al.* (1992) observed angles changing from 10° to 30°. Stuart and Evans (1995), studying *E. nitens*, obtained angles reducing from the pith to the bark, with a variation from 10° to 20°. In this case, they also relate that the angles were considerably smaller for the late wood than for the early wood. The microfibril angles for hybrids of *Eucalyptus* changed from 0° to 27° (average of 9.5°) (Bailleres *et al.*, 1995). In a study carried out by Baba *et al.* (1996), tension wood showed an MFA equal to 3.5° and normal wood 22.5°. Lima *et al.* (2004) investigating 11 *Eucalyptus* clones planted on four sites in Brazil, found angles relatively smaller: from 8.6° to 11.2°.

Three clones showed a higher MFA in wood produced on flat land than on sloping land. The exception was clone 68. However, the differences between the angles observed for both sites were small, i.e., less than 1°.

Trees growing on sloping land could be more tolerant to severe storm action. In spite of the small differences in the MFA, it is possible that trees from sloping land develop tension wood and align their microfibrils longitudinally in a way to confer to their wood higher tension strength parallel to the grain. Actually, the inclination of the land propitiates the formation of tension wood, which is characterized by small MFA, as was found by Baba *et al.* (1996).

It was not possible to find a significant linear relationship between the microfibril angles (MFA) and the levels of tolerance (T) of the clones to storms. The analysis of regression resulted in the equation: $T = 61.87335 + 0.303971 \text{ MFA}$; $R^2 = 0.07\%$.

3.4 Basic density

The values of wood basic density of *Eucalyptus* clones planted on flat land and on sloping land are presented per clone in Tab. 6.

An analysis of Tab. 5 verifies that the basic density varied from 0.402 to 0.493 g · cm⁻³. These values are lower than those obtained by other authors researching *Eucalyptus* wood (Lima, 1995; Lima, 1999; Caixeta, 2000; Lima *et al.*, 2000; Lima *et al.*, 2001; Oliveira, 2001; Souza, 2002; Mori, 2003; Cruz *et al.*, 2003). [A more detailed discussion on the wood basic density of *Eucalyptus* can be seen in other presentation of this Conference (Lima *et al.*, 2005)]. It is important to mention that genetic material of *Eucalyptus* selected for pulp and paper production, in general, produces lower density than those selected for charcoal.

Tab. 6 Average values of wood basic densities ($\text{g} \cdot \text{cm}^{-3}$) of *Eucalyptus* clones planted on flat land and on sloped land

| Clone | Basic density | | |
|---------|---------------|--------------|---------|
| | Flat land | Sloping land | Average |
| 57 | 0.453 | 0.457 | 0.455 |
| 68 | 0.418 | 0.438 | 0.428 |
| 111 | 0.402 | 0.421 | 0.412 |
| 1213 | 0.493 | 0.451 | 0.472 |
| Average | 0.442 | 0.442 | 0.442 |

The highest wood basic density was observed in wood formed on sloping land (BD changing from 0.421 to 0.457 $\text{g} \cdot \text{cm}^{-3}$), but this did not occur for the clone 1213 (Tab. 6). This tendency may help to explain the higher tolerance of the trees growing on sloping land when faced by storms. It is known that there is a direct and positive relationship between density and mechanical properties of wood.

3.5 Mechanical properties

Tab. 7 shows the values of compression strength and modulus of elasticity in compression parallel to the grain of wood of *Eucalyptus* clones planted on flat land and on sloping land.

Tab. 7 Average values of compression strength (CS) and modulus of elasticity in compression parallel to the grain (MOEc) of wood of *Eucalyptus* clones planted on flat and on sloping land

| Clone | CS (MPa) | | | MOEc(MPa) | | |
|---------|-----------|--------------|---------|-----------|--------------|---------|
| | Flat land | Sloping land | Average | Flat land | Sloping land | Average |
| 57 | 52 | 54 | 53 | 7,775 | 8,135 | 7,955 |
| 68 | 43 | 47 | 45 | 6,266 | 6,533 | 6,400 |
| 111 | 47 | 56 | 51 | 6,781 | 8,378 | 7,580 |
| 1213 | 55 | 59 | 57 | 8,672 | 9,181 | 8,927 |
| Average | 49 | 54 | 52 | 7,374 | 8,057 | 7,716 |

The compression strength parallel to the grain varies from 45 to 57 MPa, while the modulus of elasticity in compression strength varies from 6,400 to 8,927 MPa (Tab. 7). In general, these values were smaller than those found by other authors working on *Eucalyptus* wood (Lima *et al.*, 1999; Caixeta, 2000; Moura, 2000; Oliveira, 2001; Cruz *et al.*, 2003). The juvenile age of the clones used in this research could be a possible reason for this [A more detailed discussion on the mechanical properties of *Eucalyptus* wood can be seen in another presentation of this Conference (Lima *et al.*, 2005)].

Clone 68, the most susceptible to the storms, presented the lowest CS and lowest MOEc (Tab. 7). For all studied clones, both CS and MOEc were lower for wood from flat land than from wood from sloping land. It is important to mention that clones planted on flat land and weaker under compression, are less tolerant to the storms.

The modulus of rupture (MOR) and the modulus of elasticity in static bending (MOEf) of the clones of *Eucalyptus* wood, planted on flat land and on sloping land are shown in Tab. 8. The MOR varies from 83 to 105 MPa and the MOEf varies from 5,434 to 6,918 MPa.

The MOR and the MOEf obtained in this study on younger trees were smaller than those observed by other authors for *Eucalyptus* wood (Lima, 1999; Caixeta, 2000; Moura, 2000; Oliveira, 2001; Cruz *et al.*,

2003). Exception is the lower MOR found by Lima (1999) for *Eucalyptus* clones.

Wood of clone 68 showed both the lowest MOR and MOEf (Tab. 8). As observed in compression, for all studied clones, both MOR and MOEf were also lower for wood from flat land than from wood from sloping land. This suggests a mechanical requirement of the tree to support the instability caused by the inclination of the land. Possibly these higher values of the mechanical properties observed from wood formed on sloping land are due to the occurrence of tension wood.

Tab. 8 Average values of modulus of rupture (MOR) and modulus of elasticity in static bending (MOEf) of wood of *Eucalyptus* clones planted on flat and on sloping land

| Clone | MOR(MPa) | | | MOEf(MPa) | | |
|---------|-----------|--------------|---------|-----------|--------------|---------|
| | Flat land | Sloping land | Average | Flat land | Sloping land | Average |
| 57 | 98 | 102 | 100 | 5,956 | 6,331 | 6,144 |
| 68 | 80 | 86 | 83 | 5,228 | 5,640 | 5,434 |
| 111 | 87 | 100 | 93 | 5,714 | 6,471 | 6,093 |
| 1213 | 102 | 108 | 105 | 6,733 | 7,103 | 6,918 |
| Average | 92 | 99 | 95 | 5,908 | 6,386 | 6,147 |

3.6 Relationship between wood mechanical properties and the tolerance of the clones to the storms

It was not possible to identify a significant linear relationship between the values of basic density and the tolerance of clones to the action of the storms. This may mean that it is not necessarily clones that produce denser wood that are the strongest against the winds. On the other hand, the dependence that tolerance (T) has on compression strength parallel to the grain (CS) can be explained by a linear equation [$T = -14.005 + 1.6224RC$; $R^2 = 53.2\%$]. This means that 53.2% of the tolerance of the trees to the storms can be related to the resistance that this wood has to the compression parallel to the grain. This equation also shows that the higher the strength, the higher is the tolerance of the trees. This relationship is even higher (69.4 %) when the tolerance is calculated as a function of the MOEc [$T = -2.8889 + 0.0094MOEc$; $R^2 = 69.4\%$]. The relationship between tolerance and MOEc is positive, i.e., the higher the MOEc, the more tolerant is the tree to the storms.

The influence that the modulus of rupture (MOR) on the tolerance of the trees to the storms can be explained by the equation $T = 0.8237MOR - 8.8067$ with $R^2 = 44.1\%$. In this case, as observed for compression strength, the relationship is positive. In terms of the modulus of elasticity, the fitted equation is $T = 0.0143MOEf - 17.89$; $R^2 = 53.7\%$.

3.7 Growth Stresses

The growth stresses measured for *Eucalyptus* clones cultivated on flat land and sloping land are presented in Tab. 8. The values change from 509 to 704 $\text{kgf} \cdot \text{cm}^{-2}$. These values are close to those found by Lima *et al.* (2004). Working with 5 clones of *Eucalyptus*, aged from 8.5 to 15 years, they found growth stresses changing from 364 to 787 $\text{kgf} \cdot \text{cm}^{-2}$. Clone 68 showed the lowest growth stresses and clone 1213 the highest. The comparison of the growth stresses of the clones planted in different topography revealed that for all studied clones, sloping land produced higher growth stresses than flat land (Tab. 9). This could indicate a greater occurrence of tension wood in trees growing on sloping land, which contributes to higher

tolerance to the storms. According to Yamamoto *et al.* (1997) the longitudinal strain produced by growth stresses becomes higher in proportion to the formation of reaction wood. This suggests that the level of reaction wood can be estimated by measurement of the strain produced.

Tab. 9 Average growth stresses ($\text{kgf} \cdot \text{cm}^{-2}$) of *Eucalyptus* clones planted on flat land and on sloping land

| Clone | Growth stress | | |
|---------|---------------|--------------|---------|
| | Flat land | Sloping land | Average |
| 57 | 587 | 649 | 618 |
| 68 | 509 | 519 | 514 |
| 111 | 573 | 704 | 639 |
| 1213 | 646 | 686 | 666 |
| Average | 579 | 640 | 609 |

The estimation of the storm tolerance of the trees (T) as a function of the growth stresses (GT) can be explained by the linear equation [$T = -15.702 + 0.1403GT$; $R^2 = 72.3\%$]. This means that 72.3% of the tolerance may be associated with these stresses. This influence is higher than those conferred by the fibre morphology, density or mechanical properties discussed earlier in this work. The equation also shows that the storm tolerance increases with the growth stresses.

4 CONCLUSIONS

For the four two-year-old *Eucalyptus* clones it can be concluded that:

Wood produced on sloping land showed higher basic density, mechanical properties (compression parallel to the grain and static bending) and growth stresses than wood produced by the same clones planted on flat land. This indicates that these characteristics may be contributing to the higher tolerance of the clones growing on sloping land to severe storms. These results indicate that the formation of tension wood in the clones growing on sloping land is associated with their higher tolerance to these storms.

The tolerance of the clones to severe storms can be significantly estimated by the fibre width, fibre lumen diameter, mechanical properties and growth stresses through linear regression models. The best descriptive equations used either the fibre width ($R^2 = 75.2\%$) or the growth stresses ($R^2 = 72.3\%$). Basic density and microfibril angle were not significant predictors of tolerance.

REFERENCES

- American Society For Testing And Materials (ASTM). 1997. Annual book of ASTM standards. Easton: West Conshohocken, 679
- Amidon T E. 1981. Effect of the wood properties of hardwoods on kraft paper properties. TAPPI, 64, 123-126
- Baba K, Ona T, Takabe K, ItOH T, Ito K. 1996. Chemical and anatomical characterization of the tension wood of *Eucalyptus camaldulensis* L. Mokuzai Gakkaishi, 42, (8):795-798
- Bailleres H, Chanson B, Fournier M, Tollier M T, Monties B. 1995. Wood structure, chemical-composition and growth strains in *Eucalyptus* clones. Annales Des Sciences Forestieres, 52, (2): 157-172
- Caixeta R P. 2000. Propriedades da madeira de *Eucalyptus*: Classificação e seleção de genótipos utilizando marcador molecular e análise multivariada. 89 Dissertação (Mestrado) – Universidade Federal de Lavras, Lavras, MG
- Cruz C R, Lima J T, Muniz G I B de. 2003. Variações dentro das árvores e entre clones das propriedades físicas e mecânicas da madeira de híbridos de *Eucalyptus*. Scientia Forestalis, IPEF – ESALQ/USP, Piracicaba, 64, 33-47
- Lima J T. 1995. The wood density of 3 *Eucalyptus saligna* Smith clones in relation to age. Annales Des Sciences Forestieres, Paris, 52, (4): 347-352

- Lima J T, Breese M C, Cahalan C M. 2000. Genotype-environment interaction in wood basic density of *Eucalyptus* clones. *Wood Science and Technology*, New York, 34 (3): 197-206
- Lima J T, Breese M C, Cahalan C M. 1999. Variation in compression strength parallel to the grain in *Eucalyptus* clones. In: International conference on the development of wood science, wood technology and forestry, 4., Missenden Abbey. Proceedings Missenden Abbey: Forest Products Research Centre, 502-510
- Lima J T, Rosado S C S, Trugilho P F. 2001. Assessment of wood density of seven clones of *Eucalyptus grandis*. *Southern African Forestry Journal*, Pretoria, 191, 21-27
- Lima J T, Trugilho P F, Rosado S C S, Cruz C R. 2004. Deformações residuais longitudinais decorrentes de tensões de crescimento em *Eucalyptus* e suas associações com outras propriedades. *Revista Árvore*, Viçosa, 28, (1): 107-116
- Lima J T, Breese M C, Cahalan C M. 2004. Variation in microfibril angle in *Eucalyptus* clones. *Holzforshung*, Berlin, 58 (2): 160-166
- Lima J T. Clonal variation in the solid wood properties of *Eucalyptus*. 1999. Dissertação (Doutorado) - University of Wales, Bangor 276
- Lima J T, Trugilho P F, Rosado S C C. 2005. Physical and mechanical properties of fast grown *Eucalyptus* wood originally planted for pulp & paper or for charcoal production. Zhanjiang, Guangdong, China. In: International Conference on Plantation *Eucalyptus*: Challenge in Product Development Minitab. Minitab for windows – release 11.11. Minitab Inc. 1996.
- Mori C L S O. 2003. Variabilidade de cores em madeiras de clones de híbridos de *Eucalyptus* spp. 64 Dissertação (Mestrado) – Universidade Federal de Lavras, Lavras, MG
- Moura M C O. 2000. Variações em características do crescimento e da madeira em clones de *Eucalyptus*. 63. Dissertação (Mestrado) – Universidade Federal de Lavras, Lavras, MG
- Oliveira L J R. 2001. Uso do Pilodyn para a estimativa da densidade básica e propriedades mecânicas da wood de eucalipto. 62. Dissertação (Mestrado) – Universidade Federal de Lavras, Lavras, MG
- Silva J R M. 2002. Relações da usinabilidade e aderência do verniz com as propriedades fundamentais do *Eucalyptus grandis* Hill ex. Maiden. 179. Dissertação (Doutorado) – Universidade Federal do Paraná, Curitiba, PR
- Souza M A M. 2002. Deformação residual longitudinal (DRL) causada pelas tensões de crescimento em clones de híbridos de *Eucalyptus*. 72. Dissertação (Mestrado) – Universidade Federal de Lavras, Lavras, MG
- Tomazello Filho M. 1985. Variação radial da densidade básica e da estrutura anatômica da madeira de *Eucalyptus saligna* e *Eucalyptus grandis*. IPEF, Piracicaba, 29, 37-45
- Yamamoto H, Okuyama T, Yoshida M. 1997. Growth stress generation and microfibril angle in reaction wood. In: Butterfield B G Ed. *Microfibril Angle in Wood*. Westport: International Association of Wood Anatomists, 225-239
- Yoshida M, Okuyama T, Yamamoto H. 1992. Tree forms and internal stress III. Growth stresses of branches. *Mokuzai Gakkashi*, 38 (7): 663-668

Physical and Mechanical Properties of Fast Grown *Eucalyptus* Wood Originally Planted For Pulp & Paper or for Charcoal Production

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ABSTRACT

Eucalyptus was established in Brazil 101 years ago to provide fuel for trains. Later it was selected, planted and managed, both for charcoal and for pulp and paper. Only around ten years ago this genus began to be employed widely for sawn timber production. Due to the lack of information, studies on the physical and mechanical properties of the fast grown *Eucalyptus* wood must be carried out to identify genetic material with better performance during processing and in use. It is important to report that these traits were not considered in the original process of selection. Thus, this work aims to present results of several assessments based on these characteristics. Most of the results were performed on clonal material and amongst charcoal and pulp and paper *Eucalyptus*, it has been possible to identify a variety of characteristics in the wood, some of them suitable for sawn timber utilization.

1 INTRODUCTION

Wood is one of the most versatile materials utilized by humanity throughout history. Its wide diversity of applications and presence in the quotidian of the person dispenses enumeration. However, its direct implication with environmental quality confirms that wood (i) is a renewable raw material, which assumes that it can be indefinitely available; (ii) is the result of carbon absorbed from the atmosphere and elaborated by the trees, which improves environmental quality and makes human and industrial impacts less damaging; (iii) in comparison with other materials requires very low levels of energy in its processing, when considering the entire productive chain, from extraction in the field to final processing, and (iv) produces bio-degradable residuals. Thus, beyond the benefits that the utilization of a material with adequate characteristics can promote, wood also allows a harmonious interaction with the environment when compared to other materials, which makes it more competitive in the market.

The physical and mechanical properties of wood, which are important for solid wood utilization, were not considered during the initial selection and testing of *Eucalyptus* species and genotypes in Brazil. Understanding the variation in these properties between genotypes, between different environments where trees are planted, and the extent of genotype \times environment interactions is important for the improvement of wood quality. Understanding the patterns of within-tree variation in mechanical properties can also provide useful information for both selection programs and wood processing.

The main objective of this paper is to relate the advances that have been achieved in Brazil on the

physical and mechanical characteristics of *Eucalyptus* wood.

2 EUCALYPTUS IN BRAZIL

When commercially introduced into Brazil, in the early 20th century, *Eucalyptus* was planted to supply firewood for fuel for trains. Progressively, it became an industrial wood to the extent that in the 1960s/70s private companies, using governmental subsidies, promoted a large program of reforestation in the country. It has been estimated that a total area of approximately four million hectares is cultivated with *Eucalyptus* species in Brazil (Souza, 1992; Pandey, 1995). The main species utilized are *E. grandis*, *E. urophylla*, *E. saligna*, *E. camaldulensis*, *E. tereticornis* and *E. cloeziana*. Nowadays, the main genetic material cultivated is represented by clones, mainly from *E. grandis* and *E. grandis* × *E. urophylla* hybrids. Unfortunately there is not a consistent survey in terms of the area, yield and quality of the stands by species, hybrids or clones. These trees, due to their fast growth, are normally short-rotated (around seven years) producing a large proportion of juvenile wood, in contrast to the higher levels of mature wood produced by *Eucalyptus* grown in Australia: for example, values for the mechanical properties of Brazilian-grown *E. grandis* wood were markedly lower than those reported for Australian-grown material (Della Lucia and Vital, 1980). It can be suggested that this difference is associated with the lower density of the Brazilian-grown material ($0.55 \text{ g} \cdot \text{cm}^{-3}$) c.f. $0.72 \text{ g} \cdot \text{cm}^{-3}$ as reported for Australian-grown material.

Equally important to the reported expansion of the planted areas is the yield gain obtained using new techniques of both genetic selection and new forestry practices in replanted areas. In Brazil, large areas reforested during the 1970's have now been substituted by new genetic material, which gives better performance both in the plantation and in industry. Results obtained in large scale plantations by Aracruz Celulose S A, for example, have assured continual reduction in the specific consumption of wood (i.e., the required amount of wood to produce one ton of pulp). The specific consumption in 1993 was 16 % less than that obtained by that enterprise some 20 years before (Bertolucci and Penchel, 1993). Exceptionally good results have occasionally been presented in the literature but they have referred to experimental or specific conditions rather than the common or average cases generally found in the country. In support of this view Eldridge *et al.* (1993) relate that small sample plots of eucalypts aged 6-8 years in East and West Africa, Brazil and Papua New Guinea have grown at rates of $70\text{-}90 \text{ m}^3 \cdot \text{ha}^{-1}$ per year. The average yield of large scale eucalypt plantations in Brazil however ranged from 18 to $20 \text{ m}^3 \cdot \text{ha}^{-1}$ per year (Pandey, 1995). Assuming a wood basic density (oven dry mass/green volume) of about $500 \text{ kg} \cdot \text{m}^{-3}$ and a total area of about 3.6 million ha the potential yield of the Brazilian eucalypt plantation is of the order of 30 million tons of dry wood per year. This figure may be higher if the area of 4.5 million hectares as reported by Souza (1992) is considered.

3 TRADITIONAL USES OF *EUCALYPTUS* WOOD IN BRAZIL

To date, the genetic selection of fast grown *Eucalyptus* cultivated in Brazil has been mainly directed towards pulp and paper and/or charcoal for steel production. For pulp the main desirable wood parameters selected have been low density, specific fiber dimensions and chemical composition. For charcoal the parameters have been high density, lignin content and calorific value. Importantly, it was not relevant if these trees presented high levels of growth stresses, high grain angle, tendency to collapse on drying or low mechanical strength since these characteristics are not crucial for either pulp or charcoal production.

However, this timber also presents possibilities of usage as solid wood in structures, furniture, tools, etc.

This has been demonstrated by Acosta (1995) and Malan (1995) where emphasis was directed towards investigation of mechanical properties.

Some significant characteristics of short rotation, fast grown *Eucalyptus* wood that differentiate it from other wood are high intensity of growth stresses, high extension of juvenile wood and a tendency to collapse during drying. As these characteristics can be genetically manipulated (Zobel and Van Buijtenen, 1989), the possibility exists of achieving a higher quality of *Eucalyptus* for use as solid wood.

4 NEW UTILISATION OF *EUCALYPTUS* AS SOLID WOOD IN BRAZIL

The economic and social development of Brazil has expanded the requirement of wood as a raw material to supply diversified requirements, mainly for building and for furniture, in addition to existing demands of the pulp and charcoal industries. On the one hand, tropical timber from the Amazon jungle, despite its large potential availability, faces ecological and infra-structural limitations to logging (the present timber production is not sufficient to meet the demand). On the other hand, as earlier described, extensive areas have been reforested with high quality *Eucalyptus* (Fig. 1) mainly for pulp and paper or charcoal for steel production. These products confront periodical market difficulties, which push the forest owners to look for new outlets for the raw material, either in the domestic or foreign markets. Within this context, *Eucalyptus* sawn timber assumes an important role in terms of trade. The first wave of this tendency has already started, with important Brazilian companies, individually or in joint-ventures, producing sawn wood. Among them, can be cited: Aracruz Celulose S A, Caf Florestal S A, Duratex S A, Florestas Rio Doce S A, Flosul S A, Klabin Fabricadora de Papel e Celulose S A. There is no reliable information about the volume of *Eucalyptus* sawn timber annually produced in Brazil, but it is sharply increasing, mainly using *E. grandis* and hybrids with *E. grandis*. However, information appertaining to investment in new sawmills and expansions to already installed sawmills indicate volumes of between 100,000 and 150,000 m³ per year, starting from 1999.



Fig. 1 Fast grown, high quality 14 years-old *Eucalyptus grandis* hybrid trees produced in Brazil

Also, the prospects for wood quality improvement are substantial, since the selection of new genetic material to be planted considers the requirement for solid wood production, and also because the silvicultural techniques directed towards timber production are starting to be adopted (pruning and thinning, for example). In this particular context it is important to note that a more demanding selection of the matrix trees is not necessarily incompatible with the traditional uses: on the contrary, the production of an appropriate tree for solid wood production may also enhance its quality for pulp and paper, charcoal etc., depending on the origin of the material.

5 NEW INVESTIGATIONS FOR NEW PRODUCTS

Since *Eucalyptus* plantations are to be evaluated for new products, it is reasonable that appropriate characteristics of the wood have to be observed and new investigations carried out. In this new scenario, in addition to many other characteristics, log shape, growth stresses, physical-mechanical characteristics, colour and primary and secondary processing characteristics must be studied. Finally, the behaviour of this wood must be assessed in service, in such a way that the consumers have confidence in the quality of the product they are acquiring.

5.1 Physical properties of *Eucalyptus* wood

Amongst the physical properties, density and dimensional stability are the most important. The basic density is the most studied wood property of *Eucalyptus* in Brazil. This is because this property is easily determined and strongly correlated to other properties. However, some papers relate investigation on the nominal density. In addition, the variation of the density within the stem, both longitudinally (base-top) and radially (pith-bark) into the stem have been investigated. Tab. 1 presents the results of the *Eucalyptus* wood basic density determined for different ages, genetic material and location of plantation.

Tab. 1 Values of basic density found by various authors for *Eucalyptus* wood produced in Brazil

| Genetic Material | Age | Basic density($\text{g} \cdot \text{cm}^{-3}$) | Author |
|--|----------------------------|--|---------------------------|
| Wood originally planted for charcoal | | | |
| 3 <i>E. saligna</i> clones | From 9 to 42-months-old | From 0.319 to 0.517 | Lima, 1995 |
| 3 <i>E. saligna</i> clones | 24-months-old | From 0.433 to 0.443 | Lima, 1995 |
| 44 <i>Eucalyptus</i> genotypes | From 13 to 17-years-old | From 0.544 to 0.731 | Caixeta, 2000 |
| 10 <i>Eucalyptus</i> hybrids | 9-years-old | | Moura, 2000 |
| 11 <i>Eucalyptus</i> clones | 6-years-old | From 0.508 to 0.594 | Souza, 2002 |
| 11 <i>Eucalyptus</i> clones | From 7.5 to 13.5-years-old | From 0.449 to 0.563 | Mori, 2003 |
| 7 <i>Eucalyptus</i> clones | From 5.5 to 10.5-years-old | | Cruz <i>et al.</i> , 2003 |
| 7 <i>Eucalyptus</i> clones | 8-years-old | From 0.477 to 0.584 | Padilha, 2005 |
| Wood originally planted for pulp and paper | | | |
| 26 <i>Eucalyptus</i> clones | 8-years-old | From 0.436 to 0.577 | Lima, 1999 |
| 5 <i>Eucalyptus</i> clones | 8-years-old | From 0.420 to 0.560 | Lima <i>et al.</i> , 2000 |
| 7 <i>E. grandis</i> clones | From 0.5 to 7.5-years-old | From 0.347 to 0.570 | Lima <i>et al.</i> , 2001 |
| 7 <i>E. grandis</i> clones | 2.5-years-old | From 0.446 to 0.511 | Lima <i>et al.</i> , 2001 |
| 5 <i>Eucalyptus</i> clones | 12.9-years-old | From 0.530 to 0.658 | Oliveira, 2001 |
| 4 <i>Eucalyptus</i> clones | 2-years-old | From 0.412 to 0.472 | Melo, 2004 |

5.1.1 *Eucalyptus* wood density

It can be observed in Tab. 1 that basic density varies from a minimum of $0.319 \text{ g} \cdot \text{cm}^{-3}$ to a maximum of $0.731 \text{ g} \cdot \text{cm}^{-3}$. Normally, wood formed in early stages of tree development is of low basic density. It has been shown in Brazil that *Eucalyptus* for solid wood production must be around 20-years-old. However, this assertive is based on the properties that older genetic material attains at age 20 years rather than the intrinsic wood characteristics. New material, propagated by cloning has shown wood with characteristics and performance, both during the processing and utilization that give good reason for its selection and planting. From the papers of several authors it is possible to verify that wood grown for pulp and paper shows lower basic density than that grown for charcoal production. It has to be mentioned that the genetic material listed on Tab. 1 does not represent the overall material cultivated to produce charcoal or pulp and paper in Brazil. Some of these materials were selected to evaluate their potentiality to be used as solid wood producers. In this aspect, it has been generally accepted that material originally selected for pulp and paper is more suitable for furniture, while material selected for charcoal is more adequate for construction application.

The variation of the density within the stem is more important than the variation amongst genetic material. This is particularly true where fast grown *Eucalyptus* from young plantations is considered. In this case wood is still in stages of maturation and the growth tendency of this property has been observed year to year. In cases where the rotation age of *Eucalyptus* plantations is around seven years, all the wood formed can be classified as juvenile wood, despite the difficulty of identifying the transition zone between juvenile and mature wood in this genus and growth conditions.

To study the variation of nominal density (dry mass/dry volume) of *Eucalyptus* wood within trees, between clones and between sites, Lima *et al.* (2000) used twenty-six eight-year-old clones of *E. grandis* × *E. urophylla* natural hybrids, planted on four experimental sites, and the results in Tab. 2 showed that nominal density increased from inner to outer parts of the log. The variation of nominal density from the inner wood to the outer wood amounted to about 22%. From the base to the top of a six meters long log the nominal density decreased. However, the difference was small, varying from 1.8% to 7.6%, depending on the site selected. The wide variation from the pith to the bark suggests that a proper method of log break-down must be applied and that the lumber produced must be sorted appropriately before utilization.

Tab. 2 Variation of nominal density with radial position in the base and top of the log of *Eucalyptus* clones growing at four sites in Brazil. Mean values for 26 clones

| Property | Site | Base | | | | Top | | | |
|---|------|-------|-------|-------|-------|-------|-------|-------|-------|
| | | Inner | Inter | Outer | Mean | Inner | Inter | Outer | Mean |
| Nominal Density ($\text{g} \cdot \text{cm}^{-3}$) | SBA | 0.457 | 0.486 | 0.540 | 0.510 | 0.442 | 0.478 | 0.532 | 0.501 |
| | SM1 | 0.480 | 0.528 | 0.615 | 0.566 | 0.474 | 0.494 | 0.565 | 0.527 |
| | SM2 | 0.498 | 0.540 | 0.598 | 0.565 | 0.485 | 0.514 | 0.562 | 0.535 |
| | ARA | 0.486 | 0.534 | 0.600 | 0.562 | 0.482 | 0.507 | 0.560 | 0.531 |
| | Mean | 0.480 | 0.522 | 0.588 | 0.551 | 0.471 | 0.498 | 0.554 | 0.524 |

Note: SBA-Southern Bahia; SM1-São Mateus 1; SM2-São Mateus 2; ARA-Aracruz.

It is important to mention that the basic density does not follow a very rigid pattern of variation within the tree. For *Eucalyptus* the most commonly found standard is that the density is gradually reduced from the base to about half the tree height, then increases from this point to the top. The differences between results

are very likely caused by the method of sampling employed by the researcher. For this reason it is very important to establish a more intensive sampling of up to 25% of the stem length to verify which point represents the lowest density as is recommended by Downes *et al.* (1997).

The research on this subject confirms the lack of a unique standard of basic density variation along the stem for *Eucalyptus*. Some of the results of these researches are presented as follows:

1) Basic density increases from base to top of the stem: Valente *et al.* (1992) in *E. globulus*; Ferreira (1972) in *E. grandis* at 11 years; Lima *et al.* (1992), in *E. tereticornis*, *E. camaldulensis* and *E. grandis*; Rosado *et al.* (1983), in *E. alba* at 5 and 7 years.

2) Basic density reduces from base to top of the stem: Shimoyama and Barrichelo (1991) in *E. grandis*, at 7 years; Rosado *et al.* (1983) in *E. microcorys* at 5 years.

3) Basic density increases from base to top of the stem, after an initial reduction: Barrichelo *et al.* (1983); Vital and Della Lucia (1987); Lima *et al.* (1992) in *E. grandis* at 3.5 years.

4) Basic density reduces from base to top of the stem, after an initial increase: Rosado *et al.* (1983) in *E. propinqua* and *E. microcorys* at 5 years.

5) Basic density does not change from base to top of the stem: Teixeira and Vargas Filho (1994) in *E. grandis* at 6 years.

On the other hand, most of the *Eucalyptus* follow a pattern of radial variation. The research confirms the lack of a definitive standard. However, in Brazil it has been found that basic density increases from pith to bark: Ferreira (1972), Brasil *et al.* (1979), Carpim and Barrichelo (1983) in *E. dunni*, *E. deanei*, *E. grandis* and *E. saligna*; Tomazello (1985) in *E. saligna* and *E. grandis*. Others patterns have not been found for *Eucalyptus* in Brazil.

5.1.2 *Eucalyptus* wood shrinkage

Eucalyptus wood is recognized as having high dimensional instability caused by the variation of moisture content. Wood of low volumetric shrinkage is required for solid product utilisation. It must be pointed out that this shrinkage is a result of the tangential, radial and longitudinal shrinkages. In Brazil, only recently (from approximately ten years ago) assessments on these characteristics were carried out. An exception is the report of Brotero (1956), reporting that the shrinkage of *Eucalyptus* wood varies from 3.5% to 8.6% in the radial direction and from 7.8% to 21.9% in the tangential direction, resulting in a volumetric variation between 13.2% and 35.7%. Note the wide variation in these figures, as well as the high magnitude of upper values.

In a more recent study, Moura (2000), working with ten nine-year-old hybrid *Eucalyptus* clones originally planted for charcoal production in the Brazilian central region, found averages for tangential shrinkage, radial shrinkage and volumetric shrinkage equal to 9.1%, 5.3% and 13.7%, respectively. In this work, it was observed that the tangential shrinkage was 9.9% in the first three-metre length log, 8.8% in the second log and 8.5% in the third log along the stem. Radial and volumetric shrinkage variation was not observed along the stem. For seven clones of similar wood, Cruz *et al.* (2003) found averages for tangential shrinkage, radial shrinkage and volumetric shrinkage equal to 9.5%, 4.5% and 13.8%, respectively (Tab. 3).

The coefficient of anisotropy, i.e. the rate of tangential shrinkage over radial shrinkage was also determined by Moura (2000) for *Eucalyptus* wood. The higher this index is from the value of one, the higher will be the propensity of the wood to present warping, cracking and splitting during drying. According to the results of Moura (2000) the average Coefficient of Anisotropy of the wood of ten *Eucalyptus* clones was 1.74, which is lower than that of 2.2 found by Cruz *et al.* (2003).

Tab. 3 Average shrinkage values of seven clones of *Eucalyptus* wood (Cruz *et al.*, 2003)

| Property | Pith to bark variation | | | Average |
|---------------------------|------------------------|--------------|-------|---------|
| | Central | Intermediate | Outer | |
| Radial shrinkage | 3.9 | 4.6 | 5.1 | 4.5 |
| Tangential shrinkage | 9.7 | 10.4 | 8.4 | 9.5 |
| Volumetric shrinkage | 13.5 | 14.6 | 13.4 | 13.8 |
| Coefficient of anisotropy | 2.5 | 2.3 | 1.7 | 2.2 |

Other papers have been published in Brazil on the magnitude and variation of linear and volumetric shrinkages. Most of them reveal similar results to those presented, here, which can be considered as average in magnitude according to the classification proposed by Durlo and Marchiori (1992). According to these authors, examples of other Brazilian species that produce timbers presenting volumetric shrinkage are as follow: *Cedrela fissilis* (Cedro) – VS = 15.7%; *Araucaria angustifolia* (Brazilian Pine) – VS = 17.6%; *Aspidosperma polineuron* (Peroba rosa); *Bowdichia* (Sucupira – VS) = 22.4%. This suggests that fast grown *Eucalyptus* wood cultivated in Brazil, in terms of dimensional stability, may be used as solid wood, both for furniture and building material.

5.2 Mechanical properties of *Eucalyptus* wood

Amongst these properties, compression strength, static bending and hardness are some of the most important. In contrast to wood density, information on the variability of the mechanical properties has been little studied by wood scientists or those involved in tree breeding. Needless to say, knowledge of the wood mechanical properties is required to define the utilization of wood in applications such as furniture and building materials. Despite this requirement, characteristics related to the strength and elasticity of wood are also fundamental, both to the structural stability of trees and safety of manufactured wood products.

Possibly the pioneer document that presents mechanical characteristics of *Eucalyptus* wood in Brazil was published by Brotero (1956). This was around 20 years before the establishment of extensive reforested areas with *Eucalyptus* to serve the large expansion of the steel and pulp and paper industries, initiated in the 1970's. Up to this time it was thought that *Eucalyptus* could be used as a multiple purpose genus, demonstrated by the wide diversity of species cultivated and the early assessment of solid wood properties. Most of those species are no longer cultivated in the country. Actually, in spite of controversies, the tendency in Brazil is to plant a reduced number of species and clones.

A second phase of studies on mechanical properties was from the 1980's up to middle of the 1990's. During this time some research was done on *Eucalyptus* solid wood. A result of this is, for example, values for the mechanical properties of Brazilian-grown *E. grandis* wood were found to be markedly lower than those reported for Australian-grown material (Della Lucia and Vital, 1980). It was suggested that this difference was associated with the lower density and younger age of the Brazilian-grown material ($0.39\text{g} \cdot \text{cm}^{-3}$) c.f. $0.72\text{g} \cdot \text{cm}^{-3}$ as reported for Australian-grown material (Hillis, 1984). Results published by Lima *et al.* (1986) show equations that associate different moisture contents to compression strength parallel to the grain, and the modulus of elasticity in static bending, amongst other mechanical properties of 40-years-old *Eucalyptus saligna* wood. Estimated values of some of these properties are presented in Tab. 4. In general, the values shown in this table for *E. saligna* are higher than those presented in Tab. 5 for the corresponding property. Possibly this is caused by the intrinsic characteristics of the genetic material, but

also by the age of the trees, which in the case of the *E. saligna* is of mature wood that is normally stronger.

Tab. 4 Estimated mechanical properties of 40-years-old *Eucalyptus saligna* wood (Lima *et al.*, 1986)

| Property | Value in MPa at 12 % moisture content |
|--|---------------------------------------|
| Compression strength parallel to the grain | 64 |
| Shear parallel to the grain | 14 |
| Modulus of rupture | 126 |
| Modulus of elasticity in static bending | 11,962 |

Tab. 5 presents a summary of various results found for mechanical characteristics of *Eucalyptus* wood, found by several authors. This wood is from trees planted to serve the requirements of the pulp paper and steel industries. Also, this wood is from fast grown young *Eucalyptus* with a high proportion of juvenile wood. It can be noted in this table that trees originally planted for charcoal produce wood slightly stronger than those for pulp and paper. However, it seems that the differences in terms of mechanical properties are not meaningful.

Tab. 5 Values of mechanical properties found by various authors for *Eucalyptus* wood planted in Brazil

| Genetic material | Age | Mechanical characteristics | Author |
|--|-----------------------|---|-------------------------------|
| Wood originally planted for charcoal | | | |
| 10 <i>Eucalyptus</i> hybrids clones | 9-years-old | CS = from 49 to 61; MOE _c = from 6,978 to 11,943 MOR = from 89 to 116; MOE _b = from 15,491 to 19,947 | Moura, 2000 |
| 44 <i>Eucalyptus</i> genotypes | 13 to 17-years-old | MOR = from 97 to 143 MOE _b = from 13,924 to 24,015 | Caixeta, 2000 |
| 7 <i>Eucalyptus</i> clones | 5.5 to 10.5-years-old | CS = 40 to 52; MOE _c = 6,590 to 8,993; MOR = 78 to 108; MOE _b = 8,768 to 19,670 | Cruz <i>et al.</i> , 2003 |
| 7 <i>Eucalyptus</i> clones | 8-years-old | JH = from 4,290 to 5,962; CS = from 45 to 57; MOE _c = from 7,357 to 9,521; MOR = from 91 to 115; MOE _b = 6,139 to 7,576 | Padilha <i>et al.</i> , 2005 |
| Wood originally planted for pulp and paper | | | |
| 26 <i>Eucalyptus</i> clones | 8-years-old | CS = 42 (B); CS = 45 (T); MOR = 67 (B); MOR = 67 (T); MOE _b = 7,660 (B); MOE _b = 8,338 (T) | Lima <i>et al.</i> , 1999 |
| 26 <i>Eucalyptus</i> clones | 8-years-old | MOR = 90 (B); MOR = 91 (T); MOE = 9,386 (B); MOE = 10,121 (T); JH = 4,784 (B); JH = 4,260 (T) | Lima <i>et al.</i> , 2000 |
| 5 <i>Eucalyptus</i> clones | 8-years-old | CS = from 49 to 69; MOE _c = from 8,367 to 11,221 | Lima <i>et al.</i> , 2000 |
| 4 <i>Eucalyptus</i> clones and one progeny | 12.9-years-old | CS = from 51 to 62; MOR = from 99 to 111 MOE _b = from 6,932 to 7,914 JH = from 5,501 to 7,404 | Oliveira <i>et al.</i> , 2001 |
| 4 <i>Eucalyptus</i> hybrids clones | 2-years-old | CS = 49 (flat terrain) CS = 54 (sloped terrain) MOE _c = 7,374 (flat terrain) MOE _c = 8,057 (sloped terrain) MOR = 92 (flat terrain) MOE _b = 99 (sloped terrain) | Melo, 2004 |

Note: CS = compression strength parallel to the grain, MPa; MOR = modulus of rupture in static bending, MPa; MOE_b = modulus of elasticity in static bending, MPa; MOE_c = modulus of elasticity in compression strength, MPa; JH = Janka hardness, N. (B) – specimens sampled in the first 3 m long basal log; (T) – specimens sampled in the second 3 m long basal log.

It can be observed in Tab. 5 and in Tab. 6 that mechanical property values increased from inner to outer wood. According to Lima (1999) discussing these results, small variations in the anatomical characteristics

correspond to moderate variations in nominal density and higher variations in the mechanical properties. This suggests that other factors might be negatively affecting the mechanical properties in the centre of the log. Some indications of the existence of such factors were the occurrence of compression failure (brittle failure) in the inner wood and the noted higher number of brash type failures for wood from this region during the bending test. According to him, the presence also of shorter fibres (for example) in the inner wood might have a weak influence on density but a pronounced effect on mechanical properties. Tab. 5 shows that mechanical properties vary more than nominal density or anatomical characteristics when observations are made from the inner to the outer regions of the log.

Variations in the properties in the base-top direction were proportionally smaller than those observed from the pith to bark (Tab. 6). It is possible that the higher spirality observed in the base of a log has somewhat contributed to reducing the values of modulus of rupture and modulus of elasticity at that position. It was observed that, contrary to nominal density, the magnitude of these properties was higher at the top than at the base of the log. Based on the relationships observed for wood from the basal bolt it may be expected that in the top bolt slightly longer and thicker fibres will be found.

Tab. 6 Radial (from inner wood to outer wood) and longitudinal (from base to top) variation in wood characteristics of 26 *Eucalyptus* clones (Lima, 1999)

| Characteristic | From inner to outer region | From basal to top position |
|--|----------------------------|----------------------------|
| Nominal density | + 22.5 | -4.3 % |
| Modulus of rupture | + 50.4 | +1.0 % |
| Modulus of elasticity | + 35.5 | + 9.0 % |
| Compression strength parallel to grain | + 41.1 | + 3.3 % |
| Janka hardness | + 48.3 | -11.7 % |

Note: The signs (+) and (-) signify that there is an increase or reduction, respectively, for the property.

5.3 Growth stresses

Growth stresses represent a limiting factor for the use of fast grown *Eucalyptus* logs for sawing. They are related to tree growth, but affect the log break-down yield, drying and machinability, due to the production of deformation and splitting during the respective processes. They are self-generated in early-formed wood during cell maturation. Both the quantification and measurement of these stresses in *Eucalyptus* trees still need much research in Brazil. Due to the importance of these characteristics, a presentation specifically on growth stresses in *Eucalyptus* in Brazil will be given in this conference. Those who need more information on the work carried out on this subject in *Eucalyptus* in Brazil must look for the paper by Trugilho *et al.* (2005).

6 FINAL CONSIDERATIONS

The values for the physical and mechanical properties of *Eucalyptus* wood planted in Brazil for charcoal or pulp and paper production, have shown that they can be considered to be adequate for the production of solid wood. These characteristics are similar to those presented by several tropical wood types commonly utilised in Brazil. However, there are still some serious problems to be solved, both related to the independent information about fundamental wood characteristics as related to the industrial processing of this wood. There is another aspect that is related to the genetic base, necessary to the dynamism of the cultivation of new materials. This

base has been gradually narrowed. Due to this aspect it is important to recommend the establishment and maintenance of new clonal tests, specifically selected for solid wood production.

If wood produced by trees at age 10 to 20-years is shown to be adequate for furniture or building material, it is possible that in the near future, *Eucalyptus* wood will perform much better. Research and development is the key for this process.

REFERENCES

- Acosta M S. 1995. Experiencia Argentina en el uso de la madera de eucalipto. In: Seminário Internacional de Utilização da Madeira de Eucalipto Para Serraria. IPEF-IPT-UFRO, São Paulo, Brasil, Proceeding: 74-91
- Barrichelo L E G, Brito J O, Migliorini A J. 1983. Estudo da variação longitudinal da densidade básica de *Eucalyptus* spp. In: Congresso Florestal Brasileiro, 4. Silvicultura, São Paulo, 8(28):726-731
- Bertolucci F L G, Penchel R M. 1993. Clonagem do eucalipto: efeitos sobre a produtividade e qualidade da madeira. *Ciência Hoje* (suplemento), 16:16-21
- Brasil M A M, Ferreira M. 1979. Características das fibras da madeira de *Eucalyptus grandis* Hill (ex-Maiden), aos 3 anos de idade. IPEF, 19:80-97
- Brotero F A. 1956. Métodos de ensaios adotados no I.P.T. para o estudo de madeiras nacionais. Instituto de Pesquisas Tecnológicas, São Paulo, 2nd edition, 62. (Technical Bulletin, 31)
- Caixeta R P. 2000. Propriedades da madeira de *Eucalyptus*: Classificação e seleção de genótipos utilizando marcador molecular e análise multivariada. Universidade Federal de Lavras, Lavras, MG. 89
- Carpim M A, Barrichelo L E G. 1983. Variabilidade da densidade da madeira de *Eucalyptus*. In: ABCP 16th Annual Meeting- 3rd Latin-American Cellulose and Paper Congress, São Paulo, 127-137
- Cruz C R, Lima J T, Muniz G I B. 2003. Variações dentro das árvores e entre clones das propriedades físicas e mecânicas da madeira de híbridos de *Eucalyptus*. *Scientia Forestalis*, Piracicaba, 64, (1): 33-47
- Della Lucia R M, Vital B R. 1983. Propriedades físicas da madeira de três regiões do tronco de *Eucalyptus saligna* Sm. *Revista Árvore*, 7(1):71-75
- Della Lucia R M, Vital B R. 1980. Características físicas e mecânicas da madeira de *Eucalyptus grandis* W. Hill ex Maiden. *Revista Árvore*, 4(1):70-74
- Downes G M, Hudson I L, Raymond C A, Dean G H, Michel A J, Schimeleck L R, Evans R, Muneri A. 1997. Sampling plantation eucalypts- for wood and fibre properties. Collingwood, Australia; CSIRO Publishing, 132
- Durlo M A, Marchiori J N C. 1992. Tecnologia da madeira: retratibilidade. Santa Maria: UFSM/CEPEF, 33 (Série Técnica, 10)
- Eldridge K, Davidson J, Harwood C, Van Wik G. 1993. *Eucalypt* domestication and breeding. Oxford: Oxford University Press, 288
- Ferreira M. 1972. Variação da densidade básica da madeira de povoamentos comerciais de *Eucalyptus grandis* W. Hill ex-Maiden nas idades de 11, 12, 13, 14 e 16 anos. IPEF, Piracicaba, (4): 65-89
- Gerard M J. 1994. Contraintes de croissance, variations internes de densité et de module d'élasticité longitudinal, et deformations de sciage chez les *Eucalyptus* de plantation. L'Université de Bordeaux I. 160. Ph.D. Thesis.
- Hillis W E, Brown A G. 1984. *Eucalypts for wood production*. Sydney: Academic Press 434
- Lima J T. 1995. The wood density of three *Eucalyptus saligna* Smith clones in relation to age. *Annales Des Sciences Forestieres*, Paris, 52, (4): 347-352
- Lima J T, Rosado S C S, Oliveira A D. 1992. Variação da densidade da madeira de *Eucalyptus grandis*, *E. tereticornis* e *E. camaldulensis* no sentido longitudinal dos caules. *Revista Ciência e Prática*, 16:123-127
- Lima J T, Breese M C, Cahalan C M. 2000. Genotype-environment interaction in wood basic density of *Eucalyptus* clones. *New York: Wood Science and Technology*, 34, (3): 197-206
- Lima J T, Rosado S C S, Trugilho P F. 2001. Assessment of wood density of seven clones of *Eucalyptus grandis*. *Southern African Forestry Journal*, Pretoria, 191, 21-27
- Lima J T. 1999. Clonal variation in the solid wood properties of *Eucalyptus*. - Bangor: University of Wales, (PhS Thesis) 276
- Lima J T, Breese M C, Cahalan C M. 1999. Variation in compression strength parallel to the grain in *Eucalyptus* clones. In: Proceedings of The Fourth International Conference on The Development of Wood Science, Wood Technology And Forestry, High Wycombe, Inglaterra, 502-510
- Malan F S. 1995. *Eucalyptus* improvement for lumber production. In: Seminário Internacional de Utilização da Madeira de Eucalipto Para Serraria. IPEF-IPT-UFRO, São Paulo, Brasil, Proceeding: 1-19
- Melo V M. 2004. Variações nas propriedades da madeira de clones de *Eucalyptus* cultivados em diferentes topografias sujeitos a tempestades. Universidade Federal de Lavras, Lavras, MG. (Master Science dissertation)
- Mori C L O. 2003. Variabilidade de cores em madeiras de clones de híbridos de *Eucalyptus* spp. 64 - Universidade Federal de Lavras, Lavras, MG. 115. (Master Science dissertation)
- Moura M C O. 2000. Variações em características do crescimento e da madeira em clones de *Eucalyptus*. 63. - Universidade Federal de Lavras, Lavras, MG. (Master Science dissertation)
- Oliveira L J R. 2001. Uso do Pilodyn para a estimativa da densidade básica e propriedades mecânicas da madeira de eucalipto. Universidade Federal de Lavras, Lavras, MG. 62. (Master Science dissertation)

- Padilha C. 2005. Avaliação da qualidade da madeira de *Eucalyptus* sp. para a utilização em pisos. Universidade Federal de Lavras, Lavras, MG. 59. (Master Science dissertation)
- Pandey D. 1995. Forest resources assessment 1990, tropical countries. Forestry paper, 112, Rome 61
- Rosado S C S, Brune A, Oliveira L M. 1983. Avaliação da densidade básica da madeira de árvores em pé. Revista *Árvore*, Viçosa - MG, 7, (2):147-153
- Shimoyama V R S. 1991. Variações da densidade básica da madeira e características anatômicas e químicas da madeira em *Eucalyptus* spp. ESALQ/USP, M.Sc. Thesis, 93
- Souza A J. 1992. Implantação e manutenção de reflorestamento com eucalipto. In: Simpósio Brasileiro Sobre Reflorestamento, Vitória da Conquista, Brazil, Proceedings. (No Published)
- Souza M A M. 2002. Deformação residual longitudinal (DRL) causada pelas tensões de crescimento em clones de híbridos de *Eucalyptus*. Universidade Federal de Lavras, Lavras, MG, 72. (Master Science dissertation).
- Teixeira M L, Vargas Filho R. 1994. Estudo da variabilidade da madeira de *E. grandis* ao longo do tronco e sua influência nas características do carvão vegetal. Revista *Ciência e Prática*, Lavras, 18, (1): 90-98
- Trugilho P F, Lima J T, Rosado S C S. 2005. Assessment of growth stresses in *Eucalyptus* trees and their relationship with the characteristics of growth and some wood properties. Zhanjiang, Guangdong, China. In: International Conference on Plantation *Eucalyptus*: Challenge in Product Development
- Valente C A, Mendes A P S, Furtado F P, Carvalho A P. 1992. Improvement program for *Eucalyptus globulus* at Portucel: Technological component. *Appita Journal*, 45, 403-407
- Vital B R, Della Lucia R M. 1987. Efeito do espaçamento na produção e na qualidade da madeira de *Eucalyptus grandis* e *Eucalyptus urophylla* aos 52 meses de idade. Revista *Árvore*, 11, 132-145
- Zobel B J, Van Buijtenen J P. 1989. Wood variation- its causes and control. Berlin: Springer Verlag, 363

Assessment of Growth Stresses in *Eucalyptus* Trees and Their Relationship with the Characteristics of Growth and Some Wood Properties

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ABSTRACT

The objective of this work was to evaluate the longitudinal growth stresses in *Eucalyptus* clones; to verify their variability; to estimate the correlation between the longitudinal growth stress and the growth characteristics of the trees and to estimate the correlation between growth stress and wood characteristics. According to the results it was observed that the effect of the clone was highly significant, indicating high genetic variability. The average estimated longitudinal growth stress was equal to $279 \text{ kgf} \cdot \text{cm}^{-2}$, varying from 112 to $433 \text{ kgf} \cdot \text{cm}^{-2}$. The correlation between growth stress and growth characteristics of the trees was not significant, nor was the correlation between growth stress and wood lignin content. Longitudinal growth stress presented positive and significant correlation with lumber split, basic density, grain angle, volumetric, radial and tangential shrinkage and cleavage strength.

1 INTRODUCTION

The genus *Eucalyptus* presents expressive diversity in species with adaptability to diverse environments. This results in high productive capacity, which makes the genus an important source of raw material, able to meet several industrial technological requirements. On the other hand, wood of this genus presents, in general, inherent adverse characteristics that jeopardize its utilization for higher-level product requirements. Thus, in spite of the advantageous silvicultural characteristics, these technological characteristics frequently present restrictions for the utilization of *Eucalyptus* by the wood industries.

Warping and splitting in logs and in lumber represent the most important limitations for utilization of *Eucalyptus* as solid wood. Both defects are caused mainly by growth stresses, representing the main cause of reduction of sawmilling productivity. Growth stresses are present in the tree before its felling and act as a way to promote its stability (Van Wyk, 1978). The growth stresses in the tree are in equilibrium, but as soon as it is cut and this state of balance is modified, log deformations and end splits do occur (Ferrand, 1983). Thus, the peripheral zone of the log which is under tension stress, tends, following cross-cutting, to be shortened while the central zone, under compression stress, to be elongated, which causes the end splits in the logs (Malan, 1979).

The causes of the high level of growth stresses are not well known, but there exist suggestions that they are related to such genetic factors as age, stem dimensions, growth rate and stem leaning (Opie *et al.*, 1984).

Growth stress can be determined in the stem of the standing tree or in logs after felling the trees.

Several methods, with different levels of difficulty, are employed to estimate stress. Most of the methods utilize measurement of the change in length of wood pieces, following the release of junctions in neighbouring tissues within the tree stem (Lisboa, 1993). Others, similarly, are based on the measurement of strain caused by perforations directly produced in logs or stems. This strain is directly related to growth stresses, especially the longitudinal component of growth stress that is developed along the stem. Some studies have assessed the relationship between longitudinal growth stress and the intrinsic characteristics of wood (Nicholson *et al.*, 1972; Nicholson and Hillis, 1975; Fernandes, 1982).

The objectives of this study is to verify the variation of the longitudinal growth stresses in *Eucalyptus* clones and to determine their correlation with both physical and mechanical wood characteristics and tree dimensions.

2 MATERIAL AND METHODS

Eleven six-year-old natural *Eucalyptus* hybrid clones were utilized in this study. The clones originated from a clonal trial, established at the spacing of 10 m × 4 m, under an agroforestry system, where, in the first year rice was planted, in the second year soybean, and from the third year pasture was planted for cattle. The clonal trial was installed at the Riacho Farm, which belongs to the Companhia Mineira de Metais (VM-AGRO) of the group Votorantim, in the Paracatu region, Northwest of Minas Gerais State, Brazil. The area is located at 17°36'09" latitude South, and 46°42'42" longitude West and at 550 meters altitude. In accordance with the classification of Köppen, the climate is Aw - tropical moist savanna, with dry winter and rainy summer. The average annual temperature is 24°C and the average annual precipitation is 1,450 mm.

The clones were initially classified according to their growth: three clones of higher volumetric productivity; four clones of mean productivity and four clones of lower productivity. From each clone three trees were selected and measured. In addition, it was required that all trees sampled have good stem shape, absence of stem bifurcation and absence of disease. Boundary trees were not selected.

The diameter at breast height (DBH), total height (TH) and annual average increments (AAI) for each clone were determined. The volume of individual trees was determined by Smalian formula.

To calculate the annual average increments (AAI) a correction factor ($F_c = 0.43$) was adopted, since the volume calculation was executed only up to 9.30 m high in the tree, leaving a considerable volume out of the calculation, representing the top of the tree.

The longitudinal residual strain (LRS) and the grain deviation were determined at the standing tree, i.e., before felling the tree, at the DBH and at 3 m height in the stem. The measurements were performed on the North, South, East and West faces of the stem. For the measurement of LRS, an extensometer CIRAD FORÊT was utilized and the grain deviation was determined with the help of a scriber. Following the measurements, the trees were felled and sampled for wood characteristics determination according to the scheme of Fig. 1.

For the analysis, two bolts 60 cm long were collected from each tree, one of them cut at the DBH and the other around 3.0 m height in relation to ground level (Fig. 1). These two bolts were transported to the Wood Technology Laboratory of the Universidade Federal de Lavras (UFLA) for the determination of the wood properties.

Basic density, anhydride density and shrinkage were the wood physical characteristics studied in this work. For the determination of density and shrinkage, the same specimens were utilized. They were prepared with dimensions of 2.5 cm × 2.5 cm × 2.5 cm and labelled to identify the tree, the longitudinal position and

the clones from where they came. These samples were soaked in water to achieve maximum moisture content. In the determination of the volumes by the method of immersion, both in the saturated and in the oven dry condition, liquid mercury was used. Oven-dried weights of the samples were also determined.

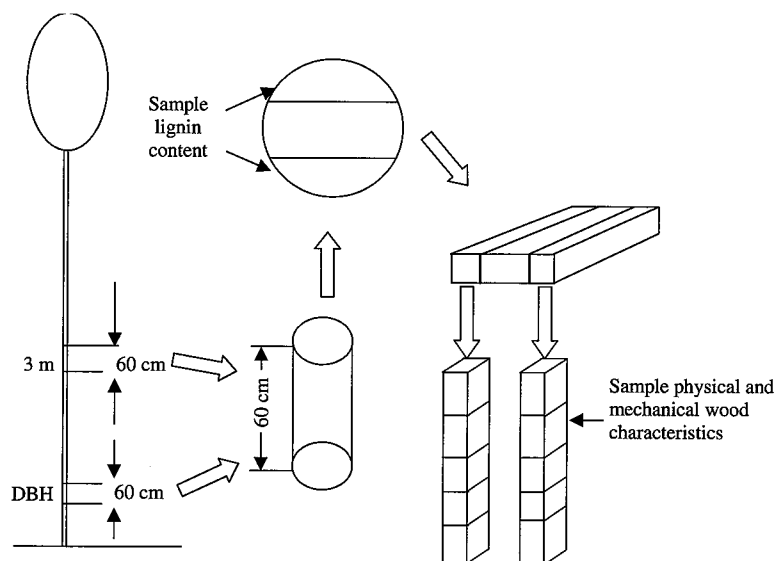


Fig. 1 Sampling in the tree for determination of the chemical, physical and mechanical wood characteristics

The study of the wood dimensional stability was based on ASTM D143-94 (American Society for Testing and Materials-ASTM, 1997) procedures. The measurements of the tangential and radial dimensions were made directly on the sample using a digital calliper, with 0.01 mm of accuracy.

The insoluble lignin content (Klason) was determined in accordance to the method described by Gomide and Demuner (1986). The insoluble lignin content in sulphuric acid was determined by spectrophotometry, applying the equation described by Goldschimid (1971). The total lignin was considered as the sum of both soluble and insoluble lignin content. The samples used for these analyses were removed from the slabs obtained from each bolt, as shown in the Fig. 1 These pieces were cleaned on the surface to avoid contamination of the samples by fungi, oil and dust Using a plane, shavings were collected and ground in a Wiley grinder. After that they were classified in both 40 and 60 mesh sieves. For the analyses the fraction restrained in the 60 mesh sieve was used.

Tension parallel to the grain (strength and modulus of elasticity) and cleavage strength were determined as mechanical properties. The tests were carried out in the Emic DL 30,000 testing machine in accordance with Standard Methods of Testing Small Clear Specimens of Timber D 143-94 (ASTM, 1997). Details of the tests are presented in Tab. 1.

Tab. 1 Summary of the conditions of the tests (D143-94, ASTM, 1997)

| Test | Property | Test speed(mm · min ⁻¹) |
|--|-----------------------|-------------------------------------|
| Parallel to the grain tension strength | Strength | 1.0 |
| | Modulus of elasticity | 1.0 |
| Cleavage | Strength | 2.5 |

Before the tests, the specimens were conditioned in a climatization room at (20±3) °C and 60% relative humidity to achieve constant weight over a period of two months. The samples stabilised at about 12% moisture content. The data of the measured characteristics were presented as the average value obtained in

the two positions of measurement.

The rest of the material was transported as logs, as shown in Fig. 2, for immediate conversion to sawn lumber at the VM Sawmill. The method of conversion consisted of cutting two slabs using twin circular saws, which produced a central cant. This piece was then processed to sawn lumber using a multiple circular saw. The sawn lumber was produced in the dimensions of 12.0 cm × 2.0 cm and length in accordance with the position of the log. The longest split in each end of each piece was measured and marked. To solve the problem of the different lengths of the logs, the split index was determined, utilizing the average value in accordance with the equation:

$$IS(\%) = \frac{\sum_{i=1}^n C_i}{\sum_{j=1}^m L_j} \times 100$$

where

IS(%) = index of splitting in percentage;

C_i = length of the longest split, in each end of the n lumber pieces obtained from the m logs;

L_j = length of the lumber of the m logs.

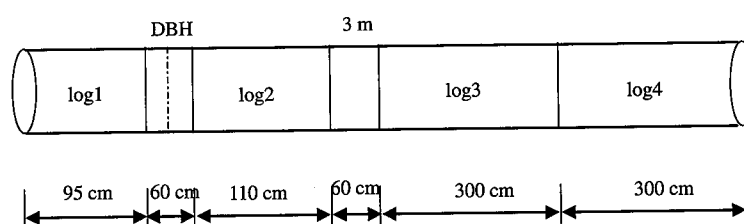


Fig. 2 Scheme of the bolts removal for determination of the wood properties and logs breakdown

The results were assessed using the randomized completely experimental design, with three replicates (sampled tree). Also, determination of the simple correlation was made between the longitudinal residual strain (LRS) and both the growth and wood characteristics.

3 RESULTS AND DISCUSSION

The average values for growth, longitudinal residual strain (LRS), index of splitting of lumber (IS) and grain deviation, for the *Eucalyptus* clones are presented in Tab. 2.

Average LRS of the standing trees, caused by the growth stresses in the studied clones was 0.090 mm (Tab. 2). This value is higher than that found by Lima *et al.* (2003) (0.071 mm), working with *Eucalyptus* clones of different ages and by Muneri *et al.* (2000), who obtained LRS equal to 0.077 mm. for four-year-old *E. cloeziana*. Clone 2 (LRS = 0.059 mm) presented the lowest LRS, while clone 10 presented the highest (0.145 mm). It can be observed in Tab. 2 that clone 2 did not present the highest annual average increment (AAI), nor clone 10 the smallest, suggesting that this property was not influenced by the growth rate.

The lumber splits varied between 4.1% and 19.8%, that is, respectively associated to the clones 1 and 10. The average value was equal to 9.2%, which is smaller than that found by Caixeta (2000), in *Eucalyptus*, with ages varying from 13 to 17 years.

The highest values of grain deviation occurred in clones 1 (GD = 4.1°) and 10 (GD = 4.0°), while the smallest grain deviation was observed in clone 6 (GD = 1.8°). These values were higher than those found by Lima *et al.* (2001), studying 8-years-old *Eucalyptus* clones.

Tab. 2 Average values for growth characteristics, longitudinal residual strain (LRS), index of splitting (IS) of lumber and grain deviation

| Clone | LRS (mm) | IS (%) | GD (°) | DBH (cm) | TH (m) | AAI (st · ha ⁻¹ · yr ⁻¹) |
|---------|----------|--------|--------|----------|--------|---|
| 1 | 0.073 | 4.1 | 4.1 | 24.5 | 26.9 | 32.6 |
| 2 | 0.059 | 10.1 | 3.1 | 31.1 | 28.5 | 49.1 |
| 3 | 0.120 | 17.1 | 3.8 | 27.6 | 30.8 | 51.2 |
| 4 | 0.109 | 7.2 | 2.6 | 26.7 | 26.7 | 40.3 |
| 5 | 0.080 | 6.3 | 3.1 | 25.8 | 29.3 | 42.9 |
| 6 | 0.069 | 4.8 | 1.8 | 26.8 | 30.0 | 47.0 |
| 7 | 0.073 | 7.6 | 2.8 | 30.7 | 30.6 | 53.2 |
| 8 | 0.087 | 9.8 | 2.0 | 28.9 | 31.4 | 54.7 |
| 9 | 0.096 | 9.3 | 3.3 | 27.9 | 25.9 | 43.2 |
| 10 | 0.145 | 19.8 | 4.0 | 26.2 | 29.5 | 40.9 |
| 11 | 0.078 | 5.3 | 2.5 | 25.0 | 27.0 | 38.0 |
| Average | 0.090 | 9.2 | 3.0 | 27.3 | 28.8 | 44.8 |

DBH = diameter at breast height; TH = total height of the tree; AAI = annual average increment; GD = grain deviation.

The average DBH was 27.3 cm, with clone 1 presenting the smallest value (DBH = 24.5 cm) and clone 2 the highest (DBH = 31.1 cm). The average total height (TH) was 28.8 m, while the annual average increment (AAI) was 44.8 st · ha⁻¹ · yr⁻¹. The highest and smallest AAI were observed for clone 8 (54.7 st · ha⁻¹ · yr⁻¹) and clone 1 (32.6 st · ha⁻¹ · yr⁻¹), respectively.

Tab. 3 presents the average values for the evaluated characteristics of the wood clones. Wood density (specific gravity) is one of the most studied wood properties, due to the facility for its determination, its technological importance and its relationship with other wood characteristics. The average wood basic density of the studied clones was 0.508 g · cm⁻³ and the average dry density was 0.594 g · cm⁻³. Clone 10 presented the highest average, both for basic density (0.576 g · cm⁻³) and for dry density (0.704 g · cm⁻³). The average basic density is in concordance with the values found by Cruz (2000), however it was smaller than those obtained by Silveira (1999) (not referenced), for *Eucalyptus* clones.

Tab. 3 Average values obtained for wood characteristics of six-year-old *Eucalyptus* clones

| Clone | Wood Characteristics | | | | | | | | | | | |
|---------|----------------------------|----------------------------|--------|--------|--------|------|-------------|------------|-----------|--------|--------|--------|
| | BD (g · cm ⁻³) | AD (g · cm ⁻³) | VS (%) | TS (%) | RS (%) | CA | Cleav (MPa) | Tens (MPa) | MOE (MPa) | LI (%) | LS (%) | LT (%) |
| 1 | 0.511 | 0.592 | 13.6 | 8.6 | 5.0 | 1.7 | 0.613 | 103 | 13,790 | 25.4 | 2.3 | 27.7 |
| 2 | 0.421 | 0.483 | 12.8 | 8.2 | 3.8 | 2.2 | 0.468 | 96 | 10,321 | 27.3 | 2.0 | 29.3 |
| 3 | 0.512 | 0.604 | 15.1 | 9.8 | 5.0 | 2.0 | 0.603 | 147 | 15,169 | 23.7 | 2.4 | 26.1 |
| 4 | 0.501 | 0.578 | 13.3 | 8.7 | 4.4 | 2.0 | 0.517 | 102 | 10,756 | 29.6 | 2.1 | 31.7 |
| 5 | 0.556 | 0.656 | 15.2 | 9.5 | 6.1 | 1.6 | 0.604 | 160 | 15,887 | 26.2 | 2.3 | 28.5 |
| 6 | 0.541 | 0.629 | 13.9 | 8.7 | 5.0 | 1.8 | 0.611 | 119 | 13,133 | 27.8 | 2.4 | 30.2 |
| 7 | 0.462 | 0.536 | 14.0 | 9.0 | 4.5 | 2.4 | 0.573 | 106 | 12,252 | 24.7 | 2.3 | 27.0 |
| 8 | 0.509 | 0.591 | 13.9 | 8.2 | 5.2 | 1.6 | 0.600 | 151 | 14,229 | 26.8 | 2.6 | 29.4 |
| 9 | 0.493 | 0.568 | 13.0 | 8.1 | 4.7 | 1.7 | 0.495 | 134 | 16,043 | 23.2 | 2.2 | 25.4 |
| 10 | 0.576 | 0.704 | 18.0 | 11.8 | 6.3 | 1.9 | 0.689 | 127 | 13,668 | 25.8 | 2.4 | 28.2 |
| 11 | 0.512 | 0.596 | 14.0 | 8.7 | 5.1 | 1.7 | 0.560 | 147 | 16,658 | 27.0 | 2.4 | 19.4 |
| Average | 0.508 | 0.594 | 14.2 | 9.0 | 5.0 | 1.87 | 0.526 | 126 | 13,810 | 26.1 | 2.3 | 27.5 |

BD = basic density; AD = dry density; VS, TS and RS = volumetric, tangential and radial shrinkage, respectively; CA = coefficient of anisotropy; Cleav = cleavage strength, Tens = parallel strength tension; MOE = modulus of elasticity in parallel tension; LI, LS and LT = insoluble, soluble and total lignin content, respectively.

The variation of the dimensions of a wood piece caused by its hygroscopicity can jeopardize and even disqualify it for some end-uses, causing, in some cases, its substitution by other materials. Clone 10 presented the highest average volumetric shrinkage, radial shrinkage and tangential shrinkage: 18.0%, 6.3% and 11.8%, respectively. On the other hand, clone 2 presented the lowest averages for these three characteristics: 12.8% (volumetric shrinkage), 3.8% (radial shrinkage) and 8.2% (tangential shrinkage), indicating that this clone has preferred potential to be used for solid wood products, contrary to clone 10. These results are in concordance with those found for *Eucalyptus* clones by Moura (2000).

The average coefficient of anisotropy, which means the rate between tangential shrinkage and radial shrinkage, was highest for clone 7 (2.4), while both clones 5 and 8 presented the lowest averages, 1.6. The average between clones was 1.87, close to the value found by Xavier (2001), equal to 1.81 and slightly higher than the CA = 1.74 found by Moura (2000).

Average tension strength parallel to the grain was 126 MPa. Clone 5 presented the highest (160 MPa) and clone 2 presented the lowest (96 MPa) values for tension strength. The average modulus of elasticity in parallel tension was 13,810 MPa (Tab. 4). These values are in accordance with those obtained by Xavier (2001) and Moura (2000). Lima (1999) relates that these clones can be classified as having average strength properties.

The average cleavage strength was equal to 0.575 MPa. Clones 1 and 2 were those that presented the highest and lowest averages values, equivalent to 0.613 and 0.468 MPa, respectively (Tab. 4). These values are in concordance with those listed by Mainieri (1978), for Brazilian tropical wood with similar basic densities to those found in this work.

Tab. 3 provides the results for the average values of insoluble, soluble and total lignin contents for the studied clones. Clone 4 showed the highest average value for insoluble lignin (29.6%), while clone 9 gave the lowest value (23.2%). The soluble lignin average was 2.3%, varying from 2.0% to 2.6%. Total lignin content changed from 25.4% to 31.7%, with an average of 28.4%. This value is slightly higher than that found by Trugilho *et al.* (1996), for *Eucalyptus saligna* of different ages. However, this value is within of the variation normally found in *Eucalyptus* wood.

Tab. 4 presents the correlation matrix between the longitudinal residual strain (LRS) and the growth characteristics of the trees. According to this table it can be observed that these correlations are weak, indicating an independence between these characteristics. This result also suggests that the longitudinal growth stresses, derived from LRS, are not affected by the growth characteristics. AAI is not an independent variable, therefore should not be included in the analysis.

Tab. 4 Matrix of phenotypic correlation between longitudinal residual strain (LRS), diameter at breast height (DBH), and total height (TH)

| | LRS | DBH | TH |
|-----|-----|---------|--------|
| LRS | 1 | -0.26ns | 0.10ns |
| DBH | | 1 | 0.42ns |
| TH | | | 1 |

ns: non significant.

Tab.5 presents the correlation values between LRS and the evaluated wood characteristics. Longitudinal residual strain (LRS) showed a significant coefficient ($r = 0.68$) with the index of splitting of lumber. This result indicates that through the measurement of LRS in the tree it is possible to anticipate the tendency of the lumber to crack. The value of the coefficient of correlation was relatively low possibly due to factors

such as the effect of the clone, different dimensions of the lumber and its relative position within the log, in this case considering that LRS is measured in the peripheral region of the log. Perhaps if the lumber was removed only from the outside of the log, the correlation between the index of splitting and LRS could tend to be stronger. Also, it was observed that LRS has positive and significant correlation with grain deviation (0.34), basic density (0.52), dry density (0.58), volumetric shrinkage (0.69), radial shrinkage (0.46), tangential shrinkage (0.71) and cleavage strength (0.40). These results are in accordance with those found by Nicholson and Hillis (1975) and by Fernandes (1982). Lima *et al.* (2003) also found positive and significant correlation between LRS and basic density (0.53) for natural hybrids of *Eucalyptus*. LRS did not show any correlation with the coefficient of anisotropy, parallel tension strength, modulus of elasticity or lignin content. The lack of correlation with lignin content found in this work is different from the results found by Nicholson *et al.* (1972), working with 30-years-old *Eucalyptus regnans*.

Tab. 5 Values of simple correlations between wood characteristics

| | LRS | GD | IS | BD | AD | VS | RS | TS | CA | Cleav | Tens | MOE | LI | LS | LT |
|-------|-----|-------|--------|--------|--------|--------|--------|--------|---------|---------|---------|---------|---------|---------|---------|
| LRS | 1 | 0.34* | 0.68** | 0.52** | 0.58** | 0.69** | 0.46** | 0.71** | -0.04ns | 0.40** | 0.24ns | 0.17ns | -0.12ns | 0.17ns | -0.11ns |
| GD | | 1 | 0.31* | 0.14ns | 0.19ns | 0.33* | 0.15ns | 0.40* | 0.16ns | 0.23ns | -0.06ns | 0.12ns | -0.43** | 0.02ns | -0.43** |
| IS | | | 1 | 0.15ns | 0.24ns | 0.53** | 0.16ns | 0.51** | 0.16ns | 0.21ns | 0.12ns | -0.02ns | -0.29* | 0.11ns | -0.28ns |
| BD | | | | 1 | 0.99** | 0.73** | 0.87** | 0.64** | -0.52** | 0.71** | 0.43** | 0.43** | -0.04ns | 0.33* | -0.01ns |
| AD | | | | | 1 | 0.82** | 0.89** | 0.73** | -0.47** | 0.74** | 0.42** | 0.40* | -0.07ns | 0.33* | -0.03ns |
| VS | | | | | | 1 | 0.81** | 0.93** | -0.18ns | 0.72** | 0.28ns | 0.22ns | -0.18ns | 0.24ns | -0.15ns |
| RS | | | | | | | 1 | 0.70** | -0.59** | 0.70** | 0.44** | 0.42** | -0.20ns | 0.32* | -0.17ns |
| TS | | | | | | | | 1 | 0.02ns | 0.71** | 0.17ns | 0.06ns | -0.13ns | 0.15ns | -0.12ns |
| CA | | | | | | | | | 1 | -0.20ns | -0.36* | -0.37* | 0.02ns | -0.18ns | 0.00ns |
| Cleav | | | | | | | | | | 1 | 0.23ns | 0.20ns | -0.12ns | 0.42** | -0.08ns |
| TRA | | | | | | | | | | | 1 | 0.74** | -0.18ns | 0.44* | -0.13ns |
| MOE | | | | | | | | | | | | 1 | -0.43** | 0.29* | -0.40* |
| LI | | | | | | | | | | | | | 1 | 0.00ns | 0.99** |
| LS | | | | | | | | | | | | | | 1 | 0.00ns |
| LT | | | | | | | | | | | | | | | 1 |

LRS = longitudinal residual strain; GD = grain deviation; IS = index of splitting of lumber; BD = basic density; AD = dry density; VS, TS and RS = volumetric shrinkage, tangential shrinkage and radial shrinkage, respectively; CA = coefficient of anisotropy; Cleav = cleavage strength, Tens = parallel tension strength; MOE = modulus of elasticity in parallel tension; LI, LS and LT = insoluble lignin content, soluble lignin content and total lignin content, respectively. * significant at 5% of probability; ** significant at 1% of probability; ns: non significant by the F test.

The grain deviation showed significant and positive correlation with the index of splitting (0.31), volumetric shrinkage (0.33) and tangential shrinkage (0.40) and was negative with the insoluble and total lignin contents (-0.43).

The index of splitting showed positive and significant correlation only with the volumetric shrinkage (0.53) and tangential shrinkage (0.51). With insoluble lignin content the correlation was negative (-0.29). Due to the fact that the correlation between volumetric shrinkage and tangential shrinkage have been high (0.93), any of them can be used to predict the tendency of splitting in lumber.

Basic density and dry density showed significant and positive correlation with shrinkage (VS, RS and TS), but significant and negative with the coefficient of anisotropy. This result is in concordance with the technical literature. However, the level of correlation was higher between the densities and radial shrinkage. The two forms of expression of density correlate significantly and positively with cleavage strength, tension strength parallel to the grain and with the modulus of elasticity.

Volumetric shrinkage, radial shrinkage and tangential shrinkage showed significant and positive correlation with cleavage strength, with coefficients equivalent to 0.72, 0.70 and 0.71 respectively.

In general, the insoluble lignin content and total lignin content did not show significant correlation with the other wood characteristics. However, the correlation of these contents of lignin were significant but negative with the grain deviation and with the modulus of elasticity. The content of soluble lignin showed significant and positive correlation with basic density, dry density, radial shrinkage, cleavage strength and with tension strength and modulus of elasticity in tension parallel to the grain. However, the values were of small magnitude.

4 CONCLUSIONS

1) The longitudinal residual strain (LRS) did not show a correlation with tree growth expressed as diameter at breast height, total height or annual average increment.

2) The correlation between LRS and index of splitting was significant (0.68), which makes that characteristic a reliable tool for the selection of clones less prone to the development of splitting.

3) The LRS showed significant and positive correlation with the basic density, dry density, grain deviation, volumetric shrinkage, radial shrinkage and tangential shrinkage and cleavage strength.

4) There was not an observed correlation between LRS and the contents of insoluble, soluble and total lignin, indicating that the lignin content does not affects the value of LRS.

5) The grain deviation showed a significant and positive correlation with the index of splitting, volumetric shrinkage and tangential shrinkage.

6) The index of splitting showed a significant and positive correlation with volumetric shrinkage and tangential shrinkage, but was negative with insoluble lignin content.

REFERENCES

- American Society for Testing and Materials-ASTM. 1997. Standard Methods of Small Clear Specimens of Timber. In: Annual book of ASTM standards, Danvers. 23-53 (Designation: D 143-94)
- Caixeta R P. 2000. Propriedade da madeira de *Eucalyptus*: classificação e seleção de genótipos utilizando marcador molecular e análise multivariada. 89. Dissertation (Master Science in Forest Production)-Universidade Federal de Lavras, Lavras
- Cruz C R. 2000. Caracterização da madeira de clones de *Eucalyptus* para utilização na indústria madeireira. 64. Dissertation (Master Science in Wood Technology). Universidade Federal do Paraná, Curitiba
- Fernandes P S. 1982. Variações de densidade da madeira e sua relações com as tensões de crescimento em progênies de *Eucalyptus urophylla* S. T. Blake. 85. Dissertation (Máster Science in Wood Science and Technology) - Escola Superior de Agricultura "Luiz de Queiroz", Piracicaba
- Ferrand J Ch. 1983. Growth stresses and silviculture of *Eucalyptus*. Australian Forest Research, Melbourne, 13 (1): 75-81
- Goldschimid O. 1971. Ultraviolet spectra. In: Sarkanen K V, Ludwig C H. Lignins: occurrence, formation, structure and reations. New York: John Wiley and Sons, 241-266
- Gomide J L, Demuner B J. 1986. Determinação do teor de lignina em material lenhoso: método Klason modificado. O Papel, São Paulo, 47 (8): 36-38
- Lima J T, Breese M C, Cahalan C M. 2005. Desvio da grã em madeira de clones de *Eucalyptus*. Revista Scientia Forestalis, Piracicaba. (unpublished)
- Lima J T. 1999. Clonal variation in the solid wood properties of *Eucalyptus*. 276. (PhD Thesis) University of Wales, Bangor
- Lima J T, Trugilho P F, Rosado S C S, Cruz C R. 2003. Deformações residuais longitudinais decorrentes de tensões de crescimento em *Eucalyptus* e suas associações com outras propriedades. Revista Árvore. Viçosa, 28(1):107-116
- Lisboa C D J. 1993. Estudo das tensões de crescimento em toras de *Eucalyptus grandis* Hill ex. Maiden. (Doctorate Thesis)- Universidade Federal do Paraná, Curitiba. 298
- Mainieri C. 1978. Fichas de características das madeiras brasileiras. Piracicaba, Instituto de Pesquisa Tecnológica do Estado de São Paulo – IPT- Divisão de madeira
- Malan F S. 1979. The control and-splitting in saw logs: A short literature review. South African Forestry Journal, Pretoria, 109, 8-14
- Moura M C de O. 2000. Variações em características do crescimento em clones de *Eucalyptus*. Dissertation (Master Science in Forest Production)-

Universidade Federal de Lavras, Lavras. 63

- Muneri A, Knight J, Legate W, Palmer G. 2000. Relationships between surface longitudinal growth strain and tree size, wood properties and timber distortion of 4 year old plantation grown *Eucalyptus cloeziana*. In: Iufro Conference -The Future of Eucalypts for wood products, 2000, Launceston, Austrália, Proceedings Launceston, IUFRO, 292-300
- Nicholson J E, Campbell G S, Bland D E. 1972. Association between wood characteristics and growth stress level: a preliminary study. Wood Science, Madison, 4 (2): 109-112
- Nicholson J E, Hillis W E. 1975. Some tree growth-wood property relationships of Eucalyptus. Canadian Journal Forest Research, Melbourne, 5, 424-432
- Opie J E, Curtin R A, Incoll W D. 1984. *Eucalyptus* for wood production. Melbourne: CSIRO, 434
- Souza M A M. 2002. Deformação Residual Longitudinal (LRS) causada pelas tensões de crescimento em clones de híbridos de *Eucalyptus*. 2002. 72. Dissertation (Master Science in Wood Technology) - Universidade Federal de Lavras, Lavras
- Trugilho P F, Lima J T, Mendes L M. 1996. Influência da idade nas características físico-químicas e anatômicas da madeira de *Eucalyptus saligna*. Revista Cerne Lavras 2 (1): 94-111
- Van wyk J L. 1978. Hardwood sawmilling can have a bright future in South Africa. South African Forestry Journal, Pretoria, 109, 47-53
- Xavier K G. 2001. Divergência genética em clones de Eucalyptus avaliada por marcadores RAPD, e variações nas propriedades da madeira. Dissertation (Master Science in Forest Production) – Universidade Federal de Lavras, Lavras. 107

Longitudinal Growth Stress In *Eucalyptus Dunnii* Maiden

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ABSTRACT

The objective of this study was to evaluate the longitudinal growth stress in standing trees 8, 13, 15 and 19 years old *Eucalyptus dunnii* Maiden. The material was obtained from Santa Catarina State, Brazil. Longitudinal growth stress was indirectly measured by the "CIRAD-Forêt" method, in the standing tree, and estimated through the modulus of elasticity in tension parallel to the grain. The results indicate that the longitudinal residual strain (LRS) and the estimate of the longitudinal growth stress showed a tendency to increase with the age of the material. Variation in LRS and in the estimate of the longitudinal growth stress was similar for all ages. LRS changed from 0.107 mm (8 years-old) to 0.123 mm (19 years-old), while the estimate of the longitudinal growth stress changed from 260 kgf · cm⁻² (8 years-old) to 392 kgf · cm⁻² (15 years-old). LRS presented positive and significant correlation with the estimate of the longitudinal growth stress. The stronger correlations were obtained with trees at 13, 15 and 19 years of age.

1 INTRODUCTION

Species of the *Eucalyptus* genus generally present a high level of growth stress. This stress contributes to the mechanical effort generated by the tree during growth to help it maintain its stability (Van Wyk, 1978), in answer to such environmental agents as light, wind and slope of the land. Forest management practices such as pruning, thinning and spacing density, also may contribute to the development of such stress.

Growth stress is longitudinally, radially and tangentially oriented in the stem of living trees (Kubler, 1987). It should not be confused with the stress resulting from the crown weight or with sap stress, or even with the stress resulting from reaction wood or stress developed during wood drying. (Dinwoodie, 1966). The highest level of growth stress is axial in the stem, which is the reason most studies have been directed to it (Wilkins, 1986).

Growth stress originates in the cambial region of the stem, during the maturation of the cells. According to Wilkins (1986) two hypotheses exist to explain the cause of this stress: one was formulated by Watanabe and Boyd, which relates the swelling of the cell wall and further contraction of the cellulose molecule due to lignin deposition; another hypothesis, by Kubler, proposes that the shortening of the peripheral cells results from the contraction of the crystalline cellulose of the microfibrils into the S₂ layer of the cell wall. The cells (fibres) in development tend to contract longitudinally and simultaneously expand laterally. As these cells are integral components of the tissues, they are almost entirely restricted from undergoing these dimensional changes (Wilhelmy and Kubler, 1973).

The growth stresses are in equilibrium while the tree is standing, but as soon as it is felled, deformation as movement and end splitting in the log occur as a result of the modification of that equilibrium state (Ferrand, 1983). Thus, the peripheral zone of the log, under tension, after felling, tends to contract, while the core area, under compression, expands. The deformation and splitting generated in logs and in sawn lumber jeopardize the utility of the wood and profitability of sawmills.

The measurement of growth stress can be done in the trees or in logs. Tensions can be determined by the movement of the length of wooden sections (strain) after the release of the stress, which follows cutting of neighbouring tissues, within a stem. This method was developed by Jacobs (1938).

Nicholson (1971) developed a method to measure the stress in small areas around the stem circumference. Accordingly, the longitudinal residual strain can be determined through the release of stress, proportioned by two holes, cut above and below an extensometer attached on the stem (Nicholson method). The measurement of the peripheral strain applies only to wood recently formed below the cambium. According to Archer (1986), this method is a relatively simple, method of rapid execution and only locally destructive. The cutting of the two holes provides an estimate of the total stress released between them, with the obtained value only 15% less than that obtained with the removal of the complete piece of wood being measured (Nicholson, 1971). Thus, the growth stress could be compared among trees in genetic improvement programs and test treatments for reduction of the stress in logs. The CIRAD-Forêt modified the Nicholson method by proposing the cutting of a central hole between two attached pins, one distanced 45 mm from the other, on the surface of the stem.

The evaluation of the longitudinal growth stress by the indirect and non-destructive method, by means of the longitudinal residual strain, measured by an extensometer (strain gauge) can be a useful tool for the science and technology of wood, and consequently for forest improvement. In the case of wood technology, the importance is characterized by the study of the distribution of this stress along the stem and its relationship with other wood characteristics. In the case of genetic improvement, the importance results from the possibility of selecting the best genetic material, i.e., that tree which presents reduced propensity to wood damage caused by the growth stress. The objective of this work was to determine the level of longitudinal growth stress in standing trees of *Eucalyptus dunnii* Maiden at 8, 13, 15 and 19 years of age.

2 MATERIAL AND METHODS

Eucalyptus dunnii trees at 8, 13, 15 and 19 years of age were used. Saplings derived from seeds established the populations, and each tree was considered as a different genotype. Twelve trees were assessed at eight years and 16 trees at the other ages, totalling 60 trees. The trees were randomly selected in the plantations, taking care to choose the most representative according to diameter classes. Trees from the borders and those that presented disease symptoms were not selected. The 15 years-old trees were cultivated at the São João dos Cavaleiros farm, while the others were cultivated at the Rio da Areia farm.

This material was supplied by the Procopiak Corp., located in the Canoinhas region, on the Northern plateau of Santa Catarina State, Brazil. The latitude is 26°10'S and longitude 50°23'W and the altitude is 734 m. According to the Köppen classification, the climate is the Cfa type, temperate climate without a dry season and rainfall well distributed throughout the year. The average annual temperature is 18°C and the rainfall varies from 1,800 to 2,400 mm.

The longitudinal residual strain (LRS) was measured with the CIRAD-Forêt instrument (growth stress gauge), at 1.30 m height on the tree stem (DBH). The cardinal positions were marked and LRS measured

around the stem. During measuring, the diameters (DBH) of the trees were obtained with a tape measure. The total height (TH) of trees was measured after felling.

The basal three metre length log was taken to the sawmill where two opposite slabs were removed from each log, in the same position where LRS was measured. A sample measuring 5.0 cm × 2.5 cm × 50.0 cm removed from each slab, was used to determine basic density and tension strength parallel to the grain according to the standard D-143-94 of the American Society for Testing and Materials (1997).

The longitudinal growth stress (LGS) was calculated by the Equation 1:

$$LGS = \frac{LRS \times MOE}{45} \quad (\text{Eq. 1})$$

where LGS is the longitudinal growth stress, in $\text{kgf} \cdot \text{cm}^{-2}$, wood at 12% moisture content, LRS is the longitudinal residual strain, in mm; MOE is the modulus of elasticity in tension parallel to the grain, in $\text{kgf} \cdot \text{cm}^{-2}$.

3 RESULTS AND DISCUSSION

Tab. 1 presents the average values of the *E. dunnii* tree growth characteristics with their respective coefficients of variation (CV). Tab. 2 presents the average values of the modulus of elasticity (MOE), tension strength parallel to the grain (TS_p), longitudinal residual strain (LRS), the estimate of the longitudinal growth stresses (LGS) and, wood basic density (BD) with their respective coefficients of variation (CV). High coefficients of variation were observed in longitudinal residual strain and estimate of the longitudinal growth stress characteristics.

Tab. 1 Average values for the *Eucalyptus dunnii* tree growth characteristics

| Age (years) | Farm | Diameter at breast height (cm) | Total height (m) |
|-------------|--------------|--------------------------------|------------------|
| 8 | Rio da Areia | 25.70 | 27.41 |
| | CV (%) | 17.96 | 6.56 |
| 13 | Rio da Areia | 38.00 | 36.80 |
| | CV (%) | 14.24 | 8.95 |
| 15 | São João | 42.50 | 43.53 |
| | CV (%) | 15.61 | 5.57 |
| 19 | Rio da Areia | 47.20 | 44.46 |
| | CV (%) | 13.59 | 3.68 |

Tab. 2 Average values of the tension strength parallel to the grain (TS_p), modulus of elasticity in tension (MOE), longitudinal residual strain (LRS), longitudinal growth stress (LGS) and wood basic density (BD) of *Eucalyptus dunnii* wood

| Age (years) | Farm | TS_p ($\text{kgf} \cdot \text{cm}^{-2}$) | MOE ($\text{kgf} \cdot \text{cm}^{-2}$) | LRS (mm) | LGS ($\text{kgf} \cdot \text{cm}^{-2}$) | BD ($\text{g} \cdot \text{cm}^{-3}$) |
|-------------|--------------|--|---|----------|---|--|
| 8 | Rio da Areia | 1,385 | 169,225 | 0.107 | 368 | 0.525 |
| | CV (%) | 18.66 | 19.81 | 23.66 | 25.84 | 11.52 |
| 13 | Rio da Areia | 1,558 | 213,255 | 0.113 | 544 | 0.563 |
| | CV (%) | 22.18 | 19.23 | 33.02 | 43.48 | 6.91 |
| 15 | São João | 1,800 | 260,499 | 0.111 | 648 | 0.608 |
| | CV (%) | 24.59 | 14.03 | 26.64 | 33.58 | 6.75 |
| 19 | Rio da Areia | 1,609 | 212,282 | 0.123 | 602 | 0.581 |
| | CV (%) | 20.30 | 15.96 | 35.88 | 46.49 | 6.59 |

The modulus of elasticity in tension parallel to the grain (MOE) (Tab. 2) obtained for outer wood (slab) was higher than the average MOE normally found in the literature for eucalypts wood for all assessed ages. This fact suggests the presence of reaction wood, as also observed by Lima *et al.* (2005), who found higher MOE in *Eucalyptus* wood produced by trees growing on sloping land.

The estimate (LGS) was higher than that obtained by Boyd (1950), *apud* Gaiotto (1993) (70 to 280 $\text{kgf} \cdot \text{cm}^{-2}$). Trugilho *et al.* (2002) assessed *Eucalyptus* clones at six years of age planted in Minas Gerais State, Brazil, and reported longitudinal growth stress ranging from 139 to 448 $\text{kgf} \cdot \text{cm}^{-2}$, using MOE obtained for wood with 12% moisture content. This difference can be related to the effects of age, genotype and sites of sampling and measurement. The growth stress estimates presented the same behaviour as MOE and BD, increasing from age 8 years to 15 years and then decreasing at 19 years (Fig. 1, Fig. 3 and Fig. 4). The LRS presented a tendency to increase with age (Fig. 2).

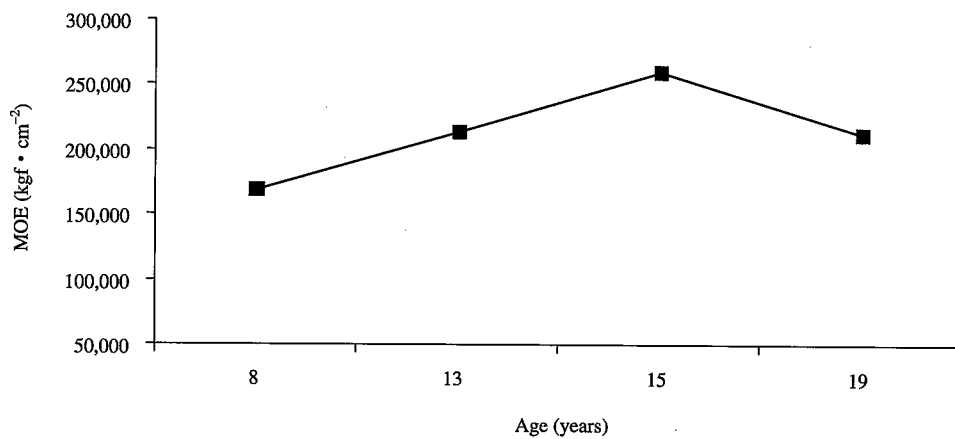


Fig. 1 Modulus of elasticity in tension parallel to the grain (MOE) in relation to the age of *Eucalyptus dunnii* trees

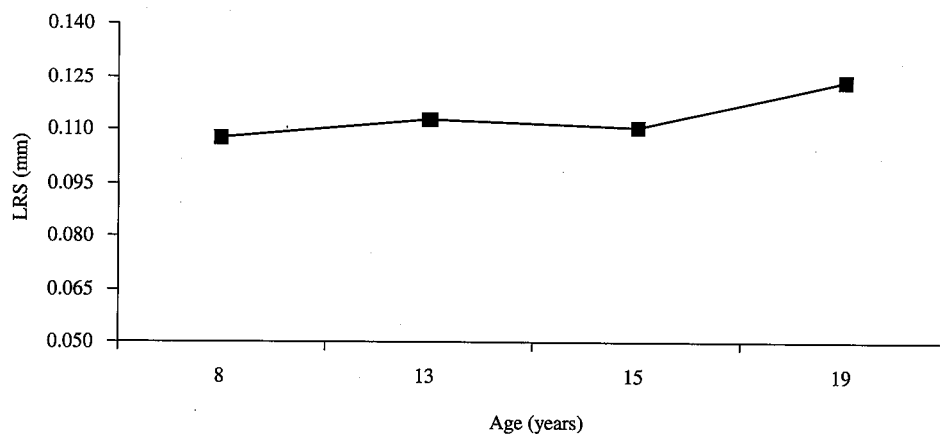


Fig. 2 Longitudinal residual strain (LRS) in relation to the age of *Eucalyptus dunnii* trees

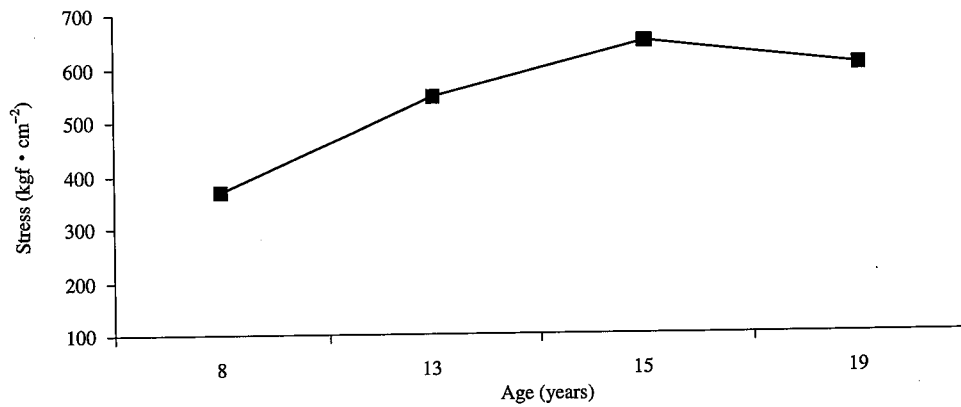


Fig. 3 Longitudinal growth stress (LGS) in relation to the age of *Eucalyptus dunnii* trees

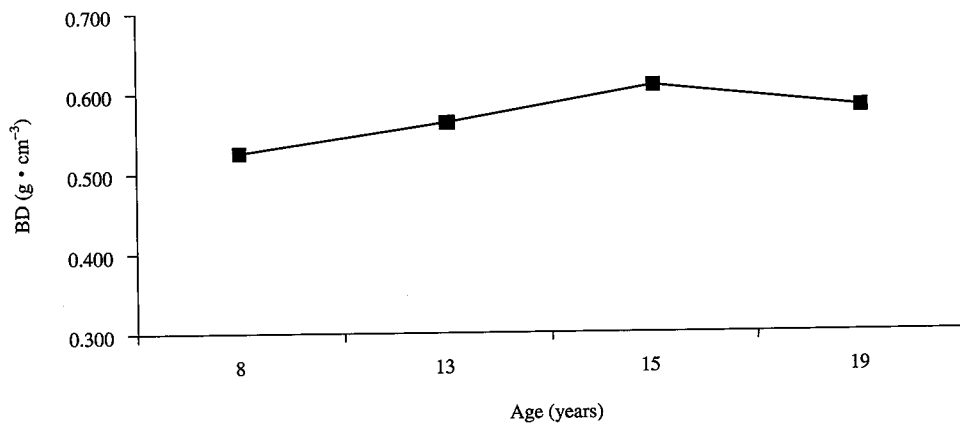


Fig. 4 Wood basic density (BD) in relation to the age of *Eucalyptus dunnii* trees

Tab. 3 presents the general matrix of correlation between the assessed characteristics LGS presented strong correlations with MOE and with BD. MOE presented strong correlation with BD. LRS presented moderate correlation with LGS. It must be considered, however, that the effect of the age can be influencing the values of these correlations.

Tab. 3 General matrix of correlation

| | MOE | LRS | LGS | BD |
|-----|-----|--------|--------|--------|
| MOE | 1 | 0.1520 | 0.9197 | 0.9681 |
| LRS | | 1 | 0.5249 | 0.3744 |
| LGS | | | 1 | 0.9751 |
| BD | | | | 1 |

4 CONCLUSIONS

The estimate of the longitudinal growth stress was higher than that obtained in literature.

The growth stress estimates presented the same behaviour as modulus of elasticity in tension parallel to the grain and basic density, increasing from age 8 years until 15 years and then decreasing from 19 years. The longitudinal residual strain increased with the age of the tree.

Correlations of the modulus of elasticity with both longitudinal growth stress and basic density were

high; also high was the correlation of the longitudinal growth stress with basic density; while the correlation between longitudinal residual strain and longitudinal growth stress was moderate.

REFERENCES

- Archer R R. 1987. On the origin of growth stresses in trees – Part 1: Micro mechanics of developing cambial cell wall. *Wood Science and Technology*, New York, 21 (2): 139-194
- Boyd, J.D. 1950. The growth stresses: III The origin of growth stresses. *Australian Journal of Scientific Research. Serie B – Biological Sciences*. Melbourne, 3 (3): 294-309
- Dinwoodie J M. 1966. Growth stresses in timber: a review of literature. *Forestry*, London, 39 (2): 162-270
- Ferrand J C. 1983. Growth stresses and silviculture of Eucalyptus. *Australian Forest Research*, Melbourne, 13 (1): 75-81
- Gaiotto M R. 1993. Avaliação da madeira de *Eucalyptus saligna* e *Eucalyptus urophylla* para produção de lâminas. Piracicaba, ESALQ-USP, 119. (M.Sc. Thesis)
- Jacobs M R. 1938. The fiber tension of wood stens with special reference to the genus Eucalyptus. Canberra: Commonwealth Government Printer, 39. (Bulletin n° 22).
- Kubler H. 1987. Growth stresses in trees and related wood properties. *Forest Products Abstracts*, Oxford, 10 (3): 61-119
- Lima J T, Trugilho P F, Rosado S C S. 2005. Tolerance of Eucalyptus trees to the action of storms and their relationships with wood properties. Zhanjiang, Guangdong, China In: *International Conference on Plantation Eucalyptus: Challenge in Product Development*
- Nicholson J E. 1971. A rapid method for estimating longitudinal growth stresses in logs. *New York: Wood Science and Technology*. 5, 40-48
- Trugilho P F. 2004. Tensão de crescimento em árvores vivas de clones de *Eucalyptus* spp e de *Eucalyptus dunnii* maiden e propriedades da sua madeira. Curitiba, UFPR, 123. (Post-doctorate Thesis)
- Trugilho P F, Lima J T, Rosado S C S, Mendes L M, Mori F A, Souza M A M. 2002. Avaliação da tensão de crescimento em clones de *Eucalyptus*. *Floresta e Ambiente, Seropédica/RJ*, 9, 1
- Van Wyk J L. 1978. Hardwood sawmilling can have a bright future in South Africa. *South African Forestry Journal*, Pretoria. 109, 47-53
- Wilhelmy V, Kubler H. 1973. Stresses and checks in log ends from relieved growth stresses. *Wood Science*, Madison, 6 (2): p.136-142
- Wilkins A P. 1986. Nature and origin of growth stresses in trees. *Australian Forestry*, Melbourne, 49 (1): 56-62

Growth Stresses Assessment in Standing *Eucalyptus* Cultivated in Different Regions in Brazil

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ABSTRACT

Growth stress may be longitudinally, radially and tangentially oriented in the tree stem. The most severe and variable stress is longitudinal. For this reason many studies have been directed to it. When this stress is released, during cutting of the tree or during log processing, defects as distortion and end splits can appear. In spite of its importance, up to a few years ago, growth stress had not been the object of many studies in Brazil. However, over the last six years, more research effort on this subject has been carried out. Thus, this work reports the variation of longitudinal growth stress and strain presented in *Eucalyptus* trees cultivated in several regions in Brazil. The results indicate that there exists high variability in the assessed genetic material both inside and amongst regions. The longitudinal growth stress generally presents high genetic heritability, indicating that it is under strong genetic control. From this it can be suggested that it is possible to select individuals with lower stress levels, able to produce sawn lumber of better quality.

1 INTRODUCTION

Growth stress is characterized as one of the main problems that limit the utilisation of *Eucalyptus* as a sawn wood producer, in view of the fact that this stress causes distortion and end splits, once it is released after the tree is felled. Lisboa (1993) describes that growth stress has to be differentiated from other stresses that can be developed within the stem, as gravitational forces from the weight of a tree occur before the tree is cut. Also, they cannot be confused with sap stresses resulting from daily or seasonal variation, stresses that develop during drying or any type of external stresses acting on the tree.

Growth stress can be defined as the stress found in the woody green stem, representing a type of mechanism developed by trees to remain erect. This stress is present in the stem of many species; however, its influence is higher in broadleaves than in conifers. According to Mattheck and Kubler (1995), growth stress has great importance for tree survival, since it counterbalances unavoidable points of weakness in their structure. In this respect, Kubler (1987) affirmed that growth stress acts in the prevention of mechanical breakage by strengthening against bending, i.e. reinforcing the tree against the action of external forces, such as those induced by wind. This was confirmed by Lima *et al.* (2005) for *Eucalyptus* clones subject to the action of storms. Due to its dynamic nature, growth stress has an important role in the reorientation of crowns, stems and branches, as exemplified by reaction wood, which is considered as a special case of growth stress (Kubler, 1987).

Growth stress originates after the modification of the cells during the phase of lignification of the S2

layer of the wall of these cells. According to Hillis and Brown (1978), at the deposition of the lignin in the transverse walls of the cells, they expand, causing a retraction in the axial direction. The neighbouring cells, already presenting higher rigidity, restrain the reduction of the cell length, generating longitudinal tension stress. This stress continues to be successively produced in the layers of newly formed cells. As the tree increases its diameter, successive layers of new cells in tension apply a high compression stress on the central zone of the stem. This stress has a wide magnitude, and can be in tension or compression, depending on both its localisation into the xylem and its acting direction: longitudinal, tangential or radial (Chafe, 1979). Kubler (1987) alerts that the tension in the longitudinal direction of the stem is primarily responsible for distortion in sawn wood products. High compression stress is also responsible for the occurrence of brittleheart near the pith.

The longitudinal deformation of growth is caused by a longitudinal tension stress in external layers of the stem, with growing intensity outward, and by a longitudinal compression stress in the central zone of the stem, which increases near the pith (Jacobs, 1938). These stresses exist in the tree as a way to confer stability to the tree, similar to the steel cable stretching an antenna, which then is pressed against the soil (van Wyk, 1978).

While *Eucalyptus* trees generally develop high growth stress, particularly *E. grandis* (Malan, 1984), (Haslett, 1988) found *E. muelleriana* as an example, presented low stress levels.

Large variations of the level of growth stress can occur around the circumference of the tree (Nicholson, 1973; Nicholson and Hillis, 1975), which has been explained by the stem inclination (Nicholson, 1973), by the variation of the grain angle of the wood (Archer, 1987), by the occurrence of reaction wood (Walker, 1993) or even by the curvature of the stem (Dinwoodie, 1966), especially when the curvature occurs in two perpendicular planes, as mentioned by Schacht *et al.* (1998).

The variation in the level of this tension along the stem is not always consistent (Schacht *et al.*, 1998). It can be (i) increasing for up to seven metres of height in the stem (Yao, 1979; Chafe, 1981), then reducing up to 11 m (Yao, 1979); (ii) decreasing until 11 or 12 m (Skolmen, 1974; Purnell, 1988); (iii) continually increasing or (iv) uniform along the stem (Kubler, 1987).

The causes of elevated levels of growth stress are still not well understood, despite there being strong evidence that they are linked to the genotype, age, size of the log, growth rate and stem inclination. Boyd (1980), in his explanation of proposed theories in respect of wood growth stress, concluded that the only theory able to explain stress differences was related to the microfibril angle of the S₂ layer. Archer (1987) affirms that with decreasing microfibril angle; there will be higher internal growth stress.

The effect of growth stress can be observed in the log after the tree has been felled and in the sawn lumber, just after log break-down in the sawmill. It results in the reduction of the sawn yield, which in extreme cases can adversely affect production. Therefore, due to its direct effect on the performance and the final result of industrial processes, the reduction and the best distribution of growth stress in wood becomes a primary research objective.

The choice of genetic material with lower growth stress associated with improved techniques in the sawmill can reduce the problems of end splits and distortion in the wood (Muñiz, 2002). In this aspect, a program for establishment of *Eucalyptus* plantations to provide for the solid wood market could be based mainly on technical fundamentals that require growth stress quantification in different genotypes and their association with environmental factors that may affect the performance of the material. Also, it is important to develop adequate techniques and conditions for stress measurement.

In this context, the determination of strain measurements in standing trees can become a simple, rapid

and precise tool for obtaining the growth stress. Additionally, these methods are required to be non-destructive, so the measurement does not jeopardize the future use of the tree.

Considering that growth stress reduces *Eucalyptus* wood quality, this project had as an objective the assessment of the magnitude of growth stress indirectly measured by the longitudinal residual strain in standing trees, sampled in different regions in Brazil.

2 MATERIAL AND METHODS

Genetic material of *Eucalyptus* collected in different regions of Brazil was assessed. Tab. 1 presents the geographic locations of samples.

Tab. 1 Places of sampling

| State | Company | Material | Quantity | Genetic origin |
|----------------|-------------------------|----------|----------|---------------------|
| Espirito Santo | Aracruz Celulose* | Clone | 5 | Hybrid |
| Minas Gerais | CMM** | Clone | 138 | Hybrid |
| Minas Gerais | CMM** | Matrix | 70 | Hybrid |
| Minas Gerais | Vallourec& Mannesmann** | Clone | 8 | Hybrid |
| Minas Gerais | Cenibra*** | Clone | 6 | Hybrid |
| Minas Gerais | Plantar** | Clone | 11 | <i>E. urophylla</i> |
| Minas Gerais | Carvovale**** | Clone | 9 | <i>E. urophylla</i> |
| Minas Gerais | Carvovale**** | Matrix | 101 | <i>E. urophylla</i> |
| Santa Catarina | Procopiak***** | Matrix | 64 | <i>E. dunnii</i> |

* Littoral region in the North of the State; ** Northwest region of the State; *** Rio Doce valley; **** Northern region of the State; ***** Northern plateau of the State.

The longitudinal growth stress was indirectly determined by measuring the longitudinal residual strain (LRS). For all genetic material assessed, LRS was determined at 1.30 m of height in the stem in four cardinal points marked around the stem circumference. A device and the method developed by the CIRAD-Fôret was employed for the measurement of the LRS.

The assessed *Eucalyptus* clones were sampled in clonal tests and commercial stands, while the matrix *Eucalyptus* trees considered were top individuals remaining of commercial stands. Both the clones and the matrix trees were assessed at different ages.

The measurement of the LRS in the clones used from 3 to 15 replicates. This way, LRS was measured in a total of 790 trees (clones + matrix trees).

The hybrid genetic material measured consisted of the following crosses: *E. grandis* × *E. urophylla*; *E. grandis* × *E. camaldulensis*, and *E. grandis* × *E. tereticornis*.

3 RESULTS AND DISCUSSION

Tab. 2 presents the average values of LRS determined for the different locations and genetic material of *Eucalyptus*. The results show a high variability among the genetic material within and between the studied regions. The LRS for the matrix trees varied from 0.052 to 0.123 mm while for clonal material varied from 0.058 to 0.109 mm. The overall average LRS was 0.087 mm with coefficient of variation (CV) of 23.5%. Notably, there was a large variability amongst the hybrids and matrix-trees, which is desirable for forest genetic improvement.

Tab. 2 Average values of longitudinal residual strain (LRS)

| Company | Material | Age (years) | LRS (mm) |
|------------------------|----------|-------------|----------|
| Aracruz | Clone | 8.5 | 0.073 |
| | | 11 | 0.058 |
| | | 15 | 0.074 |
| CMM | Clone | 4.1 | 0.074 |
| | | 7.6 | 0.083 |
| | | 8.6 | 0.069 |
| Vallourec & Mannesmann | Matrix | 19 | 0.052 |
| | Clone | 7 | 0.075 |
| Cenibra | Clone | 2 | 0.097 |
| | | 7 | 0.099 |
| Plantar | Clone | 6.5 | 0.088 |
| | | 11 | 0.109 |
| Carvovale | Clone | 6.5 | 0.099 |
| | Matrix | 15 | 0.070 |
| Procopiak | Matrix | 8 | 0.107 |
| | | 13 | 0.113 |
| | | 15 | 0.111 |
| | | 19 | 0.123 |
| General average | | | 0.087 |
| CV (%) | | | 23.52 |

LRS presents a tendency to increase with increasing tree age, in spite of the fact that this relationship is not very evident. But it seems clear that the higher differences in the LRS occurred due to genetic and environmental factors.

For the clones planted in Minas Gerais State, the LRS presented a high coefficient of heritability, i.e. this characteristic is under strong genetic control. The values for coefficient of heritability changed from 85.48%, at 8.6 years of age, 94.03%, at 7.6 years of age, and 92.38%, at 4.1 years of age of the tree.

4 CONCLUSIONS

For *Eucalyptus* trees planted in Brazil, longitudinal residual strain, an index of growth stress: (i) presented high variability amongst both the genetic material and places of sampling; (ii) has not presented a very close relationship with the age of the genetic material; (iii) presented high genetic coefficient of heritability; (iv) can be considered as a new and efficient tool for material selection in forest genetic improvement.

REFERENCES

- Archer R R. 1987. On the origin of growth stresses in trees – Part 1: Micro mechanics of developing cambial cell wall. New York: Wood Science and Technology, 21, (2): 139-194
- Boyd J D. 1980. Relationship between fiber morphology, growth strains and physical properties of wood. Australian Forest Research, Melbourne, 10 (4): 337-60
- Chafe S C. 1979. Growth stresses in the trees. Australian forest research, Melbourne, 9, (3): 203-223
- Chafe S C. 1981. Variation in longitudinal growth stress, basic density and modulus of elasticity with height in the tree. Australian forest research,

Melbourne, 11 (1): 79-82

- Dinwoodie J M. 1966. Growth stresses in timber: a review of literature. *Forestry*, London, 39 (2): 162-270
- Haslett A N. 1988. A guide to handling and grade-sawing plantation-grown eucalypts. *Forest Research Institute Bulletin*, Wellington, 142, 1-72
- Hillis W E, Brown A G. 1978. *Eucalyptus* for wood production. Melbourne: CSIRO, 434
- Jacobs M R. 1938. The fiber tension of wood stems, with special reference to the genus *Eucalyptus*. *Bulletin Commonwealth Forestry Bureau*, Canberra, 22, 7-37
- Kubler H. 1987. Growth stresses in trees and related wood properties. *Forest Products Abstracts*, Farnham Royal, 10 (3): 61-119
- Lima J T, Trugilho P F, Rosado S C S. 2005. Tolerance of *Eucalyptus* trees to the action of storms and their relationships with wood properties. Zhanjiang, Guangdong, China In: *International Conference on Plantation Eucalyptus: Challenge in Product Development*
- Lisboa C D J. 1993. Estudo das tensões de crescimento em toras de *Eucalyptus grandis* Hill ex. Maiden. Curitiba/PR, UFPR, 298. (Doctorate Thesis)
- Malan F S. 1984. Studies on the phenotypic variation in growth stress intensity and its association with tree and wood properties of South African grown *Eucalyptus grandis*. University of Stellenbosch, Stellenbosch. (Doctorate Thesis). 272
- Mattheck C, Kubler H. 1995. *Wood - the internal optimization of trees*. Berlin: Springer, 129
- Muñiz G I B. 2002. Fatores que limitam a utilização da madeira de *Eucalyptus*. In: *SÓLIDOS DE EUCALIPTO: AVANÇOS CIENTÍFICOS E TECNOLÓGICOS*, 2002, Lavras. *Anais Lavras: UFLA*, 30-63
- Nicholson J E. 1973. Growth stresses differences in *Eucalyptus*. *Forest science*, 9 (3): 169-174
- Nicholson J E, Hillis W E. 1975. Some tree growth-wood property relationships of *Eucalyptus*. *Canadian Journal Forest Research*, Ottawa, 5, 424-432
- Purnell R C. 1988. Variation in wood properties of *Eucalyptus nitens* in a provenance trial on the Eastern Transvaal Highveld in South Africa. *South African Forestry Journal*, Pretoria, 144, 10-22
- Schacht L, Garcia J N, Vencovsky R. 1998. Variação genética de indicadores de tensão de crescimento em clones de *Eucalyptus urophylla*. *Scientia Forestalis*, Piracicaba, 54, 55-68
- Skolmen R G. 1974. Lumber potential of 12-year-old *Eucalyptus saligna* trees in Hawaii. USDA. Forest Service. PSW research note, Washington, 288, 1-7
- Van Wyk J L. 1978. Hardwood sawmilling can have a bright future in South Africa. *South Africa Forestry Journal*, Pretoria, 107, 47-53
- Walker J C F. 1993. Characteristics of stem wood and their manipulation. In: Walker J C F, Buterfield B J, Langrish T A G, Harris J M, Uprichard J M. *Primary wood processing: principles and practice*. London: Chapman and Hall, 153-196
- Yao J. 1979. Relationships between height and growth stresses within and among white ash, water oak, and shagbark hickory. *Wood Science*, New York, 11, (4): 246-251

Eucalypt and *Acacia* Species for Production of Solid Wood Products in China

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ABSTRACT

The area of eucalypt and acacia plantations in China is currently expanding at a rapid rate and there are now over 1.5 million ha and 200,000 ha respectively of established plantations of these species. At present the vast majority of these plantations are being managed for the production of pulpwood and the main species are *Eucalyptus urophylla* and its hybrids, *E. grandis*, *E. globulus*, *Acacia mangium*, *A. crassicarpa* and some *A. auriculiformis*.

The areas of eucalypt and acacia plantations that are allowed to grow sufficiently long enough to produce larger diameter trees for sawn timber production are very limited. Those plantations currently available to provide larger diameter material for efficient sawn timber production were generally established prior to the mid-1980s and comprise mainly *E. citriodora*, *E. urophylla* × *grandis*, *E. urophylla* × *camaldulensis*, *E. urophylla* × *tereticornis* or *A. auriculiformis*.

It is suggested that genetic improvement of some of the current eucalypt and acacia species, along with introduction of other species lesser known in China, should be pursued to support development of forest plantations for sawlog production. Priority species for this include *E. camaldulensis*, *E. pellita*, *E. torelliana*, *E. saligna*, *E. cloeziana*, *A. cicinnata*, *A. melanoxylon* and *A. dealbata*. In combination with appropriate silvicultural practice, there is potential for the right varieties of these species to produce high density, fine grain quality sawn timbers suitable for a wide range of applications.

1 INTRODUCTION

The area of eucalypt plantations in China now exceeds more than 1.5 million ha (Qi, 2002) and that of acacias exceeds 200,000 ha. China ranks third in the world with respect to total planted area of eucalypts coming behind only India and Brazil. Eucalypts and Acacias are favoured plantation species in China on account of their versatile timber and the international demand for their products enabling earnings of foreign exchange from export of the raw materials they provide.

There are more than 900 species and subspecies of *Eucalyptus* and more than 1,200 species of *Acacia*. The natural distribution of eucalypts is mainly restricted to Australia with a few species extending into Papua New Guinea, Indonesia, East Timor and even the southern Philippines. In contrast, *Acacia* species occur naturally in every continent except Europe and Antarctica.

Whilst only one acacia species occurs naturally in China, *A. richii* (commonly known as Taiwan xiangsi), there are about 800 species found in Australia and 150 in Africa. The majority of the African

acacias are suitable for growing only in arid and semi-arid environments and, having shrub like forms, are not suited for timber producing plantations. In contrast, many of the acacias occurring naturally in Oceania are found in lush environments and a number have proven well suited for establishment of fast growing timber plantations.

More than 60 exotic acacia species have been introduced into China since about 1930. Up to the end of the 1970s, those introduced from Oceania were mainly planted for the forestation of wastelands and as shelterbelts along roadsides, railways and around villages. *A. auriculiformis* became one of the most commonly planted species during that period. After 1984, many research projects were carried out on acacias, especially species-provenance testing, to improve their suitability for high yielding timber plantations.

Over the past 10 years, acacia plantations have been expanding rapidly in China and their total area is now estimated to be over 150,000 ha (Zhang, 2002). Since the early 1990s *A. mangium* has been the most commonly planted acacia species in China, being favoured for establishment of fast growing pulpwood plantations (Wang, 1990). Most of the Acacia plantations in China are in Guangxi, Guangdong and Hainan, with smaller areas in Fujian, Jiangxi and Yunnan. The current rate of establishment of new acacia plantations in China is approximately 20,000 ha per year. Although most of these plantations are managed for the production of pulpwood, if given appropriate management they would have potential to also produce logs for solid wood products.

From the late 1960s to the early 1980s, the area of eucalypt plantation increased rapidly in China. However, the main objectives for most of the eucalypt plantations during that period were the forestation of wastelands or other under-productive areas and, the production of timber for construction, furniture manufacture and a range of other applications. The main species planted during that period included *E. citriodora*, *E. exserta*, *E. Leizhou* 'No. 1', *E. saligna* × *exserta*, *E. globulus* and *E.* '12 ABL'. The taxon *E.* '12 ABL' is a landrace developed from seed introduced to China in the 1970's from the Congo. Many of the *E.* '12 ABL' clones and seedlings planted in China are suspected to be hybrid combinations involving *E. grandis* and some other eucalypt taxa (Eldridge *et al.*, 1993). *E. Leizhou* 'No. 1' is a local hybrid that has developed from a supposed naturally occurring hybrid between *E. exserta* and some other broader leaf eucalypt (Turnbull, 1981).

Before about 1990 the quality of management and silviculture in eucalypt plantations in China was generally low. Also, there was a lack of the appropriate processing technology for eucalypt wood. Consequently, up until then, eucalypt timber was primarily used for lower-quality, lower value applications. In the late 1980s and during the 1990s however, there were marked improvements in the management and silviculture of eucalypt plantations in line with developments in other major eucalypt growing countries. Associated with this was a change in the focus of plantation management to the production of short rotation pulpwood to take advantage of the strong demand for eucalypt woodchips in international markets. At the same time, much work was done on the introduction, selection and improvement of eucalypt species enabling rotations for pulpwood production to be reduced down to as short as five years.

Recently foreign corporations have become increasingly interested in investing in high quality eucalypt plantation developments, as well as major wood processing industries, in China. This foreign interest has marked a new phase for China's eucalypt plantation industry, which is increasingly characterized by rapid growth rates, higher quality raw materials and high investment. However, even with foreign investment the focus of these plantations and associated industries is still shorter rotation plantations for fibre production. Although most eucalypt fibre is exported as unprocessed wood chips, there is an increasing amount being bought by numerous new MDF fibreboard factories in China which have either recently been completed or

are under construction. In addition, feasibility studies are currently under way for a number of new large capacity eucalypt pulp mills.

However, currently there is a rapidly increasing market demand within China for quality hardwood sawn timber. This increasing demand is due to large annual increases in gross domestic product (GDP); increased residential construction; reductions in tariffs and a more open trading system since China's entry to the World Trade Organisation. This increase in demand has been accompanied by rapidly decreasing availability of hardwood resources from within China due to sharp reductions in timber harvesting from natural forests after severe floods in 1998. Therefore, now there is a great need for increased plantation production of quality hardwood timbers.

The development and management of eucalypt and acacia plantations specifically managed for the production of larger sized quality hardwood logs for higher value solid products will be a new direction in the development of plantation resources in China.

2 EUCALYPT PLANTATION SPECIES IN CHINA

2.1 Species for fibre production

Most eucalypt plantations in China are currently managed for short rotation pulpwood/fibre production. The main species planted at present are *E. urophylla* and its hybrids, *E. grandis* and its hybrids, and *E. globulus*. All these species are favoured for their fast growth, good stem form (straight unforked trunks with small branches) and the fact that their juvenile wood produces a good quality short-fibred pulp.

2.1.1 *E. urophylla* and its hybrids

E. urophylla is native to Indonesia, where its natural range extends across about 500 km between latitude 7°30'S and 10°S and longitude 122°E and 127°E. *E. urophylla* has the largest altitudinal range of any eucalypt ranging from 100-3,000 m above sea level (CAB International 2,000). In its natural habitat the total rainfall is 1,000-1,500 mm per year with a summer maximum, the mean maximum temperature of the hottest month is up to 29°C and the mean minimum of the coldest month 8-12°C (Wang, 2002). The species does not withstand frost. The density of *E. urophylla* plantation-grown timber is about 500 kg · m⁻³, but more mature timber from trees over 12-15 years old can range up to 700-800 kg · m⁻³. Its heartwood has a reddish colour and is relatively strong. Younger more juvenile wood is used principally for pulp and large size more mature timber is suitable for production of sawn timber that can be used for construction, including structural uses.

E. urophylla and its hybrids are the most widely planted eucalypts in China. The main hybrids in use include *E. urophylla* × *grandis*, *E. urophylla* × *camaldulensis* and *E. urophylla* × *tereticornis*. With these hybrids, it is only clones selected for rapid growth that are used in plantations. Selected clones are mass propagated through tissue culture and rooting of stem cuttings. Growth of the best *E. urophylla* hybrid clones can reach up to 8-10 m in height and over eight cm breast height diameter per year. Plantations of *E. urophylla* and its hybrids are grown for fibre in China with rotation length of only five year to six years, and are primarily found in Guangxi, Guangdong, Hainan, and Fujian provinces.

Most of the *E. urophylla* timber (including that from its hybrids) currently produced in China is utilized

to produce woodchips for export, for making paper pulp or for fibreboard manufacture.

2.1.2 *E. grandis*

In its natural habitat, *E. grandis* is a medium sized to very tall forest tree. It is native to the east coast of Australia between latitudes 16°-32°S. Where it occurs in northern New South Wales and southern Queensland, it is found at altitudes ranging from sea level up to about 600 m above sea level. In central and northern Queensland the altitudinal range is from 400 to 1,250 m. The climatic indicators for its natural distribution in Australia are: mean maximum temperature of the hottest month 24-32°C; mean minimum temperature of the coldest month 3-17°C; mean annual temperature 14-22°C; mean annual rainfall 1,790-2,480 mm (Boland *et al.*, 1984; Booth *et al.*, 1988). The rainfall varies from a uniform/bimodal to a summer maximum in the north, with a dry season of 0-5 months each year. The species is tolerant of light frosts down to -6°C.

Sapwood of *E. grandis* is a very pale pink and the heartwood varies from almost white to pink, or dark red-brown with a pink tinge (Keating and Bolza, 1982) and is moderately strong (Boland *et al.*, 1984). The air-dry density of the wood is 600-750 kg · m⁻³ and the timber has moderate strength and durability with straight grain but can have a coarse texture (Turnbull and Pryor, 1984). In China, its timber is used mostly as a source of fibre used for paper pulp or manufacture of fibreboard. Larger size logs can be used for production of sawn timber for packing cases, house construction, flooring or even higher quality furniture (Turnbull and Pryor, 1984). However, growth stress and its effects can cause some degrade of logs and sawn timber. Uniform plantation conditions including uniform spacing and/or longer rotations to produce larger sized logs can each help minimise growth stress. Larger size logs also have potential for production of veneer.

In China, growth rates of *E. grandis* are generally lower than that of *E. urophylla* and clones of *E. urophylla* hybrids. The *E. grandis* plantations are established with either vegetatively propagated clones or seedlings and one-year growth ranges up to eight metres in height and over six cm in breast height diameter. Plantations of *E. grandis* and its hybrids grown in China are managed for fibre production on rotations of seven to eight years. *E. grandis* (including *E. grandis* hybrids) is the second most dominant eucalypt plantation species in China, and it is primarily planted in Guangdong, Guangxi and Fujian provinces.

2.1.3 *E. globulus* (including the sub-species *E. maidenii*)

E. globulus comes from a relatively wide natural range in Australia that includes areas in Victoria, New South Wales, and Tasmania. Its native habitat occurs at an latitudinal range 31°-42°S and an altitudinal range of 0-1,000 m above sea level. In its habitat there is winter or uniform rainfall, the total rainfall averages 750-1,500 mm per year, the mean maximum temperature of the hottest month is 21-27°C and the mean minimum of the coldest month of about 4°C (Wang, 2002). This species is not adapted to warmer sub-tropical and tropical climates. However, it has the capability of withstanding moderate frost, and it tolerates much colder winters than either *E. urophylla* or *E. grandis*.

In natural stands, tree height can extend up to 40 metres, usually with a good trunk and a heavy crown. Its wood has a light yellow-brown colour, open texture and is moderately strong but of low durability. As the species is very difficult to propagate vegetatively as either rooted cuttings or through tissue culture, plantations of this species can only be established using seedlings.

The density of juvenile *E. globulus* wood is about 500-600 kg · m⁻³; and in older larger sized trees the density of mature timber can range up to over 800 kg · m⁻³. Timber cut from mature trees in its natural stands in Australia has been used for construction, poles, piles and even railway sleepers. However, its plantation timber is prized as source of very high quality fibre for pulp production, and a lesser amount is used for manufacture of fibreboard or for poles.

In general, the growth of *E. globulus* is slower than that of *E. urophylla* and *E. grandis*. Its average one-year growth can range up to six metres in height and over six cm in breast height diameter. Plantations grown for fibre production in China are generally managed on rotations of about 8-10 years. Leaves of *E. globulus* are rich in 1,8-cineole oil. Foliage from plantations and other plantings in Yunnan is regularly harvested for production of these oils.

In China *E. globulus* is mainly planted in Yunnan and Guizhou provinces. Interestingly, it is thought to be one of the first eucalypt species introduced to China, and was first planted in Yunnan more than 100 years ago.

2.2 Species with potential for solid wood products

Over recent years, many new eucalypt and acacia species have been introduced to China and the introduction of new species and varieties is continuing. Today, a number of the more recently introduced species, along with some that have a longer history in China but that have only ever been planted on limited scales, can show fast growth and have wood properties suited to higher value end uses. With some additional research, a range of these has the potential for establishment as high yielding plantation species suitable for production of larger diameter timbers for a range of higher value solid wood products.

2.2.1 *E. citriodora*

E. citriodora is native to coastal areas of central and northern Queensland in Australia. Its natural stands occur in the latitudinal range of 22°-26°S and within an altitudinal range of 80-800 m above sea level. In its natural habitat, rainfall occurs predominantly in summer, the mean annual rainfall is 625-1,250 mm, the mean maximum temperature of the hottest month 29-35°C, and mean minimum of the coldest month 5-10°C. Even though its natural range is restricted to tropical and subtropical areas, the species does have the ability to tolerate light frosts.

In natural stands, *E. citriodora* is a handsome tree of excellent form of heights of up to 30 m with a well-shaped but sparsely foliated crown. Its timber is ash-brown in colour with a wavy grain; and it is strong, hard and fairly durable. The density of its juvenile wood is about 600 kg · m⁻³, and that of timber from older more mature trees ranges up to as high as 800-900 kg · m⁻³. It produces a good quality sawn timber useful for a wide range of applications including construction, flooring and fine furniture. Younger trees can be source of quality poles, and its timber is relatively easy to impregnate under pressure with preservative chemicals for added durability and use in many exterior applications/industrial purposes.

Eucalyptus citriodora was one of the earlier introduced eucalypt species to China. In the 1960s-1970s it was planted on a larger scale in Guangdong, Guangxi, Yunnan, Fujian, Jiangxi, Zhejiang and Hainan. However, most of the *E. citriodora* plantations existing today in China are over 25 years old and very little of this species is planted at present as its growth is far slower than that of more recently introduced plantation species such as *E. urophylla* and *E. grandis*.

In China, timber of *E. citriodora* has been used for furniture, construction and boat building. However, with only very limited availability at present, the use of its timber is now mainly restricted to high quality furniture and decorative applications.

Leaves of *E. citriodora* can be used as a commercial source of citronella oil. In Zhangzhou city, Fujian province, there are over 600 ha of the species managed primarily for the production of such oils.

2.2.2 *E. exserta*

The natural habitat of *E. exserta* extends through a latitudinal range of 17°-28°S and an altitudinal range 0-800 m above sea level in Queensland, Australia. Within this area, its stands occur from the coast to distances of up to 300 km inland from the sea. The climate in its natural habitat is one of summer rainfall with a mean annual total of 625-1,250 mm. The mean maximum temperature of the hottest month ranges up to 35°C, and the mean minimum of the coldest month ranges down to 5°C (Wang, 2002).

In natural stands, mature *E. exserta* trees range in height up to 15-25 m, frequently with a straight bole and an attractive crown. Its wood has a pale pinkish brown colour with interlocked grain, and it can be somewhat brittle, hard and is moderately durable. The density of the timber from mature trees in natural stands is over 800 kg · m⁻³, but that from younger faster grown plantation trees would be somewhat lower. In the past, *E. exserta* in China has been used for pulpwood and for construction and furniture timbers. However, on account of the limited availability of this species its timber is now used primarily for higher quality, higher value furniture and other decorative applications.

Eucalyptus exserta was one of the earlier introduced eucalypt species to China. In the 1960s-1970s it was commonly planted in Guangdong, Guangxi and Hainan provinces. Now however, only relatively small areas of this species can be found in Guangdong, Guangxi, Yunnan, Fujian, Jiangxi, Zhejiang and Hainan provinces and most of these are over 25-30 years old. As the growth of *E. exserta* is much slower than many of the more recently introduced plantation eucalypts (e.g. *E. urophylla* and *E. grandis*), it is no longer planted on any significant scale in China.

2.2.3 *E. Leizhou* 'No. 1'

Eucalyptus Leizhou 'No. 1' is a local taxon, which has developed from a supposed naturally occurring hybrid between *E. exserta* and some other broader leaf eucalypt (Turnbull, 1981). The Leizhou Forestry Bureau in Guangdong selected it in the late 1960s. In the 1970s and 1980s it was planted widely in Guangdong, Guangxi and Hainan provinces, with smaller areas also planted in Yunnan, Fujian, Jiangxi, and Zhejiang provinces (Wang, 2002).

The height of *E. Leizhou* 'No. 1' ranges up to 30 m, frequently with a straight trunk and an attractive crown. Its wood has a pale reddish brown colour, a plain grain and is somewhat brittle, hard and only of moderate durability. The density of the wood from mature plantation grown trees is up to 780 kg · m⁻³. During the 1970s to 1980s, wood from *E. Leizhou* 'No. 1' was used for a range of applications including furniture and construction. In the 1990s though, it was mainly used as a source of wood chips for pulp production.

Although *E. Leizhou* 'No. 1' shows greater resistance to many pests, diseases and typhoons, it is rarely planted at present on account of its much slower growth than a number of other eucalypt species including *E. urophylla* and its hybrids.

2.2.4 *E. camaldulensis*

E. camaldulensis is native to Australia and has the most widespread natural distribution of any eucalypt species. Its natural stands are found distributed across all Australian states except Tasmania. The species has both a southern form (temperate zone) and a northern form (tropical/sub-tropical form). Its natural habitat extends through a latitudinal range of 15°-38°S, and an altitudinal range 0-600 m above sea level. The average rainfall in its natural habitat is generally within the range of 250-625 mm per year, the mean maximum temperature of the hottest month is 29-35°C and the mean minimum temperature of the coldest month 2-20°C (Wang, 2002).

In its natural habitat, *E. camaldulensis* trees can grow up to heights of 25-30 m, but the trunk in many natural stands/trees can be rather crooked. Its sapwood is generally pinkish to light red in colour and its heartwood is red to dark red brown in colour with a close texture and interlocked or wavy grain. Wood from older naturally grown trees is hard, durable, resistant to termites and very durable even in contact with the ground and/or water. Wood from older trees from natural stands can range up to 980 kg · m⁻³ but that from younger faster grown plantation material can be as low as 480 kg · m⁻³. *E. camaldulensis* is valued for a range of purposes in Australia varying from honey production, plantings for rehabilitation of degraded sites/wastelands, shelterbelts and ornamental plantings and for production of higher quality sawn timbers. Its timber can also produce good quality charcoal. In China, only a limited amount of older, larger sized *E. camaldulensis* is now available for harvest and is good as sawn timber for furniture, construction and decorative applications.

Eucalyptus camaldulensis was among the earlier eucalypt species introduced to China, and for a time it was commonly planted along roads and railways across a broad geographic area of southern China from southern Hainan to northern Hubei and Jiangsu provinces. At present though, planting is restricted primarily to Hunan and other cooler areas of south central China. In Hunan there is increasing interest in planting the southern form which has become favoured for its cold tolerance and rapid early growth – the cold tolerance of the southern forms is far superior to that of *E. urophylla* and/or *E. grandis*.

In general, growth rates of *E. camaldulensis* are lower than *E. urophylla* and *E. grandis*. Its one year height can range up to six metres and its breast height diameter up to six cm. However, there are large differences between provenances in growth rate, stem form and cold tolerance. Production of *E. camaldulensis* logs suitable for solid wood products requires rotation lengths of over 12 years. The earlier introduced varieties of this are little planted today in China. Now, plantations of newer improved varieties are expanding rapidly in Hunan, and Guangxi provinces.

2.2.5 *E. pellita*

E. pellita is native to areas in north and far north Queensland, southwest Papua New Guinea and western Irian Jaya of eastern Indonesia. Its latitudinal range is 8°-19°S and its altitudinal range extends up to about 800 m above sea level. The provenances sourced from far north Queensland and Papua New Guinea have shown the best growth and stem form in plantations (CAB International, 2000). In its natural range it experiences a summer rainfall pattern with total average rainfalls of 900-2,400 mm per year, the mean maximum temperature of the hottest month is 24-33°C and the mean minimum temperature of the coldest month is 12-16°C (Wang, 2002).

In natural stands tree height can range up to about 47 metres with a good trunk and a heavily branched crown. Its sapwood is pale creamy brown and its heartwood is reddish brown. The timber from older trees in natural stands can have densities ranging up to $790 \text{ kg} \cdot \text{m}^{-3}$ and it is strong and hard, durable and resistant to termites. However, the density of timber from younger plantation grown material is much lower and is normally in the range of $510\text{-}560 \text{ kg} \cdot \text{m}^{-3}$ and the durability is much lower. The timber of *E. pellita* from natural stands in Australia has been used for a wide range of building and heavy construction uses. In China, the plantation grown timber of this species has proved to be very well suited to high quality, high value furniture and decorative applications as well as construction purposes.

The better seed sources/provenances of *E. pellita* show relatively fast growth in plantations in China and match that of good quality *E. grandis*. One-year growth can range up to six metres in height and over six cm in breast height diameter. Even so, the production *E. pellita* logs for solid wood products requires it to be grown with a rotation of over 12 years.

Eucalyptus pellita is one of the more recently introduced eucalypt species to China and it is showing good potential on better sites with good quality management. Although this species is little known in China and only very limited areas have been established to date, it is now being planted on a small scale in Zhanjiang, Guangdong; Dongmen, Guangxi; and in Longyan, Fujian. Plantations of this species are generally established using seedling material. Like *E. urophylla* though, *E. pellita* is not frost tolerant and therefore not suited for planting in the cooler environments of south central China.

2.2.6 *E. torelliana*

The natural range of *E. torelliana* occurs on and around the Atherton Tablelands, Queensland, in Australia. It is found within a latitudinal range of $16^{\circ}\text{-}19^{\circ}\text{S}$ and an altitudinal range of 100-800 m above sea level. Its stands are generally found on the edges of rainforest and in environments that have a peak of rainfall in summer and a mean annual rainfall of 1,000-2,000 mm or more. In its natural habitat the mean maximum temperature of the hottest month is 29°C and the mean minimum of coldest month is $10\text{-}16^{\circ}\text{C}$ (Wang, 2002).

In natural stands *E. torelliana* can attain heights of up to 30 m with a good straight trunk and a deep dense crown. Its crown is probably the densest of all the eucalypts and it will shade out most undergrowth in a plantation. In China, *E. torelliana* has mainly been planted to date as an ornamental and roadside tree on account of its attractive dense crown.

The heartwood of *E. torelliana* is brown in colour, hard, durable above ground and of medium density. It provides a useful attractive sawn timber that is valued for many purposes. In Hainan province, limited amounts of older larger sized *E. torelliana* trees that are available for harvesting are generally used to supply timber for furniture and decorative applications.

Eucalyptus torelliana was among the earliest of the eucalypts introduced to China. Although once widely planted in Hainan, relatively little remains there today. Limited older plantings can also be found scattered through Guangdong and Guangxi provinces.

In general, *E. torelliana* grows much slower than *E. urophylla* and *E. grandis*. However, some newer selections and improved varieties have increased growth rates with 2-years-old trees reaching heights of more than seven metres and breast height diameters of over seven cm. The rotation length for production of *E. torelliana* logs for manufacture of solid wood products will be over 15 years.

2.2.7 *E. saligna*

E. saligna is native to coastal regions of south-eastern Australia with a latitudinal range of 24°-36°S and an altitudinal range of 50-1,200 m above sea level. The climate of its natural habitat ranges from temperate to subtropical, with uniform rainfall distribution in the southern regions of its range and summer rainfall in the north. The mean annual rainfall in these habitats varies from 625 mm up to more than 1,600 mm, the mean maximum temperature of the hottest month is generally around 28-30°C and the mean minimum of the coldest month can be as low as 3-4°C (Wang, 2002).

In natural stands, trees can attain heights of up to 55 m with a clean straight bole of half to two-thirds of total tree height. Its heartwood is pink to red in colour, hard, stiff, and coarse textured, moderately durable and with a density in the range of 495-770 kg · m⁻³. The timber of *E. saligna* is an important general-purpose hardwood in Australia, and it is now a highly valued timber that is used for high quality furniture and flooring. Although problems with growth stress have previously limited its use for sawn-timber in Hawaii, improved silviculture and proper seasoning/drying of the timber can overcome these limitations. In China, limited quantities of older *E. saligna* timber available have proven good for use in furniture, construction and decorative applications.

In general, the growth rate of *E. saligna* is similar or slightly lower than that of *E. grandis*. The best growth of *E. saligna* is obtained in moist and cool mountainous environments that are either too cool and/or too dry for *E. grandis*. The best growth of the species has been recorded from genetically improved trees grown in fertilized plots on good quality soils and ranges up to 50 m³ · ha⁻¹ · yr⁻¹. *E. saligna* can grow in moist and cool mountainous plots. As for solid wood products, the rotation of *E. saligna* will need to be more than 12 years.

E. saligna seedlings have a considerable capacity to harden so as to resist frost damage. In Australia saplings of the species have been known to survive undamaged in frosts as cold as -9°C (Burgess, 1984). However, it is important to realise that these trees were only able to survive such low temperatures on account of being hardened for several weeks at night temperatures lower than 5°C prior to the severe frosts.

Eucalyptus saligna plantations are commonly established using seedlings. However, the species can readily be propagated as rooted cuttings and therefore selection and propagation of superior clonal stock is possible and would provide opportunities for genetic improvement of growth and form.

Although *E. saligna* was planted quite widely some time ago in Guangxi, few of these plantings remain. Today it is again being planted in Guangdong, Guangxi, Hainan and Hunan where it is favoured in cooler more mountainous environments.

2.2.8 *E. cloeziana*

The natural range of *E. cloeziana* is along the eastern coastal area of Australia within a latitudinal range of 16°-26.5°S and an altitudinal range of 60-900 m above sea level. Its natural stands are scattered within this range, sometimes near the coast but at other times well inland. The best natural stands are found on the moist soils of the lower slopes of valleys. In the northern occurrences it may grow on tablelands and upper slopes. In its natural range the mean maximum temperature of the hottest month ranges up to 29°C, and the mean minimum temperature of the coldest month is usually around 8-12°C (Wang, 2002). The species does not tolerate frost.

In natural stands trees can grow to heights of up to 35-45 metres. When young, the species has strong

apical dominance and sheds its young branches very well. This growth habit can lead to good quality pole stands. The mature trees have a relatively dense crown, and enable it to effectively dominate the site and suppress competing vegetation. Its heartwood is a yellow-brown colour, heavy, strong and very durable. The species provides an excellent sawn timber that can be used for a wide range of purposes. Smaller sized trees also provide excellent quality poles (FAO, 1979). Limited amounts of 7-15 years old *E. cloeziana* logs that have been harvested in China have provided sawn timber good for furniture and other decorative applications.

Eucalyptus cloeziana can show vigorous growth in the seedling and pole stages on good quality sites. However, germination of the seed and propagation in the nursery can be more difficult than many other eucalypt species. Also, the seedlings require special care during planting out and early establishment. In China, the best volume growth of *E. cloeziana* has been in fertilized plots on good quality soils and can range up to $40 \text{ m}^3 \cdot \text{ha}^{-1} \cdot \text{yr}^{-1}$. However, growth rates of $25\text{-}30 \text{ m}^3 \cdot \text{ha}^{-1} \cdot \text{yr}^{-1}$ are more commonly obtained for *E. cloeziana* plantations established using seedlings.

Eucalyptus cloeziana is one of the more recently introduced eucalypt species and it was planted only on a limited scale in Guangxi during the 1980s. Today however, few of these older trees remain. Currently it is being planted on a limited scale in Guangdong, Guangxi and Fujian provinces.

3 ACACIA PLANTATION SPECIES IN CHINA

3.1 Species for conservation and environmental plantings

From the late 1970s to early 1990s, most acacia plantings in China were undertaken for catchment protection (soil water reservation) and greening of the environment. During this period, many acacia species new to China were introduced for these purposes including *A. concurrens*; *A. auriculiformis*; *A. flavescens*; *A. leptocarpa*; *A. coleii*; *A. holosericea*; *A. ampliceps*; *A. brassii*; *A. crassicarpa*; *A. dunii*; *A. podalyrifolias*; *A. cincinnata*, and *A. nerrifolia*. (Zhang, 2002).

Most of these acacia species have proved to have little direct economic value as the majority of them have relatively slow growth and only develop into small trees or multi-stemmed bushes. However, their importance lies more in the environmental benefits from their use in soil conservation and amenity plantings. Many are capable of adapting to relatively harsh environments including poor soils and/or dry climates (Wang, 1990).

3.2 Species for timber production

3.2.1 *A. mangium*

A. mangium occurs naturally in north and far north Queensland, southwest Papua New Guinea and eastern Indonesia. Its latitudinal range is 6°-19°S and its altitudinal range extends up to about 400 m above sea level. The provenances sourced from far north Queensland and Papua New Guinea have shown the best growth and stem form in plantations (Zhang, 2002).

For the first two years, *A. mangium* will show good apical dominance and sheds its young branches. Beyond that though, it can lose apical dominance and branches become persistent and large, unless grown at close spacings. The immature and mature trees have a dense crown. Juvenile wood of *A. mangium* has a

pale-yellow colour and is moderately strong but not durable and it has a density of around $420 \text{ kg} \cdot \text{m}^{-3}$. This juvenile wood is regarded as excellent quality pulpwood material.

Acacia mangium was introduced to China in about 1979 and it has since proven to be one of the fastest growing acacias in China, with growth of selected clones averaging more than $20 \text{ m}^3 \cdot \text{ha}^{-1} \cdot \text{yr}^{-1}$. On good quality sites five to seven year old trees can reach heights of up to 20 m with breast diameters over 28 cm (Wang, 1988).

The total plantation area of *A. mangium* is expanding rapidly at present, on account of its rapid growth rates. It is now being planted in Hainan, Guangdong, Fujian, Guangxi and Yunnan provinces and its total plantation area is estimated to be over 60,000 ha (Zhang, 2002). Plantations can be established using either seedlings or rooted stem cuttings of selected clones.

3.2.2 *A. auriculiformis*

A. auriculiformis is native to scattered areas in northern coastal Australia, Papua New Guinea, and eastern Indonesia. Its latitudinal range extends from 7°S to 20°S and its altitudinal range is 0-400 m above sea level. In general, provenances from the eastern part of its range in Australia, along with those from Papua New Guinea (PNG) are better than those from the central and western part of its range in Australia. The eastern and PNG provenances tend to have faster growth, fewer and smaller branches, straighter stems, narrower crowns and are less susceptible to wind damage (Pinyopusarek and Williams, 1990).

At age five years *A. auriculiformis* trees can have heights of up to 15-20 m. Its timber is a pale-yellow-brown colour, strong, low durability and has a density of around $560 \text{ kg} \cdot \text{m}^{-3}$. It is considered as being good pulpwood material. To produce *A. auriculiformis* sawlogs requires rotations of over 12 years. There are scattered plantings of *A. auriculiformis* in Guangdong, Fujian, and Guangxi provinces which are now over 25 years old and mature trees from these are suitable for furniture timbers, construction timbers and other decorative timbers.

Acacia auriculiformis was one of the earliest of the exotic acacias introduced to China. It was initially widely planted in Hainan, Guangdong, Fujian and Guangxi provinces, particularly along roadsides, canals, railways and around villages. Since the early 1990s great emphasis has been placed on selection and genetic improvement of the species and there are now some improved clones available that offer far superior growth. These clones can yield over $20 \text{ m}^3 \cdot \text{ha}^{-1} \cdot \text{yr}^{-1}$ on the better sites. Plantations are currently being established in Hainan, Guangdong, Fujian, Guangxi and Yunnan provinces.

3.2.3 *A. crassicarpa*

The natural range of *A. crassicarpa* lies within latitudes 8° - 20°S in coastal regions of the northern Queensland and in Papua New Guinea, and within an altitudinal range of 0-200 m above sea level.

In China, five-year-old trees can reach heights of 15-20 m. Whilst immature trees can have a dense crown, older more mature trees can have a more open spreading crown. The wood of *A. crassicarpa* has pale-yellow colour, moderate to low durability and the juvenile wood has a density of around $550 \text{ kg} \cdot \text{m}^{-3}$. The wood of *A. crassicarpa* is considered to be a very good pulpwood material.

Acacia crassicarpa is one of the more recently introduced acacias to China. On better sites improved clones can have growth rates exceeding $20 \text{ m}^3 \cdot \text{ha}^{-1} \cdot \text{yr}^{-1}$. Plantations of this species are currently being established at an increasing rate in Hainan, Guangdong, Fujian, Guangxi and Yunnan provinces (Zhang, 2002).

3.2.4 *A. cincinnata*

The natural distribution of *A. cincinnata* is in the eastern coastal regions of Australia between latitudes 16°-28°S, longitudes 145°45'-153°E and within an altitudinal range of 0-750 m. Some of the best provenances for growth and form in exotic plantations are those from north of 18°S (Zhang, 2002).

In natural stands in Australia, trees can grow up to heights of 20 m or more. Mature wood from older trees in natural stands is reddish-brown in colour, hard, moderately durable and has a density of around 580 kg · m⁻³. This timber is well suited to appearance grade products such as high-grade furniture and building joinery.

Acacia cincinnata was introduced to China more than 30 years ago and has been planted on a limited scale in Hainan, Guangdong, Fujian, Guangxi and Yunnan provinces.

3.2.5 *A. melanoxylon* and *A. dealbata*

Acacia melanoxylon's natural distribution spans a latitudinal range of 16°-43°S from northern Queensland, through eastern New South Wales and Victoria and into Tasmania. Natural stands occur at altitudes ranging from 0 to 1,500 m above sea level and in areas where the climate has an average of rainfall 750-1,500 mm · yr⁻¹; mean minimum temperatures of the coldest month of 1-10°C and up to 80 days of frost per year (Zhang, 2002).

The natural range of *A. dealbata* is more restricted and it occurs in Tasmania, Victoria, and New South Wales in Australia within a latitudinal range of 29°-43°S and an altitudinal range of 100-900 m above sea level. In its natural habitat the average rainfall is 700-1,400 mm · yr⁻¹ and the mean minimum temperature of the coldest month is 1-6°C (Zhang, 2002). It has a stronger capability of withstanding frost, and it tolerates much colder climates than the tropical acacias (*A. mangium*, *A. auriculiformis* and *A. crassicarpa*) that are not frost tolerant.

Acacia melanoxylon and *A. dealbata* were introduced to China in 1980s. Because of their relatively good frost tolerance, they have been planted in cooler subtropical areas such as Jiangxi and inland parts of Fujian provinces.

The heartwood from older trees of these species has a reddish to very dark brown wood colour, is hard and of low to moderate durability. The density of their timber is around 550 kg · m⁻³. The timber from both species can be used for high-grade furniture and a range of other decorative applications.

4 CONCLUSIONS

Eucalypts were first introduced to China more than 100 years ago. Since then, they have proven well adapted to many sites in southern China and capable of providing high yields of versatile and valuable timber. Acacias, being nitrogen-fixing species, have also proved adaptable to a range of sites in southern China. As with eucalypts, their timber has been useful for a range of wood products including pulpwood, firewood, charcoal, and sawn timber for construction.

It is in the last 20 years that the most rapid expansion of eucalypt plantations has taken place in China, in order to supply high quality pulpwood. Today, the expansion of the eucalypt plantation resource for production of pulpwood in southern China continues at rapid rate and in more recent years, this has also been accompanied by a rapid increase in the establishment of fast-growing acacia pulpwood plantations.

With both eucalypts and acacias, there are substantial differences between species in respect to growth rates, adaptability and wood properties. Thus, the rational and efficient use of the large areas of acacia and eucalypt resources needs very careful consideration.

Some of the faster growing eucalypt and acacia species have wood properties that are well suited for higher value solid wood products, e.g. furniture, doors, joinery, flooring, veneer, plywood and laminated lumber. Given increasing demand for such products and diminishing supplies from traditional sources in China at present, there is an urgent need to develop the technology of eucalypt and acacia species with respect to higher value, high quality solid wood products. Based on experience in plantations overseas and that with eucalypts from their natural forests in Australia, a program has been initiated in China to study the silviculture, wood properties and processing technologies for development of quality eucalypt and acacia plantations to provide high value solid wood products.

The eucalypt and acacia species that do have potential for production of such solid wood products in China, can be divided into three distinct categories:

1) Species of which there is a currently a substantial plantation resource. Even though most of this resource is dedicated to short rotation pulpwood production, if given appropriate silvicultural management the species could produce good quality larger diameter logs for high value end-uses – this category includes *A. mangium*, *E. urophylla* and its hybrids (e.g. U₆, EC₄, DH₃₃₂₉, DH₃₃₂₇ etc.), *E. grandis* and *E. globulus*.

2) Species which were once more widely planted in southern China. These species are currently diminishing in availability, even though the species are particularly good for quality solid wood products – this includes *A. auriculiformis*, *E. citriodora*, *E. exserta*, *E. Leizhou* 'No. 1', *E. '12 ABL'* and *E. saligna* × *exserta*.

3) Species currently being tested in plantations and/or trials, that have been selected for their ability to yield high value appearance grade timbers – this includes *A. cicinnata*, *A. melanoxylon*, *A. dealbata*, *E. camaldulensis*, *E. pellita*, *E. torelliana*, *E. saligna* and *E. cloeziana*.

REFERENCES

- Boland D J, Brooker M I H, Chippendale G M, Hall N, Hyland B P M, Johnston R D, Kleinig D A, Turner J D. 1984. Forest trees of Australia. 4th ed. Melbourne: Thomas Nelson and CSIRO. 687
- Burgess I P. 1984. Tolerance of two years old *Eucalyptus grandis* and *Eucalyptus saligna* to winter frost in Canberra. In: Proceedings IUFRO Colloque international sur les eucalyptus résistants au froid. Bordeaux, September 1983, Paris: AFOCEL, 358-366
- Booth T H, Nix H A, Hutchinson M F, Jovanovic T. 1988. Niche analysis and tree species introduction. Forest Ecology and Management. 23(1): 47-59
- CAB International. 2000. Forestry Compendium – a silvicultural reference. Global Module. Wallingford, UK: CAB International. CD ROM
- Eldridge K G, Davidson J, Harwood C E, van Wyk G. 1993. Eucalypt domestication and breeding. Oxford: Oxford University Press, 288
- FAO. 1979. Eucalypts for planting. M R. Jacobs. Forestry Series No. 11. In: Rome: FAO. 677
- Keating W G, Bolza E. 1982. Characteristics, properties and uses of timbers. Volume 1. South-east Asia, Northern Australia and the Pacific. Melbourne, Australia: Inkata Press. 362
- Pinyopusarerk K, Williams E R. 1990. Variation in Seedling Morphology of *Acacia auriculiformis*. In: Advances in Tropical Acacia Research, ACIAR Proceedings No. 35: 67
- Qi S X. 2002: Eucalyptus in China. China Forestry Press
- Turnbull J W. 1981. Eucalypts in China. Australian Forestry, 44(4):222-234
- Turnbull J W, Pryor L D. 1984. Choice of species and seed sources. In: Hillis W E, Brown A G. Eds. Eucalypts for Wood Production. Sydney, Australia: CSIRO, Australia and Academic Press, 6-65
- Wang G X. 1988. Early performance of *Acacia mangium* at Dongmen, Guangxi. Proceedings of the use of Australia trees in China workshop, Chinese Academy of Forestry. 135
- Wang H R. 1991. The History of *Acacia* Introductions to China. In: Advances in Tropical Acacia Research, ACIAR Proceedings, 35: 64-66
- Wang H R. 2002. Taxonomic issues of introduction. Eucalyptus in China, China Forestry Press, 40-54
- Zhang F Q. 2002. Exotic *Acacias* and Its Utilization in Plantations for Pulp Production. Tropical Forestry Research in China, Research Institute of Tropical Forestry Chinese Academy of Forestry, 49-53. (in Chinese)

Loss of Sawn Recovery Associated with Growth Stress and Potential Indicators of Sawlog Quality-A Case Study with *Eucalyptus globulus* Labill.

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ABSTRACT

A study was carried out to assess the loss of sawn recovery due to log end splits and spring in slabs and to evaluate the potential of various wood property measurements as sawlog quality indicators. Thirty dominant or co-dominant, straight trees were selected from a 32-years-old thinned plantation of *Eucalyptus globulus* Labill. Longitudinal growth strain at the tree surface at breast height was estimated. One full-diameter increment core of 12 mm diameter was removed from each tree at breast height and one strip specimen prepared from each core. Microdensity, microfibril angle (MFA), Young's modulus (E_t), and cellulose crystallite width of the strip specimens were determined using SilviScan-2 technology. The severity of end splits in the butt logs was quantified using split indices. The butt logs were quarter-sawn following a pre-determined sawing pattern. The curved-edge off-cuts were collected and their total volume for each butt log was estimated. The end splits in the dried sawn boards were measured and the volume of the boards containing the splits calculated.

The estimated reduction in sawn recovery due to removing the curved edges in the slabs was found to be equivalent to 6% of the log volume. The estimated reduction in recovery due to end-docking log-end splits was found to be equivalent to 1% of the log volume, or approximately 4% of the dried board volume. These would translate into a large annual loss for sawmills.

The mean longitudinal displacement, indicating growth stress, was found to be a moderately successful indicator of the severity of log end splits. However, it had no direct relationship with the volume of end docking, nor with the volume of the curved-edge off-cuts. The radial variation of MFA appeared to be the most useful indicator of spring in dried boards. The radial variation of Young's modulus appeared to be more useful than other wood properties in predicting distortion in green slabs (i.e. flitch and slab movement during sawing). Microdensity and cellulose crystallite width, either as tree means or as descriptors of their radial variation, showed no significant relationship with log-end split indices, spring in dried boards, the volume of curved-edge off-cuts, and the volume of end docking.

1 INTRODUCTION

Eucalyptus globulus Labill. (Tasmanian blue gum) is the most extensively planted eucalypt species in Australia, with an approximate area of 395,000 ha as of June 2002 (NFI, 2003). The majority of these plantations have been established for wood chip export. There has been a growing need and interest in

establishing plantations for sawlog production as log supplies from natural hardwood forests are likely to decrease in the future.

One of the key factors limiting efficient use of young eucalypts as sawlogs is high growth stress (Malan, 1997; Garcia, 1999; Muneri *et al.*, 1999; Waugh, 2000; Maree and Malan, 2000; Yang *et al.*, 1996, 2002; Yang and Waugh, 2001). The release of residual growth stress results in log-end splitting, flitch movement and further splitting of the log-end splits during sawing, sawn board distortion and thickness variation, and reduced choices of sawing patterns. Sawn board distortion (spring and/or bow) of various severities has been reported when processing plantation blue gum (Thomson and Hanks, 1990; Brennan *et al.*, 1992; Waugh and Yang, 1993; Moore *et al.*, 1996; Northway and Blakemore, 1996; Yang and Waugh, 1996; Washusen *et al.*, 2004).

Whilst the fundamental aspects of split formation and propagation have been investigated by many researchers, there is only limited knowledge of the loss of sawn timber recovery due to log-end splits and flitch/slab distortion. There has also been limited progress towards identifying useful, reliable and non-destructively measurable hardwood sawlog quality indicators.

A study was recently undertaken to quantify the impact of log-end splits and spring in sawn slabs and to investigate the potential of using wood property characteristics measured at breast height as sawlog quality indicators (Yang and Pongracic, 2004). *Eucalyptus globulus* Labill. was selected because of its significance in Australia. The study only dealt with sizing cuts that removed the curved edges in green slabs and end-docking^① that removed end splits in dried boards. The key results are reported in this paper. The terms 'growth strain' and 'growth stress' in this paper respectively refer to the residual longitudinal strain and stress that exist in standing trees or logs unless otherwise specified.

2 MATERIALS AND METHOD

2.1 Tree selection

Thirty dominant or co-dominant straight trees with good stem form were selected from a 32-years-old thinned plantation of *E. globulus* Labill. grown at a location south of Traralgon in central Gippsland, Victoria. These trees were considered to contain low levels of tension wood and the logs on harvesting were capable of being sawn in a conventional sawmill (Washusen *et al.*, 2004).

2.2 Growth strain estimation and wood property measurements

Growth strain at breast height was estimated using a CIRAD-forêt method at four circumferential locations corresponding to the North, South, East and West cardinal directions, which produced measurements of the longitudinal displacement upon stress release.

One 12 mm diametrical increment core was removed from each tree at 1.3 m height in the North-South direction. One SilviScan specimen was cut from the centre of each conditioned core using two sets of twin-blade saws. Microdensity, cellulose microfibril angle (MFA), cellulose crystallite width (W_{cryst}) and Young's modulus^② (E_L) were obtained using SilviScan-2 (Evans, 2005; Evans *et al.*, 1999). Microdensity was recorded at 0.05 mm intervals. MFA, W_{cryst} and E_L were recorded at 5 mm intervals.

① It is assumed that end docking was applied at a later processing stage to remove end splits in the dried boards.

② The E_L was calibrated against the dynamic E_L of *E. delegatensis* because the calibration for *E. globulus* was not available. This should not affect the outcome of the relationship analysis.

2.3 Log-end splits

The 30 trees were harvested and stored under water spray at the Black Forest Sawmill in Victoria for approximately two months before sawing. Some stress relaxation during storage would have occurred but was not recorded. The characteristics of log-end splits (split length on the log end and log surface, and split width at the log end) of each butt log were measured the day before sawing. The length of radii corresponding to the four cardinal directions was also measured on the large end of each butt log.

Split Index 1 (SI-1) and Split Index 2 (SI-2) were calculated respectively using Equations 1 and 2 to describe the severity of log-end splits. In deriving SI-2, it was assumed that: (i) a split plane has the shape of an isosceles right-angled triangle to start with, and (ii) when a split propagates from the periphery along the log surface ($SL_{SURFACE} > 0$), the split plane also extends the same distance along the log axis (Fig. 1). Neither split index has units since SI-1 was weighted by the mean radius and SI-2 was weighted by the mean radius squared. The purpose of weighting was to standardize the severity of split plane.

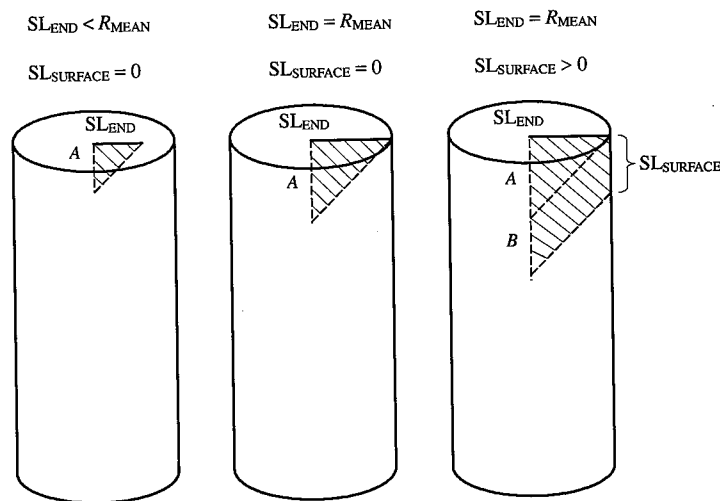


Fig. 1 Illustration of the symbols used in calculating Split Index 2 (SI-2)

The shaded area is the inner split plane

$$SI - 1 - \text{Single} = (SL_{END} + SL_{SURFACE}) / R_{MEAN} \quad (1)$$

$$SI - 2 - \text{Single} = [(SL_{END} \times A / 2) + (SL_{SURFACE} + B) \times SL_{END} / 2] / R_{MEAN}^2$$

$$= [(SL_{END} \times SL_{END} / 2) + (SL_{SURFACE} \times SL_{END})] / R_{MEAN}^2 \quad (2)$$

Where:

SL_{END} = split length on the log end;

$SL_{SURFACE}$ = split length on the log surface;

R_{MEAN} = mean radius of the log end;

A equal to SL_{END} ;

B equal to $SL_{SURFACE}$.

There is little published knowledge about the actual shape of the split plane. It may easily differ from an isosceles right-angled triangle and take a three-dimensional shape in the presence of deviated wood grain. The assumptions for Equations 1 and 2 are therefore relatively crude and may be improved in the future.

The split indices can also be calculated for a log end. SI-1-LogEnd equates to the sum of all SI-1-Single values at a log end. Similarly, SI-2-LogEnd equates to the sum of all SI-2-Single values at a log end. One advantage of SI-1-LogEnd and SI-2-LogEnd is that they reflect the overall splitting severity of a log end, therefore are more suitable for data analysis.

2.4 Sawing

The logs were quarter-sawn. The sawing strategy was to produce sawn boards in dimensions that were common to the Australian market. The nominal thickness and length of the green boards were 28 mm and 3,000 mm; the widths varied between 57 mm, 77 mm, 105 mm, 140 mm, and 163 mm. The most common widths were 77 mm and 105 mm.

2.5 Measurement of the volume of the curved-edge off-cuts

For safety reasons, green slabs cannot be accessed during sawing. The effect of spring in green slabs on sawn recovery was instead assessed indirectly by estimating the volume of the curved-edge off-cuts (i.e. the cuts that are needed to remove the spring in the slabs associated with growth stress release). Approximately half of these off-cuts were recovered during sawing as the rest were unable to be collected. The maximum width of each off-cut was measured after sawing. The volume of each off-cut was estimated by treating it as a 28 mm thick, 3,000 mm long, triangle-shaped object. The approximate total volume of these off-cuts for each log was twice the estimated volume of the collected off-cuts.

To treat the sapwood of blue gum boards against lyctid borer infestation, the green boards were block-stacked and dipped in a 10% m/v solution of Diffusol Wood Preservative Concentrate (a diffusible Boron formulation), then wrapped in plastic for 6 weeks, prior to drying. The boards were dried at the sawmill using a commercial drying schedule. See Washusen *et al.* (2004) for details of the drying schedule.

2.6 Measurement of spring and end splits in dried boards

Spring was measured before and after drying. The proportion of dried boards that exceeded 10 mm spring^① was calculated for each log as the number of dried boards exceeding 10 mm limit divided by the total number of dried boards from that log, expressed as a percentage. Bow was not measured before and after drying because it was small and can be controlled through correct drying practices.

Some green sawn boards inevitably contained end splits that initially existed at the log ends. These splits may become longer during sawing and drying. To prevent over-estimating the lost wood associated with log-end splits, only the initial log-end splits present in the dried boards were measured. These splits were quite easy to recognise as they were stained with soiled water.

It was assumed that the dried boards would be end-docked to remove the end splits and cut to commercial lengths simultaneously. The volume of the docked ends per board was equal to the total effective length of the splits in that board multiplied by the cross-sectional area of the board. The proportion of end-docking was calculated for each log in two different ways: the volume of the docked ends of the dried boards divided by the log volume, and the volume of the docked ends of the dried boards divided by the

① In assessing board distortion, the spring limit of 10 mm was adopted from the CSIRO Forestry and Forest Products grading criteria for appearance products of 100 mm wide and 3,000 mm long. These grading criteria were very similar to the current Australian Standard for hardwood sawn and milled products (AS 2796.1) but defined the limit for each type of defect more precisely.

volume of all dried boards from that log.

3 RESULTS AND DISCUSSION

3.1 General observations on the trees

The mean diameter at breast height over bark (DBHOB) was 461 mm, and ranged from 372 to 580 mm. Almost every butt log had a much longer radius at the West side and, consequently, a much shorter radius at the East side (Tab. 1). The difference in growth ring width between the West and East sides was much greater near the pith, indicating that the eccentric growth occurred at greater pace when the trees were young.

Tab. 1 Mean values of radius length and the longitudinal displacement at each cardinal direction ($n=30$)

| Properties | North | East | South | West | Mean |
|-------------------------|-------|-------|-------|-------|-------|
| Mean radius (mm) | 204 | 197 | 207 | 257 | 216 |
| Mean radius / DBHOB (%) | 50 | 43 | 45 | 56 | 47 |
| Mean displacement (mm) | 0.094 | 0.087 | 0.088 | 0.103 | 0.093 |

3.2 Log-end splits

Log-end splits were not severe overall and were about one to two mm wide on the large ends of most logs. The small log ends had noticeably fewer splits and showed no surface splits. Splits were rarely aligned between two ends of the same log, as frequently observed in logs of other eucalypt species. Only two logs showed severe end splits, where the split width was three mm or more and the total split length on the log surface was greater than 400 mm. The overall low level of end splitting may be attributed to the frequent presence of interlocked grain in *E. globulus* (Bootle, 1983) by comparison with other species such as *E. regnans*, in which more fracture energy is required to split the wood.

The split indices were not related to the degree of pith eccentricity (expressed as the ratio of the East to West radii). Pith eccentricity is often perceived as an indicator of reduced uniformity in wood properties and likely occurrence of tension wood on the wider side of a hardwood tree trunk. The results here showed that pith eccentricity was not a reliable indicator of log end splits and suggest that the split formation and severity are driven by a much more complex mechanism that involves several wood properties and tree geometry.

3.3 Spring and end splits in dried boards

Spring measured after drying is the initial spring due to the release of growth stress plus the spring caused by differential longitudinal shrinkage during drying (Kliger *et al.*, 1997). Of the total 503 boards, 26% showed various amounts of spring in the green state; most spring was below 10 mm with the mean being six mm (Tab. 2). Spring increased in these boards and developed in other originally straight boards during drying. The average increase was five mm and the maximum increase was 37 mm. Only six boards remained straight during drying. Most boards sprang in the same direction during drying as when they were green. Spring measured before and after drying was found to be not significantly correlated. The mean percentage of dried boards exceeding ten mm spring for the 30 logs was 43% and reached 88% for one log (Tab. 2). Dried boards generally need to be trimmed to appropriate sizes to remove excessive spring to make

saleable wood products at a later stage. As such, the magnitude of spring will affect the recovery and value of the final sawn products. This aspect was not investigated in this study.

Tab. 2 Spring and loss of recovery due to sizing cuts and docking of end splits ($n=30$)

| Measurements | Mean | SD | Range |
|--|------|------|----------|
| Spring in green boards (mm) | 6 | 4 | 2-20 |
| Spring in dried boards (mm) | 11 | 7 | 0-40 |
| Dried boards with spring > 10 mm (% of dried boards) | 43.0 | 23.6 | 0-87.5 |
| Width of curved-edge off-cuts (mm) | 24 | 13 | 5-82 |
| Volume of curved-edge off-cuts per log (%) | 6.0 | 1.9 | 1.1-9.6 |
| Volume of end docking per pre-docking board volume (%) | 3.76 | 3.02 | 0.7-13.5 |
| Volume of end docking per log (%) | 0.97 | 0.76 | 0.2-2.9 |

Forty-seven percent of the dried boards had end splits. The average length was 165 mm and the longest was 810 mm. End splits in the dried boards are a combination of initial log-end splits and their likely extension during drying in response to differential longitudinal shrinkage across the boards.

3.4 Reduction in sawn recovery due to removal of curved edges and end splits

The study showed approximately 4% of the dried board volume would be lost as a result of end docking (Tab. 2). If the final volume recovery of dried sawn product was 26%, then for an average log of 0.38 m^3 (200 mm radius and 3,000 mm length), the lost volume due to end docking would be 0.004 m^3 ($0.38 \text{ m}^3 \times 26\% \times 4\%$). At an average price of $\text{A\$}914 \cdot \text{m}^{-3}$ (pers. comm. Washusen) for dried sawn product, the expected value of the lost product is $\text{A\$}3.66$ ($\text{A\$}914 \times 0.004 \text{ m}^3$) per log or $\text{A\$}9.63$ per cubic metre of log.

The reduction in sawn recovery due to removal of the curved edges in slabs per log was calculated as a percentage of the volume of the curved-edge off-cuts divided by the log volume and multiplied by 100. The average loss was found to be 6% for the 30 logs (Tab. 2). If the volume recovery of green sawn boards was 38% and the volume loss of the curved-edge off-cuts was 6%, then for an average log of 0.38 m^3 (200 mm radius and 3,000 mm length), the green recovery would drop by 0.02 m^3 ($0.06 \times 0.38 \text{ m}^3$). At an average price of $\text{A\$}360 \cdot \text{m}^{-3}$ for green sawn timber, the expected value of the lost recovery is $\text{A\$}7.20$ ($\text{A\$}360 \times 0.02 \text{ m}^3$) per log or $\text{A\$}18.95$ per cubic metre of log. While this value seems low on a log basis, a mill has also to consider that the costs of removing the curved edges may have a significant effect on the efficiency of the mill. The 6% loss of log volume is partially associated with the quarter-sawn strategy and may be reduced if the logs were back-sawn. On the other hand, the loss could have been higher for commercial operations from this plantation due to less careful log handling. Also, the removal of spring in the dried boards would incur additional loss of wood and loss of productivity.

3.5 Relationships between log-end splits and removal of curved edges and end splits

The volume of end docking (as a percentage of log volume) was significantly correlated with SI-1-LogEnd ($R^2 = 0.31, p < 0.01$) and with SI-2-LogEnd ($R^2 = 0.32, p < 0.01$). Such moderate correlations were more or less expected because the volume of end-docking is also affected by log size, sawing patterns and board dimensions. Once a board is cut, the volume of end docking is determined by the cross-sectional area of the board; the

smaller the cross-sectional area, the less the volume of end docking for a given length of end split.

There was no significant relationship between log-end split indices and the volume of the curved-edge off-cuts. This is because, although log-end splits and spring in slabs are both fundamentally linked to growth stress, their formation and magnitude also depend on other factors such as green wood toughness and rigidity components in respect of log-end splits (Jullien *et al.*, 2003) and the gradient of longitudinal modulus of elasticity in the radial direction in respect of spring.

3.6 Wood properties and their relationships with sawlog processing and product variables

The basic statistics for microdensity, MFA, W_{cryst} , and Young's modulus measured using SilviScan-2 are summarized in Tab. 3. An example of within-tree variation of these properties in the radial direction is given in Fig. 2. Each property appeared to show a trend but the trend for MFA and E_L is far more defined in all the trees. The pith-to-bark trend (slope) and the smoothness of the trend lines for these wood properties were found to differ considerably between trees.

Tab. 3 Basic statistics for area-weighted microdensity, microfibril angle (MFA), Young's modulus (E_L), and cellulose crystallite width (W_{cryst})

| Measurements | Sample size | Mean | SD | Range |
|---|-------------|------|------|-----------|
| Density at 12% MC ($\text{kg} \cdot \text{m}^{-3}$) | 30 logs | 775 | 41 | 697-867 |
| MFA (degree) | 30 logs | 12.4 | 1.6 | 10.2-18.6 |
| W_{cryst} (nm) | 30 logs | 3.30 | 0.05 | 3.21-3.42 |
| E_L (GPa) | 30 logs | 19.6 | 2.4 | 13.5-24.8 |

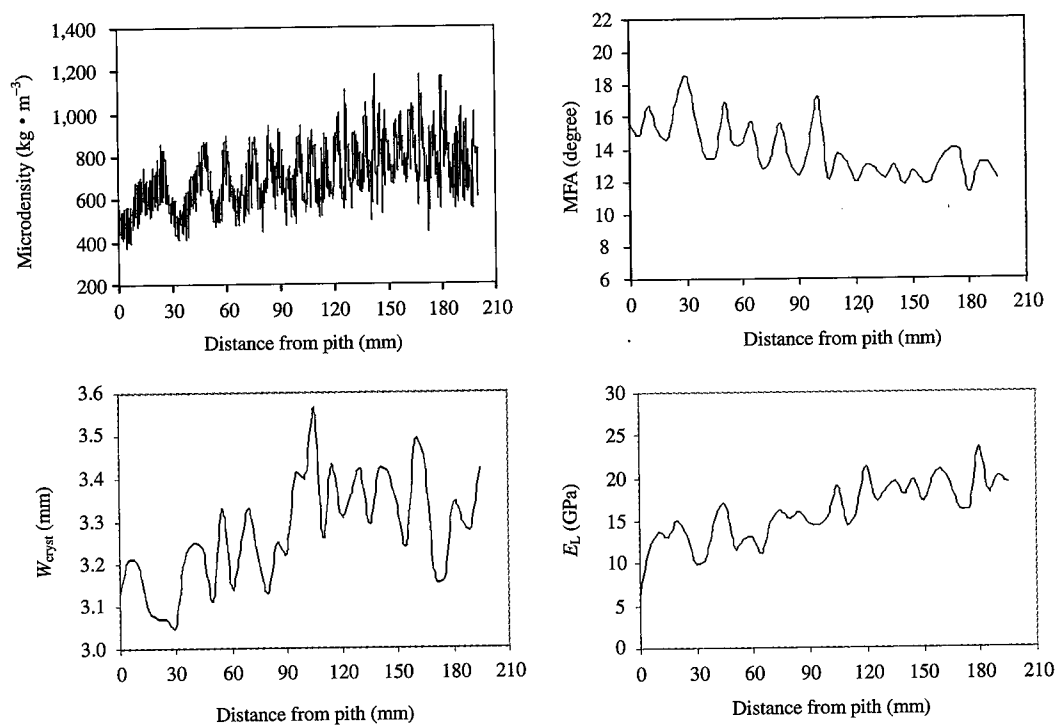


Fig. 2 Pith-to-bark SilviScan measurements of microdensity, MFA, W_{cryst} , and Young's modulus on the North side of tree 52

The correlation coefficients for correlations between wood property measurements (the longitudinal

displacement and SilviScan data) and sawlog processing and product variables (spring, loss of recovery) are given in Tab. 4.

Tab. 4 Correlation coefficients for correlations between wood property measurements and sawlog processing and product variables

| | SI-2-LogEnd | Volume of curved-edge off-cuts (%) | Volume of end docking (%) | Spring in dried boards | boards exceeding 10mm spring(%) |
|----------------------------------|-------------|------------------------------------|---------------------------|------------------------|---------------------------------|
| Displacement ^① (mean) | 0.53** | n.s. | n.s. | 0.53** | 0.56** |
| Displacement / DBHOB | 0.39* | n.s. | n.s. | 0.61*** | 0.65*** |
| Density (mean) | n.s. | n.s. | n.s. | n.s. | n.s. |
| Density slope | n.s. | n.s. | n.s. | n.s. | n.s. |
| MFA (mean) | n.s. | n.s. | n.s. | -0.43* | -0.58** |
| % of MFA < 12 degrees | n.s. | 0.32* | n.s. | -0.57** | -0.72*** |
| W_{cryst} (mean) | n.s. | n.s. | n.s. | n.s. | n.s. |
| W_{cryst} slope | n.s. | n.s. | n.s. | n.s. | n.s. |
| E_L (mean) | n.s. | n.s. | n.s. | 0.38* | 0.49** |
| E_L slope | n.s. | 0.42* | n.s. | 0.49** | 0.51** |

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

The mean longitudinal displacement per log was significantly correlated with the SI-2-LogEnd ($R = 0.53$). It was not significantly correlated with the volume of the curved-edge off-cuts. This indicates that distortion of flitches and slabs at the release of log internal stress during sawing is a complex matter. A sophisticated strain measurement system and mechanical modelling will be needed to understand how flitches and slabs move during sawing. The mean longitudinal displacement was also significantly correlated with spring in dried boards ($R = 0.53$) and the percentage of boards with greater than 10 mm spring ($R = 0.56$). The relationship would become stronger if the displacement was divided by DBHOB (Tab. 4). These relationships were not intuitive because a component of the spring in dried boards was caused by across-board differential longitudinal shrinkage that is often associated with factors such as spiral grain and MFA variation across board.

Mean density and density trend pith to bark (slope) were not significantly correlated with any of the sawlog processing and product variables listed in Tab. 4.

Mean MFA was negatively correlated with spring in dried boards ($R = -0.43$) and with the percentage of boards with greater than 10 mm spring ($R = -0.58$). Relationships of similar strength were also found for the mean slope of MFA (trend pith to bark) - a measure of radial variation of MFA (correlation coefficients not shown in Tab. 4). Larger MFA slope would infer greater MFA variation across a quarter-sawn board. Interestingly, the percentage of MFA values smaller than 12 degrees, which is a measure of the cross-sectional variation of MFA, had stronger relationships with the processing and product variables than mean and the slope of MFA (Tab. 4). These results clearly indicate the potential of using MFA variation to predict spring in dried boards at the log level. If the results are substantiated, tree growers should consider growing future sawlogs with reduced MFA slope or cross-sectional MFA variation through breeding, site selection and silvicultural management.

Variation in mean cellulose crystallite width was relatively small among individual logs, ranging from 3.21 to 3.42 nm (Tab. 3). It is worth noting that the mean W_{cryst} in this study (3.30 nm) was much higher than the mean W_{cryst} (2.88 nm) of a group of 10-year-old blue gum trees (Jeeralang, King Island, and South East

① Strain raw data.

Tasmania provenances) (Yang *et al.*, 2003). It is possible that differences in operating conditions in SilviScan when the two sets of specimens were scanned had contributed to some extent to such large difference in mean W_{cryst} (pers. comm. R Evans).

If 3.4 nm of W_{cryst} is accepted as the threshold between normal wood and tension wood, which was proposed in a recent study on blue gum (Washusen *et al.*, 2004), then 12 butt logs in this study would be classified as containing appreciable amounts of tension wood, since wood with W_{cryst} greater than 3.4 nm was found in 36% of the core samples from these logs.

It was found that mean W_{cryst} , W_{cryst} slope and the percentage of W_{cryst} values greater than 3.4 nm were not significantly correlated with any of the sawlog processing and product variables listed in Tab. 4. The lack of relationships may point to a possibility that the presence of tension wood had not been adequately revealed due to the limited sampling in this study. The increment cores were taken from North-South direction, but the pith eccentricity occurred in the East-West direction, therefore the sampling may have missed some tension wood if it did exit at the West side of the logs. On the other hand, if the sampling was the reason, such bias would have extended to the MFA and E_L (Young's modulus) measurements as well and affect their relationships with the sawlog processing and product variables. It appears, based on results in this study that using W_{cryst} to predict the propensity of sawn board spring or bow during drying is less straight-forward than using MFA.

Mean E_L and E_L slope (trend pith to bark) were significantly correlated with spring in dried boards and the percentage of boards with greater than 10 mm spring (Tab. 4). The relationships, however, do not suggest that E_L had some causal effect on spring development during drying. The E_L slope relationship instead is a reflection of the causal effect of MFA variation on spring formation during drying, as E_L is largely influenced by MFA (Evans and Ilic, 2001; Yang and Evans, 2003) and the E_L variation pattern would reflect the MFA variation pattern. The relationship between the E_L slope and the volume of curved-edge off-cuts was significant but modest.

To summarize the relationships based on the data in this study, the longitudinal displacement is the only useful predictor for log end splitting severity, the radial variation in MFA (such as the percentage of MFA smaller than 12 degrees) has the best potential in predicting spring in dried boards, and the radial variation of E_L is most useful in predicting distortion in green slabs (i.e. simultaneous bending of flitch and slab during sawing). Increasing the number of wood properties does not significantly improve the strength of these respective relationships. Density and W_{cryst} have little potential to be useful predictors for the sawlog processing and product variables listed in Tab. 4.

4 CONCLUSIONS

The estimated reduction in sawn recovery due to end docking to remove end splits in the dried boards was equivalent to 1% of the log volume, or approximately 4% of the dried board volume. This equates to A\$9.63 in lost dried product per cubic metre of logs if recovery of dried sawn product is 26% and the average price of dried sawn timber is A\$914 · m⁻³.

The estimated loss of green sawn recovery due to removing curved edges was equivalent to 6% of the log volume. This equates to A\$18.95 in lost green product per cubic metre of logs if recovery of green sawn product is 38% and an average price of green sawn timber is A\$360 · m⁻³.

The annual combined effect of log-end splits and the curved-edge off-cuts on a 40,000 m³ per annum sawmill would be over A\$1 million, due to removing the end splits initially present in the logs and the

curved edges related to spring in the slabs. This figure needs to be viewed in the context of quarter-sawn strategy and relatively low level of log end splitting. It may vary considerably with different logs and different log cutting methods and equipment.

Spring increased by an average of five mm during drying. If ten mm were set as the spring limit, then 43% of the dried boards would have exceeded this limit and need shortening or sizing cuts at a later stage to reduce or remove the excessive spring. This would incur further loss of wood and productivity.

The mean longitudinal displacement can indicate the severity of log end splits with moderate success and is the only useful indicator in this regard. It had no direct relationship with the volume of end docking nor with the volume of the curved-edge off-cuts. The radial variation of MFA appeared to be the most useful indicator for spring in dried boards. The radial variation of E_L is the most useful but relatively weak predictor for spring in green slabs (i.e. simultaneous bending of flitch and slab during sawing). Microdensity and cellulose crystallite width, either as tree means or as descriptors of radial variation, showed no significant relationships with log-end split indices, spring in dried boards, the volume of curved-edge off-cuts, or the volume of end docking.

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REFERENCES

- AS2796.1. 1999. Timber - Hardwood - Sawn and milled products: Product specification. Standards Australia
- Bootle K R. 1983. Wood in Australia – Types, properties and uses. McGraw-Hill Book Company, Sydney New York St Louis
- Brennan G K, Hanks WR, Ward SL. 1992. Processing plantation-grown Tasmanian blue gum. Department of Conservation and Land Management. WURC Technical Report, 41, 14
- Evans R, Ilic J. 2001. Rapid prediction of wood stiffness from microfibril angle and density. *Forest Products Journal*, 51(3):53-57
- Garcia J N. 1999. Theory and practice on the high quality Eucalyptus lumber production on forest improvement and sawmill techniques. In: Proceedings of XII Silvotecnica Eucalypt in Chile: Present and Future. Corma Concepción, 1-22
- Jullien D, Laghdir A, Gril J. 2003. Modelling log-end cracks due to growth stresses: calculation of the elastic energy release rate. *Holzforschung*. 57(4):407-414
- Kliger R, Perstorper M, Johansson G. 1997. Variability in wood properties and its effect on distortion and mechanical properties of sawn timber. In: Timber management toward wood quality and end-product value. Conference proceedings of CTIA/IUFRO International Wood Quality workshop, Quebec city, Canada, September 1997
- Malan F S. 1997. South Africa's experience. In: Timber Management Toward Wood Quality and End-product Value, CTIA/IUFRO International Wood Quality Workshop, Quebec City, Canada, August, 18-22, 1997, III, 3-16
- Maree B, Malan F S. 2000. Growing for solid hardwood products - a South African experience and perspective. In: The Future of Eucalypts for Wood Products, Proceedings of IUFRO Conference, Launceston, Tasmania, Australia, 19-24 March 2000, 319-327
- Moore R G, Siemon G R, Eckersley P, Hingston R A. 1996. Sawlogs from 13-year-old *Eucalyptus globulus* – management, recovery and economics. In: Farm Forestry and Plantations - Investment in Future Wood Supply, Australian Forest Growers Conference, Mount Gambier, South Australia, September 1996, 13
- Muneri A, Leggate W, Palmer G. 1999. Relationships between growth strain measured with CIRAD-Forêt Growth Strain Gauge and some tree, wood and sawn timber characteristics of twenty three 10-year-old Eucalyptus cloeziana trees. *Southern African Forestry*. 187:1-9
- National Forest Inventory. 2003. National Plantation Inventory Annual Update – March 2003, Bureau of Rural Sciences, Canberra
- Northway R L, Blakemore P A. 1996. Evaluation of drying methods for plantation grown eucalypt timber: Sawing, accelerated drying and utilisation

- characteristics of *Eucalyptus globulus*. FWPRDC Report PN006.96, 31
- Thomson A, Hanks W R. 1990. Sawmilling study of Tasmanian blue gum grown in Western Australia. Department of Conservation and Land Management. WURC Technical Report No.13, 9
- Washusen R, Reeves K, Hingston R, Davis S, Menz D, Morrow A. 2004. Processing pruned and un-pruned *Eucalyptus globulus* managed for sawlog production to produce high value products. CSIRO Forestry and Forest Products Client Report (for FWPRDC) No. 1429
- Waugh G. 2000. Use of twin saw systems for young, fast-grown eucalypts. In: The future of eucalypts for wood products, proceedings IUFRO conference, 19-24 March 2000, Launceston, Tasmania, Australia, 175-183
- Waugh G, Yang J L. 1993. Potential for plantation-grown eucalypts as a resource for sawn products in Tasmania. CSIRO Division of Forest Products Final Report No. FP-303, 90
- Yang J L, Evans R. 2003. Prediction of MOE of eucalypt wood from microfibril angle and density. *Holz als Roh- und Werkstoff*, 61:449-452
- Yang J L, Fife D, Waugh G, Downes G, Blackwell P. 2002. The effect of growth strain and other defects on the sawn timber quality of 10-year-old *Eucalyptus globulus* Labill. *Australian Forestry*, 65(1):31-37
- Yang J L, Ilic J, Evans R, Fife D. 2003. Interrelationships between shrinkage properties, microfibril angle and cellulose crystallite width in 10-years-old *Eucalyptus globulus* Labill. *New Zealand Journal of Forestry Science*, 33(1): 47-61
- Yang J L, Pongracic S. 2004. The impact of growth stress on sawn distortion and log end splitting of 32-years-old plantation blue gum. CSIRO Forestry and Forest Products Client Report No. 1398, 33. (for FWPRDC PN03.1312 Project)
- Yang J L, Waugh G. 1996. Potential of plantation-grown eucalypts for structural sawn products. I. *Eucalyptus globulus* Labill. spp. *globulus*. *Australian Forestry*. 59(2): 90-98
- Yang J L, Waugh G. 2001. Growth stress, its measurement and effects. *Australian Forestry*, 64(2):127-135
- Yang J L, Waugh G, Peacock M, Martin A. 1996. Log end split literature review. CSIRO Forestry and Forest

Determining Drying Characteristics of Plantation-Grown Eucalypt Timber for Resource Assessment and Improvement

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ABSTRACT

Timber from mature and native forest regrowth eucalypts in Australia has traditionally been air dried, steam reconditioned when below fibre-saturation moisture content and then kiln dried. Most eucalypt species grown in plantations produce wood of lower density than from native forest regrowth but drying for high product quality is not always faster; often drying degrade is increased.

The product potential of plantation-grown eucalypt timber is often limited and drying costs become a major factor in determining the viability of establishing processing operations. Thus determining drying properties and appropriate drying processes is critical.

Results from studies designed primarily to assess wood quality provide indications of the drying properties for several species and are used to discuss strategies which may be most effective in drying plantation-grown eucalypts with minimal drying degrade and drying cost.

Drying tests using aggressive drying conditions have been undertaken to exacerbate drying degrade and distinguish drying characteristics of wood from trees with different genetic and/or silvicultural treatment. Linking drying performance to resource characteristics can be valuable for planning establishment and improvement in plantation resources.

1 INTRODUCTION

Eucalypt plantations in Australia have been established primarily as a resource for producing paper pulp. While the solid timber industry is currently mostly reliant on regrowth native forest, the future will increasingly depend on plantations. Thus there is a need for information on which to base the selection of genetic material and silvicultural practices so that sawlogs can be produced at reasonable cost and of adequate wood quality. Drying trials can be orientated in quite different ways.

Drying is a critical component of processing eucalypts. Many species are subject to considerable drying degrade and to avoid this very conservative drying practices are often chosen; this can add significantly to drying time and hence drying costs. Attempts to shorten drying time by using more severe conditions may aggravate drying degrade and reduce product value. Successful processing will require a balance between these opposing approaches.

During trials with samples from existing plantation resources the effects of different silvicultural treatments have been investigated. Because quantities of trial material have been limited, and the primary

assessment criterion has usually been wood quality, a conservative approach using gentle drying conditions has had to be used.

For a species where a range of genetic material has been planted, an aggressive approach with quite severe drying conditions has been used to deliberately induce drying degrade and identify material with minimal degrade. Provided other aspects of wood quality meet desired criteria the results may be used to choose material for further planting.

Two case studies are presented to illustrate different approaches to designing drying trials:

A plantation of *Corymbia* spp. (Spotted Gum) (previously included in the genus *Eucalyptus*) which had been managed to produce clearwood, provided the opportunity to assess wood quality, processing characteristics and product value (Hardwood *et al.*, 2005) The cost of drying and the cost of drying degrade was assessed.

As part of a study on genetic variation in wood properties of 10-years-old *Eucalyptus dunnii*, accelerated kiln drying was used to generate drying degrade. Dried boards were assessed and types of degrade linked to genetic source (Washusen, 2005).

2 DRYING FOR COMMERCIAL PROCESSING ASSESSMENT: *Corymbia* spp.

This study was conducted to determine product quality and processing costs, and hence the value of logs from the resource. Two drying treatments were used; the first to minimise drying degrade and maximise product value; the second to minimise drying time and assess the penalty in drying degrade for reduced drying cost.

2.1 Objectives of the drying tests

- 1) Determine drying times and costs for commercially practicable kiln schedules for appearance products from plantation *Corymbia* spp.
- 2) Determine drying degrade from kiln schedules used, to enable product value losses to be calculated.

2.2 Materials and preparation

Logs of 18-40 cm small end diameter were obtained from thinning operations in plantations of *Corymbia* species in south-west Australia. Sawing produced backsawn boards 28 mm thick. A sample of 3.0 m³ of 106 mm × 28 mm boards was selected for drying tests. The boards were dipped for Boron treatment of Lyctid susceptible sapwood, wrapped in plastic sheet and stored for 4 weeks for diffusion of the treatment.

2.3 Procedures

Two drying treatments were applied on matched stacks of timber: an initial predrying phase with conventional final drying (Tab. 1) and an accelerated kiln drying schedule with periodic high humidity treatments (Tab. 2). Each stack was restrained by a weight on top as for softwood drying.

Tab. 1 Conventional drying schedule (predrying) used in the first drying run

| MC (%) at start of step | Dry bulb (°C) | Wet bulb depression (°C) | Relative humidity (%) | Equilibrium moisture Content (%) | Air velocity (m/s) | Time |
|-------------------------|---------------|--------------------------|-----------------------|----------------------------------|--------------------|------------|
| 65* | 45 | 2 | 88 | 18 | 1.5-2.0 | 0-13 days |
| 22 | 50 | 10 | 65 | 8.5 | 1.5-2.0 | 13-17 days |
| Steam | | | | | | 4 hours |
| 15 | 60 | 10 | 58 | 8.5 | 1.5-2.0 | 17-23 days |
| 13 | 70 | 6.5 | 74 | 10.5 | 1.5-2.0 | 23-28 days |

* In this period temporary kiln control failures led to periods where the kiln was shut down for repair.

Tab. 2 Drying schedule incorporating high humidity treatments at 8 hours intervals

| MC (%) at start of step | Dry bulb (°C) | Wet bulb depression (°C) | Relative humidity (%) | Equilibrium moisture Content (%) | HHTDBT/WBD | Air velocity (m/s) | Time |
|-------------------------|---------------|--------------------------|-----------------------|----------------------------------|------------|--------------------|------------|
| 59 | 50 | 3 | 84* | 16 | 60/2 | 1.5-2.0 | 0-2 days |
| | 55 | 4 | 81* | 14.2 | 65/2 | 1.5-2.0 | 2-3 days |
| | 60 | 5 | 77* | 12.7 | 70/3 | 1.5-2.0 | 3-4 days |
| | 65 | 8 | 67* | 9.8 | 75/3 | 2.0 | 4-5 days |
| | 70 | 10 | 62 | 8.5 | 80/4 | 2.0 | 5-6 days |
| | 80 | 4 | 84 | 13.2 | — | 2.0 | 6-7 days |
| 25 | 70 | 15 | 47 | 6.4 | 80/4 | 2.0 | 7-9 days |
| 11 | 70 | 15 | 47 | 6.4 | 80/4 | 2.0 | 9-11 days |
| Steam | | | | | — | 0 | 6 hours |
| | 70 | 7 | 73 | 10.0 | — | 2.0 | 11-14 days |
| | 70 | 5 | 78 | 12.0 | — | 2.0 | 14-15 days |

* High humidity treatments for 1 h were applied at 8 hours intervals.

2.4 Results

Fig. 1 shows the kiln conditions of Tab. 2.

2.5 Drying defects in sawn timber and their impact on product quality and recovery

Grading was conducted using criteria developed for the Australian market for furniture and other appearance timber (Hardwood *et al.*, 2005). There was contrasting drying performance in the two drying runs (Fig. 2):

Using the conventional schedule, downgrade due to drying defects was minor. Only 2.6% of green product was graded below select grade and 12.2% of select grade boards were shorter than 1.8 m. This downgrade was primarily due to spring (crook) that developed or worsened during drying.

Degrade was more pronounced with the second drying run. 18.6% of green select grade product was graded below standard grade and 5.3% of select and standard grade boards were shorter than 1.8 m. The major source of defect was end splitting and spring that led to a high proportion of the downgraded product to be rejected. The other major defect was surface checking that generally reduced products to utility grade.

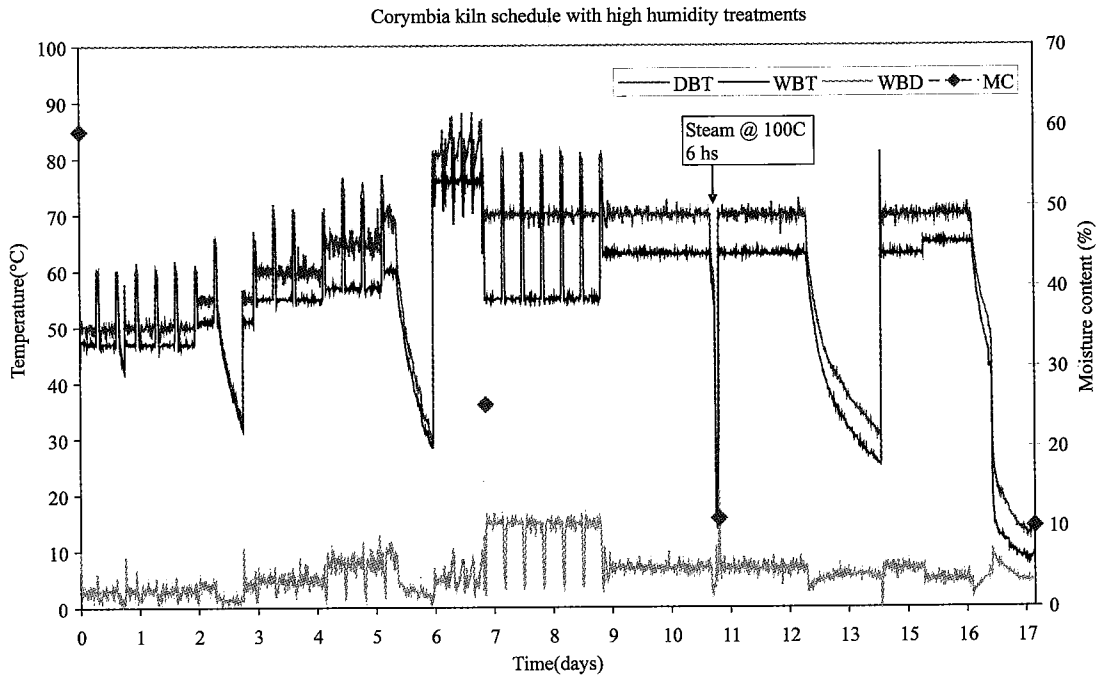


Fig. 1 Accelerated drying with periodic high humidity treatments

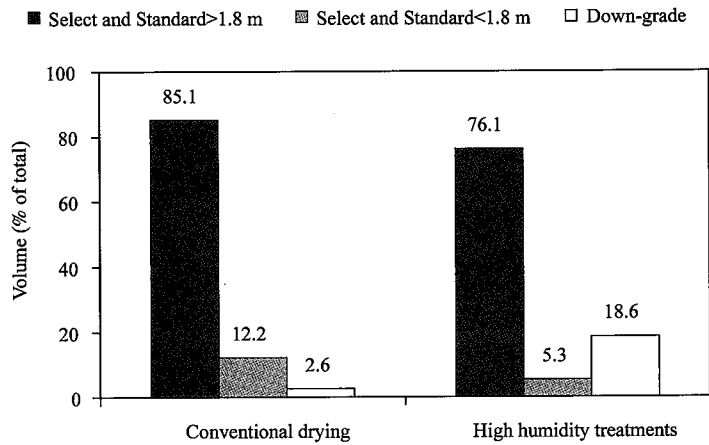


Fig. 2 Full-length select grade boards from the two drying runs of *Corymbia* sp.

2.6 Discussion

Given these results it appears feasible to apply high temperature drying with periodic high humidity treatments. However, drying defect could be reduced if the drying schedule were extended in the middle stages of drying by reducing the wet bulb depression. More work is warranted to develop drying schedules; it appears feasible to dry 28 mm thick back-sawn *Corymbia* timber in 21 days with degrade at the levels for the first (conventional) drying run.

This provides a basis for constructing models of different approaches to drying and estimating drying costs. These, together with sawing costs and product value, can be used to estimate total processing costs and the value of the logs to a sawmill.

3 DRYING FOR ASSESSMENT OF GENETIC VARIATION OF DRYING CHARACTERISTICS: *Eucalyptus dunnii*

An aggressive kiln schedule was used to identify material from a provenance-progeny trial which developed significant drying degrade.

3.1 Objectives for the drying test

Determine the drying characteristics of boards from logs of a range of genetic material; identify material with low and high levels of drying degrade.

3.2 Materials and preparation

Butt logs from 40 trees representing 27 families of a 10-years-old *E. dunnii* provenance-progeny trial were sawn to 2.4 m long 100 mm × 25 mm boards.

3.3 Procedures

Boards were distributed randomly in preparing the stack for kiln drying. A weight was placed on the stack to provide restraint as used with softwood kiln stacks. A kiln schedule was applied with initial gentle drying phases similar to predrying and with periodic high humidity treatments during the middle phase when conditions were progressively increased in temperature and reduced in humidity, together with conventional latter phases. A 6-hours steam reconditioning treatment was applied at an average moisture content of approximately 14%, followed by equalising and conditioning phases. Fig. 3 shows the kiln conditions.

After drying the boards were assessed for warp and drying degrade. Internal checking was assessed after cross-cutting at mid length.

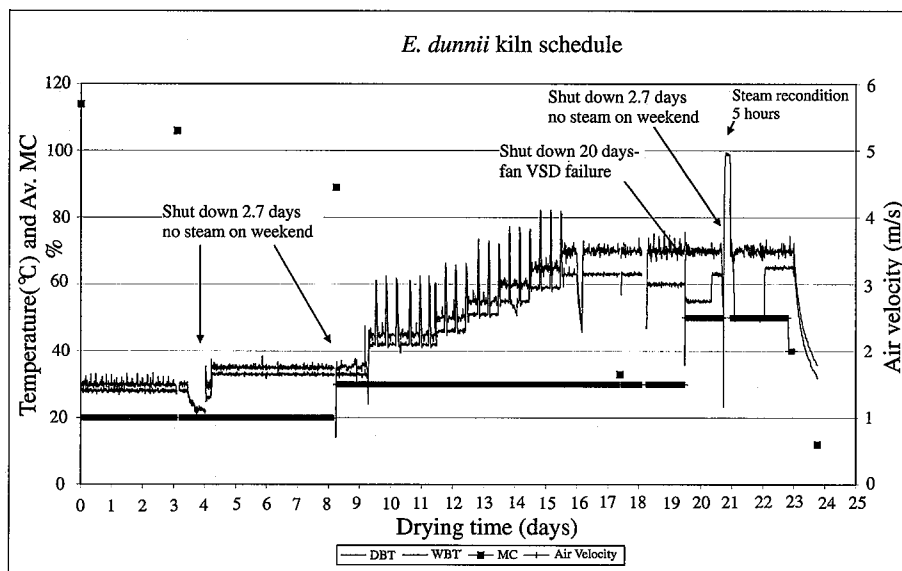


Fig. 3 Kiln conditions used for drying *E. dunnii* 100 mm × 25 mm boards

3.4 Results

For many of the defects that were scored, the boards are relatively free of value-limiting levels of defect. The most serious defects were judged to be cup, end-splitting and spring in declining order of severity. Cupping was the most serious defect despite restraint on the stack, with mean cup depth of 3.05 mm. In 25 mm thick boards this level of cupping would result in considerable down-grade of product even if boards were dressed to 19 mm, i.e. removal of 6.0 mm of wood will still result in about 50% of boards being undersized. Across the 40 logs, mean length of end-splitting, combining end splitting at both the top and bottom of the boards amounts to 218 mm, which would remove about 10% of total board length if end splits were docked.

External and internal checking would not have significantly lowered product value. Unrecoverable collapse, leading to corrugated surfaces of one or both faces of the boards, while significant, was mostly associated with board sections that included the central pith of the log, and would therefore be less prevalent in most of the boards sawn from larger-diameter logs.

Significant differences between families were demonstrated for some of the individual board forms of degrade. Cupping of the upper and lower faces of the boards appears to be under some degree of genetic control, with significant differences in these traits among open-pollinated families.

The other less economically important traits of spring and bow did not appear to be under genetic control, although it must be kept in mind that the sample size of a total 40 trees from 27 families, and only 2-4 boards from each log, is small for the detection of significant genetic differences. The sample size is too small for the accurate estimation of heritability for cupping. Variance components for trees within families were all less than their standard errors, indicating that differences between trees within families were not significant, which was to be expected as only 13 of the 27 sampled families were represented by more than one tree.

3.5 Discussion

Drying defects were generally at low levels and the species shows good potential for producing high quality sawn timber. It should be possible to develop a kiln schedule that would take about 28 days to satisfactorily dry 25 mm thick boards. The determination that some drying defects, particularly cup, were under genetic control can be used to guide further planting of this species.

3.6 Conclusions

These two examples illustrate different approaches to drying tests when different information is needed. The first case shows an attempt at determining drying times and hence drying costs, as well as drying degrade, for a species where some plantations are approaching the age when critical management decisions must be made. The second case describes how an aggressive approach can assist in selecting genetic material for plantation establishment by identifying material with high levels of drying degrade of different types.

4 ACKNOWLEDGEMENTS

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REFERENCES

- Harwood C. *et al.* 2005. Genetic variation in wood properties of *Eucalyptus dunnii* relevant to solid wood products. FWPRDC Project PN04.3003 Report
- Washusen R. 2005. Evaluation of product value and sawing and drying efficiencies for low rainfall hardwood thinnings. A report for the Joint Venture Agroforestry program. RIRDC Project No. CSF-65A. 43

Intermittent Drying Technologies Suitable for Plantation-grown *Eucalyptus* Timbers*

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ABSTRACT

The effects of continuous and intermittent drying regimes on the total shrinkage and collapse have been investigated for six species of difficult-to-dry planted *Eucalyptus* timbers. The results have shown that total shrinkage and collapse in all eucalypt woods examined were greater for continuous drying than intermittent drying with the exception of an intermittent drying run based on change of relative humidity (RH). Periodic cycling of RH can lead to the increase of total shrinkage and collapse in green/saturated wood in higher drying temperature conditions (more than 60°C) rather than increasing collapse recovery and was especially obvious for lower-density eucalypts.

Total shrinkage and collapse increase with increasing drying temperature, in both continuous and intermittent drying regimes, while the increasing magnitude of both parameters becomes apparently larger for continuous drying than for the intermittent drying regime, in particular for higher temperature conditions. However, it is possible to elevate drying temperature to reduce drying time for the intermittent drying regime. Increasing drying duration at each intermittent drying period had a greater effect on total shrinkage and collapse for all eucalypt wood examined. When a drying duration of six hours at an intermittent drying period is used, the differences in shrinkage and collapse between continuous and intermittent drying regimes are very slight. The duration of an intermittent drying period has a comparatively larger effect on total shrinkage and collapse for five lower-density eucalypt species, but a smaller effect on two higher-density eucalypts that were included in the study. Accordingly, we may draw a conclusion that an intermittent drying regime is very likely to be a potential drying practice for collapse-prone lower-density plantation-grown eucalypt timbers.

1 INTRODUCTION

It is well known that Eucalypts with their characteristically high shrinkage and low mass diffusivity are notoriously difficult to season without degrade. Considering the premium price which can be obtained for^① appearance grade timber, the drying behaviour of Eucalypts is consequently becoming more important, since drying is recognized as a vital element in the value-added processing of solid wood products (Vermaas, 2000). In order to improve drying quality in plantation-grown eucalypt wood, a large number of studies have

* This research has been accomplished at Ehime University in Japan.

been conducted by many researchers. Pre-drying treatments have been widely reported for protecting green degrade (Hartley and Gough, 1990). The primary emphasis on this aspect is placed upon pre-treatment of the wood through pre-air drying (Bekele, 1995; Jankowsky and Santos, 2005), pre-steaming (Alexiou *et al.*, 1990a; Alexiou *et al.*, 1990b; Chafe, 1990), pre-heating/soaking (Chafe, 1993; 1994a; 1995b; 1995a; Glossop, 1994; Ruben *et al.*, 1995) and pre-freezing (Glossop, 1994; Ilic, 1995; 1999). Owing to frequently severe collapse and honeycombing occurring at higher drying temperature conditions for most plantation-grown eucalypts, low temperature drying is often used for the entire drying process (Vermaas and Neville, 1988a; 1988b; Vermass and Bariska, 1995). In order to solve the problem of lengthy time requirements for lowtemperature drying conditions, a systematical investigation of accelerated drying schedules was performed by Vermaas and Neville (1988a; 1988b) and Alexiou (1991). Some studies for plantation-grown eucalypt timbers were also reported on vacuum drying by Ananias (1994) and Fernandez-Golfin and Alvarez Noves (1995; 1996), radio-frequency vacuum drying by Rozsa and Avramidis (1996) and a combination of air-drying and vacuum drying by Liu *et al.* (2002). However, from the viewpoint of practical utilization on an industrial scale, it appears that most research attention has been focused on investigating conventional kiln drying aspects (Vermass, 2000; Bekele, 1994; Innes, 1996; Vermaas, 1995; Oliver, 2000; Northway and Blakemore, 1999; Northway, 1996; Northway, 2001; Doe and Lee, 2000). Recently, there are also some studies on intermittent drying which have been reported.

Intermittent drying schedules were developed by Lerz *et al.* (1987). Langrish *et al.* (1992) found that the drying quality of timber from red beech could be improved by intermittent drying. Vermaas (2000) reported that good results could be obtained with an intermittent drying schedule in the drying of *Eucalyptus grandis*, but a consequence is longer drying time. The reductions of surface and inner checks of *Eucalyptus regnans* by using intermittent drying were observed by Chafe (1995a; 1995b) and Doe and Lee (2000). Evaluation of collapse-type shrinkage processes combined with investigations on the feasibility of application of intermittent drying to seven species of young fast-grown *Eucaluptus* from China was carried out by Wu *et al.* (2004; 2005a; 2005b). This research was a theoretical analysis of both transient collapse and maximum transient collapse developments and conclusions were drawn as to the possibility of intermittent drying being suitable for collapse-prone plantation-grown eucalypts.

The main objective of the present study is to continue to explore the application of intermittent drying to plantation-grown eucalypts, in particular to collapse-susceptible eucalypts on the basis of the investigations conducted by Wu *et al.* (2005b) This would provide both an in-depth evaluation of the opportunity for improved industrial practices and also some technological parameters for the optimizing of intermittent drying schedules.

2 MATERIALS AND METHODS

2.1 Sample wood collection

Six species of eleven-years-old plantation-grown eucalypts planted in China were selected (see Tab. 1), and three trees of each species marked for north and south orientation. A two metre length log from breast height upward was removed from each tree (in total 18 logs), sealed at both ends with melted wax, wrapped in plastic film and shipped to Ehime University in Japan.

Tab. 1 Growth traits and basic density in sample trees

| Species | Mean Height (m) | Diameter at breast height (cm) | Moisture content (%) | Basic density(g · cm ⁻³) |
|---|-----------------|--------------------------------|----------------------|--------------------------------------|
| <i>Eucalyptus urophylla</i> | 27.5 | 22.8 | 115.7 | 0.4798 |
| <i>E. grandis</i> | 25.2 | 22.5 | 98.7 | 0.4647 |
| <i>E. grandis</i> × <i>E. urophylla</i> | 24.5 | 27.5 | 119.5 | 0.4610 |
| <i>E. dumii</i> | 21.5 | 25.5 | 127.3 | 0.5063 |
| <i>E. cloeziana</i> | 22.5 | 23.5 | 83.4 | 0.6887 |
| <i>E. pellita</i> | 21.5 | 21.5 | 84.2 | 0.6611 |

2.2 Specimen preparation

Fifteen 25(R) × 100(T) × 200(L)-mm matched specimens from two 28-mm-thick backsawn boards cut along the north-south direction for each log were made (in total 45 specimens), for each species of eucalypt. Simultaneously, one-millimeter-thick slices were cut from each end between every specimen.

2.3 Procedures of continuous and intermittent drying regimes

Forty-five green specimens for every species of eucalypt were divided into four groups, as shown in Tab. 2, for continuous and intermittent drying regimes. The same number of specimens for each drying run was required. The number of specimens for each group consisting of various runs was assigned according to Tab. 2. Moreover, it should be noted that the specimens from each of three trees for every species of eucalypt within each group were required to be end-matched ones to eliminate the effect of the variation of wood properties due to different positions of wood on the indices measured as much as possible. End-matching of specimens between groups for each species of eucalypt was not required and may not have occurred.

Tab. 2 Summaries of both continuous and intermittent drying regimes

| Code | Number of specimens (per species) | Items | Intermittent drying | | | | | | | | |
|---------|------------------------------------|---------|---------------------|------|-------|---------------------|-------|-------|-------------------|------|-------|
| | | | Drying period | | | Intermittent period | | | Continuous drying | | |
| | | | Run 1 | Run2 | Run 3 | Run 1 | Run 2 | Run 3 | Run 1 | Run2 | Run 3 |
| Group 1 | 9 | T(°C) | 60 | 60 | | 30 | 30 | | 60 | | |
| | | RH(%) | 66 | 66 | | 58 | 58 | | 66 | | |
| | | Time(h) | 3 | 3 | | 3 | 6 | | | | |
| Group 2 | 12 | T(°C) | 60 | 60 | 60 | 30 | 30 | 30 | 60 | | |
| | | RH(%) | 66 | 66 | 66 | 58 | 58 | 58 | 66 | | |
| | | Time(h) | 1 | 3 | 6 | 3 | 3 | 3 | | | |
| Group 3 | 18 | T(°C) | 45 | 60 | 70 | 30 | 30 | 30 | 45 | 60 | 70 |
| | | RH(%) | 61 | 66 | 70 | 58 | 58 | 58 | 61 | 66 | 70 |
| | | Time(h) | 3 | 3 | 3 | 3 | 3 | 3 | | | |
| Group 4 | 6 | T(°C) | 60 | | | 60 | | | 60 | | |
| | | RH(%) | 92 | | | 66 | | | 66 | | |
| | | Time(h) | 2 | | | 4 | | | | | |

All specimens, prior to drying tests, were weighed in order to evaluate moisture content during the

drying process using the method reported by Boone *et al.* (1993) and Terazawa (1994). The cross-sectional area of each specimen in its initial green state was the same as that of the corresponding 1-mm thin section.

The continuous drying regime was used as the control for comparing intermittent drying treatments within each group. All specimens for each drying run were dried in a NLH-001 experimental kiln (Nagano Scientific Ins. Co., Japan) which automatically controlled temperature and relative humidity (RH) at constant drying temperature and RH conditions to equilibrium. Drying continued until each group reached a nominal final equilibrium moisture content (EMC) of 10%. Intermittent drying regime strategies are shown in Tab. 2. For each group, initial drying conditions were identical to that used for continuous drying down to 20% moisture content. Then, every complete intermittent drying regime was composed of a different set of conditions (or kiln run), shown in Tab. 2 under the same run number for both drying period and intermittent period. Under test procedures, drying phases in both periods were required to alter based on Tab. 2. Therefore, Drying period (Run1) and Intermittent(Run1) make up a single set of conditions, with a different set of conditions for Run2 and Run3.

Of the four groups, drying strategies for Group 1 were selected to analyse the effects of intermittent durations on the magnitude of shrinkage and collapse and for Group 2 to examine the influence of drying duration in high temperature drying conditions on drying qualities. The emphasis in Group 3 was to investigate drying temperatures affects, and for Group 4 to examine the effects of alternate alteration of RH on shrinkage-collapse properties. Each intermittent drying regime was performed in the light of conditions as shown in Tab. 2. The specimens were dried at first in a PR-2FP mini-drying chamber (Tabai Espec Co. Japan) equipped with a micro-computer able to carry out the automatic control of the drying program to a moisture content (MC) of 20%, at which point, drying was stopped and an intermittent drying regime applied instead of the corresponding continuous drying regime, until 10% MC was reached.

For all specimens with 10% MC under continuous and intermittent drying regimes, 3 mm thick cross sections were cut from the mid-length of the specimen to calculate total shrinkage by measuring cross-sectional areas of these sections.

2.4 Collapse-free shrinkage tests

The one-mm-thick slices initially cut at the ends of the drying specimens were used for the determination of collapse-free shrinkage (Kauman, 1960). Before drying tests, cross-sectional areas of all slices were measured, then they were slowly dried in the NLH-001 experimental kiln set for 25°C and six levels of RH of 96%, 92%, 84%, 76%, 66% and 56% respectively and finally allowed to dry to a nominal equilibrium moisture content of 10%, which was required to be consistent with that under both drying regimes.

2.5 Measurements of transverse sectional areas by using image analysis technique

To begin with, all one-mm-thick slices were scanned prior to drying into non-compact picture files using a GT-8700 Epson Colorio Transparent Scanner. This also provided image files of the initial green cross sections of the corresponding specimens used for both continuous and intermittent drying regimes. All one-mm slices and the three-mm sections which were obtained from the specimens following drying, were equilibrated to 10% EMC and again scanned, providing a further set of image files to calculate the actual areas of the samples examined, all the corresponding image files were first transformed into binary files

using Image J software (Scion Co.) on computer, then the actual area for each sample was automatically calculated using Image J software.

2.6 Determination of total shrinkage, collapse-free shrinkage and collapse

Total shrinkage was calculated as the ratio of the difference between the cross-sectional area of samples at 10% EMC to that in the green state. Similarly, the total shrinkage calculated from the one-mm-thick slices was used to provide a measure of normal or collapse-free shrinkage. Collapse was calculated as the difference between the total shrinkage and collapse-free shrinkage.

3 RESULTS AND DISCUSSIONS

3.1 Effects of intermittent duration on total shrinkage and collapse

Fig. 1 and Fig. 2 show that for six of the eucalypts and especially for the five lower-density species, there were higher total shrinkage and collapse values for continuous drying than for intermittent drying. For intermittent drying, total shrinkage and collapse of wood in the five lower-density species decreased with intermittent duration at an intermittent cycle period, but not for the two higher-density eucalypts, i.e. *E.cloeziana* and *E.pellita*. It is generally believed that higher collapse usually occurs in low-density eucalypt, while less or low collapse happens in higher-density eucalypts (Wu *et al.*, 2004; chafe *et al.*, 1992; Bello, 1997).

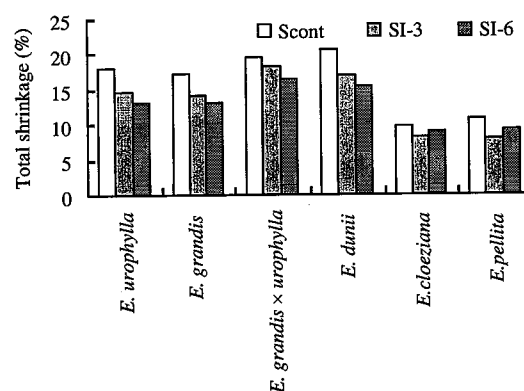


Fig. 1 Effects of intermittent duration on total shrinkage in six species of eucalypt woods. Scont represents continuous drying; SI-3 and SI-6 stand for intermittent duration of 3 and 6h in low temperature states at a intermittent circle period, respectively

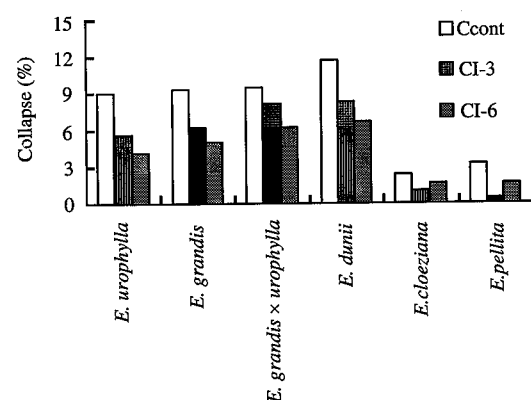


Fig. 2 Effects of intermittent duration on collapse in six species of eucalypt woods. Ccont represents continuous drying; CI-3 and CI-6 stand for intermittent duration of 3 and 6h in low temperature states at a circle intermittent period, respectively

Wu *et al.* (2005a; 2005b) reported that under continuous drying conditions with relatively higher temperature and lower relative humidity the magnitude of residual collapse finally depended on the degree of both transient collapse and maximum transient collapse transformed into permanent sets. Also, it is possible that both transient collapse and maximum transient collapse developed in wood at moisture contents above FSP under higher temperature and lower RH drying conditions may be mostly recovered during low temperature interruption as applied through an intermittent cycle period. Overall collapse recovery is also more likely to be brought about with intermittent duration because of a greater waiting-response time for

collapse recovery. This would result in increased overall collapse recovery at the completion of the intermittent drying process, compared to continuous drying. Although the partial transient collapse recovery could also be realized under a continuous drying process, the degree of overall collapse recovery is reduced compared to intermittent drying because more transient collapse and maximum transient collapse should be transformed into permanent sets to develop residual collapse leading to the increases of both collapse and total shrinkage consisting of two parts of residual collapse and normal shrinkage in severe continuous drying conditions. As opposed to low-density eucalypts, it appears that total shrinkage and collapse in high-density eucalypt wood slightly increased with intermittent duration. This may be related to comparatively lower transient collapse and maximum transient collapse (Wu *et al.*, 2005a; 2005b), as well as related to higher extractive contents (Chafe *et al.*, 1992; Bello, 1997).

3.2 Effects of drying duration on total shrinkage and collapse

With prolonging drying duration at an intermittent cycle period, we found that total shrinkage and collapse sequentially increased for all species examined. When drying duration reached six hours, total shrinkage and collapse almost approached that which occurred under continuous drying conditions, as shown in Fig. 3 and Fig. 4. This demonstrated that reduced drying duration with an intermittent cycle period improved drying quality. A shorter drying duration can decrease total shrinkage and collapse but is more expensive; a longer drying duration can shorten total drying time but will usually result in increased collapse and drying degrade. Accordingly, for collapse-prone eucalypt wood, we must find the optimal point to balance the relationship between drying duration at an intermittent drying cycle period and drying quality.

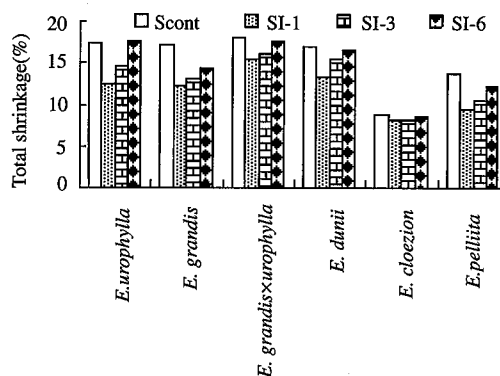


Fig. 3 Effects of drying duration on total shrinkage in six species of eucalypt woods. Scont represents continuous drying. SI-1, SI-3 and SI-6 represent drying duration of 1, 3 and 6h in high temperature states at a intermittent circle period, respectively

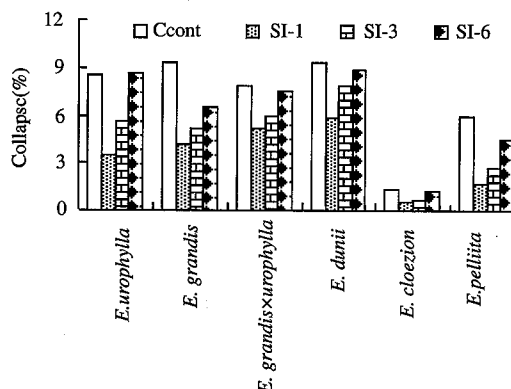


Fig. 4 Effects of drying duration on collapse in six species of eucalypt woods. Ccont represents continuous drying; CI-1, CI-3 and CI-6 represent drying duration of 1, 3 and 6h in high temperature states at a intermittent circle period, respectively

3.3 Effects of drying temperatures on shrinkage and collapse

From Fig. 5 and Fig. 6, it can be seen that drying temperatures had a large effect on total shrinkage and collapse, especially under a continuous drying regime. For continuous drying, with increasing drying temperature, total shrinkage and collapse in low-density eucalypts markedly increased, while there was a slight increase for the high-density eucalypts; For intermittent drying, it seemed that drying temperature had a slight effect on total shrinkage and collapse, in particular for the two high-density species.

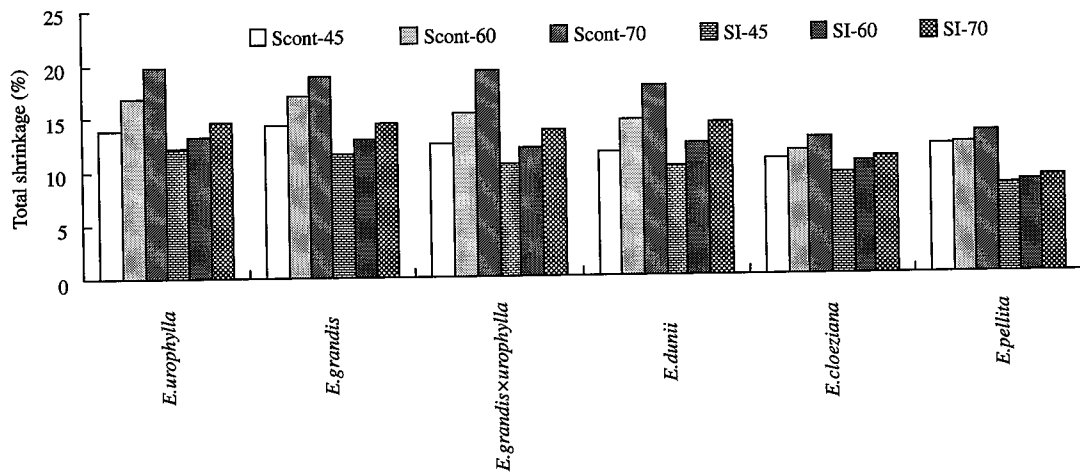


Fig. 5 Effects of drying temperatures on total shrinkage in six species of eucalypt wood. Scont-45, Scont-60 and Scont-70 represent continuous drying temperatures of 45, 60, 70°C respectively; SI-45, SI-60 and SI-70 stand for drying temperatures of 45,60, 70°C in high temperature states at a intermittent circle period, respectively

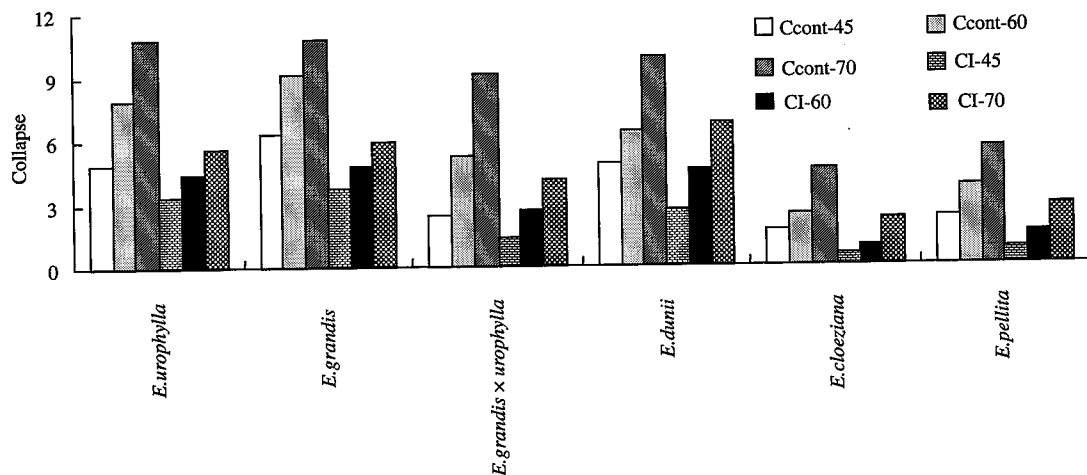


Fig. 6 Effects of drying duration on collapse in six species of eucalypt wood. Ccont-45, Ccont-60 and Ccont-70 represent continuous drying temperatures of 45, 60, 70°C respectively; CI-45,CI-60 and CI-70 stand for intermittent drying temperatures of 45, 60, 70°C in high temperature states at a intermittent circle period, respectively

Kauman (1960), stated that hydrostatic tensions and macroscopic drying stress may be taken as the principle collapse-inducing forces. It was reported by Pang (1996) and Pandey (2000) that the seasoning behaviour of eucalyptus is characterized by a slow rate of drying, with collapse, high shrinkage and pronounced stresses exacerbated by a steep moisture content gradient. This further explains why continuous high temperature drying can develop a larger stress gradient due to a larger moisture content gradient caused by non-uniform capillary water transient migration, as well as unsteady-state hygroscopic water diffusion in wood. This can result in the occurrence of severe collapse. On the contrary, the periodic interruption during the intermittent process can allow partial equilibration of moisture content and stress relaxation in different regions of the material. This facilitates improved recovery of recoverable collapse and a reduction in overall collapse.

It is possible to conclude that while continuous drying schedules may be more suitable for high-density eucalypts, intermittent drying schedules would be more suitable for low-density and collapse-susceptible eucalypts. The increased time taken by intermittent drying can be compensated by elevating drying temperature, but this must not be at the expense of lowering drying quality.

3.4 Effects of alternate alteration of relative humidity on total shrinkage and collapse

Fig. 7 and Fig. 8 show that in same drying temperature conditions for continuous and intermittent drying regimes, Periodic cycling of RH in intermittent drying process results in the slight increases in total shrinkage and collapse rather than the decreases expected. This perhaps can be explained that higher total shrinkage and collapse in intermittent drying regime only based on periodic cycling of RH was caused by lower permanent set in the shell due to lower drying stresses, and that higher permanent set in continuous drying limited the further shrinkage in the shell so as to lead to this difference between both drying regimes. It seems to imply that higher temperature and higher humidity pre-heating treatments in initial drying state are not suitable for collapse-susceptible plantation-grown eucalypt wood.

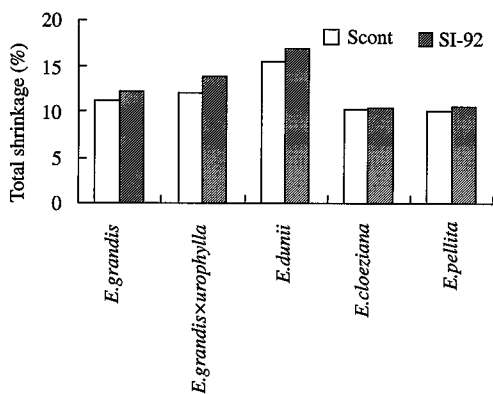


Fig. 7 Effects of alternate alteration of high-low relative humidity(RH) on total shrinkage in six species of eucalypt woods. Scont represents continuous drying; SI-92 represents high RH of 92% in intermittent states at a intermittent circle period

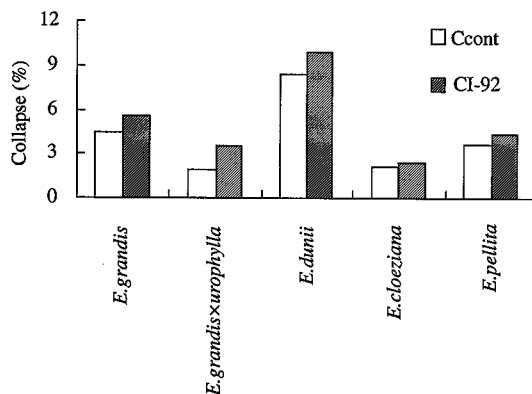


Fig. 8 Effects of alternate alteration of high-low relative humidity(RH) on collapse in six species of eucalypt woods. Ccont represents continuous drying; CI-92 represents high RH of 92% in intermittent states at a intermittent circle period

4 CONCLUSIONS

The differences in total shrinkage and collapse between continuous and intermittent drying were used to analyse the effects of intermittent duration, drying duration, drying temperatures and periodical alteration of high-low relative humidity on total shrinkage and collapse for six species of plantation-grown eucalypt wood under intermittent drying regimes. The conclusions drawn are as follow:

1) Total shrinkage and collapse in six species of eucalypt wood exhibit higher values for continuous drying than for intermittent drying with the exception of intermittent drying based on change of relative humidity.

2) Periodical cycling of high-low RH can lead to the increase of total shrinkage and collapse in green/saturated wet wood using higher drying temperature conditions (more then 60°C) rather than recovery of collapse, especially for lower-density eucalypts. Higher temperature and higher humidity pre-heating treatments prior to drying are not suitable for collapse-susceptible plantation-grown eucalypts.

3) With increasing drying temperature, total shrinkage and collapse increase in both continuous and intermittent drying regimes There is an increase in differences in shrinkage and collapse between both drying

regimes, particularly for higher temperature conditions. Elevating drying temperature to compensate for the intermittent-waiting time for intermittent drying regimes must be approached cautiously to minimise drying degrade.

4) Drying duration has the greatest effect on total shrinkage and collapse for all eucalypt wood examined. For a drying duration of six hours using an intermittent drying period, there was little difference in shrinkage and collapse between continuous and intermittent drying regimes.

5) Total shrinkage and collapse decreased with decreased cycling time for the intermittent duration drying strategy for the four species of low density eucalypts, but showed the opposite effect for the two high-density eucalypts.

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REFERENCES

- Alexiou P N, Marchant, Groves KW. 1990a. Effect of pre-steaming on moisture gradients, drying stresses and sets, and face checking in regrowth *Eucalyptus pilularis* Sm. Wood Sci Technol, 24:201-209
- Alexiou P N, Wilkins A P, Hartley J. 1990b. Effect of pre-steaming on drying rate, wood anatomy and shrinkage of regrowth *Eucalyptus pilularis* Sm. Wood Sci Technol, 24:103-110
- Alexiou P N. 1991. Optimisation of an accelerated drying schedule for regrowth *Eucalyptus pilularis* Sm. Holz Roh werkst. 49:153-159
- Ananias R A, Rivas O, Novoa M, Garay M, Steinhagen H P. 1994. Vacuum drying and pre-drying of eucalypt on an industrial scale. Ciencia-e-Investigacion Forestal, 8(1):5-20
- Bekele T. 1995. Degradation of boards of *Eucalyptus globulus* Labill and *E. camaldulensis* Dehnh during air drying. Holz Roh werkst, 53: 407-412
- Bekele T. 1994. Kiln drying of sawn boards of young *Eucalyptus globulus* Labill and *Eucalyptus camaldulensis* Dehnh grown on the Ethiopian highlands. Holz Roh werkst, 52:377-382
- Bello E D. 1997. Specific gravity-volumetric shrinkage relationship of some Philippine wood species. FPRDI Journal, 23(2):15-30
- Boone R S, Kozlik C J, Bois P J, Wengert E M. 1993. Dry kiln schedules for commercial woods-Temperature and Tropical. The Forest Products Society. 136
- Chafe S C. 1987. Collapse, volumetric shrinkage, specific gravity and extractives in *Eucalyptus* and other species.Part2:The influence of wood extractives. Wood Sci Technol, 21:27-41
- Chafe S C. 1990. Effect of brief presteaming on Shrinkage, collapse and other wood-water relationships in *Eucalyptus regnans* F.Muell. Wood Sci Technol, 24:311-326
- Chafe S C. 1995a. Preheating and continuous and intermittent drying in boards of *Eucalyptus regnans* F.Muell. □.Effect on internal checking, shrinkage and collapse. Holzforschung, 49: 227-233
- Chafe S C. 1995b. Preheating and continuous and intermittent drying in boards of *Eucalyptus regnans* F.Muell.□. Changes in shrinkage and moisture content during drying. Holzforschung, 49: 234-238
- Chafe S C. 1994a. Preheating green boards of mountain ash (*Eucalyptus regnans* F. Muell.)1.Effects on external shrinkage, internal checking and surface checking. Holzforschung, 48:61-68
- Chafe S C. 1994b. Preheating green boards of mountain ash (*Eucalyptus regnans* F. Muell.)□. Relationships amongst properties. Holzforschung, 48:163-167
- Chafe S C. 1993. The Effect of boiling on Shrinkage, collapse and other wood-water properties in core segments of *Eucalyptus regnans* F.Muell. Wood Sci Technol, 27:205-217
- Chafe S S, Barnacle J E,Hunter A J, Northway R L, Rosa A N. 1992. Collapse: An Introduction. CSIRO, Div. of Forest Products Publications Advisory Unit, Melbourne, Australia, 1-9

- Doe P, Lee M. 2000. Drying backsawn timber from Tasmanian regrowth eucalypt, In: Proc. of IUFRO Inter. Conf. on the future of eucalypts for wood products. Tasmania, Australia, 220-227
- Fernandez-Golfin J I, Alvarez Noves H. 1996. Kiln and continuous vacuum drying of *Eucalyptus globulus*, oak, and chestnut 27 and 50mm thick boards. In: Proc of the fifth international IUFRO wood drying conference, Quebec, Canada. 185-189
- Fernandez-Golfin J I, Alvarez Noves H. 1995. Vacuum and kiln drying of *Eucalyptus globulus* 27 and 50mm thick boards. In: Proc of the international conference on vacuum drying of wood '95, High Tatras, Slovak Republic, 215-222
- Glossop B R. 1994. Effect of hot-water soaking or freezing pre-treatments on drying rates of two eucalypts. Forest Prod J. 44(10): 29-32
- Hartley J, Gough D K. 1990. Future sawn wood drying in Australia. 179-190
- Ilic J. 1999. Influence of prefreezing on shrinkage-related degrade in *Eucalyptus regnans* F.Muell. Holz als Roh- und Werkstoff. 57:241-245
- Ilic J. 1995. Advantage of prefreezing for reducing shrinkage related degrade in eucalypts: General considerations and review of the literature. Wood Sci Technol, 29:277-285
- Innes T C. 1996. Collapse during seasoning of eucalypt timbers. In: Proc. of the 5th International IUFRO Wood Drying Conference, Quebec, Canada, 533-537
- Jankowsky I P, Santos GRD. 2005. Drying behavior and permeability of *Eucalyptus grandis* Lumber. Maderas Ciencia y Tecnología, 7(1): 17-21
- Kauman W G. 1960. Contributions to the theory of cell collapse in wood: Investigations with *Eucalyptus regnans*. Aust J Appl Sci, 11:122-145
- Langrish T A G, Keey R B, Kumar M. 1992. Improving the quality of timber from red beech(*N. fusca*) by intermittent drying. Drying Technol, 10:947-960
- Lerz R, Winckler F, Dressel B, Töpel M. 1987. Intervalltrocknung von Schnittholz. Holztechnologie (Leipzig), 28(4):210-211
- Liu Y, Wu Y-Q, Qiao J Z, Zhu L F. 2002. A study of drying characteristics and drying schedules of eucalyptus plantation Wood. Journal of Central South Forestry University, 22(4):44-49
- Northway R L. 1996. Drying strategies for plantation-grown eucalypts: In: Proc of the fifth International IUFRO Wood Drying Conference, Quebec, Canada. 289-296
- Northway R L. 2001. An assessment of techniques to monitor drying stresses and dimensional changes in timber from plantation-grown eucalypts for kiln schedule development and kiln control. In: Proc of the Sixth International IUFRO Wood Drying Conference, Tsukuba, Japan. 54-59
- Northway R L, Blakemore P. 1999. Kiln drying plantation eucalypts: drying strategies. In: Proc of the sixth international IUFRO wood drying conference, Stellenbosch, South Africa, 79-87
- Oliver A R. 2000. Advances in drying plantation-grown eucalypt timber: an overview of Tasmanian research. Australian Forestry, 63 (4): 246-249
- Pandey C N. 2000. Potential of plantation grown eucalypts as source of raw material to wood based industry in India. In: Proc.of IUFRO Inter. Conf. on the future of eucalypts for wood products, Launceston, Tasmania, Australia, 45-50
- Pang S. 1996. Moisture content gradient in a softwood board during drying: simulation from a 2-D model and measurement. Wood Sci. Technol. 30:165-178
- Rozsa A N, Avramidis S. 1996. Radio frequency vacuum drying of eucalypt timbers. In: Proc. of the 5th International IUFRO Wood Drying Conference, Quebec, Canada, 135-138
- Ruben A, Anabias A, Lorena Espinoza G, Kauman WG. 1995. Preheating Chilean *Eucalyptus globulus* at 80°C in water-saturated air. Holzforschung, 49: 179-181
- Terazawa S. 1994. A Complete Collection of Wood Drying. Kaisei-Sha Press
- Vermaas H F, Neville C.J. 1988b. Evaluation of low temperature and accelerated-low temperature drying schedules for *Eucalyptus grandis*, Holzforschung, 43(3):207-212
- Vermaas H F. 2000. A review of drying technology for young fast-grown eucalypts. In: Proc. of IUFRO Inter. Conf. on the future of eucalypts for wood products. Tasmania, Australia, 193-203
- Vermaas H F. 1995 Drying eucalypts for quality material characteristics: pre-drying treatments, drying methods, schedules and optimization of drying quality. South Afr For J, 174:41-49
- Vermaas H F. 1998. Drying of Eucalypts with special reference to young, fast-grown plantation Material. Proceedings 1st International Seminar on Solid Wood Products of High Technology. Belo Horizonte, Minas Gerais, Brazil, 106-118
- Vermaas H F, Neville C.J. 1988a. Low temperature drying *Eucalyptus grandis*: A preliminary laboratory evaluation. Holzforschung, 42 (4): 265-271
- Vermaas H F, Bariska M. 1995. Collapse during low temperature drying of *Eucalyptus grandis* W Hill and *Pinus sylvestris* L. Holzforschung und Holzverwertung, 47(2):35-40
- Wu Y Q, Hayashi K, Cai Y, Sugimori M, Liu Y. 2005a. Effects of continuous and intermittent drying runs on shrinkage and collapse properties in plantation-grown eucalypt wood from China. The 55th Annual Meeting of the Japan Wood Research Society, Kyoto, Japan. 221-225
- Wu Y Q, Hayashi K, Liu Y, Cai Y C, Sugimori M. 2005b. Collapse-type Shrinkage Characteristics in Wood from Plantation-grown *Eucalyptus* in China Subjected to the Continuous and Intermittent Drying Regimes. Proc. 9th International IUFRO Wood Drying Conf., Nanjing, China. 441-449
- Wu Y Q, Hayashi K, Liu Y, Cai Y C. 2004. Effects of drying temperature on shrinkage, cell collapse and surface color in seven species of plantation-grown eucalyptus wood from China. 7th Pacific Rim Bio-based Composites Symposium, Nanjing, China. 355-369

Pilot Drying Test on *Eucalyptus citriodora* Plantation Wood

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ABSTRACT

Results of a pilot drying test conducted in a trial with 60 m³ of wood using a conventional drying kiln in a Beijing wood processing plant. Results showed that a laboratory optimized drying schedule could be used for drying of 25 mm thickness *Eucalyptus citriodora* plantation wood. The drying quality based on visible defect factors and final moisture content after drying of 8.5% met the National Sawn-timber Drying Quality Standard second grade requirement, and the average moisture content difference through the wood cross-section of 1.9% met first grade requirement. The drying stress index of 3.8%, nearly met the National Sawn-timber Drying Quality Standard second grade requirement (3.5%). This result would suggest that in the practical drying of *E. citriodora* plantation wood, a longer high-humidity stabilisation period is needed. The main drying deformation defects of *E. citriodora* plantation wood observed in pilot drying was cupping, bowing and twisting. To reduce drying deformation, it is suggested that in the practical drying on *E. citriodora* plantation wood, some measures such as selecting the wood with pith or close to pith for separate drying, decreasing the stickers space and heavy stack top-loading methods should be considered.

1 INTRODUCTION

Wood drying is one of the most important steps in wood processing. Before final use, wood must be reasonably dried to avoid drying defects, thereby improving strength and stability, for use as value-added solid wood products. After laboratory testing of five species of tropical plantation woods, improved drying schedules were developed. To make these research results applied in future production, one species, *Eucalyptus citriodora*, was selected for a pilot drying test.

2 TEST MATERIAL AND METHOD

2.1 Pilot Testing Equipments

Pilot Plant: Beijing Youwei Wood Industry Co. Ltd., Located in Changping District, Beijing.

Drying testing kiln: 60 m³ capacity, conventional drying kiln heated by hot water; forklift stack loading; semi-automatic controlling.

Other testing facilities: Electronic heated oven, Electronic balance, Digital callipers, Portable electric-resistance MC meter and Electromagnetic MC meter, etc.

2.2 Test Material

The detail description of testing material for pilot drying was as followings:

- Species: *Eucalyptus citriodora*
- Sample dimensions: 1,500 mm × 120 mm × 25 mm
- Initial Moisture Content: 35%-40%
- Target Moisture Content: 8%-10%
- Total number of pieces: 570 pieces
- Testing sample volume: 2.56 m³

Because the total volume of the *E. citriodora* plantation wood samples was not enough for the 60 m³ capacity kiln, after consulting with the plant management, the decision was to dry the *E. citriodora* plantation wood samples mixed with wood of other species which had drying characteristics close to that of the *E. citriodora* plantation wood samples, so that the total volume of wood to be dried could be match the capacity of the drying kiln. The detailed description of mixed drying materials was as followings:

- Species: *Catalpa bungei*
- End-use for: solid wood flooring
- Sample size: 1,000 mm × 100 mm × 30 mm
- Initial Moisture Content: about 35%
- Target Moisture Content: 8%-10%
- Total volume: about 45 m³

2.3 Test Method

Based on the laboratory optimized drying test results, the pilot test drying schedule of *E. citriodora* plantation wood was selected, as shown in Tab. 1. Because the drying characteristics of the other material was similar to that of the *E. citriodora* plantation wood samples, to guarantee the pilot test result, the pilot schedule of *Eucalyptus citriodora* plantation wood samples was used for drying all of the wood in the kiln.

To compare the influence of end-sealing on the end checks, half of these samples were end-sealed with asphalt varnish, and the other half without end-sealing.

Tab. 1 Pilot test drying schedule

| MC (%) | Dry-bulb T(°C) | Wet-bulb T(°C) | Notes |
|-------------|----------------|----------------|--------------------------|
| Pre-heating | 55 | 54 | Pre-heating, 3 hours |
| Above 35 | 50 | 47 | |
| 30~35 | 55 | 50 | |
| =30% | 70 | 68 | Conditioning, 3 hours |
| 25~30 | 60 | 54 | |
| 20~25 | 65 | 57 | |
| =20% | 75 | 72 | Conditioning, 3 hours |
| 15~20 | 70 | 55 | |
| 10~15 | 75 | 55 | |
| Below 10 | 80 | 55 | |
| =8% | 85 | 79 | End-treatment, 3-5 hours |

Notes: Species: *E. citriodora*; Sample dimensions: 1,500 mm × 120 mm × 25 mm; Initial MC: 35%-40%; Target MC: 8%-10%.

3 RESULT AND ANALYSIS

3.1 Visible drying defects

During and after drying, visible drying defects including end checks, end-to-surface checks, surface checks and internal checks. Results showed that some small end and end-to-surface checks occurred in the early stage of drying. Result showed that the end checks and end-to-surface checks of samples with end-sealing with asphalt varnish were less than those without end-sealing, but the difference was not so significant. However, to get better drying quality it suggested that if possible, end-sealing should be applied to all wood before drying.

The anatomical structure of *E. citriodora* plantation wood was a factor which contributed to many very small surface checks occurred during the early drying stage, and which closed up during the later stages of the drying process. After machining a 2 mm layer from the surface of the dried wood, all of the tiny surface checks were removed. Therefore, these tiny surface checks were not taken into account as a visible drying defect. Surface checks of length more than 5 cm could have an influence on the final use of dried *E. citriodora* plantation wood. Therefore, the total length of these larger surface checks was calculated, and by dividing by ($2 \times$ sample length), the percentage of surface checking rate could be determined. Results showed that the surface checking rate for *E. citriodora* plantation wood pilot drying was 5.6%, which is within the National Sawn-timber Drying Quality Standard (GB/T 6491-1999) second grade requirement.

No internal checking was found after cutting these *E. citriodora* plantation dried wood during follow-up finger-joint pilot testing carried out by project group.

3.2 Final moisture contents (W_f)

The drying curve for the *E. citriodora* plantation wood pilot drying trial is shown in Fig. 1.

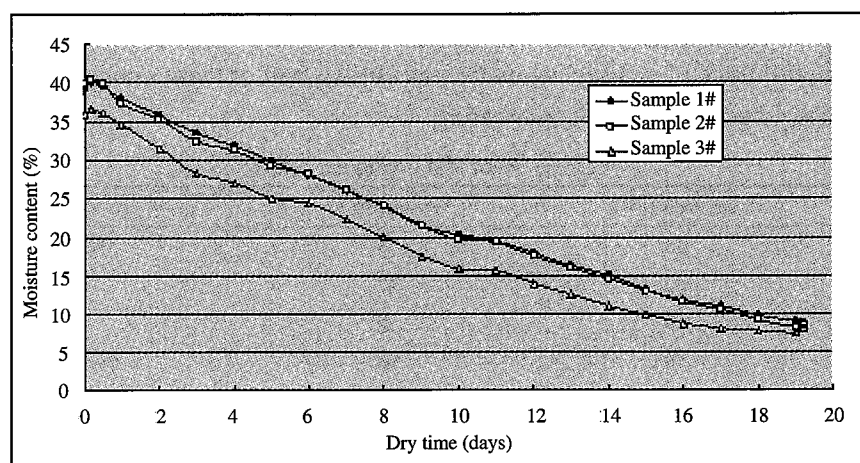


Fig. 1 The drying curve of *Eucalyptus citriodora* plantation wood

The moisture content after drying is an important factors for evaluating wood drying quality. In this pilot drying study, final moisture contents (W_f) and moisture content differences through product cross-section (W_g) were measured, and results summarised in Tab. 2. These results showed that the average final moisture content of *E. citriodora* plantation wood after drying was 8.5% met the National Sawn-timber

Drying Quality Standard (GB/T 6491-1999) second grade requirement.

Tab. 2 Pilot test drying results on moisture content and drying stress

| Index | Max. | Min. | σ | V% | Average |
|-------|------|------|----------|------|---------|
| W_i | 40.5 | 35.2 | 8.21 | 25.2 | 38.5 |
| W_f | 10.9 | 7.2 | 0.61 | 15.8 | 8.5 |
| W_g | 2.2 | 1.1 | 0.16 | 9.8 | 1.9 |
| Y | 5.0 | 1.6 | 0.53 | 15.8 | 3.8 |

Notes: W_i —initial moisture content(%); W_f —final moisture content(%); W_g —moisture content gradient (%) along the thickness direction; Y —drying stress(%); σ —variance; V%— indicates of variance(%).

3.3 Moisture content difference through the product cross-section (W_g)

Besides the final moisture contents (W_f), another important factor of moisture content is the moisture content difference through the product cross-section (W_g). If the wood is dried with a big moisture content difference through the product cross-section, the final wood products may not be dimensionally stable. The moisture content difference through the product cross-section (W_g) of *E. citriodora* plantation wood after drying was measured and results summarised in Tab. 2. Results showed that the average moisture content difference through the product cross-section (W_g) was 1.9%, which met the National Sawn-timber Drying Quality Standard (GB/T 6491-1999) first grade requirement.

3.4 Drying stress index (Y)

Drying stress index (Y) is also an important factor. Similar to the influence of moisture content difference through the product cross-section, if the dried wood with residual drying stress, the final wood products may not stable in dimension and there is a danger that further checks will develop.

The drying stress index (Y) of *E. citriodora* plantation wood after drying was measured and is also summarised in Tab. 2. The results showed that the drying stress index (Y) was 3.8%, which almost met the National Sawn-timber Drying Quality Standard (GB/T 6491-1999) second grade requirement of 3.5%. It would be recommended that in the commercial drying on *E. citriodora* plantation wood, a longer high-humidity end-treating time is needed.

3.5 Drying deformation

The main drying deformation defects of *E. citriodora* plantation wood in the pilot drying project were cupping, bowing and twisting. Result showed that cupping deformation was more prevalent with products which included the pith or were sawn close to pith. Drying deformation of samples on the top position of a stack were more severe than those on the lower position of stack. This suggested that in the commercial drying on *E. citriodora* plantation wood to reduce the drying deformations then the following procedures should be followed:

- 1) Pre-sorting. Products which included the pith or were sawn close to the pith can be selected out prior to stacking, and a special very slow drying schedule used for these selected woods.
- 2) Decrease stickers space.
- 3) Use heavy stack top-loading.

4 CONCLUSIONS

Through this pilot drying study it was shown that an improved laboratory drying schedule could be used for the drying of 25 mm thickness *E. citriodora* plantation wood.

The drying quality based on visible defect factors met the National Sawn-timber Drying Quality Standard (GB/T 6491-1999) second grade requirement.

The final moisture content of *E. citriodora* plantation wood was 8.5%, met the National Sawn-timber Drying Quality Standard second grade requirement; meanwhile the average moisture content gradient difference through the product cross-section (W_g) was 1.9%, met first grade requirement.

The drying stress index (Y) was 3.8%, was close to the National Sawn-timber Drying Quality Standard second grade requirement of 3.5%. This would suggested that in the commercial drying of *E. citriodora* plantation wood, a longer high-humidity end-treating time is needed to ensure drying stresses were within required limits .

The main drying deformation defects of *E. citriodora* plantation wood in the pilot drying study was cupping, bowing and twisting. To reduce the drying deformations, it is suggested that the following measures should be followed in commercial drying practices:

- 1) Pre-sort products which included pith or were sawn close to the pith can be selected out during stacking, and dried using a special mild drying condition schedule for these selected woods.
- 2) Decreasing the stickers space.
- 3) Heavy stack top-loading.

REFERENCES

- Gao R Q, Teng T L, Li X L. 2005. Drying tests on improved-preserved treated rubberwood. *Chinese Forestry Science and Technology*. 4 (3): 45-52
- Jose N G, Isarael L D L. 2000. Log end splitting and improvement in sawing *Eucalyptus grandis*. *The Future of Eucalypts for Wood Products Proceedings, Tasmania Australia*: 113-123
- National Quality and Technique Inspection Bureau. 2000. Drying quality of sawn timber. China Standard Press. Beijing: 1-10
- Vermaas H F. 2000. A review of drying technology for young fast-grown Eucalypts. *Proceedings of IUFRO Conference—'The future of eucalypts for wood products'*. Launceston, Tasmania, 225-226

Experimental Study on Sawing of Plantation Eucalypts in China

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ABSTRACT

The experimental study was carried out examining three different sawing strategies for four species of plantation *Eucalyptus* in China. Sawing strain, bow deformation, sawing inaccuracy and the influence of end-splits were analysed. The results show that the bow deformation is directly related to the sawing sequence, but the sawing strain showed no relationship with the sawing process. High lumber hardness contributed to the thickness variation of *E. citriodora* and *E. exserta* but the large variation in *E. urophylla* × *grandis* was contributed by high growth stress. The end-splits in lumber of the eucalyptus species had a big influence on lumber recovery, with *E. urophylla* × *grandis* showing the worst end-splits following sawing. The *Eucalyptus* lumber could be used in value-added solid wood products if suitable sawing equipment and sawing strategies are selected.

1 INTRODUCTION

Along with the rapid economic development in China, there is an increasing shortage of supply of lumber, which in recent years has reached about 80 million cubic metres per year. Moreover, since the Chinese government's policy has been implemented on natural forest protection and environment, and with the 1998 prohibitions on harvesting of natural forest, the demand for wood products has transferred from natural forest to plantation forest and imported timbers. *Eucalyptus* is the third largest plantation species in China, just behind Poplar and Chinese Fir. The overall area of *Eucalyptus* plantation is about 1.6 million hectares, mainly distributed in the southern part of China. Some species of tropical plantation trees such as *Eucalyptus* spp. and *Acacia mangium* etc. grow very fast, but the present use of eucalypt plantation in China is primarily for the production of wood chips (Lu, 2000). Eucalypts are not easily utilised for value added products, such as solid wood, as high growth stress can result in end-splitting of logs during harvesting and considerable distortion and sawing inaccuracy during sawing (Jiang, 2000). These factors greatly influence lumber recovery and productivity, and the situation is made worse by smaller diameter logs harvested from younger trees (Waugh, 2000). Sawing is the first manufacturing process in processing for solid wood products, and it can influence product quality in downstream manufacturing.

This project examines the sawing performance of four plantation eucalyptus species in the southern part of China to determine improved processing strategies for high value added solid wood products from tropical plantation wood.

2 MATERIALS AND METHODS

2.1 Materials

Four eucalypt species; *E. citriodora*, *E. exserta*, *E. grandis*, and *E. urophylla* × *grandis* were used for sawing studies. All the logs were collected from Dongmen Forest farm in Nanning, Guangxi, and ten stems were harvested for each species.

All trees were unpruned and were planted on commercial forest land. The ends of the logs were sealed with asphalt to prevent end-drying after logging. The logs were stacked according to species and water spraying applied to keep them in a green condition by preventing drying degrade.

The length of each log section was from 2.00 to 2.20 meters. The taper of these species was small, so three to four sections could be harvested from each tree. The tree and log parameters are listed in Tab. 1.

Tab. 1 The condition of eucalyptus tree and log sections

| Species | Height of tree (m) | Height under branch(m) | Age (years) | DBH (mm) | Diameter Range of log sections (mm) |
|---|--------------------|------------------------|-------------|----------|-------------------------------------|
| <i>E. citriodora</i> | 30.67 | 16.57 | 37 | 287 | 180~233 |
| <i>E. exserta</i> | 19.96 | 10.76 | 27 | 261 | 145~194 |
| <i>E. urophylla</i> × <i>E. grandis</i> | 31.08 | 20.26 | 14 | 248 | 175~220 |
| <i>E. grandis</i> | 27.49 | 12.02 | 13 | 282 | 175~249 |

Note: the height and DBH (diameter at breast height) in Tab. 1 are averaged; The diameter of log sections refers to the Small End Diameter (SED), and bark is not included.

2.2 Strain measurement in the sawing process

The equipment for the sawing experiment consisted of a headrig band saw with a manually adjusted sizing carriage.

Before each sawing pass, nails were placed into the existing sawn surface or in the case of the opening cut on the log side face which was to be perpendicular to the sawing surface, Each measuring point consisted of two nails, alternately placed in a tangential or longitudinal direction to the axis of the log (Fig. 1) and their distance apart, measured before sawing and again just after the lumber containing the nails was sawn off. The strain changes in the longitudinal and tangential directions were then calculated using the formula:

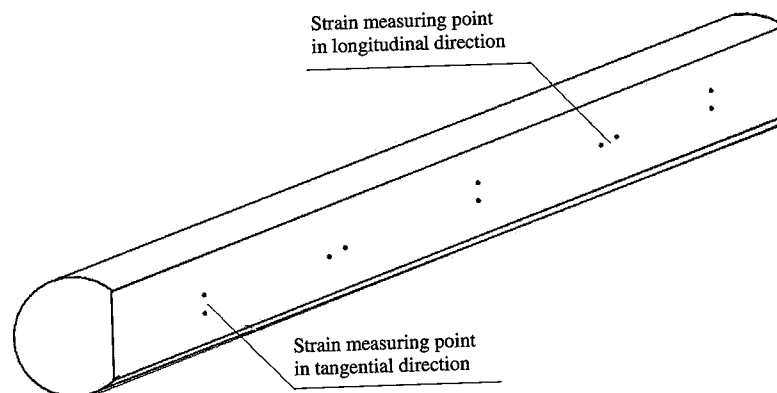


Fig. 1 Distribution of measuring points for strain change in lumber sawing

$$\text{Strain} = (D_a - D_b) / D_b \times 100\%$$

Where:

D_b = the dimension before the lumber is sawed off;

D_a = the dimension after the lumber is sawed off.

The logs were sawn using three different sawing patterns: live sawing, cant sawing and around sawing; and the strain changes were measured following the above procedure.

2.3 Deformation of sawn lumber

Bow deformation in sawn lumber (bending in the longitudinal direction) was recorded for all pieces for each sawing strategy. Bow can reflect the extent of growth stress release. The higher the stress gradient in the original log is, then the greater the expected bow deformation.

2.4 Lumber recovery and influence factors

Thickness variation and end-splitting were measured for the sawing of the four Eucalyptus species and analyzed after sawing experiments. Logs were sawn to produce 25 mm thickness lumber on the headrig band saw. Besides the dimension mentioned, log diameter and length, lumber width, length and thickness, the frequency and dimension of knots, and other lumber defects were also recorded in association with the sawing process. These measurements were used in the later evaluation of lumber grade and recovery.

3 RESULTS AND DISCUSSION

3.1 Strain changes in the sawing process

The strain distribution in the sawing process is analysed and displayed in Fig. 2- Fig. 9. X-coordinates show the log's position, while the number 1, 2, 3... shows the section position progressively from the bottom to the top section of the trunk. The abbreviations shown in the figures are: T-tangential, R-radial, Sap-Sapwood, Core-Core wood, Live-live sawing, Cant-cant sawing, Around-around sawing, for example, 'T_live' represents tangential direction with live sawing pattern. The results showed the variation in strain was very large.

Fig. 2 and Fig. 3 show the strain in the sawing process for three kinds of sawing strategies for *E. citriodora*. The strain in both the tangential and radial (T and R) directions is more uniform with the cant sawing strategy than that of other two strategies, The strain difference between T and R with the cant sawing strategy is small, and the absolute value of strain is close to zero (i. e. strain free), therefore it is possible to saw lumber with less sawing defect. In live sawing and the around sawing strategies, the strain fluctuation is very big, and this may result in checks and deformation of the lumber. As for the longitudinal strain, strain in the top sections from the trees was large, while the strain from the bottom section was comparatively small.

Fig. 4 and Fig. 5 show the results of *E. exserta*. The around sawing strategy shows the most even strain in T and R directions, while tangential and radial direction strain is small. Strain resulting from the cant sawing strategy showed the biggest fluctuation. In the longitudinal direction, the strain of the sapwood was even among the sections from bottom to top, while the corewood strain showed the largest variation.

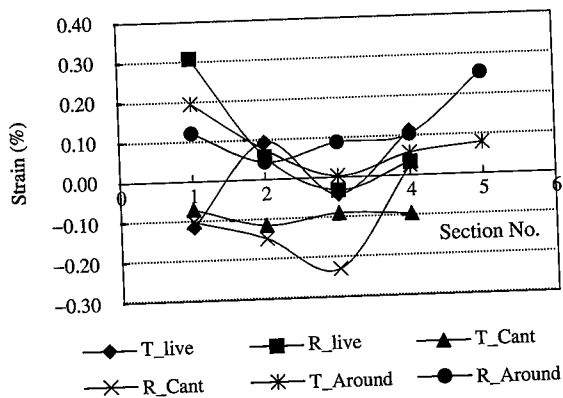


Fig. 2 Strain distribution of *E. citriodora* in tangential and radial direction

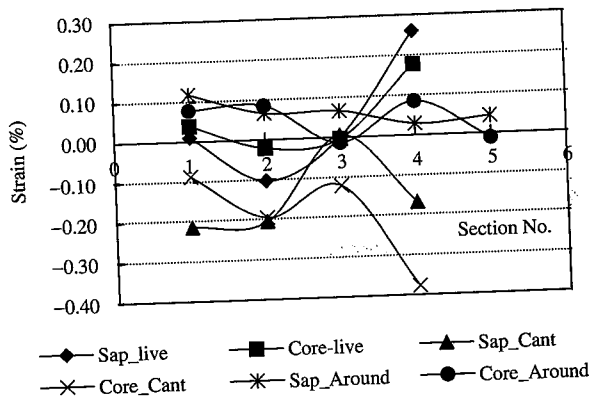


Fig. 3 Strain distribution of *E. citriodora* in longitudinal direction

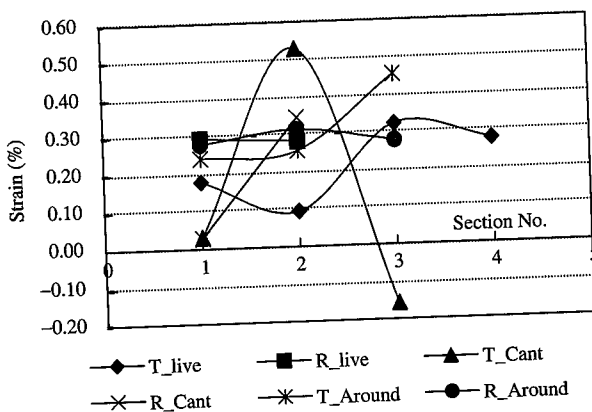


Fig. 4 Strain distribution of *E. exserta* in tangential and radial direction

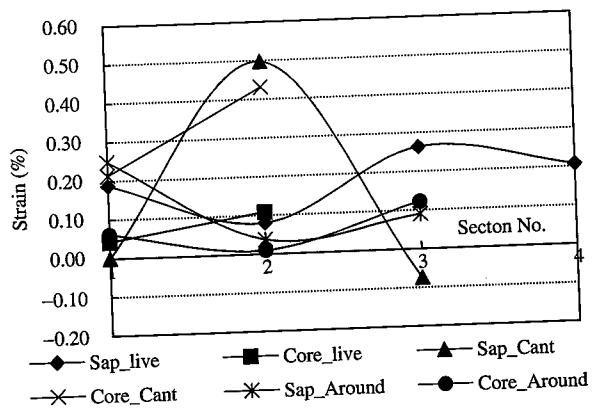


Fig. 5 Strain distribution of *E. exserta* in longitudinal direction

Fig. 6 and Fig. 7 show that for *E. urophylla* \times *grandis*, the strain in the around sawing strategy has a very large variation, while the strain with the live sawing strategy was even. The difference between T and R is small; the strain value with cant sawing is the smallest among the three different sawing strategies. In the longitudinal direction, there was a small strain difference between sap and core with the live sawing pattern.

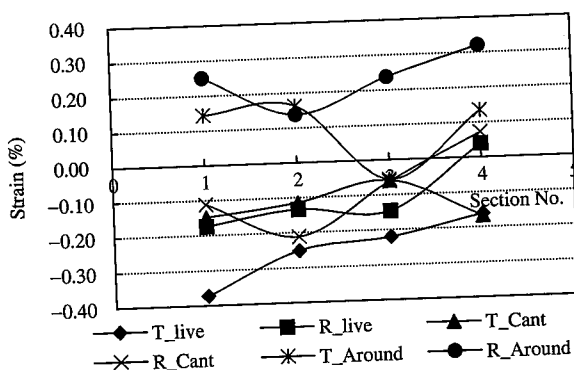


Fig. 6 Strain distribution of *E. urophylla* \times *grandis* in T and R direction

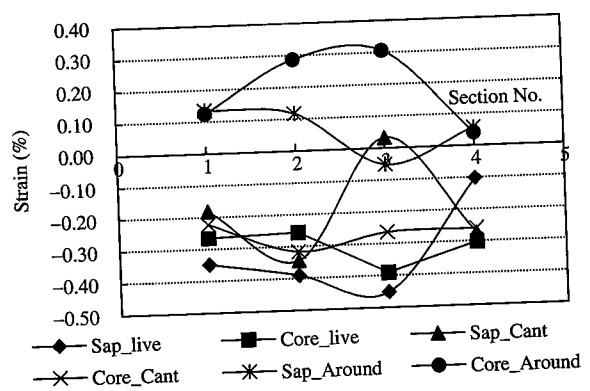


Fig. 7 Strain distribution of *E. urophylla* \times *grandis* in longitudinal direction

Fig. 8 and Fig. 9 show that for *E. grandis*, the around sawing strategy showed the largest variation in strain in the radial and tangential directions (R and T), while the live sawing and cant sawing strategies were more even. In the longitudinal direction, all of the three strategies resulted in large fluctuations in strain values.

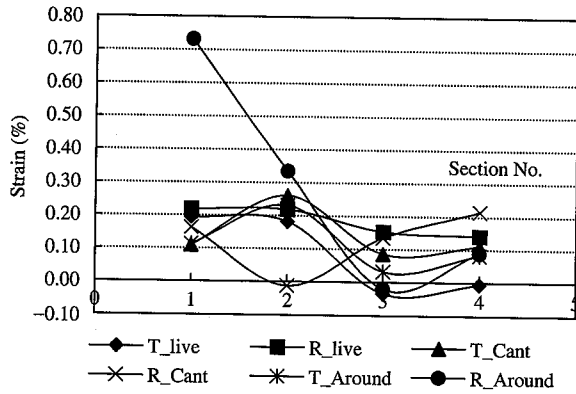


Fig. 8 Strain distribution of *E. grandis* in tangential and radial direction

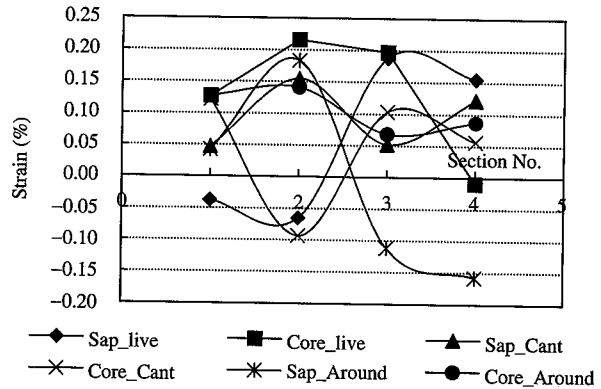


Fig. 9 Strain distribution of *E. grandis* in longitudinal direction

The results showed no regularity exist in strain in sawing process, this is in accordance with other research result (Tomaselli, 2000).

3.2 Deformation of lumber

The most deformation which occurred in the sawing process was bow deformation of the lumber. The results are displayed in Fig. 10 to Fig. 15 for *E. citriodora* and *E. grandis* for the three different sawing strategies. The X-coordinates represent the location of lumber in the log, 0 is the core lumber and the other values represent the block number in relation to the pith of the log, Positive and minus values are used to indicate the two directions from the pith. In the live sawing and cant sawing strategies, the larger minus values represent which pieces of lumber were cut first., In the around sawing strategy the sign just represents location of the lumber (displacement from the pith).

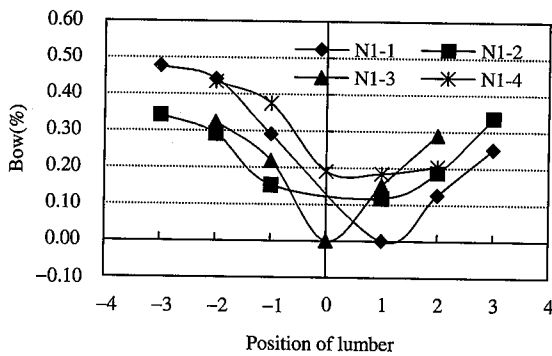


Fig. 10 The bow deformation of *E. citriodora* in live sawing

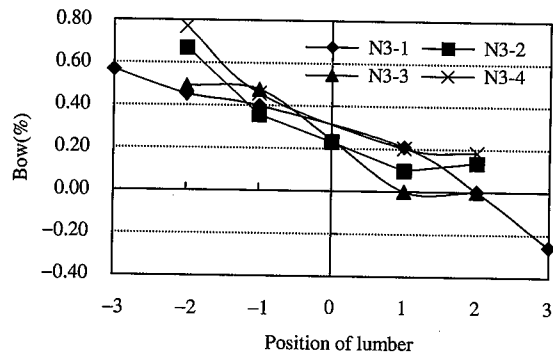


Fig. 11 The bow deformation of *E. citriodora* in cant sawing

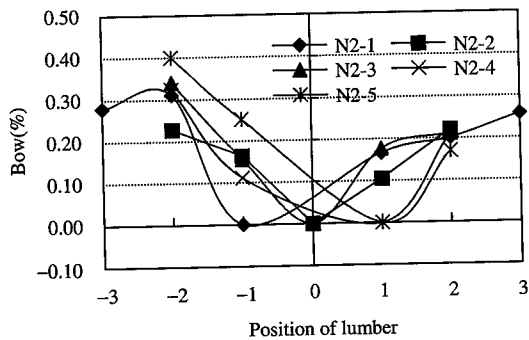


Fig. 12 The bow deformation of *E. citriodora* in around sawing

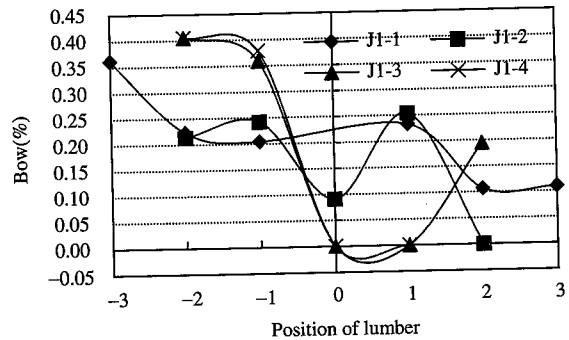


Fig. 13 The bow deformation of *E. grandis* in live sawing

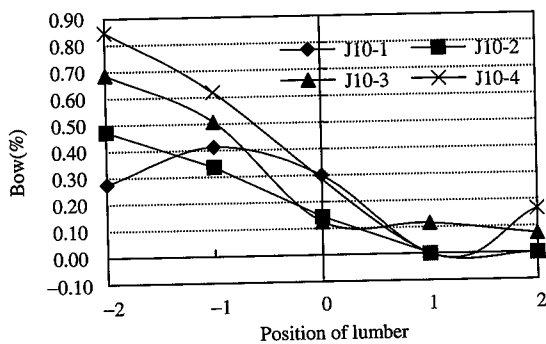


Fig. 14 The bow deformation of *E. grandis* in cant sawing

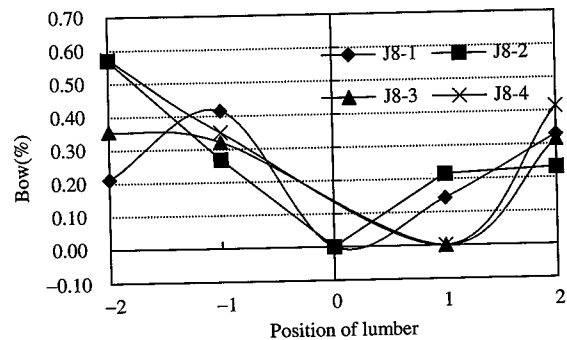


Fig. 15 The bow deformation of *E. grandis* in around sawing

In the sawing process, most of the lumber developed bow deformation except the core lumber. This bow deformation has some relationship with where the lumber was located in the original log and the sequence of the cuts in the sawing process. This is apparent in Fig. 10 to Fig. 15, especially the cant sawing.

The most appropriate sawing strategy can be shown from the results above. It is better to saw logs using a cant sawing strategy. While the bow deformation from the first cut is bigger, the strategy enables the low quality part of log to be removed first, then later, saw the rest of the log to get better quality lumber. And twin saw system is suitable for eucalyptus sawing. (Waugh, 2000).

3.3 The sawing inaccuracy of lumber thickness

The high growth stress in eucalypts can result in considerable distortion and sawing inaccuracy during sawing (Gerard, 1995), which greatly influence the sawn accuracy of lumber as well as lumber recovery and productivity. According to the national sawing standard of China, the permitted thickness deviation is ± 1 mm. However, in this study, the actual sawing variation was much larger, the range being from -3 to $+4$ mm. This big variation not only influenced lumber recovery, but also made later processing difficult due to the uneven dimensions of the lumber. The proportion of oversize deviation in the study is displayed in Tab. 2. The range of the variation of oversized pieces for the different species was from 39% to 57%. The *E. citriodora* and *E. exserta* lumber is hard and it is easy for the saw to wander during sawing, resulting in thickness inaccuracy. For *E. urophylla* \times *grandis*, the growth stress is larger, so the lumber defects in the sawing process, also result in a larger variation in dimensions.

Tab. 2 Thickness inaccuracy

| Species | Number of slabs | Number with oversize thickness | The proportion of oversized (%) |
|--------------------------------------|-----------------|--------------------------------|---------------------------------|
| <i>E. citriodora</i> | 90 | 47 | 52.22 |
| <i>E. exserta</i> | 65 | 32 | 49.23 |
| <i>E. grandis</i> | 98 | 39 | 39.80 |
| <i>E. urophylla</i> × <i>grandis</i> | 82 | 47 | 57.32 |

3.4 The influence of end-splits on lumber recovery

The most frequent defect in lumber resulting from sawing high growth stress plantation Eucalyptus is end-splitting (Jose and Isarael, 2000). Heart shake appears just after the tree is cut down, and it will extend to some extent before sawing. Most end-splitting originates from the extension of heart shakes. Tab. 3 shows the effect of end-splitting for the sawing of four Eucalyptus species. The influence of end-splits on sawn recovery of *E. citriodora* and *E. exserta* was 8.07% and 9.02% respectively, i.e. if there are no end-splits, the lumber recovery will increase about 8%~9%. For *E. grandis* and *E. urophylla* × *grandis*, the influence of end-splits was much higher, being 15.27% and 16.11%, respectively for the two species.

Tab. 3 Influence of end-splits on lumber recovery

| Species | log Volume | Volume of lumber including end-split | Recovery rate (%) | Volume of lumber without end-split | Recovery rate (%) | Recovery difference (%) |
|--------------------------------------|------------|--------------------------------------|-------------------|------------------------------------|-------------------|-------------------------|
| <i>E. citriodora</i> | 1.3936 | 0.8648 | 62.05 | 0.7522 | 53.98 | 8.07 |
| <i>E. exserta</i> | 0.8326 | 0.4699 | 56.43 | 0.3948 | 47.41 | 9.02 |
| <i>E. grandis</i> | 1.7259 | 1.0972 | 63.57 | 0.8336 | 48.30 | 15.27 |
| <i>E. urophylla</i> × <i>grandis</i> | 1.1075 | 0.7003 | 63.24 | 1.5219 | 47.13 | 16.11 |

The lumber recovery for all of the four plantation Eucalyptus species was more than 45%. The Eucalyptus lumber has advantages of high density, good colour and grain, high strength etc. The potential for utilization of the species for solid wood products is good, if the drying problem can be solved correctly.

4 CONCLUSIONS

There was a big variation in strain but no obvious trend, in both the tangential and longitudinal directions in lumber during the sawing process for the three different sawing strategies.

Bow deformation showed a clear regularity. The closer the position of the lumber to the pith of a log, then the lower the deformation. The lumber cut first had the largest bow deformation.

The thickness deviation of *E. citriodora* and *E. exserta* was large as the lumber is very hard to saw, but the large variation in *E. urophylla* × *grandis* resulted from high growth stress.

The end-splits in lumber of eucalyptus species had a large influence on lumber recovery, with *E. urophylla* × *E. grandis* showing the greatest loss.

The lumber recovery of *Eucalyptus* spp. could be improved by choosing appropriate sawing strategies. This would improve the potential for the use of Eucalyptus lumber for value added wood products.

5 ACKNOWLEDGEMENT

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REFERENCES

- Gerard J, Bailleres H, Fournier M, Thibaut B. 1995. Wood quality in plantation Eucalyptus - a study of variation in three reference properties. *Bois et Forêts des Tropique*, 245(3): 101-110.
- Jiang X M. 2000. The future of eucalyptus for wood products. Situation of the resources and wood utilization of tropical plantations in the southern part of China technical report, Beijing, 57-74
- Jose N G, Isarael L D L. 2000. Log end splitting and improvement in sawing *Eucalyptus grandis*. The Future of Eucalypts for Wood Products Proceedings, Tasmania Australia, 113-123
- Lu J X. 2000. Situation of the resources and utilization of wood of tropical plantations in the southern part of China. Situation of the resources and wood utilization of tropical plantations in the southern part of China technical report, Beijing, 39-47
- Tomaselli I. 2000. Processing Young Eucalyptus. The Future of Eucalypts for Wood Products Proceedings, Tasmania Australia, 167-174
- Waugh G. 2000. Use of twin saw system for young, fast-grown Eucalypts. The Future of Eucalypts for Wood Products Proceedings, Tasmania Australia, 175-183

Machining Properties Assessment of Wood from planted *Eucalyptus citriodora*

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ABSTRACT

The research methods in this paper are based on the standards of the American Society for Testing and Materials. Six processing activities; planing, sanding, boring, mortising, shaping and turning were selected to study the machining properties of *Eucalyptus citriodora* plantation wood. The main machining defects are revealed. The results showed *E. citriodora* planted in the south part of China is a species with great potential for solid wood utilization.

1 INTRODUCTION

With the structural change of China's timber resources, it has become more and more important to develop and utilize plantation wood. Eucalypts account for about one-third of the world's total plantation area. They are planted in 17 regions and provinces of China, with an area of over 1.5 million ha. and with a stock volume reaching 60 million cubic meters (Yin *et al.*, 2001). *E. citriodora*, is a mainly fast-growing species planted in recent years, has a good trunk shape, high growth rate, high density, beautiful color and a great potential in solid wood utilization. However, the utilization of eucalypt wood in China has been mainly limited to wood chips, paper pulp and charcoal. All these have a low added value. The higher value-adding for solid wood products from eucalypt plantations is just beginning. This study selected *E. citriodora* plantation wood as experimental material to test and assess its machining properties systemically. This would provide useful information for the design and production of solid wood products.

At present, in China the study for wood machining properties is at an early stage. Usually, describing machining properties is only from the qualitative aspect. So it is necessary for China to establish technical standards in this field. In this study, ASTM D1666-87 technical standards were used which is the standard method employed in the USA for conducting machining tests of wood and wood-base materials. The objective of this study was to evaluate the potential and suitability of solid wood utilization of *E. citriodora* plantation wood for panel, blockboard and furniture production.

2 MATERIALS AND METHODS

2.1 Materials

Logs of *E. citriodora* plantation of age 8 to 10 years were supplied by Guangxi Chengda Wood Products Company. Log diameters were 20-30 cm small-end diameter. The logs were sawn and products kiln dried to

8%~12% moisture content. The test specimens were made based on the ASTM standard requirements, with dimensions of 20 mm × 127 mm × 1,200 mm (thickness × width × length) (Fig. 1). According to ASTM standards the test lumber should be clear and sound, which means free from all defects, including knots, stain, incipient decay, surface checks, end splits, and reaction wood. However, for *E. citriodora* plantation wood, to thoroughly avoid all these defects is considerably difficult. Samples were randomly selected to represent the real characteristics of this resource. Dimensions and number for the test samples are shown in Tab. 1.

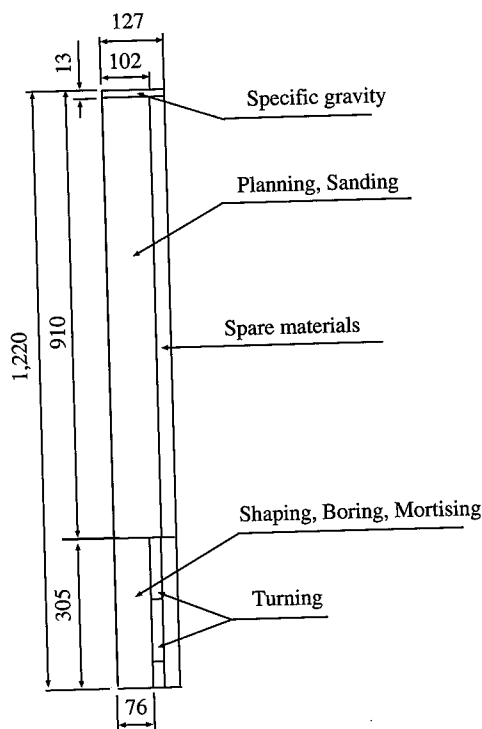


Fig. 1 Diagram for sawing lumber into smaller samples for individual tests

Tab. 1 Sample size for individual tests

| Individual test | Size: Thickness × Width × Length(mm) | Number |
|-----------------|--------------------------------------|--------|
| Planing | 19 × 102 × 910 | 30 |
| Sanding | 19 × 102 × 400 | 30 |
| Shaping | 19 × 76 × 305 | 30 |
| Boring | 19 × 76 × 305 | 30 |
| Mortising | 19 × 76 × 305 | 30 |
| Turing | 19 × 19 × 305 | 30 |

2.2 Methods

2.2.1 Planing

The planing test was conducted using a K UW-500F1 planer. Some adjustments of the bottom spindle beneath the bench, could be made to control cutting thickness. The knife parameters should be stabilized. The wedge angle was 30°. The knife material is the industry standard high-speed steel (HSS). Five treatments based on two control factors (planing thickness and feed rate) were evaluated.

2.2.2 Sanding

A WS-65 wide-belt sanding machine made by the Japanese AMITE Company was used to test sanding properties. This sander has only one head and is automatically fed. Feed rate range was from 4.3 to $20.3\text{ m} \cdot \text{min}^{-1}$, with a $5.8\text{ m} \cdot \text{min}^{-1}$ feed rate used in the sanding test. The feed rate recommended by ASTM is $6.1\text{ m} \cdot \text{min}^{-1}$. While the ASTM standard does not specify sanding thickness, based on China's practical production and testing by EDVARD KARDELJ University, the cutting thickness of 0.6 mm with sandpaper of grit 120 was adopted for this study.

2.2.3 Shaping

A single spindle shaper equipped with a moulding milling cutter was used to test shaping properties. This hand-feed shaper was made by Mudanjiang Wood Machining Factory in China and has four spindle heads, rotating at $6,000\text{ r} \cdot \text{min}^{-1}$ for this test. The milling cutters were produced by Chaoyang Tool Factory in Beijing. Before shaping, the procedure was to make a preliminary roughing cut along the grain of each specimen, then as soon as possible to make a 2 mm deep finishing cut, which differed slightly from the 1.6 mm cutting thickness recommended by ASTM.

2.2.4 Boring

Two types of bits (namely centre bit and solid nose bit) were used in the boring tests. The centre bit was fitted to a B13S bench borer produced by Japan. Spindle rotation could be varied from 500 to $3,000\text{ r} \cdot \text{min}^{-1}$. The solid nose bit was fitted to a ZQ3025 \times 5 hand feed borer, with maximum boring diameter of 25 mm . Spindle rotation could be varied from 320 to $2,800\text{ r} \cdot \text{min}^{-1}$.

The diameter of the bit types for the test was 25 mm . The spindle rotation for the B13S borer was $2000\text{ r} \cdot \text{min}^{-1}$ and for the ZQ3025 \times 5 borer was $500\text{ r} \cdot \text{min}^{-1}$. Although the solid nose bit is not commonly used in the wood industry, it is necessary to compare different manufacturing methods for an exploratory test. Bits were sharpened before every test. According to ASTM the feed rate for boring should be controlled to ensure a clean cut.

2.2.5 Mortising

A MK312 foot-feed mortiser produced in China was used in this test, with maximum machining width of 20 mm . A 13 mm hollow chisel as recommended by ASTM was fitted to the mortising machine. According to ASTM a run-through mortiser should be used, while the non run-through mortiser is more commonly used in China's furniture industry. In this test two run-through mortises were produced for each specimen. Under the test conditions, mortises should be produced with two sides parallel to the grain and two sides perpendicular to it.

2.2.6 Turning

The turning test was conducted in Italy using a TS-120 wood working lathe, which has an automatic feed knife and is fitted with a pattern panel. The feed velocity for the cutter block was $0\text{--}10\text{ m} \cdot \text{min}^{-1}$, and

returning velocity was $0-12 \text{ m} \cdot \text{min}^{-1}$. Three spindle rotations, 2,120, 3,110 and 4, 210 $\text{r} \cdot \text{min}^{-1}$, could be chosen. The maximum length for the work piece was 1,200 mm; the maximum diameter was 200 mm.

In this test, a spindle rotation speed of 3, 110 $\text{r} \cdot \text{min}^{-1}$ was used and the feed velocity for the cutter block was $6 \text{ m} \cdot \text{min}^{-1}$. As a carbide steel knife was used. The size for the pieces was $20 \text{ mm} \times 20 \text{ mm} \times 305 \text{ mm}$ (width \times thickness \times length). According to ASTM, the position of the knife must be adjusted to make a turning with 7.5mm thickness at the thinnest point of piece. All the pieces were processed four times. The cutting thickness for the first three times was 1 mm and for the last was 0.7 mm. After turning the pieces were sanded with 150-grit sandpaper.

3 RESULTS AND DISCUSSIONS

3.1 Planing

The grade for planing quality is based on the form and quantity of defects. The planing results were divided into 5 grades (Excellent, Good, Fair, Poor and Very poor) as specified by ASTM. The study revealed that torn grain is the main planing defect for *E. citriodora*. Grades 1 to 5 of torn grain samples of *E. citriodora* are shown in Fig. 2.

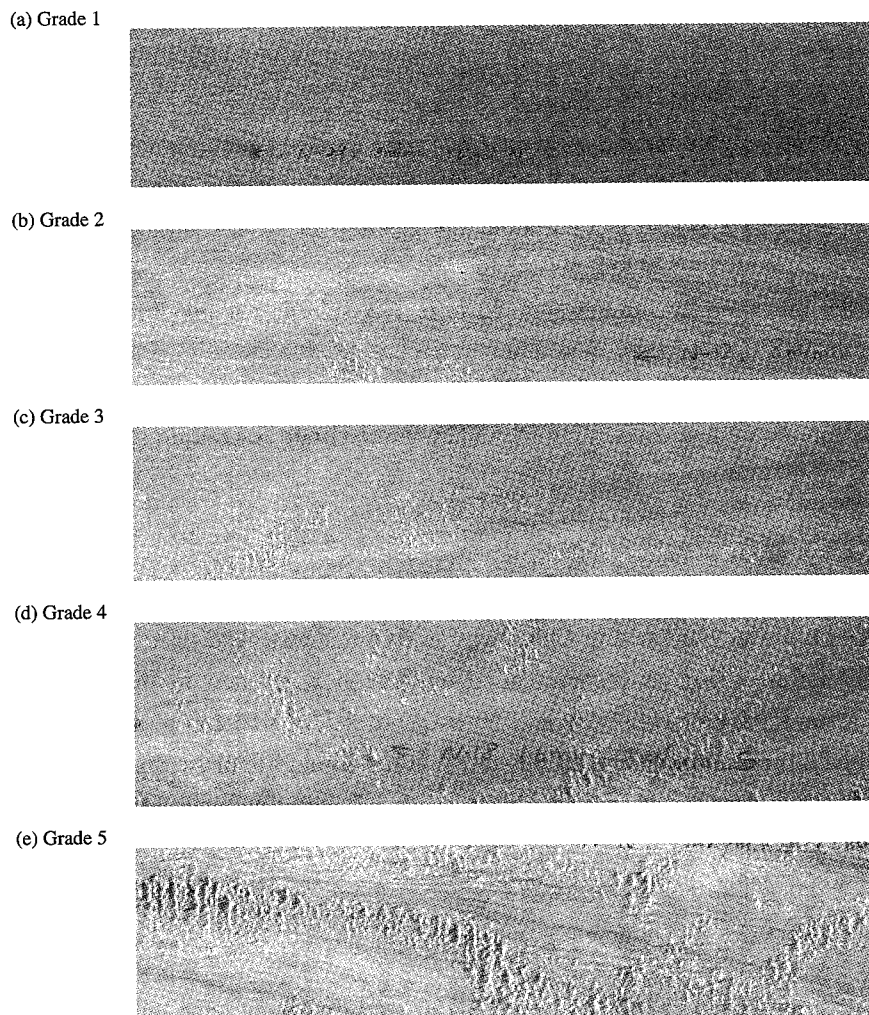


Fig. 2 Grades 1 to 5 of torn grain samples of *E. citriodora*

If feed velocity was decreased, the torn grain became more serious. The percentage of Grade 1 and Grades 1 and 2 (combined) planing samples of *E. citriodora* planing show as Tab.3. Obviously cutting conditions 1 and 2 as shown in Tab. 2 provided the most suitable conditions for planing *E. citriodora*.

Tab. 2 Five treatments of planing

| Treatment | Cutting thickness(mm) | KMPI | Feed velocity(m · min ⁻¹) |
|-----------|-----------------------|------|---------------------------------------|
| 1 | 1.6 | 20 | 8 |
| 2 | 2.5 | 40 | 8 |
| 3 | 1.6 | 48 | 9.5 |
| 4 | 1.6 | 20 | 19 |
| 5 | 2.5 | 48 | 19 |

Tab. 3 The Percentage of Grade 1 and Grades 1 and 2 planing samples of *E. citriodora*

| Cutting condition | 1 | 2 | 3 | 4 | 5 |
|-------------------|------|------|------|------|------|
| Grade 1 | 43.3 | 50.0 | 36.7 | 3.3 | 10.0 |
| Grades 1 and 2 | 76.7 | 73.3 | 66.7 | 40.0 | 43.3 |

Examples of the characteristics of torn grain observed under SEM are shown in Fig. 3. Obviously fiber tearing, fiber cutting and lifted tissue are the main reasons for planing defect.

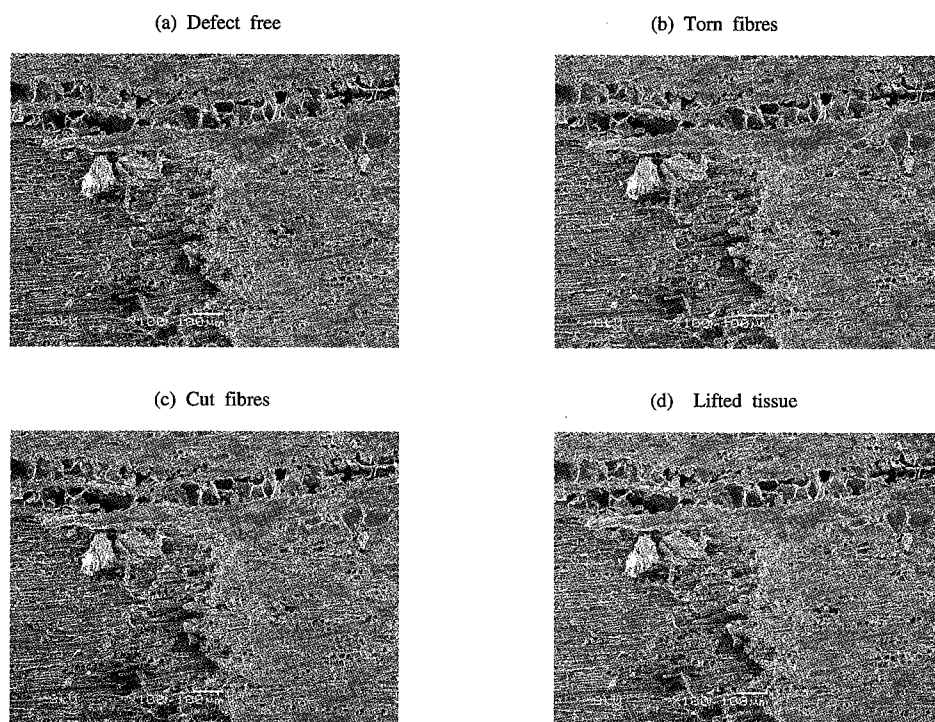


Fig. 3 SEM micrographs of planing defects of *E. citriodora*

3.2 Sanding

The experimental results showed that planing defects can be mostly removed by sanding. For example,

even the extreme planing defects produced by planing at $19 \text{ m} \cdot \text{min}^{-1}$ (Tab. 2) can be completely removed by sanding. More severe planing defects which occurred near knots and also associated with uneven grain were also reduced after sanding. Although the planing defects were largely eliminated, a new kind of defect, described in ASTM as 'A' type defect occurred. In a total of 30 pieces, there were also 20 (66.7%) with 'S' type defect.

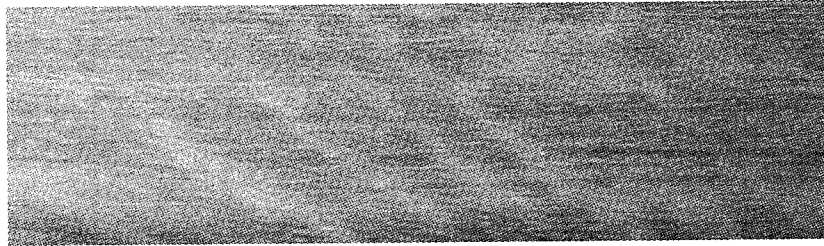


Fig. 4 Sanded samples of *E. citriodora*, showing type 'A' defects

SEM micrograph samples (Fig. 5) show that while the surface quality after sanding is better than after planing, some small wood fibers can be seen randomly distributed on the surface.

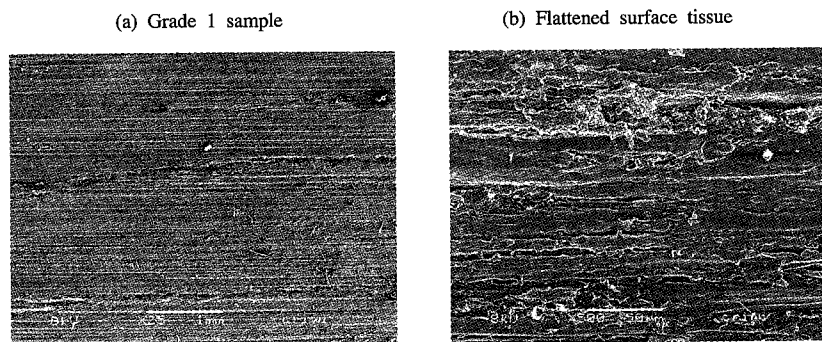


Fig. 5 SEM observation of *E. citriodora* samples

3.3 Shaping

After shaping, a new type of defect-type 'C' (Fig. 6) was randomly distributed as a non-uniform light colour on the surface profile of samples. The possible reason for the 'C' type defect is due to the high density and strength of *E. citriodora*. Although its severity is not serious, it is very prevalent. In a total of 30 pieces type 'C' defect occurred in six (20%) pieces. One piece (3.3%) had torn grain and 23 pieces (76.7%) were without defect.

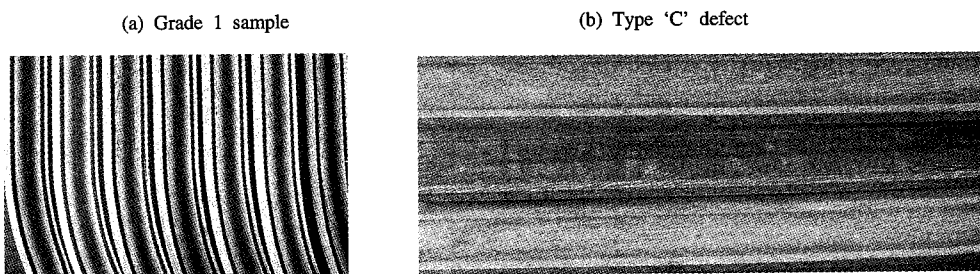
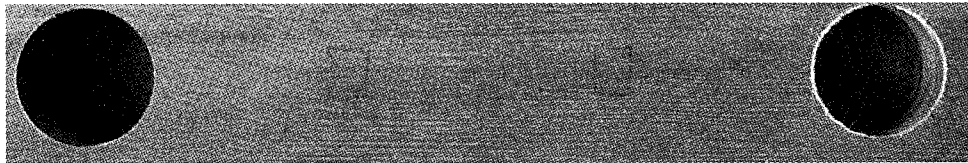


Fig. 6 Shaping samples of *E. citriodora*

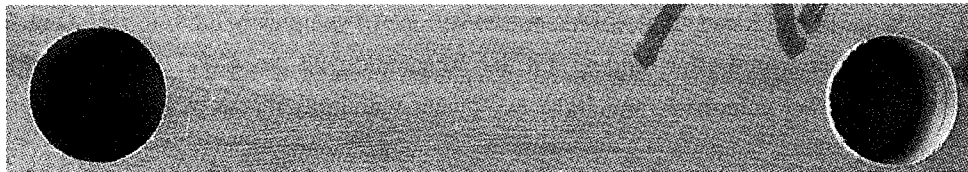
3.4 Boring

Extreme tearing and roughness of the boring hole can result in the piece being discarded. When a solid nose bit was used for boring trials, the main defects were fuzzy grain and fibre tearing. Of the 30 pieces, 11 (36.6%) showed fuzzy grain and four (13.3%) with tearing and 46.7% of pieces met Grade 1 requirements. For all holes for which the solid nose bit was used, the quality of the top edge was better than that of the bottom edge (Fig. 7). When the centre bit was used for boring, no piece showed any defect and 100% of pieces met grade 1 requirements.

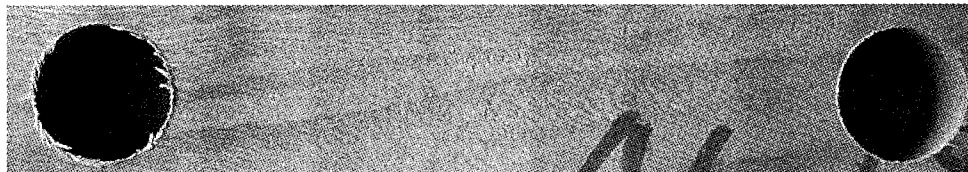
(a) Upper edges of the holes in Grade 1 sample



(b) Bottom edges of the holes in Grade 1 sample



(c) Fuzzy grain at bottom edge



(d) Tearing at bottom edge

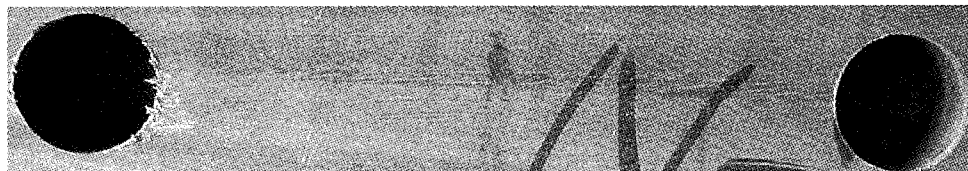


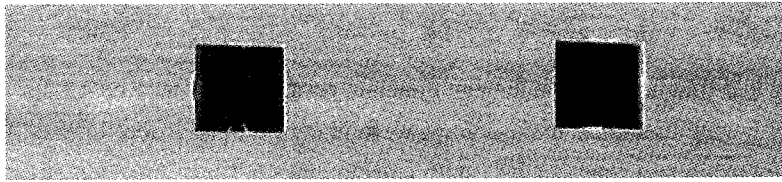
Fig. 7 Boring samples of *E.citriodora*

The left hole was bored by a solid-centre bit with spur; and the right one by a twist drill

3.5 Mortising

The study revealed that fuzzy grain on the mortised surface as the most frequently occurring defect. Almost every piece had fuzzy grain. Although its severity was not serious, fuzzy grain had a negative influence on roughness of the mortising surface. It was noticeable that there were no defects such as fuzziness and grain tearing on the top and bottom edge of the samples (Fig. 8).

(a) Top edges of the mortise surface in a Grade 1 sample



(b) Bottom edges of the mortise surface in a Grade 1 sample

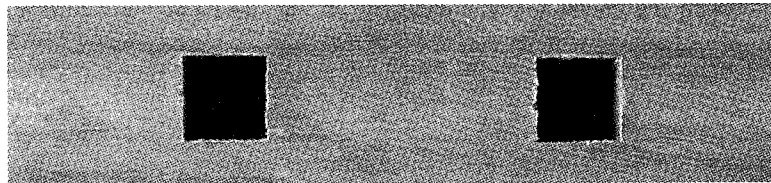
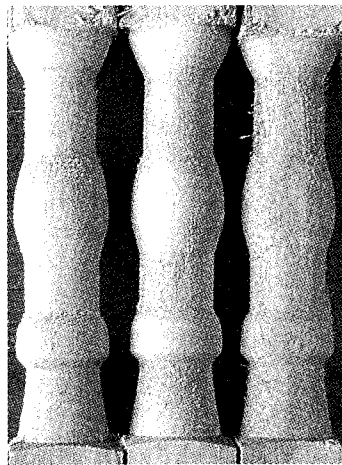


Fig. 8 Mortising samples of *E. citriodora*

3.6 Turning

After turning, pieces were sanded with 150# sandpaper. The surface quality was greatly improved by sanding with fuzzy grain and loose single fibres on the surface of samples being removed (Fig. 9). However some knife marks still appeared after sanding. Of the 30 samples, 22 pieces (73.3%) showed knife marks, however the severity of the knife marks was light, and pieces with knife marks were not down-graded.

(a) Before sanding



(b) After sanding

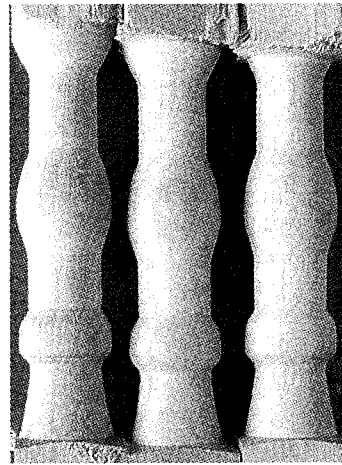


Fig. 9 Turning samples of *E. citriodora*

4 CONCLUSIONS

The overall results for machining properties of *E. citriodora* plantation wood are shown in Fig. 10. It is obvious from Fig. 9 that the boring (using the brad point bit) and mortising results were very good, with 100% of the samples meeting Grade 1 specifications. Shaping, turning and sanding (based on treatment 2 in Tab. 2) all managed to result in more than 2/3 of pieces meeting Grade 1 specification, while for planing this was reduced to 43%, however, even then, more than 75% met specifications for Grade 2 or better. Based on these results, it is reasonable to conclude that overall good machining results can be expected when utilizing

E.citriodora plantation wood and that this resource has a great potential for solid wood utilization.

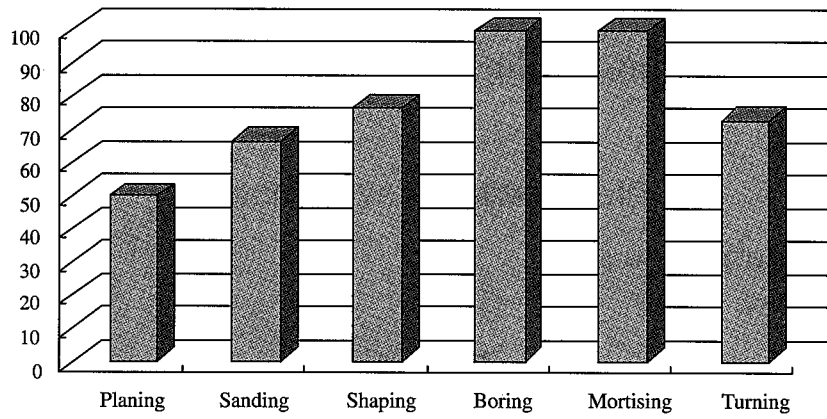


Fig.10 The proportion for excellent samples

REFERENCES

- Annual Book of ASTM Standards. 2000. Section Four Construction. Vol. 04. 10, Wood-club. D1666-87 (Reapproved 1999)
- Derek W, Roman M. 1998. Machining and Related Mechanical Properties of 15 B C Wood Species. Forintek Canada Corp, 1-4
- Edvard Kardelj University LJUBLJANA Biotechnical Faculty. 1983. Machining and Related Characteristics of Five Wood Species from Bayanga Region (Central African Republic). LJUBLJANA, 5-16
- Forest Research of New Zealand. 1998. The Comparative Research between *Pinus radiata* of New Zealand and 13 Wood Species of Northern-America. New Zealand, 1-8
- Yin Y F, Jiang X M, Lu J X, Su H Z. 2001. The status of resources and wood utilization of eucalyptus plantation in China. China Wood Industry, 15(5):3-5

Opportunities for Adding Value to Plantation Grown Eucalyptus Logs

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ABSTRACT

In recent years a great many plantations of Australian eucalypts have been established around the world as forest growers have sought to capitalise on their excellent growth and adaptability characteristics. The prime driver for this investment has been the ever increasing demand for paper/ pulp and as a consequence the focus has tended to be on the shortest possible crop rotation and species providing the best pulp yields. However, as the availability of native forest hardwood sawlogs is declining, in both quantity and quality, relative to increasing demand, more growers and processors are looking to the practicalities of using plantation grown trees to service traditional sawn wood applications. It is clear that growing and processing eucalypt timber for this purpose presents a number of significant issues in relation to both growing suitable trees and in processing them to produce high value products at costs competitive with traditional supplies. Logs from juvenile eucalypt trees have largely proved to be unsuitable for conventional sawing and drying.

This paper addresses these problems and presents outputs of twenty years of research work by experienced Australian forest industry consultants. It focuses on the issues associated with harvesting and processing juvenile eucalypt trees into high value sawn wood products from plantation to market. It addresses the basic issues of the qualities of the resource, inherent processing difficulties and what markets might best be served. Innovative processes and technology have been applied to these fundamental issues to facilitate the production of quality products suitable for world markets at realistic costs. To demonstrate the processes, high quality laminated flooring from six and eight year-old *Eucalyptus globulus* thinnings, has been produced and tested by Valuwood International.

These processes open up new options to forest growers seeking to improve their return on investment in eucalypt plantations by being able to produce a range of products from short rotation plantations without detracting significantly from productive capacity for pulp production. They also provide the opportunity for wood processors to gain access to a much larger resource base from which to produce products. Quality products can be made from juvenile eucalyptus timber if manufacturers have the foresight to invest in the right processes and technology to address the inherent wood characteristics.

1 INTRODUCTION

Australian native Eucalyptus trees are well known for their characteristics of hardiness, adaptability and excellent growth potential in even the harshest of environments. In addition the timber of a number of species is well known for its ability to produce fine sawn hardwood of outstanding appearance, strength and durability.

However those of us who have been involved in the long term operation of the hardwood native sawn timber industry in Australia are also very familiar with the difficulties of processing these timbers. These difficulties often make it hard to obtain a satisfactory sawn recovery and also result in the production of a considerable amount of material which does not readily meet the requirements of the higher value adding applications.

Added to these intrinsic problems, it has been clear for many years that the availability of large diameter high quality logs is declining and that over time this situation will worsen. With this in mind, timber industry researchers in Western Australia have taken up the challenge of developing new processes and technology to facilitate the processing of the much smaller and juvenile logs which will make up the bulk of the available resource in future. It is clear to us that much of this work now has direct application to the significant and rapidly increasing resources of plantation grown eucalypt logs now being developed around the world.

This paper addresses the problems associated with processing small and juvenile eucalypt logs and presents outputs from twenty years of research and development work by experienced Australian forest industry consultants. It focuses on the issues associated with harvesting and processing juvenile eucalypt logs into high value sawn wood products from plantation to market. It addresses the basic issues of the quality of the resource, inherent processing difficulties and what markets might best be served. Innovative processes and technology have been applied to these fundamental issues to facilitate the production of quality products suitable for world markets at realistic costs. To illustrate the opportunities we will outline the outputs of our most recent research project which sought to demonstrate the cost benefits of processing, 6, 8 and 10 years-old *E. globulus* plantation thinnings into high quality laminated flooring.

2 BACKGROUND

Australian Eucalypts have been planted in many countries across the world for a variety of reasons ranging through shelter, erosion prevention, firewood, sawn timber and land rehabilitation. They are favoured due to their ability to survive and indeed flourish in a wide variety of conditions and environments. More recently significant areas have been planted to selected varieties of Eucalypt specifically to provide woodchips for high quality hardwood paper pulp.

Whatever the original purpose for planting, increasingly now as native forest hardwoods and particularly rainforest timbers become more difficult to obtain, it appears sensible to look to these large and increasing stocks of plantation timbers to meet a growing demand for sawn timber and particularly added value timber products. However the processing of smaller and immature eucalypt logs presents a number of specific problems which have, until now, worked against their utilisation for traditional sawn timber and value added applications. So much so that in fact a number of studies by other researchers have concluded that many varieties, particularly high pulp yielding species, are unsuitable for sawn timber production. It is also worth noting that trees planted for the production of woodchip material are usually on a short rotation of around ten years which is considered the optimum span for maximising wood fibre production.

In order to understand the nature of the problems which arise I will go through the stages of production and summarise the specific difficulties which may be encountered.

2.1 Growing

Issues related to site selection and preparation will not be discussed as they were found to have little effect on the end results of our studies.

The issues related to sawn wood production might be:

Species selection — Most species are selected in relation to the primary output requirement. So if for example *Eucalyptus globulus* is selected for its excellent pulp yield it might be observed that this is a species not considered well suited to sawn wood production.

Silvicultural practice — Once again practice will generally be directed at the primary output so for example you would not usually expect to thin and prune trees planted for woodchips but this might be considered desirable for sawn wood production.

Tree form — Whilst again not particularly relevant for pulp log, shelter or land rehabilitation trees, form will be quite critical for product recovery from saw logs. In particular small diameter, short length, major branching, excess sweep and buttresses would all be expected to result in unacceptable sawn recovery rates.

Growth stress — Young rapidly growing trees develop internal growth stress which in turn may lead to the formation of brittle heart wood, end-splitting of logs and distortion during sawing.

Defects — Other tree faults such as knots, gum veins, borer damage and end splits become much more critical in very small juvenile logs.

2.2 Harvesting

Only those aspects of harvesting that relate to sawn wood production are discussed.

High volumes of small logs — Harvesting large volumes of small logs presents some specific handling and transport issues.

Selective harvesting — In some cases best results for sawn wood production might be achieved by selected harvesting of most suitable trees prior to harvesting for other products.

Speed of handling — Generally due to the vulnerability of the immature logs to early degradation it will be vital to ensure logs are moved to the processing facility virtually as soon as they are harvested. If this is not possible they will need to be kept wet or damp.

On site/Off site initial processing — Consideration may need to be given to debarking, log end sealing and perhaps even initial sawing on site.

2.3 Processing

In this context we have only considered processing difficulties specifically related to small and juvenile trees though there are some issues which may still apply even to more mature trees.

High volumes of small logs — processing high volumes of small logs presents special difficulties in handling, throughput and waste disposal.

Growth stress — Growth stress tends to make conventional processing into relatively thick boards very difficult with serious splitting of logs after harvest, substantial spring, bow, twist and further splitting of boards when sawing, as the stress is released.

Proportion of lower quality material — The basic nature of the material will mean a substantial proportion of sawn output may not be suited to appearance grade or even structural grade applications and there will be very little of the large section longer boards which are usually of higher value.

Sawn recovery — Simple mechanics of sawing small round logs into boards results in lower overall sawn recovery making sawing loss more critical (saw sizes).

2.4 Drying

This is probably the most difficult to deal with for traditional sawn boards that are more than 20 mm in thickness. Drying stress can cause uncontrolled warping, bow, cupping, twisting and shrinkage which are extremely difficult to recover. Differential radial and tangential shrinkage results in severe splitting and many eucalypt species are subject to cell collapse which together result in unacceptable levels of drying degrade. In addition, drying may well have to be done relatively slowly to avoid complete destruction of the timber (with drying being even slower for larger section size boards).

2.5 Docking and resawing

To meet product specification substantial docking and resawing may be needed to remove unacceptable faults such as loose knots, splits and excessive deformation of boards.

2.6 Gluing

In those applications which involve gluing it may be necessary to give particular attention to types of glue and processes due to adhesive bonding problems with particular Eucalypt species.

3 SMALL LOG PROCESSING

On the evidence of the issues and problems outlined above it might appear that processing of small eucalypt logs may not be practical or viable, as indeed some have already suggested. In fact we would tend to agree if conventional sawing and processing technology is used. However, given that there are now substantial plantation resources in existence and that, unlike old growth native forest resources, the volume is growing dramatically, then is there a way of processing these trees efficiently?

Can we breed the problems out? Some are looking into ways of breeding trees to minimise the impact of some of these difficulties, particularly perhaps the issue of growth stress. However it is far from clear that this is the answer and in any case it is a long term solution of little help for the use of existing plantations.

Can we grow the problems out? Almost certainly, if you are prepared to grow the trees for long enough and with the appropriate silvicultural regime to optimise their performance as saw logs. However this makes them a very long term investment indeed which may make it difficult to attract private or even government investment funds.

We believe that there is a better way based on applying modern technology to develop new processes which can process small logs efficiently to produce high value products suitable for world markets.

4 AN INNOVATIVE APPROACH

In considering an approach to processing small logs we have canvassed a wide range of options and endeavoured to look at all the relevant aspects to develop a strategy which addresses the inherent problems of the nature of the resource while allowing the production of high value products. It has always been our belief that the starting point for our considerations must be the identification of appropriate markets which will optimise our return on investment in new technology. How then can we process this material and still produce value added products in demand in the market place?

After extensive practical research we have devised an approach which is based on the green sawing of small logs into relatively thin section lamellae and then gluing the lamellae back together to make the desired product range. We believe that this approach allows most of the inherent difficulties to be overcome while still leaving a broad scope to produce a range of value added products. We have concentrated on developing processes which can be implemented at realistic cost while importantly in this context allowing for integration with other product production such as wood chip pulp or Particle Board.

To demonstrate how these processes can be applied we present a summary of our most recent major research project which considered the cost/benefits of producing a laminated flooring product from juvenile Tasmanian Bluegum (*Eucalyptus globulus*). Tasmanian Bluegum was specifically selected for this project because it is primarily grown for woodchip pulp, it is generally not considered suitable for sawn timber production, it is notoriously difficult to process but, in our case at least, it is in copious supply.

5 LAMINATED THREE PLY FLOORING

A case study in Western Australia.

5.1 Markets

We believed that project viability would be greatly enhanced by targeting the production of a commodity which was known to be in high demand already. Previous research had already identified solid wood flooring products as meeting this criterion. Initial research had also shown that important factors for such a product were appearance, durability, ease of installation and stability. From this information we were able to develop an approach for a quality product with desired features.

5.2 Product approach

In considering the type of product to be made it was important to target a quality article with good appearance which would have wide appeal in the market place while at the same time taking into account the obvious limitations imposed by the nature of the material we have to work with. In addition we wished to develop the means to overcome the majority of the issues raised above in the manufacturing process.

Due to its rising popularity laminated floating flooring was considered best suited to our situation so this product was selected for assessment. In fact we decided to produce a cross-laminated three ply in a range of lengths and widths and with each laminate of equal thickness to enhance strength, stability and cost efficiency of production. Obviously the relatively short length of the juvenile logs imposed a strong

constraint on the maximum length we could achieve but this was not considered a serious shortcoming for this type of product. The key advantages were assessed as:

- 1) We could produce an attractive product from hardwood laminates.
- 2) We expected excellent stability from the cross laminated construction.
- 3) Simple tongue and groove design for ease of installation.
- 4) Tasmanian bluegum selected due to ready availability and known difficulty in processing for conventional sawn products.

And finally and most importantly.

Design would allow us to overcome a key problem with utilisation of small eucalypt logs in that only approximately one third would need to be of appearance grade for the top surface and two thirds only structurally sound. This allows for much better utilisation as much of the material which would otherwise be unsuitable can now be used in centre or bottom layers without compromising the final integrity of the product.

5.3 Harvesting

Various options for harvesting were tested in different bluegum and pine plantations which resulted in the development of a log specification which could be applied to provide suitable material for our production.

| Log parameter | Specification / description |
|--------------------------|--|
| General condition | all logs to be free from insect or fungal attack |
| Length | 2.5 metres |
| Diameter | small end diameter under bark (s.e.d.u.b.) – 150 to 250 mm |
| Straightness | sweep not to exceed 10% of the s.e.d.u.b. along the total length as measured from the log surface to the chord created by a straight edge |
| Branch condition | to minimise the occurrence of dry encased knots, crown recession not to exceed 5 metres |
| Log preparation | branches to be flush trimmed and the bole to be square docked |
| Bark | logs may be debarked in the plantation only if delivery to water spray stockpile facilities is made within 12 hours of felling. Otherwise bark to be left on |
| Delivery | logs without bark to be delivered within 12 hours of felling logs with bark on within 48 hours |

Fig. 1 Blue gum flooring log specifications

Small logs were harvested from six, eight and ten-years-old bluegum plantations using conventional plantation harvesting equipment. The most effective approach was a 'top down' thinning of approximately ten percent of the selected area which gave the greatest return of logs meeting the required specification. We were of the view that, given that this tended to take out most of the dominant 'wolf' trees, there was some possibility that a substantial part of the lost volume may grow back into the plantation before final harvesting for woodchips.

It is vital that harvested logs are transported for processing very quickly to avoid deterioration. It is desirable to apply end-sealant treatment in dry weather. If any delay is expected, end sealant and water sprays would be essential.

5.4 Cant production

We have investigated a number of different methods for cant production but for this application we consider the best method to be either one pass with a four side chipper canter or two passes through a twin log edger. In either case, debarking will increase the value of chipwood offcuts. This approach minimises the uneven release of growth stress.

5.5 Lamellae production

In this approach a modern thin cutting frame saw, which is designed to facilitate green sawing, was used to produce lamellae in one pass. We processed 100 mm × 100 mm cants into approximately 26 lamellae using a saw kerf of 1.5 mm. We have previously investigated the use of veneer slicers to produce lamellae and believe that this is also feasible though the capital cost of suitable equipment is very high. The objective is to minimise sawing loss as far as possible to improve final recovery and this is effectively achieved in this system by the thin cutting saw.

5.6 Drying

This is one of the most difficult aspects of processing this type of resource for conventional sawn boards. We are able to achieve excellent results by using modified welded mesh sheets in place of the traditional wooden stickers. The thin lamellae were dried with weight constraints in a conventional high temperature kiln. Drying from green to 8% moisture content was possible in two hours without any end splitting or significant distortion other than collapse — a major breakthrough in drying costs.

5.7 Recovering collapse

The dried lamellae were treated in a commercial autoclave by the application of superheated steam for less than one hour and achieved excellent collapse recovery.

5.8 Dimensioning

Various means are available for dimensioning the lamellae. We favour the use of a four sided rotary planer to achieve the desired thickness and width. Alternatively we achieved the desired thickness by sanding and desired width by use of a copy shaper. Width will be related to the nature of the final flooring panels to be produced. If the production of single board width panels is favoured then width is not so critical and can be finalised by tongue and grooving in final production. However if wider panels are favoured (we did up to 180 mm, using three pieces) then width and edge finish of individual boards is critical as edge jointing will be necessary to achieve desired panel size.

5.9 Defect docking

Significant length and grade docking will be required depending on what range of flooring panel lengths are to be produced. An automated optimising docking unit for high speed processing of large

volumes of lamellae is recommended.

5.10 Laminating

We prepared a range of panels with bluegum face and backs and cross laminated with a maritime pine core. Panels were produced with bluegum core lamellae. A range of glues were tested with urea formaldehyde producing acceptable results in the bluegum/pine/bluegum panels. However the use of hot melt polyurethane is preferred in gluing bluegum/bluegum/bluegum panels. We considered a range of commercially available laminating plants for the production of panels but most involve substantial capital investment and the most appropriate arrangement will depend on the scale of operation and interworking with the production of other products, such as paper pulp.

5.11 Polishing/Finish

We tried a number of different commercially available lacquer finishes applied through a polish line. We obtained best results through a UV cured lacquer, but end users would need to determine the best solution appropriate to the particular target markets and cost structures applying in each situation.

5.12 Testing

A range of international testing regimes were applied to the manufactured flooring panels which demonstrated that their performance was comparable with most commercially available product of similar type. In addition, test floors were installed in commercial and home situations for in-service assessment. Once again performance was assessed as satisfactory.

5.13 Market evaluation

Preliminary market evaluations were carried out through a commercial display centre and other tests. Initial results indicated the product would have high market acceptance provided it can be supplied at commercially competitive prices.

5.14 VALUFLOR costing model

As part of our work, we developed a software based program to allow for detailed analysis of all costs from the plantation to the market. This model can be used to assess individual applications taking into account all relevant costing information. It can be used to work forward or back to determine viability points from the plantation through to the finished product.

5.15 Conclusion

We have been able to demonstrate that it is technically feasible to produce a high value world standard flooring product from small juvenile eucalypt logs that are not suitable for the production of high value solid wood products using conventional processing technology. This process would probably be

most efficiently adopted in conjunction with a plantation program which supports other products such as woodchips or MDF.

6 SUMMARY

Our processes and technology open up a range of options to forest growers seeking to improve their return on investment in eucalypt plantations by being able to produce a range of products from short rotation plantations without detracting significantly from productive capacity for pulp production. They also provide the basis of addressing processing difficulties for those growers who are seeking to move forward to longer rotations and more traditional sawn wood products as a direct replacement for native forest timbers in furniture, joinery and flooring products. Quality products can be made from juvenile eucalyptus timber if manufacturers have the foresight to invest in the right processes and technology to address inherent characteristics.

7 ACKNOWLEDGEMENTS

This paper contains material which is drawn from the outputs of three major research and development programs:

1) "Out of the Woods", Department of Conservation and Land Management, Perth WA. Research Manager, Mr Phil Shedley. Project investigated the supply of high quality wood for furniture production from commercial thinnings.

2) "Adding Value to Small Eucalypt Logs" Valuwood International Pty Ltd. Perth WA. Research Director-Mr Phil Shedley, Project Manager-Mr Kevin Bentley. Project investigated the use of veneer technology for the production of a range of laminated hardwood products.

3) "The Cost Benefits of Small Log Processing-Laminated Three Ply Flooring-A Case Study in WA". Valuwood International Pty Ltd Perth, WA. Research Director-Mr Phil Shedley, Project Manager-Mr Kevin Bentley. Project investigated the production of three ply-laminated flooring from juvenile plantation grown Tasmanian Bluegums.

Manufacturing of Veneer Based Products From Plantation Grown *Eucalyptus*

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1 INTRODUCTION

Fast growing *Eucalyptus* wood plantations provide a potential raw material source for successful manufacturing of veneer based products. Combining *Eucalyptus* raw material characteristics and correct processing methods together it is possible to produce competitive and profitable end-products.

2 *EUCALYPTUS* RAW MATERIAL CHARACTERISTICS

The characteristics of plantation grown *Eucalyptus* comprise several features different from conventional wood species, to be taken into consideration when planning the production of rotary cut veneer based products. Plantation grown *Eucalyptus* trees are fast growing (Fig. 1), with relatively large log size and additionally *Eucalyptus* has good strength properties. Also eucalyptus wood is hard, stiff and wear resistant. These features makes plantation grown *Eucalyptus* very attractive as a raw material for veneer based product.

Wood properties depend on which *Eucalyptus* species and/or clone is used. Location and soil properties of eucalyptus forests have additional important effects on wood characteristics. Typically, younger trees are better for rotary peeled veneer. Young logs have less growth stress in the tree stem and the density variation is also smaller. This means more stable behaviour in processing, which results in less log end-splitting, veneer splitting and uneven shrinkage of veneer. Due to *Eucalyptus* wood chemical properties the gluing of eucalyptus veneers can be challenging.

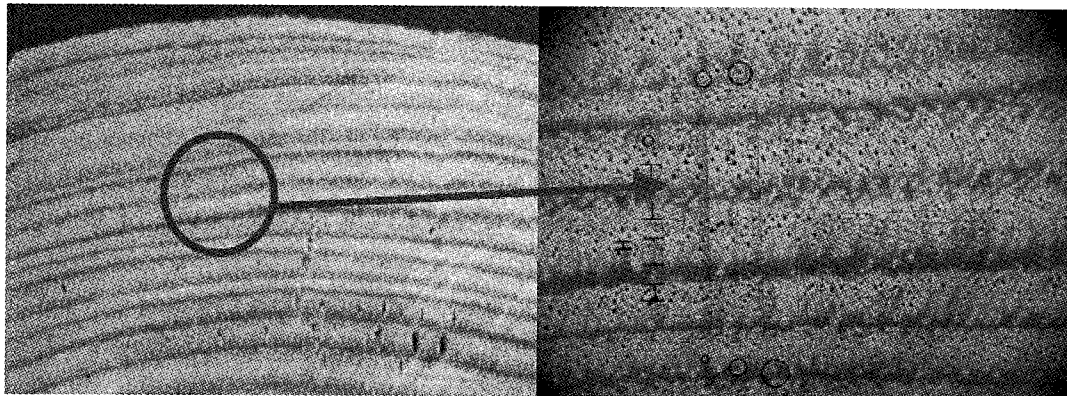


Fig. 1 *Eucalyptus* growth rings

Since there is a great variation of *Eucalyptus* raw material with different characteristics, the raw material source must be carefully studied before utilizing for veneer manufacturing. Testing of raw material is very important before deciding on final panel type. Proper testing will define the variation in characteristics of available eucalyptus raw material (Fig. 2). It should involve all processing steps such as block conditioning, peeling, veneer drying, veneer lay up, glue application hot pressing and product performance.

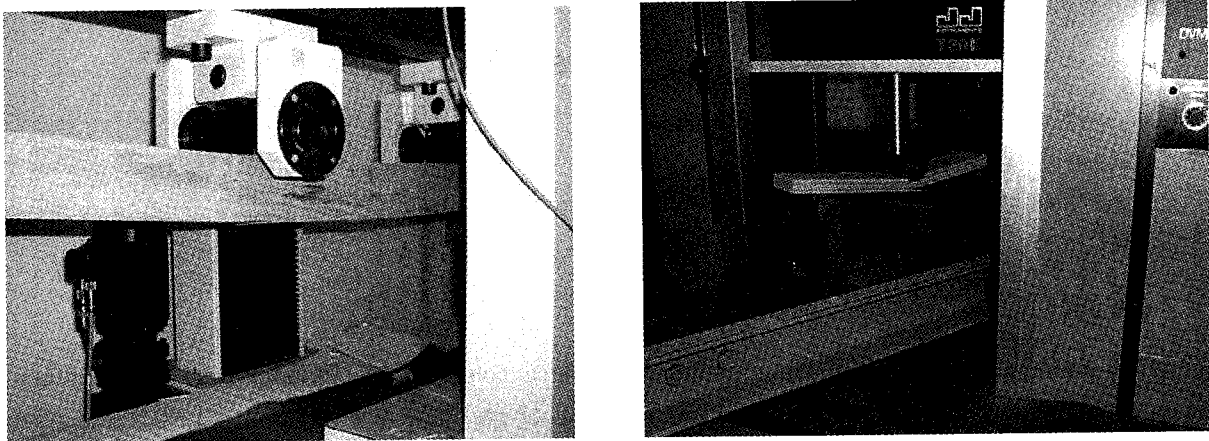


Fig. 2 Bending strength testing of *eucalyptus* LVL and plywood

3 END-PRODUCT APPLICATIONS & MILL CONCEPTS

Due to the high strength, hardness and stiffness of eucalyptus, there are several applications for eucalyptus veneer based products such as Plywood or Laminated Veneer Lumber (LVL). However, there is a need for further development of value added eucalyptus products. *Eucalyptus* veneers can be utilized in new and traditional veneer based products. *Eucalyptus* veneers can also be mixed with other species to improve the properties of various engineered wood products like plywood and LVL. *Eucalyptus* veneers can increase product strength and thus reduce dimensions of products. Panel surface hardness can also be increased.

The production concept shall be chosen based on available raw material and selected end-product. The main concepts are a veneer mill, a plywood mill producing special plywood and a LVL mill. These concepts are the basis for further development to produce value added engineered wood products from eucalyptus.

3.1 Veneer mill

The veneer mill is the first stage in the utilization of eucalyptus. In general, the production range includes face and core veneers for plywood and LVL veneers. Typically the face veneers are thin (1.0 to 1.5 mm), the core veneers are thicker (1.5 to 2.8 mm) and the LVL veneers are the thickest (2.8 to 4.2 mm). Core and LVL veneers also can include veneers to be composed, but composing of veneer sheets is recommended to be carried out at a plywood or LVL mill.

A veneer mill will benefit from a log grading operation, segregating logs based on size and quality, at the log yard but it is even better if supplied logs are already graded. The peeling line should be of high capacity to achieve efficiency, due to the rather low profit margin of veneers. A flexible veneer thickness change and automatic veneer grading will provide a wider range of products.

3.2 Specialty plywood plant

Standard plywood produced from Eucalyptus veneers only, is not a very competitive product in traditional plywood markets. In order to be more economical, Eucalyptus plywood production should also include specialty plywood. *Eucalyptus* logs should be well graded to suit the process and end-products. To maximize the profitable use of produced *Eucalyptus* veneers, the veneer grading operation should be automated. That includes both camera based visual grading and strength grading.

Eucalyptus veneers can be utilized in several different types of plywood. High *eucalyptus* veneer strength contributes to products used in construction, transportation and certain uses in the furniture industry.

Overlaying is one option to add value to plywood products. Proper processing and smaller density variation of veneers provide a good panel surface for overlaying. Overlaying of eucalyptus plywood is possible with several types of overlay materials, depending on properties of eucalyptus species and end-product applications (Fig. 3).

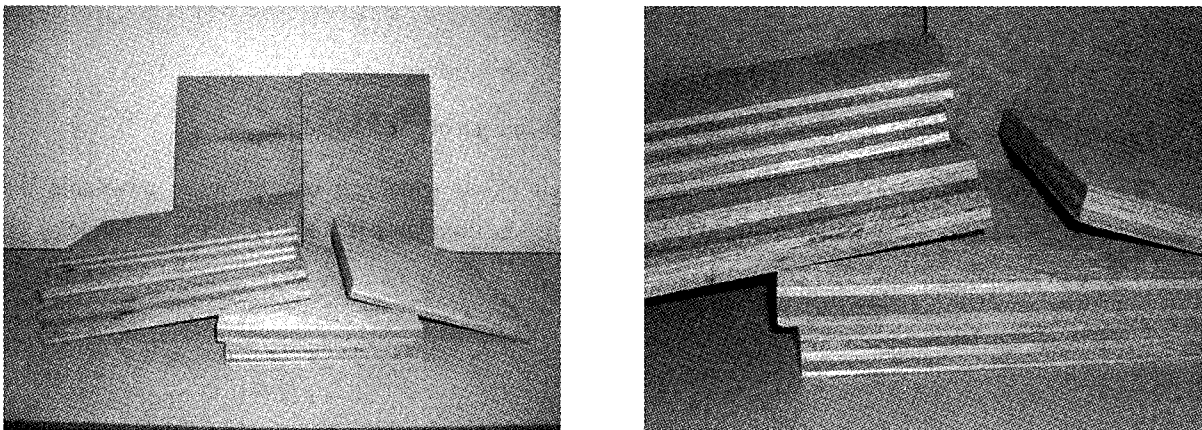


Fig. 3 *Eucalyptus* 4 and 5-ply plywood

Some examples of competitive eucalyptus products are:

- 1) Plywood for concrete forming is one application because of eucalyptus' high strength, stiffness and hardness. This type of plywood panel is already being produced and its hardness provides long time use.
- 2) Flooring panels for containers, ships and trucks are examples where eucalyptus is successfully used because of its strength, stiffness and hardness.
- 3) In the furniture industry, eucalyptus plywood can be used to replace hardwood timber.

3.3 LVL mill

Eucalyptus veneers can be well used both in structural and non-structural LVL. Since eucalyptus alone is quite heavy, mixing with other species, mainly softwood, is common and recommended. LVL products have to pass structural standards of the countries, where the products are used. Our laboratory tests show that edgewise bending Modulus of Rupture (MOR) and Modulus of Elasticity (MOE) values of 15-ply (42 mm) softwood LVL can be increased by 25% to 30% when six softwood veneers are replaced with eucalyptus veneers (Tab. 1, Fig. 4 and Fig. 6).

Tab. 1 Strength increment using eucalyptus veneer sheets in softwood LVL

| 15 -ply softwood LVL (42mm) | Edge wise MOR and MOE |
|--|-----------------------------|
| Including 4 pieces of Eucalyptus veneers | 12%...17% increase of value |
| Including 6 pieces of Eucalyptus veneers | 25%...30% increase of value |

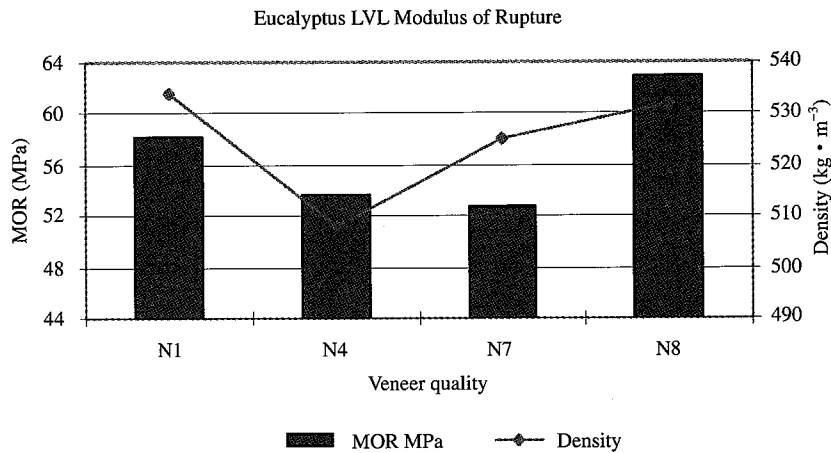


Fig. 4 Effect of veneer grading on the strength of LVL (4 grades)

The production of LVL (Fig. 5) is well established world wide and can be more profitable than production of plywood. In order to ensure competitive production, proper manufacturing technology and relatively high volume production is necessary.

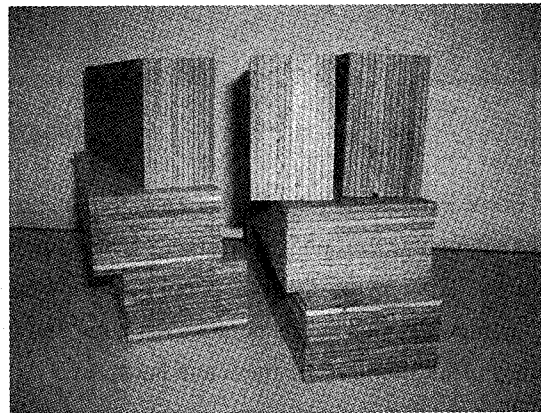
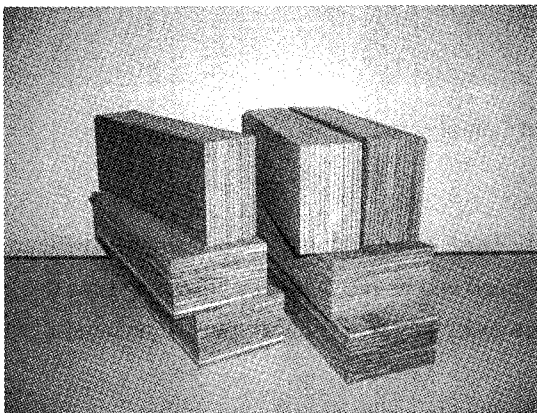


Fig. 5 *Eucalyptus* 13-ply LVL

Typical integrated LVL plants have net production of at least 45,000 m³ per year. Veneer strength grading is an important part of process control for structural LVL products.

The LVL market is still growing because of wide flexibility in LVL dimensions and very consistent strength properties. It is also one of the best wood products when comparing the relationship of production volume and price. LVL has been commercially produced since 1975 and is approved in many countries. Being a relatively new product, compared to other wood products, it requires attractive marketing. However, LVL is not a commodity product and thus needs a different marketing approach.

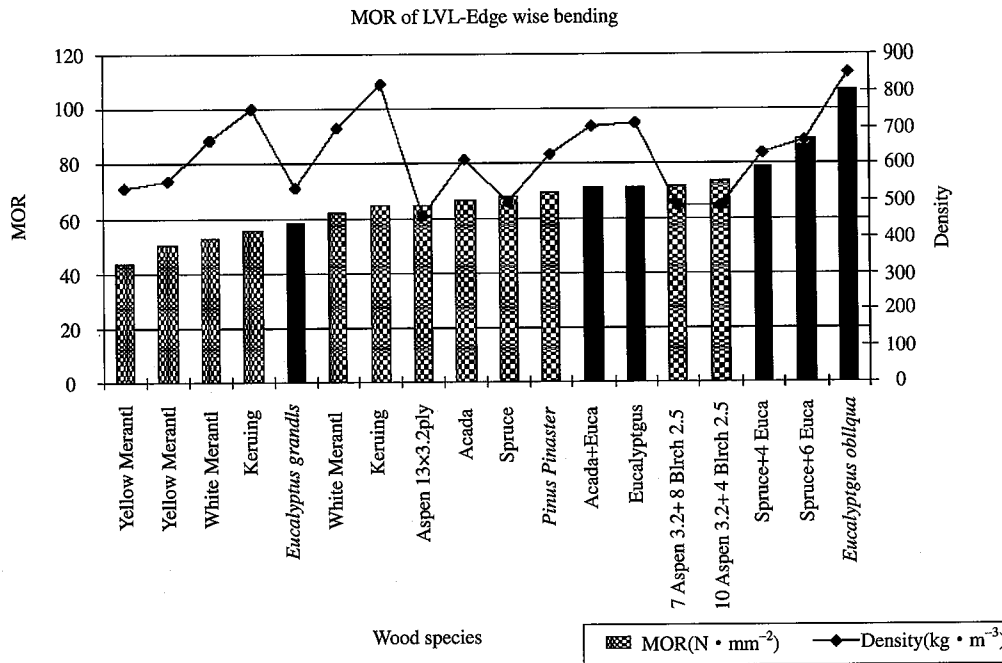


Fig. 6 Edgewise LVL bending strength test results of several wood species

4 PROCESSING OF *EUCALYPTUS*

To achieve high recovery and veneer quality from eucalypts, the raw material must be handled correctly, starting in the forest and continuing through each phase of the production process. Pre-grading of logs will improve production efficiency and veneer grade recovery. Processing and handling of eucalyptus veneer can be demanding and challenging. However, the technology is already available to meet these tough requirements.

Raute Corporation has been involved in several projects utilizing eucalyptus as raw material for different veneer based products. Our wide knowledge of eucalyptus processing is based on long experience and co-operation with our customers in projects including raw material processing tests, feasibility and market studies, technical assistance, management and development plans for production as well as machinery supplies. These projects have demonstrated that plantation grown eucalyptus is a suitable and competitive raw material for manufacturing of veneer based products.

Raute's R&D and pilot production projects included *Eucalyptus* raw materials from countries like Argentina, Australia, Brazil, Chile, Indonesia, Malaysia, Portugal, Spain, and Uruguay. A number of different *Eucalyptus* species have been tested: *E. globulus*, *E. grandis*, *E. obliqua*, *E. pellita*, *E. pilularis*, *E. saligna*, *E. marginata*, *E. diversicolor*, *E. calophylla* and *E. nitens*. Raute has supervised over twenty large-scale raw material tests related to *Eucalyptus* utilization since 1987. We have utilized our wide contacts with educational institutes (technical universities and wood technology polytechnics) and research laboratories in carrying out test trials.

4.1 Log handling and preparation

Proper handling of eucalyptus logs for veneer production must start in the forest when the trees are felled (Fig. 7). Transportation of logs from forest to the mill should happen as soon as possible to avoid

log end splitting caused by growth stress in the tree. The relationship between log length and transportation cost must also be considered. It is recommended to do the log grading already in the forest based on the end products to be manufactured. Log storage time should be as short as possible to avoid drying of log-ends.



Fig. 7 *Eucalyptus* log-ends

Pre-treatment of logs before processing is necessary. Good quality veneer can be produced if logs are conditioned before peeling. Soaking of logs in mild temperature (40 to 50°C) water was found helpful in peeling high quality veneer. Log grading is carried out at the mill's log yard based on end-product and log diameter. The final log cutting into peeling blocks is done after conditioning.

4.2 Peeling

Peeling blocks are scanned with an XY laser scanner and positioned based on optimum diameter by an automatic block charger. High peeling capacity and veneer quality (Fig. 8) can be achieved on a lathe equipped with a roller nose bar, powered back-up rolls and triple spindles. A solid nose bar is a choice only when high quality appearance veneer is needed. The green veneer ribbon is clipped into sheets with a rotary knife clipper to achieve highest accuracy and capacity. The clipped veneer sheets are graded and stacked automatically in different stacks.

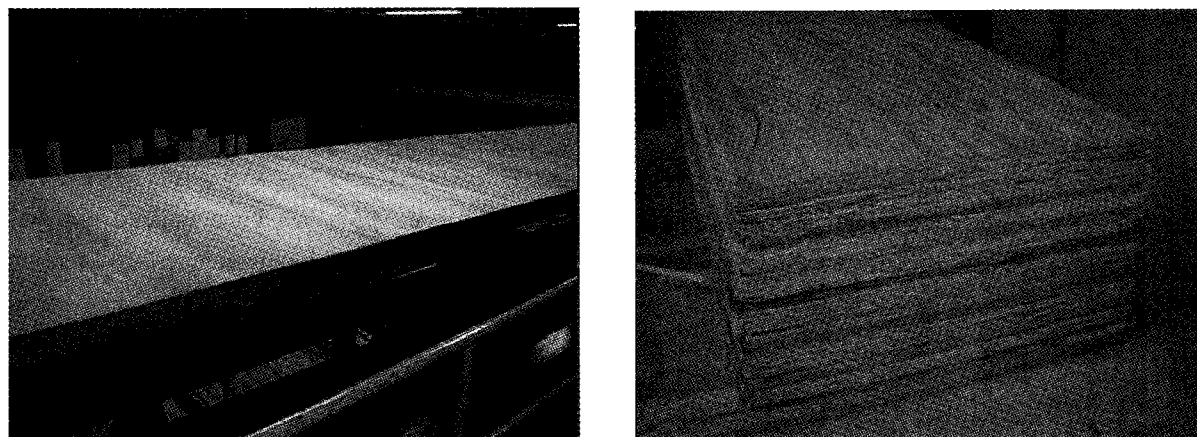


Fig. 8 *Eucalyptus* peeling: green veneer ribbon and a veneer stack

The peeling log centering operation is important. It results in higher peeling recovery and higher volume of full size sheets. Without adequate centering a large volume of random width veneer sheets are produced. This decreases the raw material yield and plant capacity.

The peeled veneer sheets are graded according to plywood or LVL product requirements. The primary target of green veneer grading is to produce stacks of consistent veneer quality for the drying process.

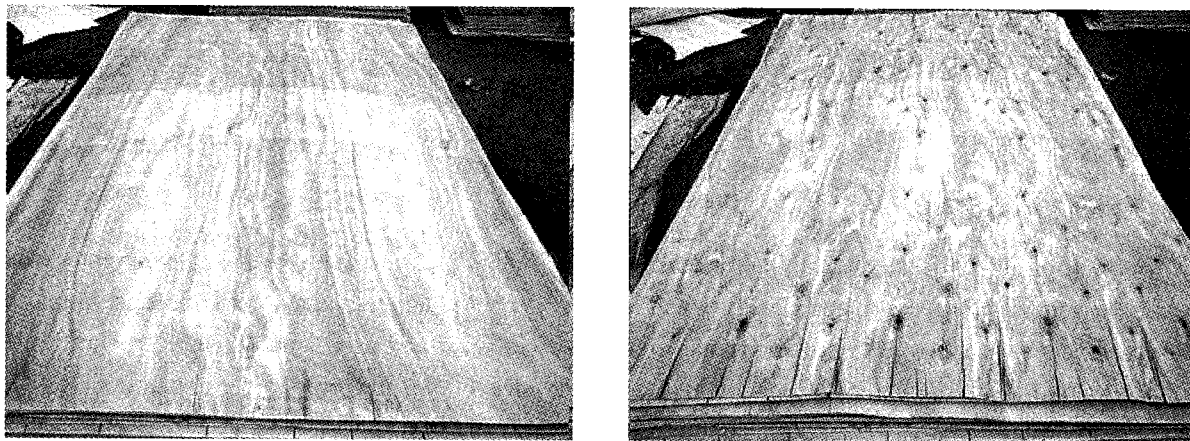


Fig. 9 Clear and knotty eucalyptus veneer

4.3 Veneer drying

To achieve high quality dry veneers the drying process of eucalyptus must be well controlled and medium temperatures should be used. For optimal drying capacity and dry veneer quality green veneers should be separated depending on their Moisture Content (MC).

The tangential shrinkage (on sheet width) of mature eucalyptus can be as high as 12.5% and uneven shrinkage occurs over the veneer sheet, but for some plantation grown eucalyptus species the shrinkage is only 6%. Drying times for eucalyptus are longer than for most other hardwood species. This is due to high wood density and problems with cell collapse, if aggressive drying conditions are used. On the average, the drying time of eucalyptus veneer is 30% to 50% longer than for other hardwoods. The high air humidity in dryer and rather low temperatures results in a high yield and quality of dry veneer. It means less splits and waves and more even final moisture content in veneers.

Over-drying of veneers should be avoided because it decreases the strength and the gluing properties of eucalyptus veneers. Using higher moisture content veneers is an option to avoid possible splitting of dried veneers, but it affects the capacity and parameters in further processing.

After drying, the veneers are graded to achieve their most efficient and economical utilization. The moisture content, visual grade and veneer strength can be measured using a Raute moisture meter, camera based Mecano VDA and Metriquard strength tester.

4.4 Lay-up and gluing

Proper processing and Quality Control in dry veneer production will result in good quality flat veneers. A flat veneer with limited end splits is required for automatic plywood and LVL lay-up lines.

Chemical properties of eucalyptus veneer and the end product applications have to be considered when

selecting the glue mixture. There are two common adhesives used for veneer gluing, Phenol Formaldehyde (PF) and Urea Formaldehyde (UF). PF is a structural adhesive used for external applications and UF can be used for internal applications only. Both adhesives are of the thermo-setting type and require hot pressing for curing. When properly formulated they can both be used with a plantation eucalyptus veneer. A relatively new economical PF foam glue application method can also be used. Good glue bonding that passes all required tests is possible to achieve with the correct glue mixture and gluing conditions.

Eucalyptus veneers can also be successfully glued with other softwood and hardwood species. Young plantation grown eucalyptus species containing less extractives are, in general, easier to process and bond with standard adhesive.

4.5 Hot pressing

Because of higher density, eucalyptus requires slightly higher pressure in hot pressing than lighter wood species. In general however, its other pressing parameters like hot platen temperature and time are similar to other hardwoods. When correct pressing parameters are established and used, good quality product can be produced (Fig. 10). Production capacity depends on the size of the hot press. A compression loss for eucalyptus is similar to hardwood species of the same density.

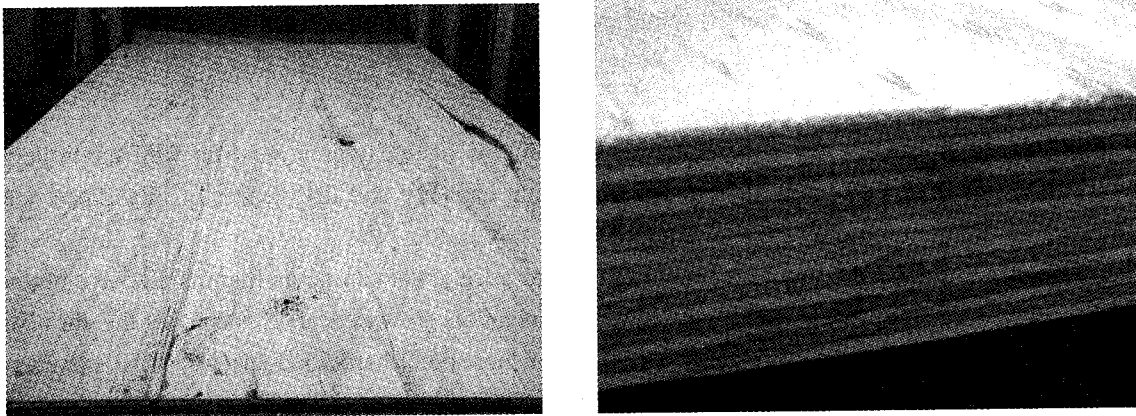


Fig. 10 Hot pressed eucalyptus LVL

5 CONCLUSIONS

1) The plantation eucalyptus species are suitable raw material for producing rotary cut veneer based products.

2) Processing of plantation eucalyptus requires attention to process and careful quality control. It is possible to develop competitive products and suitable technology is available to successfully convert eucalyptus logs into veneer based products.

3) Old-fashioned production practices should not be considered for economical long term utilization of plantation grown eucalyptus.

4) Operations based on low cost logs and a labour intensive process may not be competitive in the long run.

5) The price of eucalyptus logs will increase and the number of competitors will increase with the result that only manufacturers using modern production technology and strategies will survive.

Dyeing Tests of Timor Mountain Gum Veneers for Imitating Black Walnut

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ABSTRACT

A simplified working process was tested to dye Timor mountain gum veneers to imitate black walnut wood. The results showed that unbleached Timor mountain gum veneers of 0.65 mm thickness could be dyed in 40 minutes to imitate the colour of Black Walnut by combining dyeing solution with the permeate agent WX₁. The dyeing solution could be used twice and its total concentration was only 0.3%. The treated veneers were macroscopically similar to black walnut and could be used to make veneers to imitate Black Walnut wood.

1 INTRODUCTION

Eucalyptus, of which most species have originated from Australia have been introduced to more than 120 nations and regions. There are more than 20 of these species which have been adopted worldwide into fast-growing plantations. The fast growth of *Eucalyptus* trees has made them one of the most important plantation resources of industrial raw material. *Eucalyptus*, whose wood could be used to make pulp and produce paper, fiberboard, plywood and solid wood furniture, is the dominant tree genus now being planted in South China. Furthermore, Timor Mountain Gum (*Eucalyptus urophylla*) (TMG) and its hybrids is perhaps the most widely planted eucalypt in South China. The growth stress and drying stress of TMG are both relatively large, so it has many disadvantages, such as brittle heart, and end-splittling. In addition, it is difficult to be sawn, glued and coated. As a fast growing quality species, its favourable factors have not been fully exploited, since it is mainly grown for fuel, lightweight poles and for chips. It is absolutely urgent that we should develop our research effort to improve the utilization of *Eucalyptus*, including how to make products through improved general wood processing techniques and also how to improve efficiency for the manufacture of high added value products.

Today, the state-of-art technology for the processing of low quality veneer to imitate high value veneer requires the following processing stages: veneer (peeled or sliced) → bleaching → cleaning → dyeing (normal pressure or high pressure) → cleaning → drying → adjusting → squared timber → sliced or saw cutting → stained veneer. The authors believe that this processing procedure is overly complicated, expensive to apply and only too readily destroys veneer. At the same time, it produces large quantities of waste water, and leads to environmental downgrade. In this paper, a new dyeing technology using Timor Mountain Gum to imitate Black Walnut will be discussed.

2 MATERIALS AND METHODS

2.1 Materials

Six-year-old plantation-grown Timor Mountain Gum (*Eucalyptus urophylla* S.T.Blake), was obtained from the Forest Bureau of Yangjiang, Guangdong. Tree diameter was 17-20cm. From this resource, sliced veneer samples of dimension: length × width × thickness = 200 mm × 100 mm × 0.6 mm were prepared and dried to a final moisture content of (12±0.2)%.

The dye solution used was: acid black 10B, acid orange II; permeate agent WX₁, approximate 650 RMB/T.

2.2 Technology

The processing stages to be followed in this trial are summarised as follows:

Veneer (sliced) → dyeing (normal pressure, 85-90°C) → cleaning → drying → stained veneer

2.3 Procedure

Nine different drying test runs were carried out, based on treatments shown in Tab. 1, with six veneers treated in each test. The dyeing procedure adopted was to compound the acid orange solution II (0.1‰), and add acid black 10B and permeate agent WX₁ into the solution based on Tab. 1. Following the technology mentioned above, the test was commenced with the orthogonal table L₉(3⁴) according to test factors and selected treatment level. Six veneers were treated in parallel in each test, so 54 veneers were treated overall. Following treatment, the six veneers were divided into two groups, 3 veneers in each group. One group was air dried to a moisture content of (14±0.2)% at room-temperature, the other group was oven dried to the same moisture content but at a temperature of 105°C. Following drying, three points on each veneer were selected at random by a WSC-S colour meter according to CIE1976 (L*, a*, b*). The average (L*, a*, b*) was recorded for each group of three veneers. The, lightness index and chrominance index (ΔL*, Δa*, Δb*) were then calculated for the treated samples. This information was used to calculate the chromatic aberration ΔE of the samples as per the following formula (Tab. 2), and analyse the range (Tab.3) and color saturation ΔC*.

$$\Delta E = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{0.5};$$

$$\Delta C^* = C^*_{Dry} - C^*_g$$

Tab. 1 Factors and levels of orthogonal experiment

| Levels | V _{liquid} /V _{wood} (double) | Time (min) | Permeate agent concentration (‰) | Acid black 10B concentration (‰) |
|--------|---|------------|----------------------------------|----------------------------------|
| 1 | 2 | 20 | 5 | 0.1 |
| 2 | 4 | 40 | 10 | 0.2 |
| 3 | 6 | 60 | 15 | 0.3 |

Tab. 2 Experimental results

| | Permeate agent concentration (A/%) | Time (B/min) | $V_{\text{liquid}}/V_{\text{wood}}$ (C/double) | Acid black 10B concentration (D/%) | Air dried /untreated Veneer ($\Delta E_1/\text{NBS}$) | Oven dried / untreated Veneer ($\Delta E_2/\text{NBS}$) | Air dried/ oven dried Veneer ($\Delta E_3/\text{NBS}$) | Permeate result |
|---|------------------------------------|--------------|--|------------------------------------|---|---|--|-----------------|
| 1 | 5 | 20 | 2 | 0.1 | 7.15 | 6.37 | 1.61 | NO |
| 2 | 10 | 40 | 2 | 0.2 | 8.23 | 6.90 | 0.61 | OK |
| 3 | 15 | 60 | 2 | 0.3 | 8.94 | 7.38 | 5.34 | OK |
| 4 | 10 | 20 | 4 | 0.3 | 3.65 | 2.33 | 1.69 | NO |
| 5 | 15 | 40 | 4 | 0.1 | 3.98 | 2.69 | 1.79 | OK |
| 6 | 5 | 60 | 4 | 0.2 | 3.79 | 2.51 | 0.92 | OK |
| 7 | 15 | 20 | 6 | 0.2 | 7.98 | 6.01 | 3.67 | NO |
| 8 | 5 | 40 | 6 | 0.3 | 8.67 | 7.23 | 3.28 | OK |
| 9 | 10 | 60 | 6 | 0.1 | 9.38 | 8.02 | 5.72 | OK |

Note: Black Walnut Wood Color: $L^* = 40.61$, $a^* = 8.75$, $b^* = 11.95$.

Tab. 3 Difference analysis of orthogonal test

| Color aberration | Levels | A | B | C | D |
|------------------|------------------|---------------|------|------|------|
| ΔE_1 | 1 | 8.11 | 6.26 | 6.54 | 6.84 |
| | 2 | 3.81 | 6.96 | 7.09 | 6.67 |
| | 3 | 8.68 | 7.37 | 6.97 | 7.09 |
| | Difference R_j | 6.11 | 1.21 | 0.65 | 0.45 |
| | Principal degree | A > B > C > D | | | |
| ΔE_2 | 1 | 6.88 | 4.90 | 5.37 | 5.69 |
| | 2 | 2.51 | 5.61 | 5.75 | 5.14 |
| | 3 | 7.09 | 5.97 | 5.36 | 5.65 |
| | Difference R_j | 5.97 | 1.18 | 0.51 | 0.71 |
| | Principal degree | A > B > D > C | | | |
| ΔE_3 | 1 | 2.52 | 2.32 | 1.94 | 3.04 |
| | 2 | 1.47 | 1.89 | 2.67 | 1.73 |
| | 3 | 4.22 | 3.99 | 3.60 | 3.44 |
| | Difference R_j | 2.97 | 2.51 | 1.73 | 2.01 |
| | Principal degree | A > B > D > C | | | |

3 RESULTS AND DISCUSSION

Some of the differences in treatment outcome are reflected in the test. Tab. 3 shows the different influence of the four principal factors in the test results of Eucalyptus veneer dyeing. The higher the range value is, the greater is the influence reflected by the performance index of the factors to its horizontal variation shown in the Table. The order of technological factors influencing the dyeing results could be obviously shown through Range analysis.

3.1 $V_{\text{liquid}}/V_{\text{wood}}$ and dyeing results

Column C in Tab. 3 shows that the value of chromatism increased followed the increase of $V_{\text{liquid}}/V_{\text{wood}}$. This is because by increasing $V_{\text{liquid}}/V_{\text{wood}}$, the total dyeing amount was increased, The higher concentration

increased the probability of dye molecular contact with the veneer, which increased the speed of dyeing, therefore increasing the value of chromatism. On the other hand, the $V_{\text{liquid}}/V_{\text{wood}}$ weakly influenced chromatic aberration because the mixture of dye is different from that of pigment. Some reaction will generally happen between different dyes, while not happening between different pigments. The new triturerated penetrant has the function of activating acid black 10B and acid orange II. All of these factors promoted wood dyeing going forward, which is what we expected.

3.2 Transfer time and dyeing results

Column B in Tab. 3 also shows that the color of the sample approached black as the dyeing time was increased. It is because the process of veneer dyeing involves the dye molecules which are permeating the veneer and absorbed by the veneer at the same time. Absorption first happens in the veneer surface and then diffuses to the inner wood through any spaces in the wood structure, such as in vessels, the cell lumen, cell wall pits and intercellular spaces, and penetrates into the inner wood in the veneer sheet through the cell wall microcapillary system, and finally into the cell wall structure. That is to say, the transfer time notably contributes to chromatic aberration. Therefore, the coloration is allowed to develop more fully if the time is extended. The transfer time is one of the important factors during the wood dyeing and has a direct relationship with the thickness of sample being dyed. It defines the expenditure of processing time, the duration of the production cycle and production efficiency, so directly contributes to production costs. Therefore, with the constraint of quality assurance, it is preferred that the transfer time should be kept to a minimum.

3.3 Use level of penetrant and results of dyeing

The wood dyeing process relates to wood quality, dye quality, dye permeation in wood, adhesion of dye to wood fibres and the bonding of the dying agent with the wood cellular structure. Among which, dye permeation in wood is presupposed, and adhesion and the bonding of the dye and wood is the ultimate aim. The permeation requirement of the dye in wood relates to depth of penetration as well as the distribution of dye. Tab. 3 tells us that WX_1 could not only promote wood surface energy and activate the dye permeation in wood, but also activate acid black 10B or even strengthen the function of it. The optimal level of WX_1 is required to achieve best penetration and distribution of the dye. In productive practice, veneers stained by acid dye are unstable when they meet heat, so they often fade or even return to the original colour on exposure to heat. However, tests have shown that when these stained Eucalyptus veneers meet heat, they do not fade, moreover, the colour becomes deeper and darker. This shows that WX_1 could improve the heat stability of acid black 10B and acid orange II.

3.4 Concentrations of acid black 10B and results of dyeing

Some of the results are shown in column D in Tab. 3. When the concentration of acid black 10B was 0.1‰ and 0.3‰, ΔE_1 was 6.84 and 7.09, ΔE_2 was 5.69 and 5.65. When the concentration was 0.2‰, ΔE_1 was 6.67, ΔE_2 was 5.14. We know that dye quality grade becomes higher when more acid black 10B is added, which leads to a different level and effect of dye movement in the wood. Therefore, the concentration of acid black 10B has to be optimised, to achieve maximum benefit of dye speed colour and

production cost.

3.5 Optimized test

Considering the limitation of test conditions and the scope of the test, we were successful in optimizing the dyeing technology of Eucalyptus to imitate Black Walnut according to the results of Tab. 3. This required the following production procedure: *A* (concentrate of permeate agent) at 10%, *B* (time) of 40 minutes, *C* ($V_{\text{liquid}}/V_{\text{wood}}$) of 4 times, and *D* (concentration of acid black 10B) at 0.2‰. We directly proof-tested the dyestuff and penetrant WX_1 before using in this trial to ensure we were using an environmentally-friendly product. It was also found that, the difference in dyeing speed between earlywood and latewood gave the veneer a clear texture after dyeing, and a distinctive texture which can meet the requirements for imitating black walnut as an overlaying material.

4 CONCLUSIONS

With the new permeate agent WX_1 , the optimum condition from the test was found to be as follows:

- 1) time - 40min.
- 2) $V_{\text{liquid}}/V_{\text{wood}}$ of 4 times.
- 3) concentration of permeate agent at 10%.
- 4) concentration of acid black 10B at 0.2‰.

The results indicate that, without bleaching, Eucalyptus veneer (0.65 mm) could be directly stained to imitate the colour of black walnut with the addition of permeate agent WX_1 . The time taken for this process is only 40 minutes. The total concentration of dyestuff is less than 0.3‰. Furthermore, the dyestuff can be used continuously for three treatments. The texture of the *Eucalyptus* veneer was clear after dyeing, so it can be directly used to imitate Black Walnut as overlaying veneer.

REFERENCES

- Chen Y H, Lu R S, zheng R X, *et al.* 2002. Study on the Process of Paulownia Veneer Dyeing. Journal of Northeast Forestry University, 30(1):10-12
- Deng S P, Hu S Y, Huang B Z, *et al.* 1998. Study on Dyeing Technique of Decorative Veneer. Journal of Fujian College of Forestry, 18(2):114-116
- Sun F L, Duan X F, Feng D J. 2003. General Research and Tendency of Wood dyeing. Journal of Northwest Forestry University, 18(3):96-98
- Wang X M, Jiang Z H, Fei B H. 2003. Study on Some Problems in the Processing of Eucalypt Plantation Wood. World Forestry Research, 16(3):62-64
- Yin Y F, Jiang X M, LU J X, *et al.* 2001. Status of Resources and Wood Utilization of Eucalyptus Plantation in China. China Wood Industry, 15(5):3-5

Study on the Processing of Finger-jointed Lumber

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ABSTRACT

Finger-joints from four species of Eucalyptus, *E. citriodora*, *E. exserta*, *E. urophylla* × *E. grandis*, *E. grandis*, were prepared by using two kinds of adhesive, PVAc and API, to determine optimum processing conditions. The effect on performance of finger-joints using different density samples, different combination methods, different finger profiles and different finger types, was analyzed. The results have shown that there were some differences in finger-joints MOR by using different kinds of adhesive, and the MOR of finger-joints with API was higher than that of PVAc. The difference between fingertip and root(ΔT) also played an important role in the performance of finger-joints, the MOR of the finger-joints was highest when the ΔT was 0.1 mm when tested with ΔT of 0, 0.1 and 0.5mm. End pressure also affected the MOR of finger-joints; when the ΔT was 0.1, the optimum end pressure were 10 kN, for *E. citriodora*, *E. exserta*, *E. grandis* × *E. urophylla*, and 11.5 kN for *E. grandis* wood. MOR and MOE of finger-joints with different finger type V was almost equal with type H.

1 INTRODUCTION

Finger-joints are commonly used to produce wood products from short pieces of lumber. Such joints must have excellent mechanical performance. To produce acceptable products, a jointer must be subjected to a proper end pressure following machining and adhesive application; also technical parameters, such as machining and gluing processes must be optimized. The condition of finger geometry and end pressure play a major role in the gluing process and the final strength of the assembly.

The main function of the end pressure is to bring the mating surfaces so close together that the glue forms a thin and continuous film between them. This pressure allows a uniform distribution of the adhesive and creates an optimum glue-line thickness. Therefore, it is necessary to control the glue-line thickness to produce strong joints. A thin glue-line leads to starved joints. If the glue-line is thicker than optimal, stress concentration develops in the adhesive layer due to shrinkage during curing. Pressure must be applied to force fingers together to form an interlocking connection, giving a certain immediate handling strength. The increase of the end pressure up to a certain point gives a better contact of the fingers to obtain strong joints. However, cell damage or splitting of the finger root can be induced by excessive pressure.

Finger-joint geometry has been proven to be the most critical variable determining joint strength. Finger-tips constitute a series of butt joints and are accorded zero strength even if they are tight and apparently well bonded; the tip width is the geometric parameter that most significantly influences finger-joint strength.

CORRESPONDING AUTHOR

The objective of the study was to investigate the effect of finger profile geometry and end pressure on the performance of finger-joints in four species of Eucalyptus. The study also planned to evaluate which combination of end pressures and finger profile geometry would result in optimum finger-joint performance in each of the four Eucalyptus species.

2 MATERIALS AND METHODS

2.1 Material

Four species of Eucalyptus, *E. citriodora*, *E. exserta*, *E. urophylla* × *grandis* and *E. grandis* were selected to provide research material for this study. This material came from the Guangxi Zhuang autonomy region, age 10 to 30 years, and with a breast high diameter of above 20 cm.

After the lumber had been dried, the density and moisture content were measured and summarised in Tab. 1.

Tab. 1 Density and MC of the samples

| Species | Density($\text{g} \cdot \text{cm}^{-3}$) | MC(%) |
|--|--|-------|
| <i>E. citriodora</i> | 0.943 | 9.80 |
| <i>E. exserta</i> | 1.014 | 11.48 |
| <i>E. grandis</i> × <i>E.urophylla</i> | 0.675 | 9.52 |
| <i>E. grandis</i> | 0.609 | 9.43 |

2.1.1 Preparation of wood samples

The experiments were carried-out on samples which were machined and crosscut to dimensions of 20 mm × 60 mm × 520 mm. A total of 90 samples were prepared for each species; then the 90 wood blocks for each species were segregated into three equal groups based on density differences. The results of the density segregation are shown in Tab. 2.

Tab. 2 Average densities of groups segregated by density

| Species | Average of high density(g/cm^3) | Average of medium density(g/cm^3) | Average of low density(g/cm^3) |
|--------------------------------------|---|---|--|
| <i>E. citriodora</i> | 1.044 | 1.015 | 0.983 |
| <i>E. exserta</i> | 1.031 | 0.942 | 0.857 |
| <i>E. urophylla</i> × <i>grandis</i> | 0.713 | 0.670 | 0.641 |
| <i>E. grandis</i> | 0.672 | 0.599 | 0.557 |

2.1.2 Adhesive for the finger-jointing

Two kinds of adhesive, API and PVAc, were used in the experiments. API is a two-part adhesive, and is made of main reagent and cured reagent, with a mixing ratio is 100 : 15 carried out when the adhesive was used. The technical index of the two kinds of adhesives is provided in Tab. 3.

Tab. 3 Technical information of adhesives

| Adhesives | Type | Colour | Solid (%) | pH | Viscosity (cps, 25°C) |
|-----------|----------------|----------------|-----------|-----|-----------------------|
| PVAc | BT-09 | White emulsion | 25.7 | 4.4 | 8,740 |
| API | DYNOLINK-8000G | White emulsion | 63.8 | 6.6 | 6,750 |

2.2 Method of Experiment

The geometry of the finger (ΔT), feed speed, the amount of adhesive spreading and end pressure, were all important factors to be investigated in the finger-joints experiments.

2.2.1 Cutting of Finger Profiles

Three kinds of finger geometry were studied to determine finger parameters for optimum finger-joint strength. They were selected based on specifications in standards and data from the literature. The finger-jointing machines used a carriage clamp to secure the stacks of wood samples, then the samples were guided through a circular saw and a finger profile cutter. The ends of pieces to be jointed were first trimmed and squared cleanly by the circular saw before the profile was cut. Suction completely removed all shavings from the profiled surfaces. Finger profiles were processed as vertical orientation joints for subsequent test evaluation. The parameters of the three kinds of finger were as Tab. 4.

Tab. 4 Parameters of the fingers

| ΔT (mm) | Length (mm) | Tip width(mm) | Pitch(mm) | Slope |
|-----------------|-------------|---------------|-----------|-------|
| 0 | 11 | 0.6 | 3.8 | 1/8 |
| 0.1 | 10.6 | 0.7 | 3.8 | 1/8 |
| 0.5 | 8.9 | 1.1 | 3.8 | 1/8 |

2.2.2 Feed Speed

In the process of making finger samples, the feed speed was important regarding its effect on the roughness of the surface of the finger. In this experiment, because different Eucalyptus wood had different densities, the feed speed for *E. citriodora* and *E. exserta* wood samples was chosen as 5 mm/min and the feed speed for the *E. grandis* × *urophylla* and the *E. grandis* samples was chosen as 10 mm · min⁻¹.

2.2.3 Finger joint lay-up end pressure

End pressure is needed to ensure the closest possible contact between the finger surfaces to be glued, and for the adhesive to form a thin continuous layer uniform in thickness, without damage to the strength of the wood. It is also intended to force the fingers together to the degree that a locking action is obtained, giving a certain immediate handing strength after gluing. Since the higher the pressure the more efficient the locking action, as much pressure as the wood can withstand may be used without causing damage such as splitting at the finger roots, compression failure of the wood, and squeezing out of the glue.

In the experiment, a preliminary end pressure experiment was done to find the suitable range of pressures.

Firstly, four pieces of wood block were selected from the three density groups (high, middle, low) and then fingers were cut; ΔT values of the fingers were 0, 0.1 mm, 0.5 mm and the samples were cut to 60 mm length. PVAc was used as adhesive in the experiment with the spread amount $250 \text{ g} \cdot \text{m}^{-2}$. Two samples were combined and laid under the loading machine to be pressured as in Fig. 1. The loading speed was $2 \text{ mm} \cdot \text{min}^{-1}$.

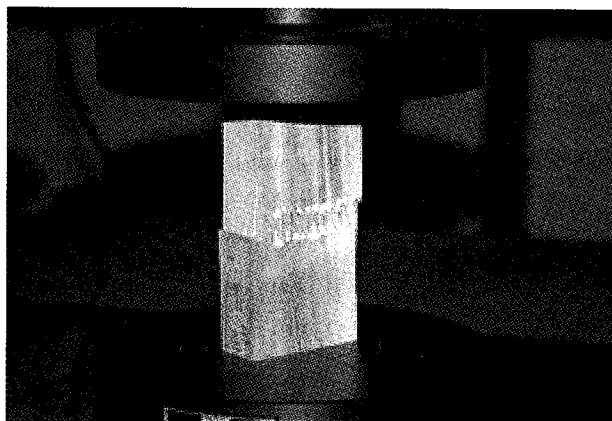


Fig. 1 The method of measuring end-pressure

2.2.4 Processing of finger-jointed specimen

After the sample fingers had been cut, the samples were jointed by the finger jointer machine and 54 samples were selected from the group. The six kinds of sample were arranged as HH, HM, HL, MM, ML, LL on the basis of density (high, medium and low). ΔT values were 0, 0.1 mm, 0.5 mm, and the end pressure as determined by the preliminary end pressure experiment was used.

Following assembly, the finger-jointed specimens were cured over a 48 hours period before further processing. No pressure was applied to the specimens during curing. Both faces of a specimen were machined to a final specimen dimension of 58 by 17.5 mm. The bending test was done by using the loading machine to measure MOE and MOR as shown in Fig. 2 according to JAS MAFF, Notification NO.590; the support span was 420 mm; the loading span was 140 mm and loading speed was $2 \text{ mm} \cdot \text{min}^{-1}$.

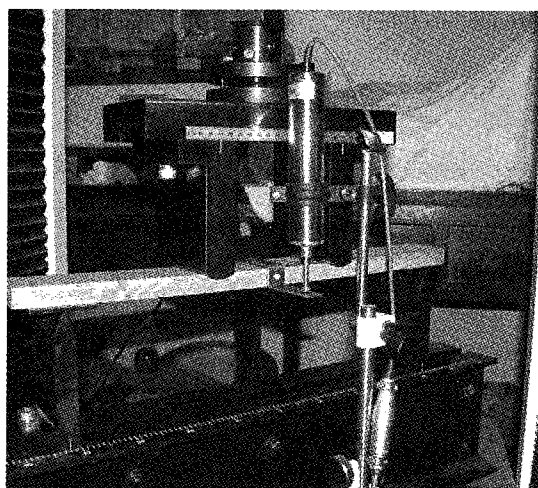


Fig. 2 Four-point bending test

Because many factors affected the strength of finger-jointed lumber, there was a need to control some

of the variables so that the effect of the end pressure and ΔT could be explored more thoroughly in this project. The design method using a full factor experiment and using SAS statistical software was used to analyse results and to discuss the effect on the performance of finger-jointed lumber by each factor and the interaction effect between the end pressure and ΔT . Finally integrative evaluation was adopted using SAS analysis and with the appearance of finger-jointed samples used to find the optimum processing condition.

2.2.5 Finger-jointed samples in different types of finger and different kinds of adhesive

In the experiment, API (DYNOLNK-8000G) was used to make finger-jointed samples. Bending tests were performed according to JAS MAFF, Notification NO.590; then MOE and MOR of finger-joints were compared for the different kinds of adhesive.

To compare the difference of MOR and MOE between V-type fingers (Fig. 3) and H-type fingers (Fig. 4), in the experiment, the H finger, ΔT was 0.1 mm.



Fig. 3 V-type finger-joint

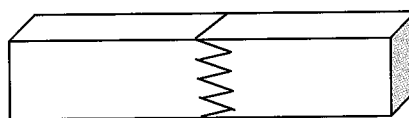


Fig. 4 H-type finger-joint

3 RESULT AND DISCUSSION

3.1 End Pressure

Fig. 5 is the typical Load-displacement curve, in this case for ΔT of 0.5. When the load head began to push the upper piece of wood used to make up the finger joint, this piece began to move, the finger-tips quickly touched the second piece making up the joint, so when loading reached F1, it was considered the finger-tips were locked together, with the two pieces tightly jointed. When the loading approached F2, it was considered the finger-tips had been damaged, when the loading reached F3, splitting occurred at the finger root and in the following stage it acted the same as solid wood under pressure, with the solid wood beginning to fail when the loading was increased to F4.

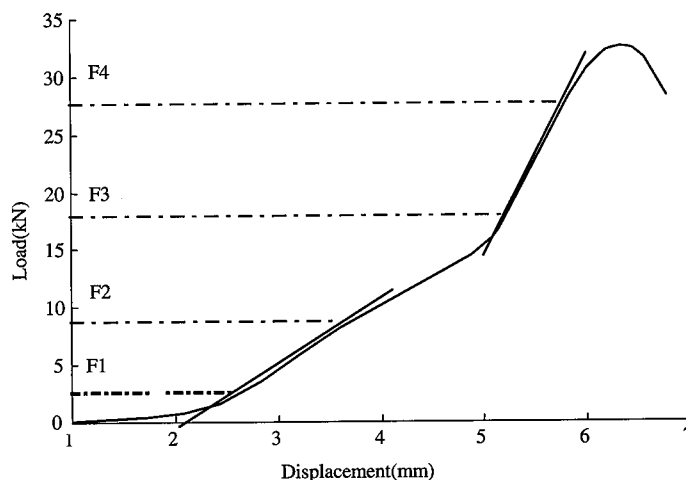


Fig. 5 Load-displacement curve

In the experiment, F1 was judged as being the pressure which could be applied before which the finger showed the first sign of damage. Tab. 5 shows the results of end pressures at F1 for different values of ΔT .

Tab. 5 End-pressure at different conditions

| Wood species | ΔT | Average pressure (MPa) | Wood species | ΔT | Average pressure(MPa) |
|------------------------|------------|------------------------|---|------------|-----------------------|
| <i>E. exserta</i> | 0 | 10.38 | <i>E. urophylla</i> × <i>E. grandis</i> | 0 | 9.82 |
| | 0.1 | 13.20 | | 0.1 | 13.72 |
| | 0.5 | 8.60 | | 0.5 | 5.74 |
| <i>E. citriodora</i> , | 0 | 11.52 | <i>E. grandis</i> | 0 | 11.46 |
| | 0.1 | 13.06 | | 0.1 | 14.63 |
| | 0.5 | 7.57 | | 0.5 | 5.35 |

3.2 Bending test

In the experiments, loading end-pressures for the four Eucalyptus species were selected from Tab. 6.

Tab. 6 Different levels of end-pressure for the four Eucalypt species

| Wood Species | Three end pressures(kN) | | | Wood Species | Three end pressures(kN) | | |
|----------------------|-------------------------|----|------|---|-------------------------|------|------|
| | P1 | P2 | P3 | | P1 | P2 | P3 |
| <i>E. exserta</i> | 8 | 10 | 12 | <i>E. urophylla</i> × <i>E. grandis</i> | 7.5 | 10 | 12.5 |
| <i>E. citriodora</i> | 8.5 | 10 | 11.5 | <i>E. grandis</i> | 9 | 11.5 | 13.5 |

Tab. 7 and Tab. 8 show the results of the bending test analysis of *E. citriodora*.

Tab. 7 MOE and MOR statistical analysis using SAS

| Index | Resource of variance | Degree of freedom | Summation of square | Average of square | F | $P_r > F$ | Significance |
|-----------|-------------------------------------|-------------------|---------------------|-------------------|------|-----------|--------------|
| MOE | Matrix | 29 | 245.494 | 8.466 | 1.32 | 0.2684 | / |
| | Combination of density | 5 | 90.635 | 18.127 | 2.82 | 0.0454 | ** |
| | End pressure | 2 | 26.903 | 13.451 | 2.09 | 0.1508 | / |
| | ΔT | 2 | 61.756 | 30.878 | 4.81 | 0.0205 | ** |
| | End pressure × ΔT | 4 | 7.207 | 1.802 | 0.28 | 0.8870 | / |
| | Combination of density × pressure | 8 | 35.947 | 4.493 | 0.70 | 0.6884 | / |
| | Combination of density × ΔT | 8 | 23.046 | 2.88 | 0.45 | 0.8766 | / |
| | Error | 19 | 122.071 | 6.425 | | | |
| Summation | 48 | 367.565 | | | | | |
| MOR | Matrix | 29 | 1495.705 | 51.576 | 1.88 | 0.0777 | * |
| | Combination of density | 5 | 336.462 | 67.292 | 2.45 | 0.0713 | * |
| | End pressure | 2 | 275.845 | 137.922 | 5.02 | 0.0178 | ** |
| | ΔT | 2 | 258.776 | 129.388 | 4.71 | 0.0218 | ** |
| | End pressure × ΔT | 4 | 255.952 | 63.988 | 2.33 | 0.0932 | * |
| | Combination of density × pressure | 8 | 216.694 | 27.087 | 0.99 | 0.4768 | / |
| | Combination of density × ΔT | 8 | 151.976 | 18.997 | 0.69 | 0.6947 | / |
| | Error | 19 | 522.146 | 27.481 | | | |
| Summation | 48 | 2017.851 | | | | | |

Note: means not significant; *means significant at 0.9 level of probability; **means significant at 0.95 level

Tab. 8 · Testing of groups for each factor

| Factor | Level | Number of specimen | MOE(GPa) | | MOR(MPa) | |
|------------------------|-------|--------------------|----------|-------|----------|-------|
| | | | Average | STDEV | Average | STDEV |
| End pressure | 8.5 | 14 | 24.998A | 3.097 | 33.637A | 7.761 |
| | 10 | 17 | 26.255A | 2.356 | 32.683A | 4.103 |
| | 11.5 | 18 | 26.019A | 2.877 | 38.567B | 6.038 |
| ΔT | 0 | 14 | 26.230A | 1.863 | 32.466A | 5.350 |
| | 0.1 | 17 | 27.476A | 2.276 | 38.484B | 6.324 |
| | 0.5 | 18 | 23.907B | 2.708 | 34.000A | 6.381 |
| Combination of density | HH | 3 | 27.383A | 2.425 | 40.651A | 9.646 |
| | HL | 14 | 24.901AB | 3.170 | 32.821AB | 6.408 |
| | HM | 13 | 26.687A | 2.042 | 37.524A | 6.651 |
| | LL | 6 | 23.002B | 1.559 | 31.378B | 5.226 |
| | ML | 9 | 26.974A | 2.040 | 35.104A | 5.164 |
| | MM | 4 | 26.540A | 3.607 | 36.822A | 5.192 |

Note: the same to Tab. 7.

From Tab. 7 it is shown that the combination of density and ΔT had a considerable effect on the MOR of finger-jointed lumber of *E.citriodora* wood; end pressure also had a large effect on MOR, while the interaction of end pressure and ΔT had no effect on MOR and MOE.

From Tab. 8 it is shown that the change of end pressure had no effect on MOE, but did result in a significant increase in MOR, of finger-jointed lumber of *E.citriodora* wood. Different ΔT can lead to different MOR and MOE, the MOR was higher when ΔT was 0.1 mm.

The results of the effect of wood density on the strength properties of finger-joints of *E. citriodora* wood are presented graphically in Fig. 6.

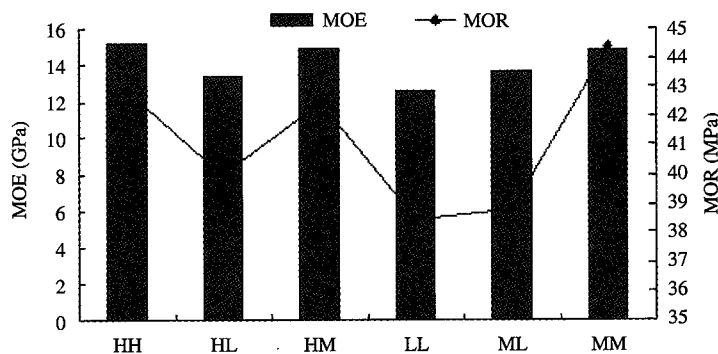


Fig. 6 Combination of different density

The combination of different density wood in finger jointing does affect the MOE and MOR, especially the MOE. From Fig. 6 it is evident that by using the higher density combination, in manufacturing finger-joints from *E. citriodora* wood, MOE could reach 27.38 GPa, and 40.65 MPa for MOR.

There is no significant difference between average results followed by the same letter (A, B or AB) When a 't' test is applied, but there is a significant difference between averages followed by a different letter (eg. Between A, B, or AB).

From Fig. 7 it can be concluded that when the ΔT was 0, the MOE of finger-joints increased with the end pressure increasing from 8.5 kN to 11.5 kN. However, when ΔT was 0.1 mm and 0.5 mm, the MOE of finger-joints increased from 8.5 kN to 10 kN, then decreased with the increase of end pressure when it was over 10 kN. When ΔT was 0.1 mm and 0.5 mm, the MOR of two types of finger-joints increased gradually as the end pressure increased from 8 kN to 11.5 kN. When ΔT was 0.1 mm, the MOE and MOR of finger-jointed lumber were higher than for other two kinds of finger-jointing when ΔT were 0 and 0.5 mm. The results show that when the end pressure was 11.5 kN, the finger-jointed lumber has the highest MOE and MOR; but there was some splitting in the finger root. Therefore, the suitable ΔT was 0.1 mm and the optimum end pressure was 10 kN for finger-jointed lumber of *E. citriodora*.

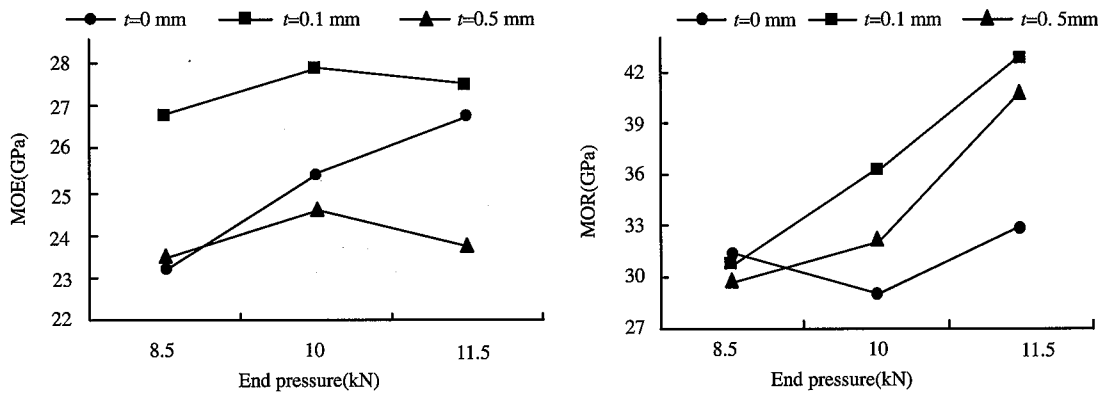


Fig. 7 Effect of end-pressure on MOE and MOR

For the other three species of Eucalyptus the following results could be summarized :

The suitable ΔT was 0.1 mm and the optimum end pressure was 10 kN for finger-jointed lumber of *E. exserta* and *E. urophylla* × *E. grandis* and for *E. grandis*, the suitable ΔT was 0.1 mm and the optimum end pressure was 11.5 kN for finger-jointed lumber.

3.3 Finger-jointed samples with different types of finger and different kinds of adhesive

Fig. 8 shows that both the MOR and MOE of finger-joints with different finger type V and H were almost the same.

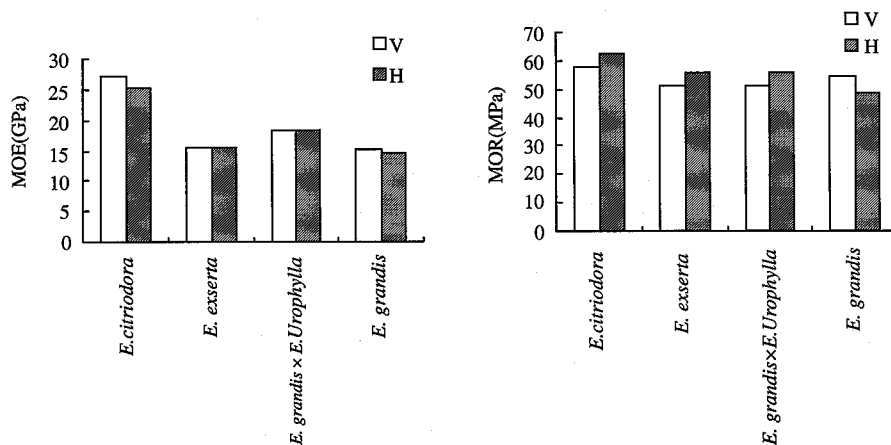


Fig. 8 Comparison between V-type and H-type finger-joints on MOE and MOR

From Fig. 9 it can be seen that there was not much difference in MOE using either API or PVAc adhesives, but for MOR, the API adhesive gave much higher results than PVAc, especially for *E. citriodora* wood, which was high density and had high extractives. For example, the MOR was 30.35 MPa for PVAc, but for API, the MOR increased to 57.69 MPa. The explanation could be that for API adhesives, the action of Vander Waals force and hydrogen bonding between the molecules of adhesive and the wood forms deep-set physical bonding of the wood. The gluing surface and the adhesive react with hydroxyl, carboxyl, phenolic hydroxyl and other reactive groups in celluloses hemicelluloses and lignin in the wood. At the same time the adhesive reacts with water in the wood, forms some chemical bond between wood and adhesive, then in the end forms a cross-linked structure, thereby increasing the strength of the gluing.

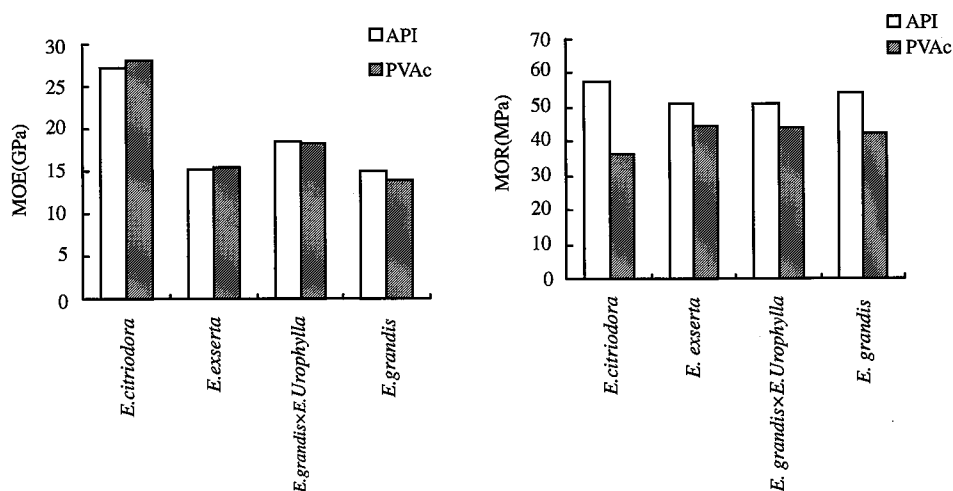


Fig. 9 Comparison between API and PVAc finger-joint on MOE

4 CONCLUSIONS

The suitable cutting feed speed for the manufacture of finger-joints for *E. citriodora* and *E. exserta* was 5 m/min and for *E. urophylla* × *E. grandis* and *E. grandis* was 10 m · min⁻¹.

The four kinds of finger-joints tested could get the highest MOE and MOR when ΔT was 0.1 mm.

The better end pressure for assembly of finger-joints for *E. citriodora*, *E. exserta* and *E. urophylla* × *E. grandis*, was 10 kN and for *E. grandis* was 11.5 kN.

MOR and MOE of finger-joints with different finger type V and H were almost the same.

REFERENCES

- Biblis E J, CARINO H F. 1993. Factors influencing the flexural properties of finger-jointed southern pine LVL. Forest Products Journal, 43(1)
- Cecilai B, Mohammad M, Roger E H, Robert B. 2003. Effects of curing time and end pressure on the tensile strength of finger-jointed black spruce lumber. Forest Products Journal, 53(11/12)
- Christine B, Caroline V, Christine G, Marcel S. 1997. Experimental assessment of the effect of length on the tensile strength of structural finger-jointed lumber. Forest Products Journal, 47(10)
- Hao J CH. 2000. Processing of finger-jointed lumber making, East-north forestry university publishing company
- Ayarkwa J, Hirashima, Y Sasaki. Y. 2000. Effect of finger geometry and end pressure on the flexural properties of finger-jointed tropical African hardwoods. Forest Products Journal, 50(11/12)
- JAS MAFF, Notification No.590, finger-jointed structural lumber for wood frame platform construction

Opportunities through Eucalyptus Agroforestry for Sustainable Development in Haryana, India.

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ABSTRACT

This paper examines the role of agroforestry in sustainable development, leading to increased farmers income, employment generation, opportunities for value addition by the industries, and environmental benefits in the state of Haryana, India. This state is primarily an agricultural state with only about 3.5% of its geographical area as natural forests. Subsequent to the introduction of a network of irrigation canals, farmers of Haryana have achieved a significant increase in productivity of wheat and paddy-fields following progressive farming systems. The Haryana Forest Department introduced Eucalyptus and Poplar based agroforestry models in the 1970s, which have been well received and adopted, initially by large and absentee farmers. The gradual establishment of backward and forward linkages has made agroforestry an economically viable activity leading to enormous development in the State. Consequently, even the small and marginal farmers have recognized agroforestry as a profitable venture. A facilitating legal policy environment, availability of adequate infrastructure and micro-finance resulted in the establishment of 300 veneer mills in the city of Yamunanagar, in Haryana. Today, the daily arrival of wood (grown in agro-forests) in this city alone is worth US\$300,000, which, after value addition in the form of plywood production, becomes worth US\$1.2 million. Further, a significant increase in tree cover (8% of geographical area) has also been achieved in the state leading to alleviation of pressure from natural forests. This success story has been well recognized by the Ministry of Environment and Forests, Government of India, which considers this land-use system as a means to achieve a tree cover of 33% of the nation's geographical area by 2025 as mandated in the Forest Policy of India, 1988.

1 INTRODUCTION

Agro-forestry practice optimizes production potential of land in more than one tier i.e. both the above and below ground systems. Conceptually it can be practised wherever agriculture is practised and needs to be spread to all areas with suitable crop-tree combination potential.

Agro-forestry means combining tree cultivation with agriculture crops. This practice is not new as 'Kheti' (agriculture) always used to be with 'bari' (fenced tree grove) under traditional practices of agriculture in India. With the advent of commercial agriculture and automation, 'bari' was neglected and present effort is directed to re-establishing this aspect of tree cultivation by making it remunerative to the landowner. However, some of the states of India have evolved various models comprising a combination of tree crops with traditional agriculture and horticulture crops in different agro-climatic zones. Some such

practices that are present in Haryana, Punjab, West Uttar Pradesh and Uttaranchal states of the Republic of India have evolved in terms of higher production and income generation, and, consequently they have acquired national and international recognition as models to be emulated. The timber output generated from agro-forestry substitutes timber grown in natural forests; thereby alleviating pressure on natural forests, which are important for conservation of precious biodiversity and ecological security of the country. Further, the availability of suitable raw material on a sustained basis has led to the establishment of forest-based industries. Today, these on-farm forestry activities have added substantially to the income of small, medium and large farmers and have created significant employment opportunities along the value chain. Thus agroforestry has been recognized as a proven strategy for poverty reduction and rural development.

2 HISTORY OF AGRO-FORESTRY PRACTICES OF HARYANA STATE

Traditionally the tree species such as 'jand' (*Prosopis cineraria*) were naturally encouraged to grow in most of the semi-arid sandy agricultural lands that were rain-fed probably for the conservation of soil moisture and productivity. Similarly, in rain-fed clayey soils, 'babul' (*Acacia nitotica*) was grown. 'Shisham' or 'tali' (*Dalbergia sissoo*) was grown in moist areas and also along the wide network of canals. These interventions served as a strategy for economic drought-proofing as the landowners could survive by felling trees and selling timber and fuel wood in social (marriages, loan repayments, illness) and climatic (drought, crop failures, floods) emergencies. Some of these practices continue even today with slight variations.

3 SUCCESS STORIES OF AGRO-FORESTRY IN HARYANA

3.1 Resurgence of eucalyptus

Conscious efforts were made to introduce eucalyptus-cultivation on field boundaries in the sub-division of Yamunanagar (then Ambala district). Initially the landowners were reluctant to plant trees as they feared land seizure by the forest department. However, subsequent harvesting and sale of the first crop resulted in very high returns to owners which was beyond their expectations. This was coupled with the effect of expansion of government plantations and large-scale private plantations by large progressive (absentee) farmers. However, as the seedlings were planted at very close spacing, the yields were significantly low. Furthermore, a market existed only for pulp and paper, and the returns to the land owners were reduced as simultaneous felling of these large plantations resulted in a glut of raw material. This led to a panic harvesting by many farmers in the state of Haryana and a further glut resulted in the market between 1980-1990. However, the revival of interest in eucalyptus occurred after its adoption by the plywood industry as it had a cost advantage, being a cheaper substitute for other sources. At present about 20 million genetically superior Eucalyptus seedlings are mass-produced annually and planted by farmers using different agro-forestry models.

3.2 Trade cycles and stability

In a free trading economy trade cycles are of common occurrence. In a predominantly agricultural economy a very large number of cultivators follow mob mentality by using those cultivation practices which

gather the highest economic returns. This causes cyclic 'lows' and 'highs' in supply and demand chains termed as trade cycles. In agricultural crops the period of adjustment (equilibrium) to counter such trade cycles is about twice the crop rotation period. However, the period of equilibrium in case of tree crops is much longer due to a longer crop rotation. For example, in case of Eucalyptus with a rotation of 10 years the resurgence has come back after (10×1.5) 15 years in the State of Haryana, in India. These long duration cycles have been seen as a negative against agro-forestry as a strategy for rural development in the recent past. However, it is pertinent to mention that most agriculture crops are susceptible to this factor (sugar cane is one of the classic examples of this phenomenon). Bulk production has to be supported by bulk utilization and, therefore, the adage 'grow your markets before you grow your trees' has to be followed. However, Eucalyptus in Haryana has shown that both market and trees can grow together and this is described in the following section.

3.3 Establishment of agro-forestry based industries

River-floated timber trees from the hills viz; deodar (*Cedrus deodara*) kail (*Pinus wallichiana*) and partal (*Abies pindrow* and *Picea smithiana*) were collected at Yamunanagar and sold to the plains regions of India. A flourishing timber trade existed before 1970 at Yamunanagar. Subsequent to stoppage of felling in the hills, timber in the form of sleepers stopped arriving. This led to a decline in the timber trade similar to the decline which has already occurred in north eastern states and hence led to the disappearance of capital, technology and technical man power. At this crucial time, ICFRE, Uttar Pradesh Forest Department and WIMCO substituted semal (*Bombax ceiba*) with Eucalyptus for plywood manufacture. The loss of supply of timber from the north-east, the availability of hassle free plantation-grown Eucalypt raw material in Yamunanagar and the culture of Yamunanagar as a wood trading city combined to create 'Chota Assam' (Mini Assam) within a quarter of a century. As of today, about 15,000 metric tones of timber per day is being converted into plywood and panel boards in 600 factories located in five states viz; Haryana, Punjab, Uttar Pradesh, Uttaranchal and Delhi, mostly centered around Yamunanagar in Haryana state. One district transacts a turn-over of up to Rs. 2 crores (0.4 million US\$) of raw material and three times that in finished product, which is a testimony to this ever expanding activity.

3.4 Increase in forest and tree cover

At present, forest cover of India is just over 20% of the area of the country (FSI, 2003). By 2012, the Government of India proposes to bring another 10% under forest and tree cover (in total, 30% of the geographical area of the country). Haryana state has 3.5% of the state's area under natural forest cover and another 4.5% under plantation tree cover i.e., about 8% of the state area is covered by trees. By 2012, it is proposed to bring a total of 20% of the state's area under tree cover. Haryana is thus an unique state in that it has more plantation tree cover than forest cover and every seven years the state has brought about another one percent of its area under tree cover (Anonymous, 2003). This has become possible because of sustained free supply of seedlings. Every year between 25-50 million seedlings are supplied to the farming sector free of cost. Most of the agricultural land utilizes soil and above ground space to an extent not more than 0.5 meters below and 3.5 meters above ground, respectively. Introduction of trees will tap soil below 0.5 m and above ground space beyond 3.5 meters and has synergy with the traditional agriculture system. This is precisely what has happened in the state of Haryana and needs to be extended to other states of India also.

3.5 Additional income to the farmer

The often-asked question is how much difference in income exists between an agricultural crop system only and an agroforestry crop system?

Initially, the eucalyptus veneer-grade timber was sold for Rs. 350 per quintal (100 kg), and the net additional income was Rs.8750 per ha. per year. At present, eucalyptus is being sold between Rs. 175-225, or an average rate of Rs. 200 per quintal. Therefore, the net additional earnings are Rs. 4,750 to 5,000 per ha per year (Tab. 1).

Tab. 1 Comparison of net annual income per ha of land practising wheat-rice rotation with and without trees

| System | Expenditure per ha per crop | Income per ha per crop | Net income per ha per crop | Remarks |
|---|-----------------------------|------------------------|---|--|
| Wheat | 13,250 | 28,250 | 15,000 | Wheat, 42.5 Quintals × @ Rs. 560=23,800 Hay, 30 Quintals × @ Rs. 150=4500 <u>Total = Rs. 28,300</u> |
| Paddy | 20,750 | 38,750 | 18,000 | Paddy, 63.55 quintals × @ Rs.590=37,495 Hay, 50.00 quintals × @ Rs. 25 =1,250 <u>Total = Rs. 38,745</u> |
| Annual income per ha | 34,000 | 67,000 | 33,000 | |
| Wheat | 13,250 | 22,975 | 9,725 | Wheat, 35 Quintals × @ Rs. 560= 19,600 Hay, 22.5 Quintals × @ Rs.150= 3,375 <u>Total = Rs. 22,975</u> |
| Paddy | 20,750 | 27,487 | 6,737 | Paddy, 45.0 quintals × @ Rs.590= 26,550 Hay, 37.5 quintals × @ Rs. 25 = 937 <u>Total = Rs. 27,487</u> |
| Eucalyptus/Eucalyptus | nominal | 21,250 | 21,250 | 500 seedlings are planted; about 400 seedlings survive to produce about 20 cubic meters of wood per ha per year. 10 cubic meters = 110 quintals plywood × Rs. 200=22,000 & 7.5 cubic meters=75 quintals of pulpwood × Rs. 65 per quintal = 4,875 & 2.5 cubic meters=25 quintal of firewood @ Rs. 45 per quintal =1125; a total of Rs. 28,000 as gross earning; Cost of logging and transportation @ Rs. 33 per quintal × 210 quintals = Rs. 6,930; Net income Rs. 21,070 |
| Additional income from eucalyptus per ha. | | | 37,712 (-) 33,000 (=) 4,712 | |

All costs are in Indian Rupees (Rs.); Current exchange rate of Rs. 44 per US\$.

On exceptionally well managed clonal eucalyptus agro-forestry farms, an output of 20 metric tonnes per quintal on a ten year cycle is claimed and often realized. This equates to about 20 m³ of wood harvested per ha · yr⁻¹.

3.6 Expansion of industry and output

About three decades ago, the peeling of eucalyptus logs was essentially for making match-splints. Subsequent success came through the manufacturing of commercial board for which the low cost of the raw material was responsible. With the passage of time, ISO certification and the establishment of in-house testing facilities, the quality of ply board products has been upgraded and the products are now comparable with the best available in the country. At least ten out of about 400 manufactures have upgraded their facilities to manufacture board to meet international standards. The day may not be too far off when

eco-certified green label timber panel products are exported in a large volume from Yamunanagar.

An estimated 600 units are presently using about 15,000 tonnes per day of farm grown-veneer logs in the five states of India, namely Haryana, Punjab, Uttaranchal, Uttar Pradesh and Delhi. About 400 units are concentrated in and around Yamunanagar and 25 units in Bahadurgarh of Jhajjar district adjacent to Delhi. About 50 units are in Ludhiana, Jullundhur and Hoshiarpur districts of Punjab state. About 50 units have been built in each of Uttaranchal and Uttar Pradesh states and about 25 units are operating in Delhi. On average, the consumption of each unit per day is 25 tonnes of veneer logs.

There is a horizontal and vertical integration in different timber-using industries, where an end product and / or waste product of one unit is an initial product of the other unit. One paper mill is mostly utilizing veneer waste, debarked stumps and pulpwood of eucalyptus to meet 82% of its raw material requirements, with the remaining 18 % being met from bamboo transported from north-eastern India. The total estimated value of daily raw material requirement that is bought by the 600 veneer manufacturing units is Rs. 25-30 million at an average of 15,000 tons of wood procured at average price of Rs. 175 per quintal.

3.7 Employment of loggers, middle men, transporters and skilled labour

A large number of people are engaged in logging and in the plywood manufacturing industry. The logging labourers, instead of being immobile, have started operating in mobile teams even outside of the state. Skill acquisition and its constant up-gradating has led to socially disadvantaged groups becoming economically self reliant even while they do not own land. Every tonne of harvested wood generates one man-day in logging operations. Thus, every day 15,000 man-days of work gets generated in the five states of India, primarily in Haryana.

The transport sector is likewise benefited, both at the time of carriage of raw material and at delivery of finished goods. At a rate of Rs. 30 per quintal for the cost of transportation, the transport industry transacts $(15,000 \times 10 \times 30) = \text{Rs. } 4.5$ million per day through raw material transportation alone.

Six hundred factories provide jobs to not less than about $600 \times 100 = 60,000$ people in the five states, who are benefited by this industry.

The plywood industry is machine intensive and imported machines or machines manufactured in other places of India were used earlier. Now more and more machines are being fabricated in Yamunanagar itself, generating additional employment and income to investors.

3.8 Tax earning by the Government

The sales tax earned by the government of Haryana was of the order of Rs. 60 million per annum from Yamunanagar district alone, mostly being paid by the paper, sugarcane, metal and plywood industries. After government entered into an understanding as to the tax that is to be specifically paid by the plywood industry, there was a three-fold increase in tax collection. While all other industries continued to function at the same level, almost all of the tax increase can be attributed to the plywood industry alone. Thus, there has been an overall tax collection spurt to the extent of Rs. 120 million from agro-forestry generated products.

3.9 Seedling supply for sustained agro-forestry

Seedlings are the most important input to sustain the momentum of agro-forestry practice. Every year

between 50-100 million seedlings are used in Haryana for plantations on government and private farmland. More than half the seedlings are used by the agroforestry sector.

The cost of raising trees in forest areas is about four times greater (INR 20 per seedling) than that of raising the same trees on farms (INR 5 per seedling). Owing to the higher fertility status of agricultural land and a farmer's personal care, growth rates of trees have been found to be superior on this land as compared to forest land. The output from 150,000 ha of government forests of Haryana is 400,000 cubic metres (only half is harvested) compared to agroforestry output from an estimated 200,000 ha of about 1.6 million cubic meters. There is a four-fold increase in production with four times lower cost of seedlings under agroforestry systems.

At present, there is a general feeling in the country that subsidies on seedlings should be discontinued, as they do not support economic efficiency and competitiveness. Such ideas, which stem from observations of international financial institutions, cannot be applied indiscriminately to every agroforestry situation in India. It is argued that in the initial stages, the seedlings are to be supplied free of cost to farmers in order to encourage them to grow trees on farmland and to create a raw material base for the industry. Once this linkage is established and stable markets developed for agroforestry-grown produce are ensured, it would be expected that this would lead to an even greater interest by landowners in planting trees on their farms. The survival of seedlings supplied to a farmer in the beginning may not be very high because of lack of experience of the farmer. Unless the farmers harvest and sell a crop of trees profitably, there is a low level of confidence, particularly regarding the backward and forward linkages in this system. For sustained agroforestry development, the seedling supply system should also factor in the wastage of some seedlings in the early phases of the efforts. As experience is gained, the seedling wastage becomes low. In areas of unrestricted cattle movement after field crop harvest, the seedling survival has been found very low. Because of the greater experience of farmers in Yamunanagar district, the survival of eucalyptus is more than 80% in comparison to other new areas where it is between 30%-60%.

The seedlings that are supplied to farmers also have ecological and economic benefits, which more than compensate for their cost. The raw material generated from the agroforestry sector has provided a substitute for forest produce and reduced the pressure on natural forests. At the same time it sustains the plywood, paper, charcoal and rayon industries. The finished product is taxable from which the government earns more tax compared to the expenditure incurred in supplying free seedlings. Thus, the tax receipt (though a deferred return) more than offsets the expenditure incurred in free supply of seedlings.

4 CONCLUSIONS

Agro-forestry on agricultural land can be an inexhaustible source of raw material. Every hectare of intensively cultivated land can produce more than ten cubic metres of wood per year through agroforestry systems. Even rain-fed and marginal agricultural land can produce at least 5.25 cubic metres of wood per year under intensive care and management. By harnessing this potential of agroforestry, timber and firewood can be generated far in excess of the projected requirements of the country. The successful agroforestry models developed in Haryana are being gradually adopted in the adjoining states. With suitable crop combinations, they are also becoming popular in other places. These efforts however seem to be very much dependent on the supply of good planting material, fair market policy and a consistent R&D support. By being a multi-functional land-use system, agroforestry seems to be the way forward for the sustainable

development of a country like India.

REFERENCES

- Anonymous. 2003. Annual Administrative Report. Haryana Forest Department. Panchkula, Haryana, India
- FSI. 2003. State of Forest Report 2001, Forest Survey of India, Ministry of Environment and Forests, Dehradun.
- Rawat J K. 1988. Economics considerations in Eucalyptus farming. *Indian Journal of Agricultural Economics*, 43(3): 317
- Rawat J K. 1989. Economic behaviour of a wood producing firm. *Indian Forester*, 115(10): 689-695
- Rawat J K, Hoodga A K, Dange R P. 1994. A feedback on social forestry project from Ambala district (Haryana). *Indian Forester*, 120(7): 591-596

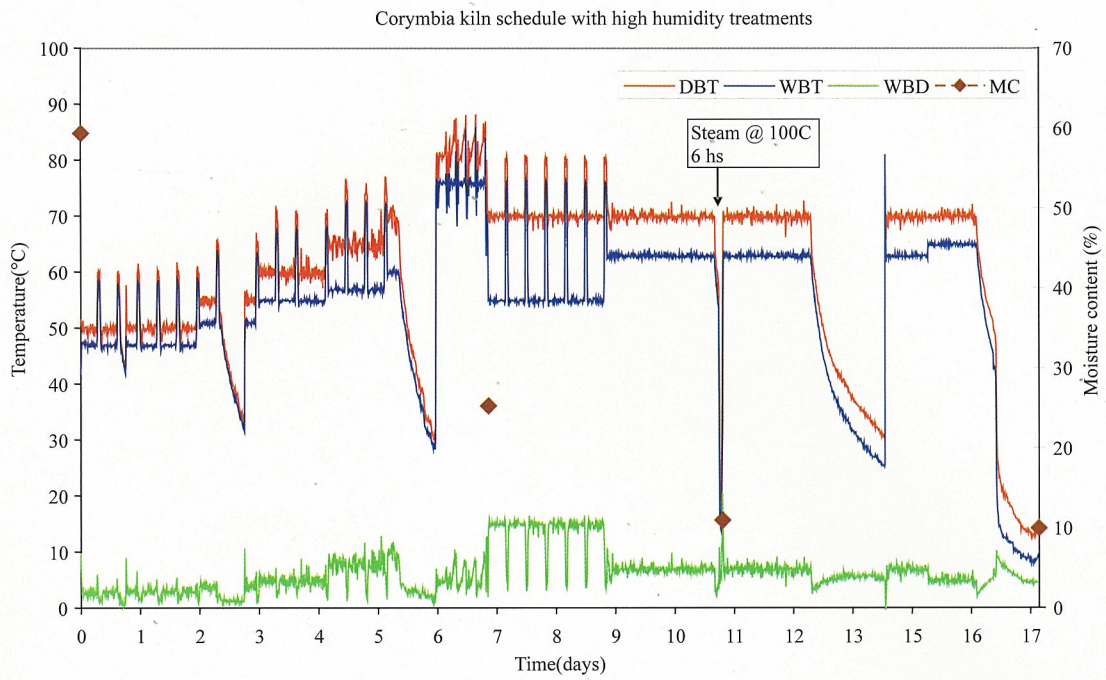


Fig. 1 Accelerated drying with periodic high humidity treatments(see page 106 in text)

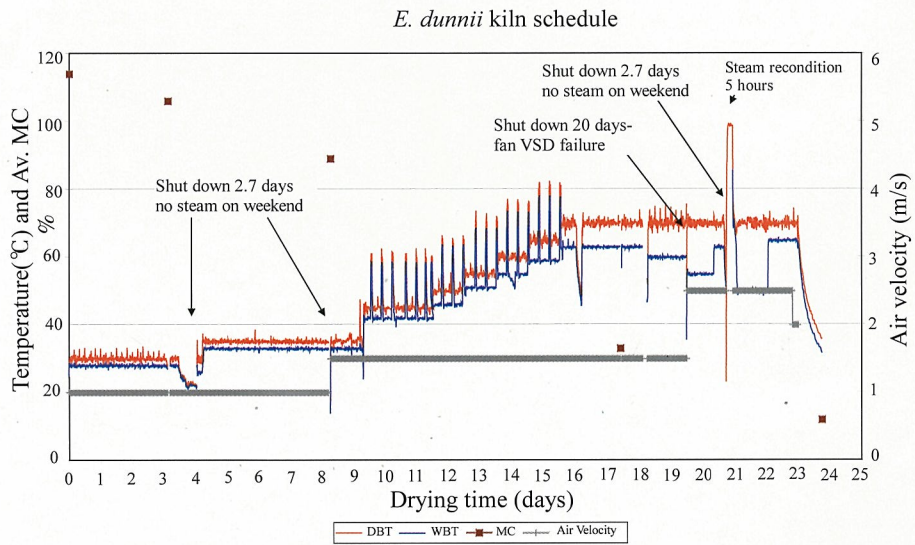


Fig. 3 Kiln conditions used for drying *E. dunnii* 100 mm × 25 mm boards(see page 107 in text)

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