

## **EUCALYPTUS IMPROVEMENT FOR LUMBER PRODUCTION**

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### **INTRODUCTION**

*Eucalyptus grandis* was introduced into South Africa about 85 years ago mainly to serve as a source of mining timber. Today this species is by far the most important eucalypt planted in the South Africa comprising about 72% of the total plantation area under eucalypts. The total area under this species is estimated at just over 380 000 hectares which is 29% of the total afforested area. About 85% of the total volume of wood produced each year is consumed by the pulp and mining industries of which about 50% is consumed by the pulp and paper industry. The remaining 15% is mainly used for the production of sawn timber and poles.

A breeding programme for *E. grandis* was started in South Africa in 1962. For many years the selection criteria were mainly good tree and growth characteristics, resistance to pest and disease, adaptability, and low levels of growth stress, spirality and brittle heart. Despite a need to include wood properties in breeding programmes, basic wood properties were not seriously considered in breeding programmes for many years, mainly because tree breeders did not know what the requirements were of the various timber processing industries.

At present there is a growing demand by the wood processing industry to change and improve the quality of the South African *E. grandis* timber resource as the wood of this species is put to a wider use.

The objective of this paper is to discuss briefly existing knowledge with regard to the wood properties and qualities of *E. grandis*, as well as methods applied up to now to improve the quality of the wood.

### **VARIATION AND INTER-CORRELATION BETWEEN WOOD PROPERTIES**

In *Eucalyptus grandis* density increases rapidly with increasing distance from the pith; especially in the zone of juvenile wood (Taylor, 1973a and 1973b; Sardinah, 1974; Stöhr and Mackay, 1983; Malan, 1988b; Bhat *et al.*, 1990). In areas of fast growth, such as South Africa, juvenile wood is of considerable importance as it constitutes a large proportion of the stem and is therefore an important source of variation. The radial increase in density, however, becomes less pronounced with increasing height (Malan, 1988b; Taylor, 1973b).

Variations in density along the stem are less consistent than those in the radial direction. As the cylinder of juvenile wood extends from the base of the stem to the top, the proportion of juvenile wood over the cross-section of the stem increases. As a result of this a decrease in density often occurs in many species, especially in softwoods. In *E. grandis*, however, density commonly increases with height above ground level although an initial decline may sometimes be present (Taylor, 1973a and 1973b; Stöhr and Mackay, 1983; Bhat *et al.*, 1990).

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Fibre length, diameter and wall thickness increase rapidly with increasing distance from the pith levelling off after about 8 to 15 years (Malan and Gerischer, 1987; Bhat *et al.*, 1990). Height in tree has little effect on fibre length, while fibre diameter increase with height in tree to about mid-height followed by a decrease higher up (Taylor, 1973a and 1973b; Bhat *et al.*, 1990).

Between-tree differences in fibre length, though small, were found statistically significant while differences in fibre diameter were small and non-significant (Taylor, 1973b). Bhat *et al.* (1990) observed no significant difference in fibre length between trees. As fibre-wall thickness is closely related to wood density, variation in wall thickness from tree to tree and within individual trees is similar to the patterns of density variation.

Vessel diameter increases with increasing distance from the pith while vessel frequency declines. The proportions of the various tissue types change relatively little with age and height above ground level (Wilkes, 1988; Malan and Gerischer, 1987; Sardinah, 1974; Taylor, 1973a and 1973b).

The inter-correlations between wood properties were studied by Malan (1991) using material obtained from an 8,5-year-old *E. grandis* diallel progeny trial consisting of 72 full-sib families. Of the 55 phenotypic correlation coefficients computed between all possible pairs of variables, 31 were significant at the 5% level of probability or higher. A summary of these results are given in Table 1. Results of a factor analysis that was subsequently performed to increase interpretability and to find the most suitable variables to describe wood property variation, indicated that about 82% of the total variation in the basic wood properties of *E. grandis* can be described by wood density, fibre length and vessel diameter.

**Table 1:** Correlations between some wood properties (n=141) (From: Malan, 1991)

Property	Fibre properties				
	Length	Diameter	Wall thickness	Lumen diameter	Wall thickness
Density	-0,25**	-0,37**	0,36***	-0,78***	0,80***
Fibre length	1	0,22*	ns	0,21*	ns
	Tissue proportions and vessel properties				
	Vessel diameter	Vessel frequency	Vessel volume	Fibre volume	Ray volume
Density	-0,33***	0,21*	-0,22**	ns	ns
Fibre length	0,31***	ns	0,20*	ns	-0,20*
Vessel volume	0,33***	ns	1	-0,61***	ns
Vessel diameter	1	-0,55***	0,33***	ns	ns
Fibre volume	ns	ns	-0,61***	1	-0,76***

\* significant at 5 % level  
 \*\* significant at 1 % level  
 \*\*\* significant at 0,1 % level  
 ns - non-significant

## FACTORS AFFECTING WOOD PROPERTIES AND VARIATION PATTERNS

### Silvicultural effects

The control of stand density, either through initial spacing or thinning or a combination of the two, are silvicultural practices strongly influencing both tree growth and wood formation. Assuming that

nutrient and water availability is similar, the individual trees of widely-spaced and/or thinned stock will grow faster than crowded trees.

Because of the impact that thinning has on crown development and growth rate, it can have a significant effect on wood formation. It is often believed that one effect of thinning is an increase in the size of the juvenile core, suggesting that thinning could result in wood of lower density, shorter fibres, higher longitudinal shrinkage upon drying, and a higher lignin content.

Studies carried out by Malan and Hoon (1992b) indicated that density variation patterns in *E. grandis* are significantly affected by the degree of suppression, having a pronounced inverse effect on wood uniformity. The density of suppressed trees increases rapidly with increasing distance from the pith, showing no strong tendency to level off towards the bark. On the other hand, the wood of trees growing more freely reaches maximum density levels fairly early in life, resulting in a stem with a large a proportion of mature wood of relatively uniform density. As a result of this the weighted mean density of trees increases with a decrease in the degree of suppression.

Fibre length and its variation across that radius is not significantly affected by thinning. However, owing to the good positive correlation that exists between wood density and fibre wall thickness (Malan, 1991), it can be expected that the less the tree is suppressed, the larger the proportion of thick-walled fibres that will be produced.

Vessel and ray sizes and their proportions are not greatly affected by thinning intensity, while vessel proportion tends to increase with increasing thinning intensity.

### **Genetic effects**

Large between-tree variations in wood properties are known to exist between trees of this species, even among trees growing within a uniform site (Malan, 1988d). These variations appear not to correlate reliably with changes in specific factors of the environment, such as temperature, altitude, latitude, rainfall and soil properties (Wilkes, 1988; Taylor, 1973a; Bhat *et al.*, 1990) suggesting that a considerable proportion of the variation must be due to genetic effects.

Studies carried out by Malan (1988d) revealed significant genetic variations for wood density, spirality, proportional volume of the various tissue types, vessel frequency, fibre length and growth stresses. Heritability estimates ( $h^2$ ) varied from 0,30 to 0,54. A highly significant negative genetic correlation of rate of growth with density and fibre length, were found suggesting that selection for increased rate of growth may have a prejudicial effect on these properties.

### **NATURAL DEFECTS COMMON TO *Eucalyptus grandis***

#### **Knots**

Although plantation grown *E. grandis* usually exhibits good self-pruning properties, branch-shedding in the lower portions of the stem only starts taking place two to three years after dying. These branches give rise to sound knots for 50 to 70 mm of their length from the pith, often with a deep check along the line of their own pith while their distal ends are usually dead and decayed, often with a plug of corky tissue mixed with kino at their ends. These knots occur mainly in the juvenile wood, causing serious degrade on boards cut from the centre of the stem. Cross-fractures are often present in association with these knots (de Villiers, 1973). In mature trees the branches are usually large and scattered in the crowns giving rise to large, tight knots. In sawn timber these knots usually develop checks during seasoning.

#### **Kino rings**

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Almost all eucalypts produce kino and it is mostly enclosed in ducts or veins, and pockets. It exhibits the general characteristic of being a viscous yet mobile orange-coloured exudation which, on exposure to air, becomes a hard, dark-coloured, amorphous, glasslike substance.

Damage caused to the vascular cambium results in the development of numerous tangentially arranged rows of traumatic kino veins which follow the growth ring. These rows of veins are referred to as kino rings. In *E. grandis* they are infrequently present and in general do not constitute a defect of much significance.

### **Spiral and distorted grain**

Interlocked grain, consisting of zones of wood with alternating spiral grain, is often observed in radially sawn *E. grandis* boards, giving it an attractive striped figure. However, if the grain angle in the alternating spiral grained zones deviates more than 4-5° from vertical axis of the board, it is difficult to obtain a smooth surface except by sanding (de Villiers, 1973).

Excessively wild, distorted or spiral grain seldom occur in South African grown *E. grandis* and is therefore not a serious problem.

### **Growth stresses and brittle heart**

High levels of growth stress in South African eucalypts are undoubtedly the most serious growth phenomenon affecting wood quality, product yield and product dimensions. A reduction in stress levels in tree stems would certainly be by far the most important improvement that can be made regarding many eucalypt species, as the impact on the wood processing industry will be impressive.

Growth stresses develop in trees as they grow, a phenomenon that eventually manifests itself when the tree is felled, cut into logs and converted into boards. Severe splitting develops in log ends following cross-cutting while further splitting and distortion takes place during conversion into sawn boards. In veneer logs splitting often renders eucalypt logs useless for peeling.

According to theory growth stresses are generated within woody tissue as a result of the tendency of differentiating cells to contract during cell maturation. Since each layer of cells added to the stem is laid down in a state of tension, it has a cumulative effect, with the result that counterbalancing compressive forces in the central part of the stem may eventually exceed the maximum crushing strength of wood, causing numerous slip planes and compression failures; a condition generally known as "brittle heart"; a common problem experienced especially by hardwood sawmillers.

The presence of this defect has a very significant effect on the quality and yield of the end-product. Brittle wood is unattractive and low in strength. Sawn boards containing brittle wood often emerge from the sawing machine in a fractured condition as they are not capable of withstanding the shocks caused by the sawing operation.

### **Factors affecting growth stress levels**

#### **Pruning**

Growth stresses do not seem to be affected by live pruning. Studies on a 12-year old *E. grandis* pruning experiment conducted in Zululand, indicated a sharp increase in degrade due to spring, which appeared to be directly proportional to pruning intensity (Lückhoff, 1967). This finding led to the conclusion that live pruning might increase growth stress levels. However, an investigation carried out on material collected when the same field trial was terminated at the age of 25 years, indicated no significant relationship between pruning intensity and the degree of log end splitting or sawn timber lost due to splitting (Bredenkamp *et al.*, 1980).

### Effect of growth rate

Log end splitting in South African grown *E. grandis* is characterised by an enormous between-tree variation. Apart from a very large variation between trees growing under apparently uniform conditions, large variations have also been experienced between groups of trees growing under similar climatic conditions but on different site qualities. Differences have also been found between geographical areas (Malan, 1979a).

Fast grown trees seem to be more prone to end splitting and this may explain why splitting in trees from good quality sites tend to be more severe. End splitting measurements carried out on material obtained from a good quality site on average exhibited twice as much splitting as compared with that obtained from a closely poor quality site of similar age (Malan, 1984a). However, differences in growth rate only accounted for a small proportion of the enormous between-tree variation which existed within each of the two sites (Malan, 1988a and c).

Results of recent studies, however, indicated that the degree of splitting in log ends increases with increasing growth rate, but if the amount of splitting is corrected according to log size, the proportion of the log end that is affected by end splits remains the same irrespective of the size of the log (Malan, 1992b).

### Mechanical factors

As indicated before marked differences in end splitting are normally found between *E. grandis* trees growing within the same general environment. Although thinning regimes aim to maintain uniformity in spacing among the residual trees in general, existing thinning practices do not accomplish absolute spacing uniformity throughout the life of a stand. From fairly early in the life of a stand a between-tree variation exists in growing space for the crowns and particularly exposure to lateral wind forces and light, and the availability of soil moisture content.

Possible relationships between the crown, the centre where wood formation is regulated, and growth stresses have been investigated for South African grown *E. grandis* (Malan, 1988c). Multiple regression analyses were used to study the relationship between mean tree splitting (the value used as an indirect measure of the level of growth stress in the tree) and a number of crown and tree properties.

Results of this study indicated that factors of environment which affect crown development and, in turn, exert variations in wood quality, have no significant effect on the level of growth stresses generated in the tree. This suggests that silvicultural practices may not be an effective tool for reducing the level of growth stress in trees since factors other than those of environment seem to be principally involved.

### Seasonal effects

Several studies indicated a strong seasonal variation in growth stress levels. Investigations carried out in Australia on *Cryptocarya erythroxylon* and in South Africa on *Eucalyptus grandis* revealed that growth stresses are higher during the wet season when soil water is freely available (Hillis, 1978; Malan, 1984a). Studies carried out on *E. grandis* in the Tzaneen area, however, showed the degree of end splitting to be the most severe during the hot and dry first half of the summer before the start of the summer rains (Malan, 1984a). This led to the conclusion that higher than normal levels of growth stresses are generated during periods when trees are growing actively under conditions of severe soil moisture shortage.

Growth stress measurements carried out in Japan on *Cryptomeria japonica* showed significantly lower values during the period of maximum cambial activity. For the rest of the year stress levels remained more or less on the same level (Okuyama *et al.* 1981).

## Genetic factors

Log end splitting in South African grown *Eucalyptus grandis* is characterized by an enormous tree-to-tree variation, even among trees growing under apparently uniform conditions. It can therefore be safely assumed that growth stresses are to some extent under genetic control. Based on this assumption lack of severe end splitting has always been an important criterion in the tree breeding programme for South African grown Eucalypts before trees were accepted for breeding purposes.

Studies on both controlled and open pollinated progeny trials indicated a significant family variation in end splitting. Results indicated that the heritability could be as high as 0,50 (Malan, 1984a) suggesting that this defect is sufficiently heritable to enable its genetic reduction. Since no relationship could be found between growth stress levels and wood properties (Malan *et al.*, 1992a) means that this could be achieved without any detriment to other wood properties.

To verify these findings, two *E. grandis* research trials, consisting of clones from four high and four low growth stress families from an open-pollinated progeny trial, were established on two locations in the eastern Transvaal.

Results not only indicated distinct differences in growth stress associated log end splitting among the young clonal progenies but the ortet/clone relationship was remarkably strong. Furthermore, diameter at breast height and tree height varied within the ranges 171 to 191 mm and 22,1 to 23,7 m but there was no relationship with stress levels whatsoever. This suggests that stress levels can be manipulated genetically through selection and cloning without sacrificing rate of growth.

## Controlling growth stress splitting

Many suggestions have been made over the years, and experiments carried out, in an attempt to reduce the effects of growth stresses in trees either by reducing the levels of stress in the standing tree or log, or by preventing or minimising split development in log end after felling and log-making.

In the following sections a number of techniques which have proved to have some reducing effect on split development due to growth stress release, are discussed.

## Silvicultural practices

Though not tested experimentally, it is generally believed that growth stress generation in stands can be minimised by keeping the growth conditions and spatial distribution in the stand as uniform as possible throughout the life of the stand (Kubler 1988). This would give the trees no reason to reorientate themselves into more favourable positions thus minimising the levels of stress generated in tree stems. Stands should be thinned lightly, frequently and uniformly, rather than haphazardly and severely after long periods.

Bariska *et al.* (1987) speculated that the effect of external forces on growth stress generation in trees should be experimentally verifiable:

(a) Supporting trees by means of sway wires to prevent sway over a period of time. This should result in the generation of lower levels of stress in tree stems.

(b) Trees with large slenderness ratios (tree length/diameter), i.e. "whippy" trees, should develop higher levels of growth stress.

(c) Trees of the same species growing in windy areas should develop higher stress levels than those growing in calm areas.

(d) The remaining trees of the same species grown at close espacement should develop higher levels of growth stresses after severe thinning in order to provide them with more mechanical support in their new, more exposed environment.

However, existing evidence suggests that silvicultural techniques do not seem to be effective to control stress levels in trees (Malan, 1988c).

### **Reducing stress levels in standing trees**

A number of techniques have been developed to treat tree prior to felling or cross-cutting. Giordano *et al.*, (1969) killed plantation trees of *Eucalyptus camadulensis* by deep girdling through the sapwood and leaving it standing for a few months. They found that deformation in sawn planks due to stress release can be reduced up to 50%. However, this technique was unsuccessful in other species (Giordano and Currò, 1973).

Malan (1979b) found a slight reduction in split development two months after girdling. Unfortunately the investigation had to be terminated because of the degrade to the stem due to drying and borer damage and the danger of falling trees.

Nicholson (1973a) found almost no reduction in longitudinal growth stress after trees have been killed and left standing for about 9 months. He noted, however, that one girdled tree which had not been completely killed and which retained its moisture content, showed the most significant reduction. The significant prerequisite to this reduction appears to have been the prevention of diameter growth during the nine months concerned and at the same time keeping the moisture at a relatively constant level.

Following a suggestion by Nicholson, Waugh (1977) used a defoliant spray (2,4,5-T) to retard growth without actually killing the trees. Results of this study indicated a reduction of 20% in growth stress levels over a period of one year but there was a high degree of individual variation in the relation between the degree of defoliation and strain relaxation.

Chafe (1977) ascribed this phenomenon to the fact that plastic deformation of wood, or creep, under constant load can be dramatically increased by changing the moisture content while maintaining the load (See his review of the work by Armstrong and co-workers). The partial alleviation of growth stresses by killing trees and leaving it standing could have been partly the result of an almost certain reduction in moisture content.

In South Africa a considerable reduction in splitting was experienced in dead and growth retarded *E. grandis* trees subjected to severe drought, even in compartments known for severe splitting problems (Mr I. Claassen, Hans Merensky Foundation, personal communication, 1993).

### **Felling and log-making**

Although little is known about the effect of felling practices or end-split development, it is generally believed that felling should be done in the direction where the softest fall would result rather than in the direction of the lean. Precautions should also be taken to avoid trees, logs or other objects lying on the ground in order to reduce felling damage such as felling shakes or minute internal fractures which could have an aggravating effect on split development due to the partial release of growth stresses (Barnaele, 1970 and 1973; Barnaele and Necesany, 1972).

Considerable attention has been given to various techniques of log-making and log handling in order to reduce log end-splitting. Studies in various countries on various species have indicated that end-splitting can be reduced considerably by cutting a circumferential groove with a chain saw on either side of the position of cross-cutting for log making (Barnacle and Gottstein, 1968; Giordano and Currò, 1973; Kubler and Chen, 1975; Conradie, 1980). The method redistributes the lateral stresses in the log end resulting in less splitting.

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Barnacle and Gottstein, 1968) found that a kerf depth equal to one-third of the log radius to be the most effective, while in South Africa it was found that in the case of *Eucalyptus grandis* a strong interaction exists between groove depth and distance from the cross-cut face. Final results indicated that, to get the maximum reducing effect on splitting, a groove depth equal to one-third of the log radius should be cut at a distance of approximately one-and-half times the log radius from the point where the cross-cut is to be made (Conradie, 1980). Kubler and Chen (1975) found for kerfs of depth one-third of stem diameter, the most effective distance from the end face to be 0,2 to 0,3 times the log diameter.

Apart from using circumferential grooves, the redistribution of growth strains in the log end can also be achieved by cutting grooves in the pith zone of the stem (Kubler and Chen, 1975). In a number of cases this technique showed positive results (Schopfer, 1975; Turnbull, 1965), while other cases it proved to be useless (Liese, 1958).

Tantichaiboriboon and Cook (1977b) investigated the effect of non-axisymmetric cuts which indicated that there are some acceptable angles of oblique cuts that redistribute stresses at log ends resulting in reduced splitting in the exposed end. They also investigated the best cut geometry if radial pressure is applied, for instance by using banding, and found that optimum results can be obtained by using certain combinations of special shaped cuts and banding pressure. Straight cuts, whether the cut is made from one side only (the conventional practice) or whether the cut is made from two sides simultaneously, give the same results. The final stresses are highest when the plane cross-cut is completed.

Mattheck and Walther (1992) developed a special cutting technique for felling trees. The first step in the process involves the cutting of the fairly large felling notch (70-90) in order to prevent the notch faces from crushing while the tree is falling, causing shear stresses that could cause cracks in the stem. The felling notch is followed by a so-called keyhole cut (about the width of chain-saw blade) made from both sides parallel to the notch a few centimetres above the notch. Finally a slanted or oblique cut is used to fell the tree. While the first two cuts minimise the bending moment when the trees falls, the slanted cut reduces the destructive effect of the growth stresses.

The use of metal bands at the points where the cross-cuts are to be made, or the use of gang nails or S- or Chooks immediately after the cross-cut has been made, all proved to reduce the amount of splitting (Tisseverasinghe, 1967; Meyer-Wegelin, 1955; Meyer-Wegelin and Mammen, 1954, de Villiers, 1973; Stubbings, 1973). Unfortunately these techniques can only be applied after the cut when the material has already deformed to some extent. When logs are to be converted, all the mentioned restraining devices have to be removed, causing splits to develop in the usual manner. This shortcoming was overcome with the development of restraining devices made of p.v.C. (Priest, *et al.*, 1985) or the use of nylon straps attached around the stem as close as possible to the cross-cut point (Chardin, *et al.*, 1986).

Through experience, the industry in South Africa has found that preparing Eucalypt sawlogs in the longest lengths that can be handled by extraction equipment, transport and sawmill, and cutting them as soon as possible, result in less splitting and a higher conversion efficiency (Priest *et al.*, 1982).

## Transportation

Split development following cross-cutting progress rapidly in the first three days reaching close to maximum values on about the third day (Malan, 1979b; Bariska, *et al.* 1987). However, split development may continue in logs for a considerable period of time afterwards especially when drying stresses begin to set in (Priest, *et al.* 1982). Results of studies proved that the amount of splitting in sawn boards can be reduced somewhat by sawing the logs as soon as possible after felling.

In view of the effect of felling impacts on split development there can be no doubt that impacts during harvesting, loading, transportation and off-loading at the processing plant, will have an important influence on the condition of the log when finally entering the plant. It may therefore be advantageous to take special measures and precautions to reduce possible damage during the whole process of log

transport; from the moment the tree is felled up to the point when the log is lined up on the infeed system of the breakdown saw.

### **Log storage**

Both Barnacle (1971 b) and Imam and Heikal (1973) have shown that drying stresses interact with the release of growth stresses to produce radial splits in the cross-cut faces. There are lots of evidence indicating that logs that were kept wet during storage, split less than logs allowed to lose moisture from the end surfaces (Turnbull, 1965; Tisseverasinghe, 1967; Barnacle, 1971b; Imam and Heikal, 1972; de Villiers, 1973;) Barnacle (1971b) found that in Eucalypts, superficial drying stresses may develop in less than 20 minutes after cross-cutting and initial cracking, and suggested that end coats should be applied immediately after cross-cutting. Strikha (1955) in fact proved that the retardation of log end drying reduces end-splitting.

Other methods of reducing end-splitting in logs have also been reported, these are: the steaming or heating of logs in a clamped state (Strikha, 1955; Platon, 1959; Kubler, 1965 and 1959; Skolmen, 1967; Gonet, 1973; Okuyama *et al.*, 1987), the storing of barked logs under manure for a few months (Giordano and Currò, 1973), the storing of logs under water sprays or in water (Nicholson, 1973a) and the drilling of a hole in the cross-cut face to remove the central compressed zone in the log end.

Both water and heat aids stress relaxation but even under the most optimum conditions, full stress relaxation is a long process and thus impractical and expensive. Moisture aids relaxation because water molecules between the aggregates of wood molecules weaken the wood's molecular cohesion while heat invigorates molecular motion.

In cases where logs need to be heated prior to processing in any case, such as for veneer peeling or slicing, stresses can be removed very effectively provided log ends are restrained (Margadant, 1981).

### **Sawing methods**

The sawing up of highly stressed logs with a single bladed saw is not recommended. Because of the presence of growth stresses, the portion remaining on the infeed system after removal of the first slab develops a convex bend. Consequently the subsequent boards sawn from the portion will vary in thickness along the length (de Villiers, 1973).

This problem can be overcome by using a log frame saw or double-log-edger in combination with machines such as the deal frame saw or the triple circular saw. These machines make symmetrically placed cuts with reference to the log cross section, thus relieving stresses symmetrically and simultaneously, and so increasing the accuracy of the sawn boards (de Villiers, 1973).

A deal frame saw with the saw blades set in an arc so that the outer blades cut ahead of those in the centre of the frame, was found to produce an increased yield of 11 % over that of a deal frame saw with blades set in a straight line (Priest, *et al.*, 1984.)

As far as seasoning is concerned, splits rarely extend more than 200 mm during the seasoning process. Some researchers feel that boards should not be dried unedged because the edger removes the outer parts where the highest tensile strength exists. Unfortunately, a certain proportion of edged boards will develop end splits and spring during seasoning, requiring trimming and edging again afterwards. On the other hand, by seasoning unedged and untrimmed boards first, a certain amount of kiln space is wasted, and there appears to be a lower total yield of sawn timber although handling costs are lower.

### **Predicting growth stress levels**

Attempts have been made to relate tree characteristics to stress levels in tree stem but these were unsuccessful (Malan, 1988c). Some relationships were found between growth stresses and wood properties (Malan and Gerischer, 1987), but they were not strong enough for predictive purposes.

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Attempts were made to develop a non-destructive method to screen trees effectively for growth stresses at the earliest possible stage of tree growth, using wood and/or tree features as indirect indicator(s) (Malan and Hoon, 1992a).

Eight families were selected from an open-pollinated trial consisting of 99 families. Four of these families performed exceptionally well as individual trees as well as families (containing low levels of growth stress) while the other four performed exceptionally poor on the same basis. Trees from these families were cloned and established in replicated field trials at two diverse sites.

Trees were sampled at the age of 1, 2 and 5 years to study the inter-relationship between growth stresses and wood and tree properties.

Differences between clones were found highly significant for diameter at breast height, tree height, stress level and wood density, confirming the fact that these features are highly heritable but no relationship could be found between stress levels and the properties of the tree or its wood.

No difference in the chemical and pulping characteristics could be found between the different clones.

### **Assessing growth stress levels in trees**

Assessment of stress levels by using the amount of end splitting in logs as an indirect measure is very time consuming, destructive and not very useful on young material. Furthermore, end split measurement is only an indirect measure of stress levels and could be affected by factors other than growth stresses, i.e. the trees' inherent capability to resist splitting.

In 1971 Nicholson developed a technique for the rapid measurement of growth strains on the periphery of tree stems. A highly sensitive mechanical strain gauge was used to measure strains. After fixing gauge points onto the surface of the stem and setting the strain gauge, stress relief to allow surface strain was obtained by removing a rectangular segment from the surface containing the gauge points. From these strain measurements growth stresses could be determined since, within the elastic limit of wood, growth strains are directly related to growth stresses.

This technique is almost non-destructive and the amount of strain was found to correlate well with the amount of splitting in the logs cut from the stem.

In 1984a Malan used a technique based on the same principle to measure surface strain in standing *E. grandis* trees. This technique was even less destructive since, instead of removing a segment from the stem, longitudinal stress relief was effectuated by drilling holes into the stem on either side of the area prepared for strain measurement. Despite the small number of readings taken, a reasonably good relationship was found between the average strain measured on the surface of the stem as measured at mid-point along the length of logs and the amount of splitting.

Since the degree of splitting, as measured at various high levels in the tree, correlates positively with one another (Malan, 1984a), it can be expected that strain measurements carried out at breast height could be used to assess the growth stress levels in that tree and of course the amount of splitting that would develop in its logs.

Since Nicholson, a number of techniques have been developed based on the principle of measuring surface displacement (Malan, 1984a; Bailléres, H., *et al.*, 1992); Krilov, 1991 a and b). All these researchers found a very good relationship between surface strain and the level of stress in the tree.

### **GENOTYPE BY ENVIRONMENTAL EFFECTS ON THE WOOD PROPERTIES OF *Eucalyptus grandis***

The effect of environment on growth stress splitting, wood density, fibre length, shrinkage and heartwood content was studied using 31 five-year-old eucalypt clones, mostly *Eucalyptus grandis* and *E. grandis* - based hybrids, grown in replicated trials at 26 sites (Malan, 1994). To study genotype by environment interaction, a statistical method described by Finlay and Wilkenson (1963) was followed.

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The regression coefficients that resulted from the analyses indicated that genotype-by-environment interaction does exist for some clones and is applicable to all the wood properties considered. A wide variation was evident in both the site means and sensitivity to environmental changes.

In the case of splitting, 16 of the clones were characterised by regression coefficients of 1,2 and more, in other words they showed some sensitivity to the environment. In general splitting showed significant negative correlations with latitude and longitude, which confirmed previous results that trees from the Zululand sites split less than those from the Transvaal sites.

In the case of density, 8 clones showed some sensitivity to the environment. Apart from the annual rainfall, no other site factors had any effect on the mean site wood density. A correlation study indicated that mean site wood density decreases as the annual rainfall increases. Density showed no correlation with volume growth, however.

Fibre length correlated positively with annual rainfall but other site factors had no significant effect. Eight clones indicated some sensitivity to environmental influences with regression coefficients varying from about 1,2 to 1.7. As far as most other clones are concerned the regression coefficients varied within very narrow limits (from about 0,7 to 1,2).

Both radial and tangential shrinkage correlated significantly and positively with altitude. Since no significant influence of latitude, longitude or volume growth could be detected it can be concluded that height above sea level is the main controlling factor. The radial shrinkage of ten clones was found to be sensitive to site, but in the case of tangential shrinkage, only five clones were found to be sensitive to changes in environment. Only three clones were common to both sets.

Heartwood content did not show any strong correlation with any site factor but the proportion of heartwood was larger in faster growing trees. Judging from the regression coefficients done stability varied from average to above average.

### ***Eucalyptus grandis* - BASED HYBRIDS**

Limited forest land and a growing demand for forest products in South Africa is placing an ever-increasing pressure on the forest industry to produce more timber, to improve quality and to adapt to the changing quality requirements of the wood processing industry. Research has indicated that the productivity of forest land can be greatly improved through sound silvicultural practices, or by using clones from suitable genotypes, or a combination of the two.

Many eucalypt species, such as *Eucalyptus tereticornis* and *Eucalyptus camaldulensis*, which are known to be adaptable to drought and cold conditions, grow extremely slowly and their wood is not suitable for most end-uses. *Eucalyptus grandis*, on the other hand, grows fast on good soils but is less resistant to drought and cold and the wood is often of low density and consequently low in strength.

Although the cultivation of hybrids in South African forestry is still in its infancy, recent results have indicated that the potential of hybrids are very encouraging (Pierce, 1991). There is good reason to believe that hybrids will grow in importance in South African forestry.

Crosses of *Eucalyptus grandis* with *Eucalyptus tereticornis*, *Eucalyptus camaldulensis* and *Eucalyptus urophylla* have been found to perform well on sites not recommended for *E. grandis*. Studies have shown that these hybrids are very adaptable to poor sites and that they out-perform *E. grandis* on the same sites (Van Wyk, 1987; Van Wyk, *et al.*, 1988; Pierce, 1991).

To study the wood properties and qualities of eucalypt hybrids, sample material of the hybrids listed earlier was drawn from six trials established on diverse marginal sites to test the performance of various hybrids under site conditions normally not very suitable for *E. grandis* planting (Malan, 1993). *E. grandis* trees were used as control.

Aspects that were examined included split development and behaviour due to growth stresses, differences and variation patterns in density, collapse, fibre length, vessel properties, sapwood width, splits and checks, and preservative penetration and retention characteristics.

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Due to the diversity in site conditions, among site differences in the growth rate of the hybrids investigated were highly significant.

No effect of site on splitting due to growth stresses could be found but growth stress splitting varied significantly among hybrids. *E. grandis* x *E. urophylla* developed less end-splitting than the other two hybrids and *E. grandis*.

On average, trees from good sites tended to produce wood of higher density than those from "slow-growing" sites but no direct relationship between growth rate and wood density was found. All hybrids exhibited density values which are more acceptable than the densities of the species used in the crosses; not too low as it is often the case in young *E. grandis* or too high as in the case of *E. camaldulensis* and *E. tereticornis*.

No important differences in fibre length could be found among the hybrids and *E. grandis*, suggesting that paper properties determined by fibre length will be largely similar. However, paper properties determined by other fibre morphological properties, such as wall thickness, lumen and fibre diameter, and fractional wall volume, will probably differ as these properties are strongly related to wood density (Malan, 1991a; Taylor, 1974). Sites appeared to have a very strong effect which may point to some genotype/environmental effect. Inter-site differences in fibre length could not be explained in terms of growth rate.

Differences in radial and tangential shrinkage between hybrids were small and of little practical significance, but in general, trees from the good sites exhibited lower shrinkage values which appeared to be related to growth rate.

*E. grandis* x *E. tereticornis* most often presented difficulty with bark stripping, but this varied from site to site with no link with any particular clone.

In general, *E. grandis* x *E. urophylla* exhibited significantly less splitting and checking during drying in the round. Differences between sites were found with regard to the width and length of surface checks, with the most severe surface checking in poles from the two north-eastern Transvaal sites.

Although the effect of site and hybrids was significant for some of the vessel properties, these effects were generally small and of little practical significance.

*E. grandis* x *E. tereticornis* showed the highest preservative retention, most probably due to the fact that this hybrid also had the largest proportion of sapwood.

Preservative retention also tended to be positively related to variables that concern splitting and checking. This is to be expected, of course, as these features increase the exposed area and number of passages for the preservative to penetrate into the wood.

Wood density had a strong adverse effect on all preservation characteristics since increased wood density decreases the ability of preservatives to penetrate wood readily. Differences in sapwood width and vessel properties had no effect on the depth of penetration or the proportion of the cross-sectional area penetrated with preservative.

This study indicated that there can be no doubt as to some possible site effects on some wood properties and qualities, but no conclusive evidence could be found to suggest that the differences observed were due to different growth rates that occurred among the six sites sampled.

## **CONCLUSIONS AND RECOMMENDATIONS**

In the South African tree breeding programme remarkable progress has been made in breeding for improved growth rate, stem form and straightness, better adaptability, and better branch and crown properties. Although these improvements were not directly aimed at the quality of the wood itself, it certainly has led to improvements in some qualities of the wood.

Wood varies from tree to tree as well as within individual tree stems. In South African commercial species radial variation is by far the most important source of variation. The extent of this variation is mainly determined by the presence of juvenile wood, its relative proportion in the stem at the time of felling, its characteristics and the steepness of the variation gradients within the juvenile zone.

#### ***EUCALYPTUS IMPROVEMENT FOR LUMBER PRODUCTION***

Research is needed to increase our fundamental knowledge on the variation of the properties of juvenile wood, to what extent these properties are controlled by genetic factors and other wise, and how radial gradients within the juvenile core and the size of the core itself can be reduced.

An important factor in fast growing stands, however, is the quality in the juvenile wood. South Africa already has a severe uniformity problem as a result of our relatively short rotation ages and the resultant large proportion of juvenile wood. This may deteriorate even further in future generations as trees are bred to grow faster.

Many important wood properties such as density is known to be controlled mainly by hereditary factors suggesting that there might be a high potential for manipulating this property through genetic means. However, little is known about how the heritabilities of juvenile properties change with age, and to what extent the size of the juvenile core is determined genetically.

High levels of growth stress in South African eucalypts are undoubtedly the most serious growth phenomenon affecting wood quality, product yield and product dimensions. A reduction in stress levels in tree stems would certainly be by far the most important improvement that can be made regarding many eucalypt species, as the impact on our wood processing industry will be impressive.

Many attempts have been made to find a short-term technique to reduce the level of growth stress in trees or to minimize its effect but none of them have met with much success. However, existing evidence indicates that tree breeding most probably constitutes the most promising, if not the only, solution to the problem of high growth stress levels in trees as studies have shown that this phenomenon is highly heritable. Impressive results can therefore be expected through the use of genetic techniques aimed at reducing growth stress levels.

The incidence of brittle heart in *E. grandis* is a common problem experienced especially by hardwood sawmillers and is probably the result of the accumulative build-up to compressive stresses in the central part of the growing stem as a result of growth stresses combined with low wood density in that part of the stem. Since studies have indicated that brittle heart is almost exclusively confined to the low density central core of the stem, it can be expected that an improvement programmed aimed at reducing the level of growth stress in trees, combined with selection in favour of higher core density, would not only result in more uniform wood and less splitting but also a lower incidence of brittle heart.

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