Project No. PN02.1308 Resource Characterisation & Improvement

Australian Government

Forest and Wood Products Research and Development Corporation

Sawing Regrowth and Plantation Hardwoods with Particular Reference to Growth Stresses Part A Literature Review

Australian Government
Forest and Wood Products Research and Development Corporation

Publication: Sawing Regrowth and Plantation Hardwoods with Particular Reference to Growth Stresses Part A Literature Review

Project no. PN02.1308

Researchers:

R. de Fégely, Jaakko Pöyry Consulting
Suite 902, 492 Kilda Road, Melbourne, Victoria 3004
Tel +61 3 9867 2700 Fax +61 3 9867 2744

Forest and Wood Products Research and Development Corporation
PO Box 69, World Trade Centre, Victoria 8005
Phone: 03 9614 7544 Fax: 03 9614 6822 Email: info@fwprdc.org.au
Web: www.fwprdc.org.au

Sawing Regrowth and Plantation Hardwoods with Particular Reference to Growth Stresses
Part A Literature Review

Prepared for the

Forest & Wood Products
Research & Development Corporation

by

R. de Fégely

The FWPRDC is jointly funded by the Australian forest and wood products industry and the Australian Government.

TABLE OF CONTENTS

GLOSSARY AND DEFINITIONS **II**

EXECUTIVE SUMMARY **III**

1. INTRODUCTION **1**

2. THE NATURE OF GROWTH STRESSES **3**

3. MANIFESTATIONS OF GROWTH STRESSES **10**

4. METHODS OF REDUCING THE UNDESIRABLE EFFECTS OF GROWTH STRESSES **16**

5. TYPES OF SAWMILLING EQUIPMENT AND THEIR EFFECTIVENESS IN CONTROLLING WARPING AND SPLITTING. **22**

6. REFERENCES **31**

Figures

Figure 2-1:	Simplified distribution of growth stresses in a tree	7
Figure 2-2:	The effect of diameter on stress gradients in a tree	8
Figure 3-1:	Traditional sawing with a bandsaw and a sequence of parallel cuts	12
Figure 5-1:	A traditional sizing carriage where the distance between the carriage head and the saw determines the size of cut	23
Figure 5-2:	Diagram of 300 mm diameter log on headsaw carriage, showing small and large-end location for taper sawing and proposed sawing pattern on log small-end	23
Figure 5-3:	Resawing strategy for a back-sawn slab from 300 mm diameter log	25
Figure 5-4:	A linebar carriage which sizes between the saw and the linebar	25
Figure 5-5:	Representation of a linebar operation showing systematic manipulation of head pressure to ensure sawline follows distortion present in log	26
Figure 5-6:	Diagrammatic representation of 300 mm diameter log being sawn on log edger system, showing log end view, small and large end diameters, end-dogging and sawing pattern and remaining log section end view following turning	28
Figure 5-7:	Spring caused by simultaneous ripping with a multi-saw edger	29

Glossary and Definitions

MOE	modulus of elasticity
Hooke's Law	Stress is proportional to strain for any elastic material subject to stress within its elastic limit
Basic density	The density of wood determined from its oven dry mass and its green or water soaked volume. It is commonly expressed in g/ml or kg/m^3
Stress	Stress is the resistance a body offers to changes of shape or volume and is measured as the ratio of the force with which the body resists the deformation to the area over which the force is exerted.
Strain	A strain is any change of volume and/or shape in a body as a result of stress and is measured by the relative deformation of the body eg the ratio of the change in volume to the original volume
Brittleheart	Brittleheart is corewood which has deteriorated under compression stress during growth of a tree because of minute transverse fractures in the fibre walls
Heart shakes	Heart shakes are star shaped cracks in the core of a tree running up the tree due to the relief of radial tension and longitudinal compression stress near the pith. The first relief of stress results in a longitudinal crack across the inner diameter. As further stress develops, another crack develops at right angles to the first. This process may continue to form a typical star shape with the widest cracks in the centre, tapering gradually towards the sapwood.
Strength group	A system of strength grouping for wood has been established by CSIRO Australia in which a species is assigned to one of seven or eight strength groups depending on whether it is being used green or seasoned. Grouping is based on minimum standard test values of small clear samples for bending strength (modulus of rupture), stiffness (modulus of elasticity) and compression parallel to the grain (maximum crushing strength).

EXECUTIVE SUMMARY

Introduction

There are large areas of eucalypt plantations around the world, many of which were originally established for the production of short fibre pulpwood, mining timbers and fuelwood. In some regions there is a realisation that these plantations can produce log products with values higher than pulpwood and this, combined with the perception that sawn timber from plantations is environmentally a better product than that from native forests, has generated a push towards using eucalypt plantations as a source of sawn timber. Additionally, in Australia, we have extensive areas of native regrowth forests, mainly various species of eucalypt, which have been, and will continue to be used for producing sawn timber.

Regrowth wood and, even more so, plantation grown wood may differ markedly in its properties from old growth wood. Problems associated with severe growth stresses in regrowth and plantation wood have important implications for sawn timber production, particularly of the higher grades. This review of the literature will deal with growth stresses under three major headings:

- The nature of growth stresses
- Manifestations of growth stresses
- Methods of reducing the undesirable effects of growth stresses

The nature of growth stresses

Growth stresses are characteristic of normal growing trees and occur in both hardwoods and softwoods. In softwoods, they are usually not troublesome. However, longitudinal growth stresses can be very important in hardwoods and are largely determined by wind; the stresses in the trunk caused by the dead weight of the tree are small by comparison.

Growth stresses cannot be measured directly. Commonly, (by using Hooke's Law), they are estimated as the product of experimental strain measurements and modulus of elasticity (MOE) in compression. Surface strain is commonly measured by removing a shallow rectangular section of wood or drilling a shallow circular hole in the wood of a standing tree or log after removing the bark. The release of tension stress in the cut fibres causes the fibres to contract longitudinally, a contraction, which can be measured very accurately

No matter how accurately this contraction can be measured, the assumed measurement of strain does not necessarily lead to a precise estimate of stress, partly because one must assume some process which trees have undergone and then recover information about that process by measuring dimensional changes after removing very small pieces from each tree; partly because wood is a highly variable material in factors such as its microstructure, its grain orientation, the distribution of its anatomical elements, its basic density, and its MOE, all of which are closely related to growth strains. Nonetheless, the measurement of strain to determine stress can give valuable comparative data and as a predictive tool.

Growth stresses are initiated during the development of the secondary wall of fibres. Lignin is deposited between microfibrils in the wall causing transverse expansion and longitudinal contraction. The greater rigidity of the nearby and already differentiated fibres restricts the extent of contraction so that a longitudinal tension stress develops. As long as a stem shows linear elastic behaviour, the stress increments caused by each new growth increment are superimposed at the periphery of the stem. Thus, the total stress at the periphery is cumulative. However, as this tension stress is continuously generated within successive layers of newly formed cells as the tree grows, it is progressively offset by compression stress in the core. Compression stresses in the corewood can progressively impose a theoretical load greatly exceeding the elastic limit of wood in longitudinal compression, giving rise to minute transverse fractures in the cell walls and the formation of brittleheart.

Measurements of longitudinal growth stresses vary greatly, e.g. in a moderately leaning tree from as little as 1.86 MPa on the underside of the lean to as much as 47.85 MPa on the topside. Straight trees have much less variation, although the variation in mean stress from tree to tree may be high, e.g. from 4.90 to 15.10 MPa.

Transverse growth stresses also occur. They are much less than the longitudinal stresses eg from 0.69 to 2.48 MPa but have been suggested as one of the causes of heart shakes in standing trees.

Conventionally, the distribution of longitudinal stress across a tree trunk is depicted as symmetrical, from maximum tension stress at the periphery, passing through a stress free layer to maximum compression stress at the boundary of the corewood where brittleheart begins. This is a simplification of what actually occurs; the distribution of stresses is not symmetric and there are many variations caused by a number of factors, which are listed in the review.

The average stress is also commonly regarded as little affected by the diameter of the tree so that the stress gradient becomes an inverse function of the diameter of the tree and the smaller the diameter the steeper the stress gradient. This is another simplification of what actually occurs. The experimental data regarding the relationship between growth stress (as determined by measurements of strain) and tree diameter in eucalypts are conflicting.

Notwithstanding some conflicting experimental data and uncertainty in our fundamental understanding of the ultimate causes of growth stresses, we do have a good understanding of their effects.

Manifestations of growth stresses

In sawmilling there are four important manifestations of growth stresses, which can cause substantial reductions in the recovery of sawn timber and/or decreases in productivity. These are:

- End splitting of trees and logs.
- Warping of wood during rip-sawing, mostly in the form of bow or spring, sometimes accompanied by splitting.
- Pinching or binding of saws during rip-sawing and crosscutting.
- Brittleheart.

Methods of reducing the undesirable effects of growth stresses

These are described and discussed according to the manifestations of growth stresses during conversion from the standing tree in the forest to the production of sawn timber in the mill.

How to reduce end splitting of trees and logs is discussed under the following categories:

- Reducing stress levels in standing trees by direct intervention, e.g. by girdling or using defoliant sprays some months before felling.
- Reducing stress levels in standing trees by genetic manipulation, e.g. by tree breeding, hybridisation and clonal selection.
- Reducing growth stresses in standing trees by silvicultural manipulation, e.g. by determining optimal thinning regimes and extending the rotation to grow bigger trees, and by growing multi-storey rather than single storey forests.
- Reducing end splitting in felled trees and logs in the forest by mechanised felling, better felling and crosscutting techniques with chainsaws, and by applying mechanical constraints such as metal bands, S or C hooks and PVC rings.
- Reducing end splitting in felled trees and logs during transport and mill storage by ensuring trees or logs are cut to as long a length as possible consistent with the machinery available, log truck configuration, and transport regulations; and by handling them as gently as possible to avoid impact damage.

- Reducing splitting during storage in mill yards by storing under water sprays and by milling logs as soon as possible after crosscutting, e.g. less than 4 hours.

Types of sawmilling equipment and their effectiveness in controlling warping and splitting are described and discussed under the following categories:

- Single saw headrig with a conventional sizing carriage.
- Single saw headrig with a line-bar carriage.
- Twin log edgers.
- Resaws and edgers.

Grade sawing, dimensional accuracy and control of warping can be achieved using appropriate equipment and sawing patterns and, because of the relative uniformity of plantation eucalypts, mass production may be possible in the future through the introduction of programmed sawing systems

1. INTRODUCTION

There are large areas of eucalypt plantations around the world, many of which were originally established for the production of short fibre pulpwood, mining timbers and fuelwood; the latter either as solid wood (sometimes hogged or chipped for industrial use) or as a feedstock for charcoal. In some regions these plantations have the potential to produce other products and this, combined with the perception among some that sawn timber from plantations is environmentally a better product than that from native forests, has generated a push towards using eucalypt plantations as a source of sawn timber. Additionally, in Australia, we have extensive areas of native regrowth forests, mainly of various species of eucalypt, which have been and will continue to be used for producing sawn timber.

Commercially important hardwood plantation species in Australia are shining gum (*Eucalyptus nitens*), southern blue gum (*E. globulus*), blackbutt (*E. pilularis*), flooded gum (*E. grandis*) and mountain ash (*E. regnans*). Other species may come into prominence as more is known about their growth and wood characteristics when grown in plantations such as sugar gum (*E. cladocalyx*) and spotted gum (*Corymbia maculata*).

Commercially important regrowth species include blackbutt, flooded gum, spotted gum, silvertop ash (*E. sieberi*), mountain ash, alpine ash (*E. delegatensis*), messmate stringybark (*E. obliqua*), jarrah (*E. marginata*), and karri (*E. diversicolor*).

Mountain and alpine ash from Victoria are marketed together as Victorian Ash. Mountain and alpine ash and messmate stringybark from Tasmania are marketed together as Tasmanian Oak. However, messmate stringybark is the dominant species in this group, about 70% of the total.

The species listed in the terms of reference for the study are as follows:

- Jarrah (Western Australia)
- Blackbutt (Queensland and New South Wales)
- Spotted gum (Queensland and New South Wales)
- Victorian Ash
- Tasmanian Oak.

Regrowth wood and, even more so, plantation grown wood may differ markedly in their properties from those of wood from mature trees. Studies of structural timber, for example, sawn from 1939 regrowth mountain ash in five localities in Victoria gave an overall strength group of S5 (unseasoned) and SD5 (seasoned) while mature mountain ash is S4 and SD3 (Shwe Thein 1988). There are also problems associated with growth stresses in regrowth and plantation wood, which

have important implications for sawn timber production, particularly of the higher grades, and which are the major concern of this literature review.
The review has been divided into three main sections under the following headings:

- A discussion of the nature of growth stresses
- A description of the manifestations of growth stresses in trees, logs and sawn timber
- Methods by which the undesirable effects of growth stresses can be reduced

Each of these sections will have a brief conclusion.

2. THE NATURE OF GROWTH STRESSES

Growth stresses are characteristic of normal growing trees and occur in both hardwoods and softwoods. In softwoods, they are not troublesome except where there is a lot of compression wood. However, longitudinal growth stresses can be of critical importance in hardwoods. These longitudinal stresses are, to an important extent determined by wind (Haslett 1988, Banks 1973); the stresses in the trunk caused by the dead weight of the tree are small by comparison (Banks 1973). The longitudinal stress at the periphery "pre-stresses" the tree to counteract compression stresses induced by wind forces on the leeward side of the tree (Kubler 1959). When the wind drops and the tree "springs back", the same effect will occur on the erstwhile windward side of the tree. Since wood is weaker in compression than in tension, by pre-stressing their outer wood in tension, hardwood trees have evolved an efficient engineering solution to supporting themselves structurally.

Trees may alter their pattern of stress to achieve small changes in vertical orientation and to attain a particular crown position in the forest (Nicholson et al. 1975), presumably to ensure they can be as competitive as possible.

Growth stresses cannot be measured directly. Commonly they are estimated as the product of experimental strain measurements and modulus of elasticity (MOE) in compression, preferably determined from samples end matched to where the strain measurements are made (Nicholson 1973a). The formula is derived from Hooke's Law that stress is proportional to strain for any elastic material subject to stress within its elastic limit. . One method of measuring surface strain in a particular part of a tree is to remove a rectangular piece of bark 100mm long in the fibre direction and 30mm wide across the fibres. Two reference points are then marked at either end of the exposed surface and the distance between them measured as accurately as possible. Then a rectangle of wood 90mm*20mm is removed to a depth of 10mm. The release of tension stress in the cut fibres causes the fibres to contract longitudinally, a contraction, which again must be measured very accurately by measuring the increased distance between the two reference points. The strain is then determined as the ratio of the difference between the distance between the two reference points before and after cutting out the rectangle of wood and the original distance between the reference points. As the strain is relieved in the rectangle of wood it, normally, becomes a little shorter. The proportional change in its length can also be used as a measure of the surface strain at that part of the tree (Jun Li Yang 2002). Strain is also commonly measured by drilling a hole or holes in the wood of a standing tree or log after removing the bark and using the difference in distances between two reference points before and after drilling as a measurement of strain. Thus, measuring stress in trees differs from measuring stress in a beam in which differing known loads can be applied and the resulting strains or deflections determined. In trees, one must assume some process, which they have undergone, and then recover information about that process by measuring dimensional changes after removing very small pieces from each tree (Archer 1987). No matter how accurately the dimensional change, in this case contraction, can be measured, the measurement of strain does not necessarily lead to a precise estimate of stress, partly because of the above and partly because wood is a highly variable material in factors such as its microstructure (including microfibril angle), its grain orientation, the distribution of its anatomical elements, its basic density, and its MOE, all of which are closely related to growth strains (Archer 1987). Nonetheless, the measurement of strain to determine stress can give valuable comparative data and can be used as a predictive tool.

Growth stresses have also been analysed mathematically, based on structural theory and some experimental results (Archer 1987), but the steps in many of the analyses are difficult to follow. Furthermore, the results are by no means conclusive and further theoretical and experimental research is needed to help in resolving the practical problems of how to deal with growth stresses in the sawmilling industry.

The first important Australian work published on growth stresses (Jacobs 1938) stated in its Foreword that "The subject, fibre tension, is not touched upon in available botanical literature" so we can take this study as a useful starting point. Growth stresses in woody stems arise from fibre tension in that "successive layers of growth differentiate in slight longitudinal tension, and are held stretched by the inside core. As a result of this a radially cumulative tension is built up which imposes an equal compression on the heart". This explanation is difficult to understand in a fundamental way and raises the question as to what causes fibre tension during growth and why the cumulative effect is such that growth stresses are a permanent feature of standing trees. Further work (Boyd 1950a, Nicholson et al. 1972) took the understanding of this issue a stage further by proposing that growth stresses are initiated during the development of the secondary wall of fibres. Lignin is deposited between microfibrils in the wall causing transverse expansion and longitudinal contraction. The greater rigidity of the nearby and already differentiated fibres restricts the extent of contraction so that a longitudinal tension stress develops. As long as a stem shows linear elastic behaviour, the stress increments caused by each new growth increment are superimposed at the periphery of the stem. Thus the total stress at the periphery is cumulative. However, as this tension stress is continuously generated within successive layers of newly formed cells as the tree grows, it must be progressively offset *pari passu* by compression stress in the core.

There was also a significant change in the qualitative estimates of how much fibre tension occurred during growth and a quantitative estimate was given in later work (Jacobs 1965). "Along the longitudinal axis of the trunks of broadleaved trees successive sheaths of cells mature in a state of strong longitudinal tension. In the case of alpine ash the stress averages 1200 psi (8.273 MPa), a very considerable force". Tension stresses must be balanced by equal compression stresses in the corewood, which it is claimed (Jacobs 1965), can progressively impose a theoretical load greatly exceeding the elastic limit of wood in longitudinal compression. For a 300 mm diameter tree, this theoretical load for alpine ash is 7950 psi (54.813 MPa). The estimated maximum crushing strength of green alpine ash is 33 MPa (Bootle 1983).

Later work (Nicholson 1973a) based on an average MOE of 2×10^6 psi (13.790GPa) estimated mean stress levels at the periphery of 18 freshly cut mountain ash logs of 1200 to 1340 psi (8.273 to 9.239 MPa) and in 10 standing trees of the same species of 1300 psi (8.963 MPa).

Transverse growth stresses also occur (Jacobs 1945, 1965). They are less than the longitudinal stresses, e.g. from 100 to 360 psi (0.689 to 2.482 MPa) but have been suggested as one of the causes of heart shakes in standing trees. Heart shakes are star shaped cracks in the core of a tree running up the tree due to radial tension and longitudinal compression near the pith (Dinwoodie 1966). The first relief of stress results in a longitudinal crack across the inner diameter. As further stress develops, another crack develops at right angles to the first. This process may continue to form a typical star shape with the widest cracks in the centre, tapering gradually towards the sapwood.

In most cases, growth stresses appear to be associated with the presence of tension wood although fundamental relationships between the two do not seem to have been investigated and severe growth stresses can occur without the presence of tension wood. However, it can affect sawmilling through its interaction with growth stresses. Tension wood is a reaction wood of hardwoods, often characterised by gelatinous fibres, and generally occurs in discrete bands in the lower 30% of tree height, surrounded by normal wood (Washusen 2002). Its extent increases towards ground level.

Conventionally, the distribution of longitudinal stress across a tree trunk is as shown in Figure 2-1. This is a simplification of what actually occurs; the distribution of stresses is not symmetric and there are many variations caused by a number of factors including:

- The direction of the prevailing wind and the consequent lean of the tree.
- The diameter, straightness and form of the bole.
- The extent to which the lean and straightness have been modified by laying down of reaction (tension) wood or of additional normal wood to give additional strength.
- The extent to which some fibre separation has already occurred in the standing tree, e.g. star and ring shakes, the presence of pockets or veins of kino, and slip planes.
- The spatial relationship of trees within the forest.

- The distribution of large and small branches, i.e. crown shape and the positioning of the crown within the forest.
- The extent of brittleheart and wandering heart.
- Genetic variation.

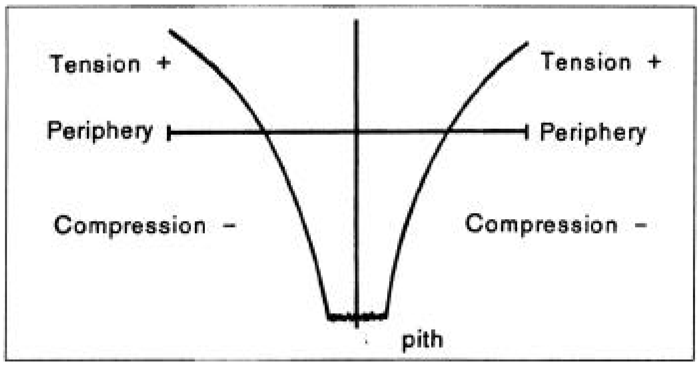
Many of the above factors are interrelated.

Moderately leaning to nearly vertical trees and trees with variously balanced crowns showed substantial differences in stress distribution (Nicholson 1973a). For a moderately leaning mountain ash (31 years old), for example, the tensile stress on the underside of the lean was 270 psi (1.862 MPa); on the topside 6490 psi (47.850 Mpa). In straight trees, tensile stress is much more evenly distributed. The stress variations in leaning trees are an effective way of generating a large restoring moment to counter the moment exerted by the offset crown. The mean level of longitudinal stress however, did not appear to be a function of tree straightness. Some very straight trees had low mean stress values while others had high, varying from 710 to 2190 psi (4.895 to 15.100 MPa) for trees growing in the same stand.

In another series of studies, again in mountain ash (Nicholson et al. 1975), the average level and range of stress was greater in three trees severely bent to a height of 4 to 6 m compared with six straight trees with variable lean (up to 2 m offset for trees about 40 m high) and one tree with pistol butt in the first 1.5 m.

Some abnormalities in the shape of the transverse section of the bole, in particular eccentric radial growth, have been associated with longitudinal growth stresses in leaning trees and the formation of reaction wood. However, these relationships have been questioned (Nicholson et al. 1975, Robards 1965, Wardrop 1964). The first study cited indicated that, of the ten trees studied, all had eccentric stem sections and that longitudinal stress was positively correlated with eccentricity in three cases, negatively correlated in another three, and not at all correlated in the remaining four.

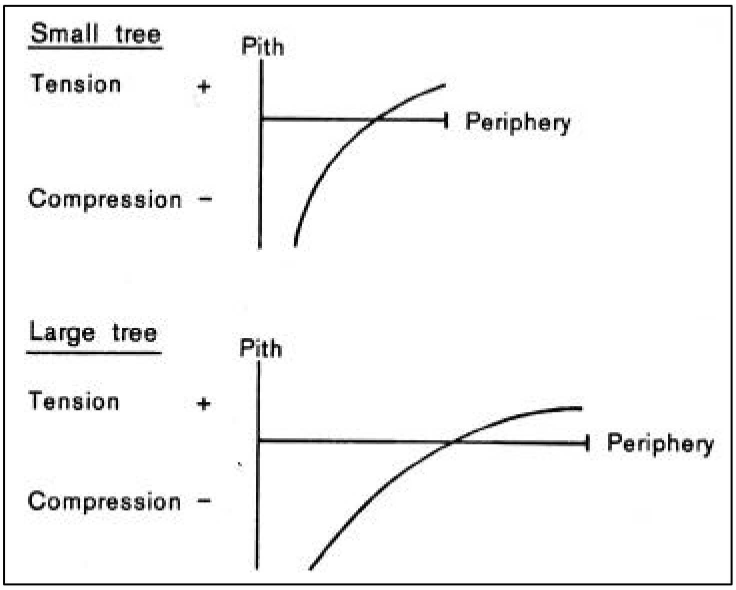
Figure 2-1:
Simplified distribution of growth stresses in a tree



Source: Haslett A.N. 1988.

Figure 2-1 shows a simplified distribution of stresses within a tree trunk and illustrates how the type of stress changes from tension in the outer part of the trunk to compression in the inner part passing through a stress free “ring” at about one-third to one half the distance from the periphery to the centre. The average level of stress may be little affected by the diameter of the trunk; however, the amount of stress at any part of the trunk is affected. As the diameter increases, the stresses are spread over a larger area and the stress gradient decreases, i.e. there is an inverse relationship between the stress gradient within the tree and its diameter (Figure 2-2) (Jacobs 1945, Boyd 1950b).

Figure 2-2:
The effect of diameter on stress gradients in a tree



Source: Haslett A.N. 1988

The experimental data regarding the relationship between growth stress (as determined by measurements of strain) and tree diameter in eucalypts are conflicting. In some, significant positive relationships have been shown (Muneri et al. 2000, Chafe 1995), in others the opposite (Muneri et al. 1999, Wilkins and Kitihara 1991a). In the latter study, there was a strong negative correlation between growth stress and diameter for trees sampled across four silvicultural treatments, but no significant correlation within each treatment. In another study (Wilkins and Kitihara 1991b), peripheral longitudinal growth strain was not related to the diameter of fifty trees but there was an inverse relationship between the stress gradient within each tree and its diameter. This supports Figure 2-2. At the practical level, sawmillers claim that larger diameter logs usually have less growth stresses than smaller diameter logs. This will be investigated in the next stage of this project.

Conclusions

It must be emphasised that growth stresses are characteristic of normal growing trees and occur in both hardwoods and softwoods. Longitudinal growth stresses can be of critical importance in hardwoods particularly for the sawmilling industry.

Growth stresses cannot be measured directly. Using Hooke's Law they are estimated as the product of experimental strain measurements and modulus of elasticity (MOE) in compression. However, experimental techniques vary so that different research workers may come up with significantly different results. Furthermore, no matter how accurately dimensional changes can be measured; the assumed measurement of strain does not necessarily lead to a precise estimate of stress. Many assumptions are made with respect to the distribution of growth stresses within a tree, which we know are not correct, e.g. the assumption that stress gradients are symmetrically disposed around a perfectly cylindrical tree Nonetheless, the measurement of strain to determine stress can give valuable comparative data and as a predictive tool. Growth stresses have also been analysed mathematically, based on structural theory and some experimental results. The results are by no means conclusive and further theoretical and experimental research is needed to resolve the practical problems of how to deal with growth stresses in the sawmilling industry.

Notwithstanding an insufficient theoretical understanding based on rigorous mathematical analyses, conflicting experimental data, and uncertainty in our fundamental understanding of the ultimate causes of growth stresses, we do have a good understanding of their effects.

3. MANIFESTATIONS OF GROWTH STRESSES

In sawmilling there are four important manifestations of growth stresses, three of which can cause substantial reductions in the recovery of sawn timber. These are:

- End splitting of trees and logs.
- Warping of wood during sawing, mostly in the form of bow or spring, sometimes accompanied by splitting.
- Pinching or binding of saws during rip-sawing and crosscutting.
- Brittleheart.

End splitting of trees and logs:

Trees may split at the butt end immediately after felling in response to the release of growth stresses. The splitting may be aggravated by pre-existing shakes within the tree, by poor felling technique, e.g. inadequate or poorly profiled scarf, back-cut poorly positioned in relation to the scarf, and poor control of felling direction so that the forces generated on impact are greater than they need to be, e.g. trees hitting rocks or fallen logs. If the angle of the scarf is such that the top of the scarf meets the bottom before the tree has begun to break away from the hinge compression and shear stresses will be imposed on the tree above the scarf and shear stresses above the back-cut (Mattheck and Walther 1992), which could aggravate the tendency to split.

Trees may not split immediately after felling but do so later, usually within a week, either during transport or storage.

Logs may split after crosscutting the tree either in the forest or at the mill. If splitting is going to occur, it progresses rapidly, reaching close to maximum values in about three days (Bariska et al. 1987). Trees of mountain ash, mountain grey gum (*E. cypellocarpa*), silvertop ash (*E. sieberi*), and shining gum having butt diameters less than about 400 mm could be felled on to even ground and subsequently crosscut without risk of splitting, provided they did not strike any hard objects on the ground (Barnacle 1970). However, when trees greater than 450 mm butt diameter were cut so they could fall freely on to even ground, splits described as chordal fractures and felling shakes occurred after crosscutting. In most of these trees, the splits were mainly in the upper part of the bole and were ascribed to felling damage and growth stresses. Good felling practices may thus reduce the damage. In an analysis of trees cut into three logs, most splitting occurred in the middle log, usually less in the top log, invariably least of all in the butt log (Garcia and de Lima 2000).

Logs may also split during rip sawing in the mill. However, since this occurs in conjunction with warping, it will be discussed in the next section.

In all cases, the severity of splitting varies considerably.

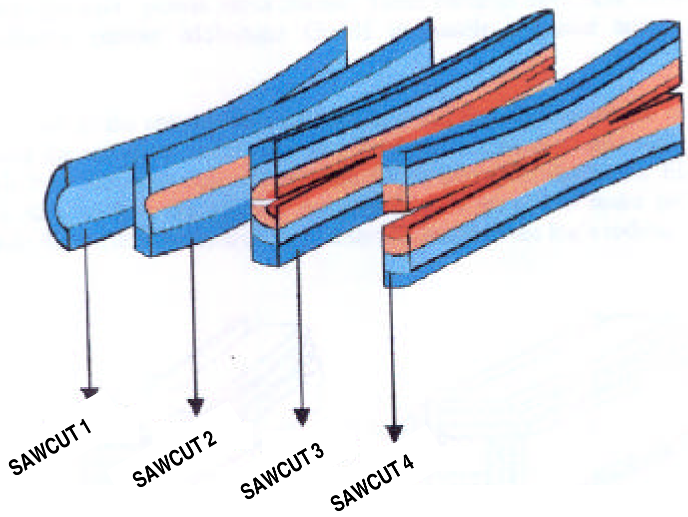
Rapid drying from the exposed end grain after felling and the differential drying stresses that this causes may aggravate end splitting. In fact, it may be difficult to distinguish between end splits, which can be ascribed to growth stresses, those due to drying out of the end grain, and those due to a combination of both. However, end splits from the release of growth stresses will occur much more rapidly than those due to drying stresses, i.e. usually within three days of felling.

Warping of wood during rip-sawing:

Stress release during rip sawing usually manifests itself by warping, sometimes accompanied by splitting. Splits may occur in the ends of sawn pieces even though they were recovered from logs in which there were no visible checks before sawing. In fact, there seems to be no overall correlation between end splitting in logs and in sawn timber of *E. grandis* or, more specifically, between the position of logs within the tree and any subsequent splitting of sawn timber (Garcia and de Lima 2000).

Taking Figure 2-1, we can transform it to an isometric representation of what happens during live sawing with a single saw (Figure 3-1) and use it as a simple example to analyse stress gradients, stress distribution and stress release during sawing (European Union 2001). Sawing patterns, in practice, will vary depending on a number of factors including the species, size, and quality of the log, the sawing equipment used, the extent and type of defect as the log is opened up, the desired products and the skill and experience of the sawyer in assessing the best recovery outcome for each log.

Figure 3-1:
Traditional sawing with a bandsaw and a sequence of parallel cuts



Dark blue:	High to moderate tension stress
Light Blue:	Moderate tension stress to no stress
Light orange:	No stress to moderate compression stress
Dark orange:	Moderate to high compression stress

Source: Executive Summary of Cooperative Research Project FAIR 98-9579 1999-2001 (European Union).

The first saw cut is made through the outer part of the wood, which has a gradient of diminishing tension stress from the periphery inwards, to produce a round back which is backsawn and bows away from the saw. If the stress distribution in the uncut log is as shown in Figure 2-1, the greatest stress gradient in the round back will be along the extrapolated horizontal centre line of the log, the least at right angles to this line along the sawn face, assuming the distance from the sawn face is shorter in the former than in the latter. Because of the greater tension stress at the periphery, stress relief occurs because the fibres at the periphery shorten more than those on the inside of the round back which thus becomes concave on the bark side and convex on the sawn face, i.e. the bark side actually shortens in length and the sawn face lengthens. At the same time, the remaining log also has a tendency to become concave and shorten on its sawn face. We will discuss later the important implications this latter phenomenon has in determining the best type of equipment and sawing patterns to use.

The second saw cut produces a parallel-sided flitch, which is mixed sawn and has a rather more complex stress distribution. In this case, the maximum stress gradient could occur at right angles to the horizontal centre line of the flitch depending on its thickness. Most of the fibres in this flitch were still under high to moderate tension stress before sawing and will shorten after sawing; however, the fibres in the light orange portion were under moderate compression and will lengthen after sawing. We now have a combination of "tension pull" and "compression push" the most likely net effect of which is again to cause the flitch to bow away from the saw cut.

The third saw cut produces another parallel-sided flitch, which is mostly quartersawn and has an even more complex stress distribution. In this case, the maximum stress gradients would occur in two opposite directions from the centre of the flitch towards the bark. In theory, these would manifest themselves by a combination of "tension pull" and "compression push" as spring towards the bark. In practice, this is impossible in a bark-to-bark flitch unless the flitch splits sufficiently in the middle to enable both halves to move independently. Stress relief may only occur when the flitch is resawn, enabling separate pieces to spring towards the bark. Stress gradients may become still more complex if brittleheart occurs in the flitch. Brittleheart will be discussed in more detail later. However, brittleheart is wood in which compression stresses have already been released through compression failure in the living tree.

The fourth saw cut produces a fully quartersawn flitch in which the effects are similar to those in the previous flitch but with greater stress gradients arising during sawing and a greater likelihood of splitting and spring towards the bark. Again, brittleheart could have some influence on stress release.

Pinching or binding of saws during rip-sawing and crosscutting:

Sometimes, especially when rip-sawing small pieces from large logs, apparently anomalous warping may occur. For example, should such logs be halved or quartered in the initial breaking down, the compression stress in the centre of the log is released. The sawn face lengthens and the flitch may have its longitudinal orientation changed to such an extent that "the peripheral edge is compressed beyond its natural longitudinal tension and actually placed in longitudinal compression". The condition may arise "when both the inside and outside edges of the flitch are in longitudinal compression while the central portion is in tension." Stress reversal has occurred so that "boards cut from either side of the flitch may pinch a saw" and not pull away as might be expected (Jacobs 1965).

When crosscutting, expansion of the fibres caused by release of the longitudinal compression stress in the corewood tends to close the kerf thus pinching the saw (Kubler 1959).

Brittleheart:

Compression stresses in the corewood can progressively impose a theoretical load greatly exceeding the elastic limit of wood in longitudinal compression (Jacobs 1965). The effect increases as the diameter of a tree increases and gives rise to minute compression failures or slip planes in the walls of some of the corewood fibres and the formation of low strength brittleheart.

Brittleheart is not always easy to detect by eye but, in general, it has a lower density than normal wood (probably because it's formed from corewood), it's easier to saw, it may be lighter in colour , end grain sawn surfaces have broken or fuzzy fibres, and it breaks with a brash fracture (Hillis 1984). Small sections, e.g. 10*10 mm, which can only be broken with difficulty by hand or not at all, can be broken easily if they consist of brittleheart. Quantitative assessments can be made from the proportion of broken fibres, with fractures at right angles to their length, in macerated samples (Dadswell 1958). Microscopic examination with polarised light of radial sections will reveal glowing lines of slip planes. Some fibres may have more than one slip plane and a continuous line of slip planes in the section indicates that the wood from which it was taken would be likely to break with a brash fracture (Hillis et al. 1973).

The sometimes lighter colour of brittleheart seems to contradict the general belief that heartwood is darker because of its higher proportion of extractives. However, brittleheart is not true heartwood; it is usually formed from corewood in which the proportion of extractives is low.

Brittleheart is not suitable as sawn wood but is used in pulp furnishes.

Conclusions:
In sawmilling there are four manifestations of growth stresses, three of which can cause substantial reductions in the recovery of sawn timber and loss of productivity. These are:

- End splitting of trees and logs.
- Warping of wood during sawing, mostly in the form of bow or spring, sometimes accompanied by splitting.
- Pinching or binding of saws during rip-sawing and crosscutting.
- Brittleheart.

These are described in detail based on the numerous references available.

End splits cause loss of recovery and productivity mainly because they have to be docked out, either in logs or sawn timber, and thus prevent sawyers from achieving the longest possible lengths of sawn timber from the logs brought in from the forest.

Warping because of growth stresses occurs during sawing and may have to be offset by face cutting to allow accurate dimension sawing to continue, again causing loss of recovery and productivity.

Brittleheart is unsuitable for sawn timber and has to be removed, usually by sawing around, causing direct loss of high value recovery. It may be used in pulp furnishes.

Pinching or binding of saws during rip-sawing or crosscutting is a nuisance and may be dangerous if the reactive force generated when rip-sawing is sufficient to hurl the sawn timber backwards from the saw or, in the case of crosscutting with a chainsaw, to cause kick-back.

4. METHODS OF REDUCING THE UNDESIRABLE EFFECTS OF GROWTH STRESSES

Introduction

This Chapter deals with methods of reducing the undesirable effects of growth stresses in the forest, during harvesting and transport to the mill, and whilst logs are stored at the mill before processing to sawn timber. Chapter 5 focuses on problems encountered during milling and how these may be overcome or significantly reduced.

End splitting of trees and logs

Reducing stress levels in standing trees by direct intervention:

Murray river red gum (*E. camaldulensis*) trees, grown in plantations, were killed by girdling deep into the sapwood and then left standing for a few months. Subsequent sawn timber from these trees warped 50% less than that from untreated controls. However, the technique could not be repeated with other species (Giordano and Currò 1973).

Longitudinal growth stress in mountain ash trees which had been killed by girdling and left standing for nine months changed little (Nicholson 1973b) with the exception of one girdled tree which did not die and retained its moisture. (However, despite retaining its moisture, the bole of the tree stopped growing during the nine-month period.)

Using 2,4-5 T as a defoliant spray to retard growth, but without killing the trees, growth stress levels dropped by an average of 20% over a year. However, there was considerable variation between the degree of defoliation and the stress relaxation achieved (Waugh 1977).

In South Africa, splitting was much reduced in flooded gum trees, which were dead or dying of drought, even in stands known for severe splitting after felling (Claassen 1993).

At present, reducing stress levels in standing trees by direct intervention does not seem to offer very much. Further, more convincing, and in the case of defoliant sprays, more environmentally desirable research work is needed.

Reducing stress levels in standing trees by genetic manipulation:

Genetic research with *E. urophylla* gave heritability values for end splitting as high as 0.89 (Schacht et al. 1998). Other work gave similar results (Garcia and de Lima 2000). End splitting of felled trees and logs; even in plantations growing under apparently uniform conditions, varies greatly from tree to tree (Malan 1995). This suggests that growth stresses are under some genetic control and, in

South Africa, lack of end splitting is an important criterion in eucalypt tree breeding programs.

Controlled and open pollinated progeny trials gave significant family variation in end splitting, and heritability as high as 0.5 (Malan 1984). This suggests, "that this defect is sufficiently heritable to enable its genetic reduction" and, since no relationship could be found between growth stresses and other wood properties, reducing them could be achieved without detriment to wood quality (Malan et al. 1992). Trials of four clones from each of high and low growth stress families of flooded gum were established in two locations in Mpumulanga province (formerly Eastern Transvaal). There were distinct differences between the clones in end splitting, and the ortet/clone relationship was remarkably strong. Further results suggested that growth stresses could be manipulated genetically through selection and cloning without reducing growth rates. However, others have reported close relationships between growth stresses and wood characteristics such as microstructure (including micorfibril angle), grain orientation, the distribution of anatomical elements, basic density, and modulus of elasticity (Archer 1987) so that reducing growth stresses might not be achieved without changing some aspects of wood quality.

Hybridisation can reduce the severity of end splitting. The effect of site, one species (flooded gum) and hybrids of flooded gum with three other species and their interactions on end splitting were tested and statistical parameters derived (Malan 1993). The three hybrids were *E. grandis* x *E. urophyllla*, *E. grandis* x *E. tereticornis*, and *E. grandis* x *E. camaldulensis*. Site had no effect on splitting but splitting among the single species and the hybrids varied significantly, the *E. grandis* x *E. urophylla* hybrid being decidedly less prone to splitting.

For plantation grown trees, tree breeding, including hybridisation, to reduce growth stresses would seem to offer some scope for improvement. However, work at clonal level, rather than species level would seem to be essential to produce more uniform trees, once those clones having lower growth stresses have been identified. Genetic modification, e.g. for protection against insect attack will improve grade recovery and could also reduce stress gradients by encouraging faster growth rates, hence larger diameter trees for a given rotation age. However, the theory that growth stress is under significant genetic control and that there is no relationship between growth stresses and other wood properties needs to be more thoroughly tested in Australia.

Reducing growth stresses in standing trees by silvicultural manipulation:

Thinning will increase diameter growth on the retained trees and thus reduce the impact of growth stresses when the trees are harvested and processed since larger diameter logs, with the same peripheral growth stresses, will produce a less steep internal stress gradient than smaller logs (Figures 2-1 and 2-2). This was confirmed by studies of four thinning regimes in beech forests in France involving 320 trees in all, which showed a significant correlation at the one percent level between progressively heavier thinning and a reduction in growth stresses (Polge 1981). The association between high growth stresses and a high proportion of tension wood was also confirmed. However, in replicated thinning studies of eight clones of *Populus deltoides* and its hybrids with *P. nigra* and *P. euramericana* in four localities in SE Australia (Waugh 1972) the results were not so certain. The more southerly plantations had growth stresses, which could be expected to cause significant distortion in sawn timber produced from them. The "effect of thinning may be that in opening up the canopy of the plantation, the remaining stems become more susceptible to the effect of wind, and to the higher angle of incidence of the sun's rays due to the higher latitude". The same clones, treated similarly at a latitude corresponding to their natural environment "did not exhibit the same high strains".

Mean stress levels in trees grown in multi-storey beech forests in France were only 60% of those grown in single storey forests (Gueneau and Saurat 1976). There was also a strong correlation "between measured tension and the density of surrounding trees in the same forest where ecological conditions were reasonably similar".

Extending the rotation can, through the production of larger diameter logs, reduce growth stresses (Hillis 1984). In this context, the average annual ring width of the entire cross section of a European beech (*Fagus sylvatica*) tree or log has not shown any statistical correlation to growth stress, but the average annual width of the last ten rings has (European Union Project 2002).

It has been suggested, though not tested experimentally, that maintaining uniform growth conditions, including even spacing within a stand, can reduce growth stresses (Kubler 1988). As discussed earlier, trees may alter their pattern of stress to achieve small changes in vertical orientation and to attain a particular crown position in the forest (Nicholson et al. 1975). If trees are evenly spaced and growth conditions are the same within a stand, significant changes in patterns of stress should, theoretically, not occur. If the pattern of stress does change, for whatever reason, this change does not necessarily imply an increase in stress. Maybe to reduce the magnitude of changes in stress, stands should be thinned lightly, frequently, and uniformly, rather than heavily, infrequently, and haphazardly (Malan 1995) but there is no evidence yet that this will reduce growth stresses.

At present, thinning and extending rotations offer the best prospects of reducing the impact of growth stresses in standing trees through their effect on diameter growth. However, there needs to be further investigation in Australia to confirm this. It should also be emphasised that some silvicultural treatments such as pruning, while not affecting growth stresses, will improve grade recovery of sawn timber.

Reducing end splitting in felled trees and logs in the forest:

Modern feller-bunchers, which can cut trees very close to the ground and which can then drop them precisely under better control than a chainsaw operator, will reduce the end splitting likely to occur when felling. However, they have limitations with respect to the topography and size of tree they can handle.

A chainsaw felling technique has been developed to reduce end splitting (Mattheck and Walther 1992) but the description in the only English language reference to it is not very clear. However, a skilful, well trained, chainsaw operator using good felling practice including an adequately sized and well profiled scarf, a back-cut well positioned in relation to the scarf and precise control of felling direction on to even ground well covered with cushioning debris, should ensure:

(a) the least possible severance forces are generated as the tree begins to fall; and

(b) minimum possible impact when the tree hits the ground.

Felling a tree as close to the ground as possible and topping as close to a fork as possible has been recommended (Mayer-Wegelin 1955, Mayer-Wegelin and Mammen 1954). This is to ensure as much cross grain as possible is contained at either end of the felled bole, thus reducing the tendency for splits to occur.

Cutting a circumferential kerf with a chainsaw on either side of the crosscutting plane can reduce end splitting of logs after crosscutting. Estimates of the best distance from each kerf-cut to the plane of crosscutting and the depth of groove are:

Distance of kerf-cut from plane of crosscutting	Depth of kerf-cut	Reference
¾ of log diameter	1/6 of log diameter	Conradie 1980
No recommendation	1/6 of log diameter	Barnacle and Gottstein 1968
0.2 to 0.3 times log diameter	1/3 of log diameter	Kubler and Chen 1975

While this method has significantly reduced end splitting in numerous trials in a several countries, its awkwardness has restricted its adoption (Hillis 1984).

Metal bands strapped tightly on either side of where crosscutting is about to be done, or hammering gang nail plates or S or C hooks into the ends of logs immediately after crosscutting, may delay the apparent onset of splitting. However, where logs are to be milled, these devices have to be removed and splits then develop in the usual way (Malan 1995). PVC rings embedded in the ends of *E. grandis* logs (from trees 24 years old), have been tried with some success provided the rings are fitted within minutes of felling a tree and immediately after crosscutting (Priest et al. 1985). They are not removed during milling and would, therefore, contaminate sawmill residues. The follow-on value of these PVC rings, if any, in containing the effect of growth stresses and associated splits during milling needs to be studied further (Priest 1986).

Reducing end splitting in felled trees and logs during transport and mill storage:

Splits may develop in logs during storage at forest landings, loading on to log trucks, transporting to the mill, and unloading and handling in the mill yard. During these various stages, there are two ways of reducing the likelihood of them occurring, or of getting worse if they are already present:

(a) Trees or logs should be as long a length as possible consistent with the machinery available, log truck configuration, and transport regulations.

(b) Trees or logs should be handled as gently as possible to reduce the possibility of impact damage.

Reducing splitting during storage in mill yards:

Splitting commonly occurs during storage in mill yards through a combination of growth and drying stresses. Drying stresses are contained by end coating logs with an impervious grease or wax, preferably immediately after crosscutting, and by water sprays, which maintain high moisture content in the logs. Furthermore, mean longitudinal growth stresses (8.14 to 9.65 MPa) in mountain ash stored under water sprays for six months dropped by 16-25% (Nicholson et al. 1972). Whether this was sufficient to have a beneficial effect during subsequent sawmilling was not stated.

After crosscutting, logs should be milled as soon as possible, the time lag, at most, four hours (Haslett 1988).

Conclusions

These have been described and discussed according to the manifestations of growth stresses during removal of a standing tree in the forest to its delivery and storage in the mill yard.

Of the methods discussed for reducing stress levels in standing trees by direct intervention, silvicultural manipulation by thinning and extending rotations would seem to offer the best prospects through their effect on diameter growth. However, there needs to be further investigations in Australia to confirm this.

Genetic manipulation by tree breeding, hybridisation and clonal selection may also provide some scope for improvement. However, the theory that growth stress is under significant genetic control and the relationships between growth stresses and other wood properties need to be more thoroughly tested in Australia.

End splitting in felled trees and logs in the forest may be reduced by mechanised felling eg feller bunchers and by better felling and crosscutting techniques with chainsaws. The follow-on value of PVC rings, if any, in containing the effect of growth stresses and associated splits during milling needs to be studied further.

Cutting a circumferential kerf with a chainsaw on either side of the crosscutting plane has significantly reduced end splitting in logs in numerous trials but its awkwardness and the extra labour involved has meant that it is little used.

End splitting in felled trees and logs during transport and mill storage can be reduced by ensuring trees or logs are cut to as long a length as possible and by handling them as gently as possible to avoid impact damage.

Storing logs under water sprays in mill yards can reduce growth stresses and milling them as soon as possible after crosscutting, e.g. less than 4 hours can reduce the impact of any residual stresses.

5. TYPES OF SAWMILLING EQUIPMENT AND THEIR EFFECTIVENESS IN CONTROLLING WARPING AND SPLITTING.

Introduction:

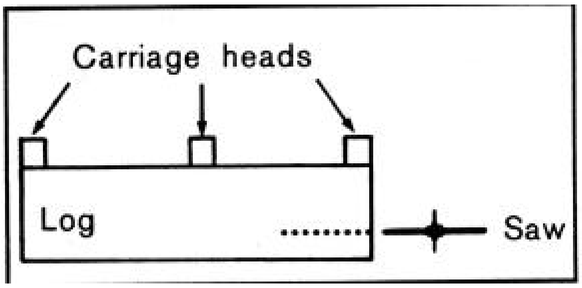
Regrowth eucalypts, preferably as large a diameter as possible, have been sawn successfully to produce high grade, high value products. However most experienced sawmillers in Australia "consider plantation eucalypts to be too difficult to process because of growth stress related distortion during sawing and drying degrade". These are "seen to be so severe that the resulting poor quality products are not suited for the manufacture of anything other than low-quality packaging products" (Waugh and Northway 2002). This is very much an Australian perception: plantation eucalypts, mostly *E. grandis*, have been sawn for many years in southern African countries to produce appearance grade seasoned and dressed products. Overall, recoveries have not been good by Australian standards, commonly 25 to 30% (total sawn timber recovery including non-appearance grades); however, log and labour costs are low and producers have been profitable, selling into domestic markets. Producers have also been unwilling to provide details of the reasons for whatever success they have achieved, presumably perceiving it to be to their competitive advantage not to do so.

Grade sawing, dimensional accuracy and control of warping can be achieved using appropriate equipment and sawing patterns and, because of the relative uniformity of plantation eucalypts, mass production may be possible in the future through the introduction of programmed systems.

Single saw headrig with conventional sizing carriage:

Figures 5-1 and 5-2 represent a possible approach to backsawing a eucalypt log 300 mm diameter and can be used to illustrate the problems associated with growth stresses when sawmilling (Haslett 1988). However, sawyers have to take account not only of growth stresses but also of defect within the log, which may not be visible until the log is opened up. Such defect may have to be contained within a single piece or eliminated entirely and will inevitably impose constraints on the sawyer. The following description of a possible sequence of saw cuts ignores defects and concentrates on reducing the impact of growth stresses.

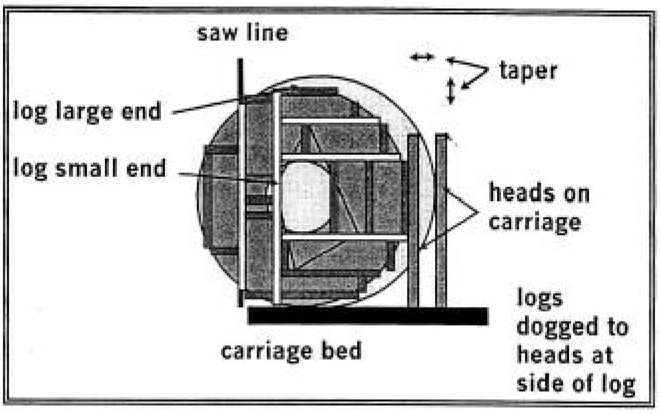
Figure 5-1:
A traditional sizing carriage where the distance between the carriage head and the saw determines the size of cut



Source: Haslett A.N. 1988

The initial saw cut in a log, sometimes referred to as the opening face, produces a roundback about 60 mm maximum thickness for subsequent resawing (Figure 5-2). The opening face is usually taper sawn, i.e. as parallel as possible to the outside of the log, by adjusting the carriage heads accordingly. Thereafter, when backsawing to produce dimensioned flitches or slabs, offsetting the log dogged to the carriage heads in relation to the plane of the saw with a hydraulic sizing mechanism determines the dimension between successive parallel saw cuts until the sawyer decides to turn the log (Figure 5-1). In Figure 5-2, the first slab would be sawn to a final product thickness of 40 mm, which brings the sawyer, in this example, to the defective core, e.g. brittleheart. The sawyer then turns the log on to the last sawn face, resets the log on the carriage for taper sawing, and proceeds as described above. The log will be turned three times in all until the breaking down is completed (Waugh and Northway 2002).

Figure 5-2:
Diagram of 300 mm diameter log on headsaw carriage, showing small and large-end location for taper sawing and proposed sawing pattern on log small-end



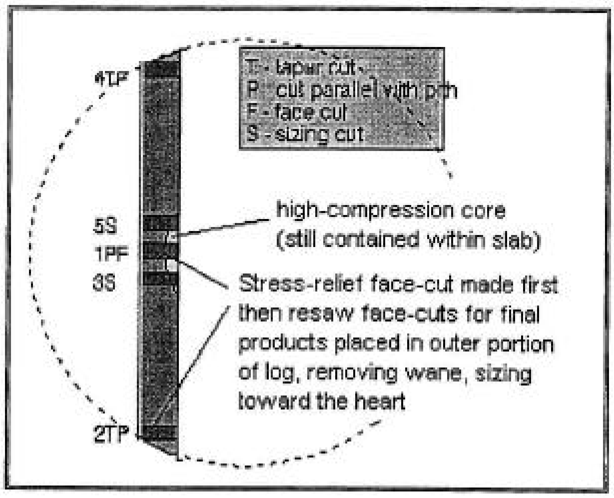
Source: Waugh G 2002.

The carriage should have at least three heads, which can be traversed sideways to allow the two outer ones to be positioned at each end of the log to be sawn (Haslett 1988).

Because of growth stresses it may be very difficult to size accurately when dimension sawing logs of less than 350 mm small end diameter and in most cases these logs are better broken down to non-dimensioned flitches (Waugh and Northway 2002) which can then be sawn accurately on a resaw or breast bench. The roundback bows towards the bark (Figure 3-1), which can be corrected on the resaw. However, even the log on the carriage will also bow and the sawn surface will be convex along its length. If sawing continues, as illustrated in Figures 3-1 and 5-2, the slab will be thicker in the middle of its length than at the ends. Thus, before cutting the first dimensioned slab a face cut (sometimes referred to as a straightening cut) may be necessary to ensure an accurately dimensioned slab can be produced. As the log is turned, further face cuts may be necessary with possible loss of recovery and certainly reduced productivity.

Each dimensioned slab will tend to be in tension in the outer sections of its width and in compression in its inner section (Figure 3-1). If resawn with a multi-edger, the boards will be accurately sized but the edges will spring. To overcome this, the slab must be ripped up the middle to relieve the stress to some extent and the final sizing achieved by sawing the outside edge of each “half slab” to remove the wane and any spring that may have occurred; then cutting the inner edge of each to produce boards of wanted dimensions (Figure 5-3). This means five single saw cuts to produce two boards. An alternative is to dry the slab and resaw, to produce boards of wanted dimensions after drying when both drying and growth stresses have disappeared. There are some disadvantages to doing this, e.g. kiln capacity is effectively reduced and, if the slabs have been cut close to the heart, drying degrade may be more severe since significant differential drying and shrinkage may occur. The loss of drying capacity may be offset to some extent by edging the slabs, removing wane and taper with twin saws before drying but leaving the final dimension cutting until after drying. The best option can only be determined by experience, conditioned by the facilities available at each mill.

Figure 5-3:
Resawing strategy for a back-sawn slab from 300 mm diameter log



Source: Waugh G 2002

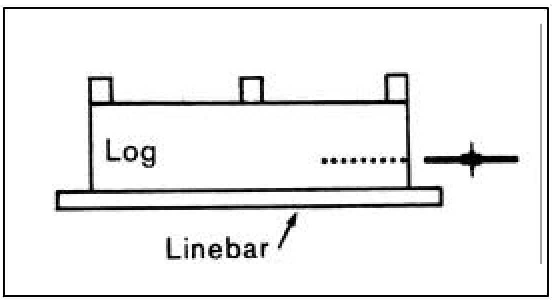
Even with logs between 350 and 500 mm small end diameter, sizing accuracy and warping due to growth stresses must be carefully monitored. Sawyers must be prepared to face cut as required (Waugh and Northway 2002).

Halving the length of a log will reduce warping by a factor of four. However, there is often a premium for long length boards in the market place; and short logs reduce productivity.

Single saw headrig with a line-bar carriage:

The hydraulically controlled sizing mechanism of the conventional sizing carriage is replaced with a line-bar (Figure 5-4).

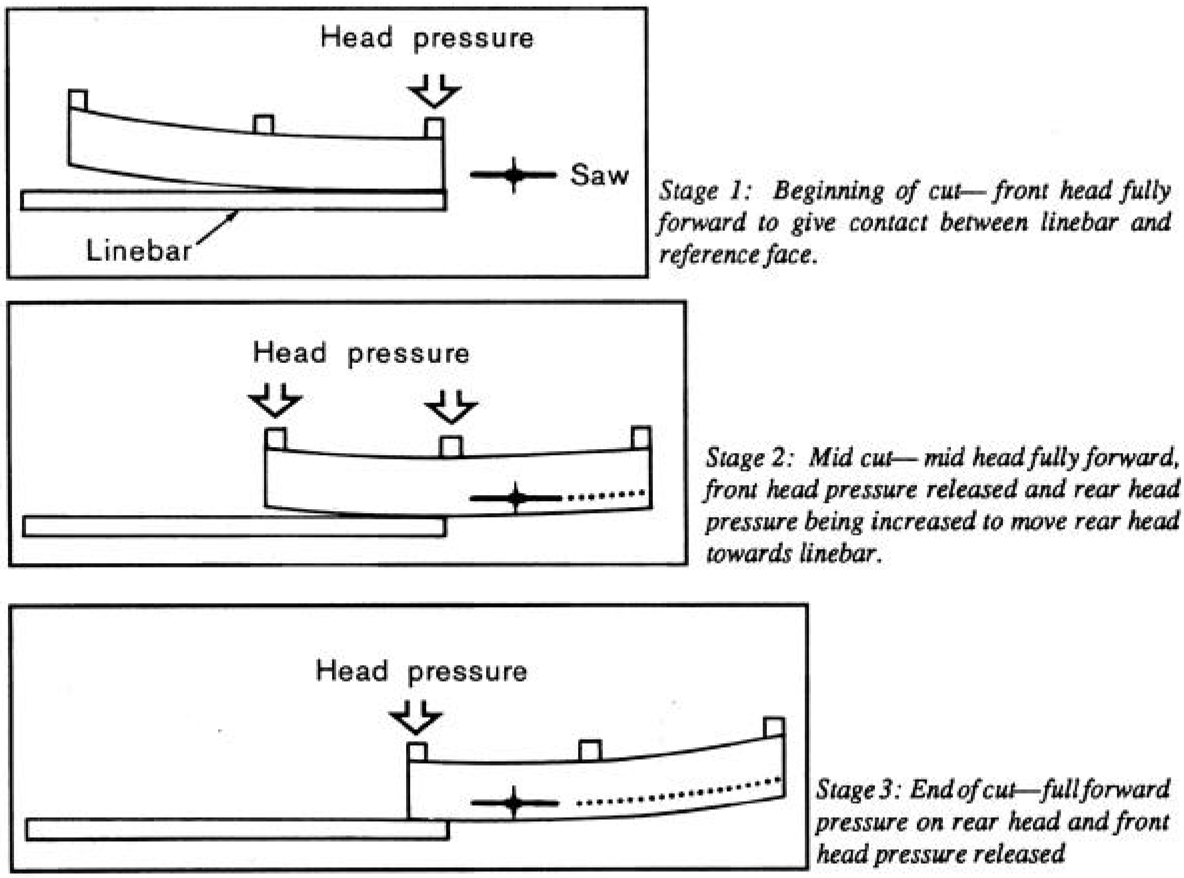
Figure 5-4:
A linebar carriage which sizes between the saw and the linebar



Source: Haslett A.N. 1988

The line bar is about six metres long, immediately in front of and parallel to the saw. The horizontal distance between the line bar and the saw determines product size. The carriage heads can operate independently, usually through pneumatic controls. As the carriage moves past the saw, pressure can be applied to the carriage head closest to the front of the saw so the log or flitch is always in contact with the line bar as close as possible to the cutting edge of the saw (Waugh and Northway 2002). Figure 5-5 shows the sequence of pressure changes as the log moves through the saw.

Figure 5-5:
Representation of a linebar operation showing systematic manipulation of head pressure to ensure sawline follows distortion present in log



Source: Source: Haslett A.N. 1988

Manipulating head pressures is difficult and requires training and practical experience to build up the necessary skills. A warning light connected to a pressure switch, which activates when insufficient pressure is exerted, can help; otherwise the sawyer must pressurise intuitively (Haslett 1988). The sawyer's position has also been changed from near the saw to the in-feed end of the carriage track. Although this is further away from the action, the sawyer can see better what is happening to the log in relation to the line-bar.

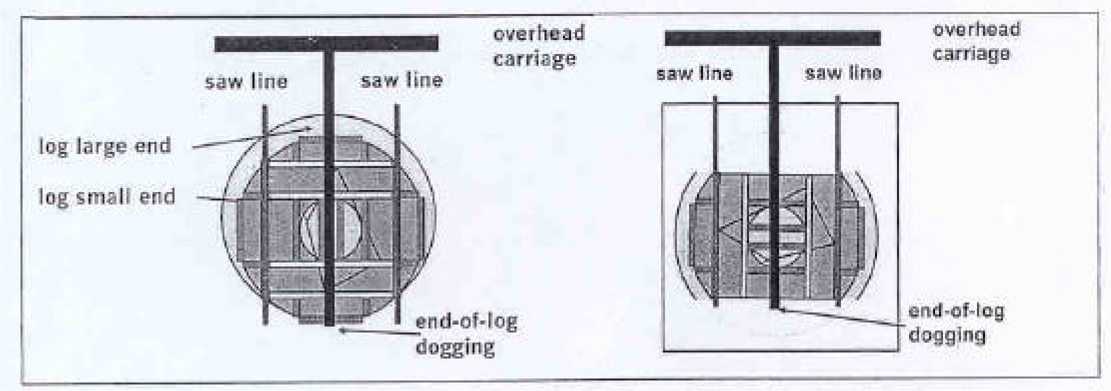
Despite the difficulties in operating line-bar carriages, they are well suited to sawing regrowth and plantation eucalypts for grade recovery. Using the same sawing pattern discussed above, setting up for taper sawing is straightforward and, by ensuring maximum pressure is applied just in front of the saw, the sawyer can size products accurately, without face cutting, even though warping has occurred. When backsawing logs too small for quartersawing, i.e. minimum small end diameter of 400 to 450 mm, warping will appear as a bow, which can be eliminated during drying through careful stacking.

Twin log edgers:

Twin circular or bandsaws mounted side-by-side can saw simultaneously, although circular saws require some offset, particularly with eucalypts, and have to be mounted on separate shafts (Waugh 2000). A log is fed into the saws either dogged to an overhead carriage, with the dogs penetrating the transverse section at either end, or resting on a feed chain, which runs between the saws. The saws make parallel cuts in the first pass, removing two round backs and leaving a central cant. The round backs may bend away from the saws with the release of growth stresses but the cant should remain straight, since the stresses in the horizontal planes, assuming symmetric stress distribution (Figure 2-1), balance each other out. However, log edging concentrates growth stresses in the vertical plane (Figure 3-1), the severity of their gradients depending on the diameter of the log (Figure 2-2). When the cant is brought back for resawing, the likelihood of splitting increases as it becomes thinner and, if the stress distribution across the cant should become asymmetric, for instance because of wandering heart or an eccentric and/or elliptical bole, of bowing. Without face cutting, any further resawing will produce badly dimensioned pieces.

A suggested solution (Waugh 2000) would be to produce a central cant having a width of more than 50% of the small end diameter of the log, e.g. a 300 mm log could have a cant width of 200 mm after the first pass. The cant would then be turned on its side and either brought back and resawn through the log edger or fed through another twin saw to produce a square cant (Figure 5-6). However, the square cants must be dried before resawing, otherwise the residual stresses would result in warping.

Figure 5-6:
Diagrammatic representation of 300 mm diameter log being sawn on log edger system, showing log end view, small and large end diameters, end-dogging and sawing pattern and remaining log section end view following turning



Source: Waugh G 2000

End dogging may not work well if logs have already split at their ends from the release of growth stresses. Unsplit logs may split when the dogs are inserted; variable pressure dogging is advisable.

Twin log edgers cannot taper saw. This will tend to reduce both grade and volumetric recovery since proportionally more waste will occur in good wood rather than in the core.

While twin log edgers reduce the opportunities for grade sawing, they can enhance productivity when milling small logs (Waugh 2000). However, to achieve this, the problems imposed by the release of growth stresses and consequent warping will have to be resolved by modern control systems, which will permit sawing and the movement of sawn timber within acceptable limits. The greater uniformity of well-managed regrowth and plantation eucalypts, both in terms of log sizes and wood quality, combined with higher log inputs, should make this possible.

Resaws:

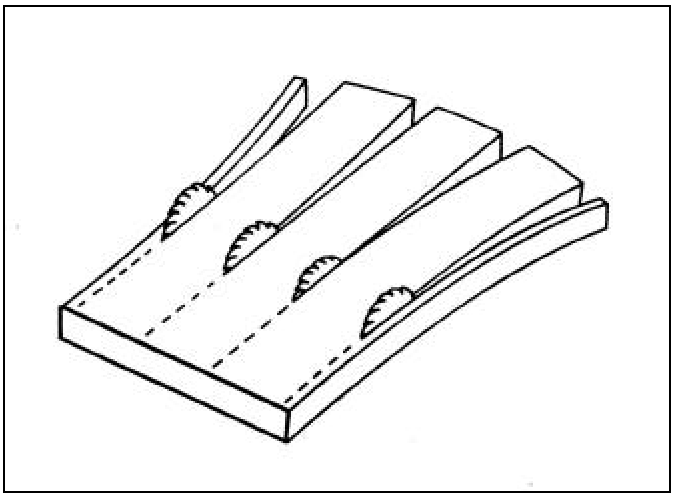
Four-man breast benches with a single circular saw used to be the most widely used resaws in the Australian hardwood milling industry. They have been modernised by reducing the number of men needed to operate them and nowadays one-, two-, and three-man benches are more common. They may also have a bandsaw rather than a circular saw. Breast benches have several advantages; those relating to growth stresses include:

(a) They are very flexible and can adjust to any size and shape of flitch arriving from the head rig, cutting them to whatever sawing pattern is necessary to reduce the impact of growth stresses

(b) Except for the one-man benches, they can face cut easily and thus remove distortion due to warping. However, one-man benches are commonly fitted with line bars and may thus be able to deal with warped sawn timber by "following the warp".

Edgers are a more specialised type of resaw which have been used in eucalypt sawmills in Australia. However, when multi-edging slabs containing residual stresses, they have some disadvantages (Figure 5-7).

Figure 5-7:
Spring caused by simultaneous ripping with a multi-saw edger



Pinching or binding of saws during rip sawing and crosscutting:

In general, these are not critical problems arising from growth stresses since rip-sawing patterns can normally be adjusted to take care of them. They are more likely to occur because of residual drying stresses when rip-sawing seasoned timber with a thin kerf bandsaw. Similarly, when crosscutting in the forest for example, binding is most likely to occur by stresses induced in a tree or log because of its position on uneven ground. However, experienced chainsaw operators can usually avoid such problems by precise directional felling and/or by crosscutting sequentially in such a way as to relieve the stresses as they proceed. When felling and crosscutting with mechanical harvesters, the tree is gripped in such a way that binding cannot occur.

Brittleheart:

Brittleheart is usually excluded by sawing around at the headrig so that it's part of the corewood residue when all "true" wood has been removed. However, since it can be difficult to detect by eye, it sometimes turns up in sawn timber.

Conclusions

These have been described and discussed according to the manifestations of growth stresses during production of sawn timber in the mill.

Types of sawmilling equipment and their effectiveness in controlling warping and splitting during milling are described and discussed under the following categories:

- Single saw headrig with a conventional sizing carriage.
- Single saw headrig with a line-bar carriage.
- Twin log edgers.
- Resaws and edgers.

Of the first three types of equipment, a single saw headrig with a line bar carriage is the most effective in offsetting the impact of warping during sawing. However, manipulating head pressures is difficult and requires training and practical experience for sawyers to build up the necessary skills. While twin log edgers reduce the opportunities for grade sawing, they can enhance productivity when milling small logs

In general, pinching or binding of saws during rip sawing and crosscutting because of growth stresses are not critical problems since sawing patterns can normally be adjusted to take care of them. They are more likely to occur because of residual drying stresses when rip-sawing seasoned timber with a thin kerf bandsaw.

Brittleheart is usually excluded from sawn timber by sawing around at the headrig so that it is part of the corewood residue when all "true" wood has been removed. However, since it can be difficult to detect by eye, it sometimes turns up in sawn timber.

6. REFERENCES

Archer R R 1987: Growth stresses and strains in trees, Springer Verlag Series in Wood Science, Berlin Heidelberg.

Banks C C 1973: The strength of trees. Journ. of the Inst. of Wood Science, 6:2 44-50.

Bariska M, Knuffel WE, and van Rensburg Z 1987: Literature survey on selected properties of eucalypts, CSIR Special Report, O/HOUT 62.

Barnacle J E 1970: Incidence and development of felling damage in round timber, Australian Forestry 34:3, 161-169.

Barnacle J E and Gottstein J W 1968: Control of end splitting in round timber-promising new method, CSIRO DFP Tech. Note No. 4.

Bootle K R 1983; Wood in Australia (Appendix 3), McGraw-Hill Book Company, Sydney.

Boyd J 1950a: Tree growth stresses III. The origin of growth stresses, Aust. J. Sci. Res., B.3: 294-309.

Boyd J 1950b: Tree growth stresses II. The development of shakes and other visual features in timber, Aust. J Appl. Sci 1: 296-312.

Conradie W E 1980: Utilisation of S African grown Eucalyptus grandis as veneer logs, Part 1. Control of end splitting in veneer logs, CSIR Special Report, Hout 206.

Chafe S C 1995: Peripheral growth stresses and tree diameter in Eucalyptus, Journ. Inst. Wood Science 13:5 523-525.

Claassen I 1993: Hans Merensky Foundation, pers. comm. via F S Malan.

Dadswell H E 1958: Wood structure variations occurring during tree growth and their influence on properties, Journ. of the Inst. of Wood Science, 1 2-23.

Dinwoodie J M 1966: Growth stresses in timber: a review of literature. Forestry, 39:2 162-170.

European Union 2001 FAIR Project CT –98 9579 (published in CIS-Madera 6:8-37): Sistemas de aserrado adecuados para procesar Eucalyptus globulus con tensiones de crecimientio (Sawmilling systems suitable for processing Eucalyptus globulus affected by growth stresses)

European Union 2002 FAIR Project CT –98 3606: Stresses in beech.

Garcia J N and de Lima I L 2000: Log end splitting and improvement in sawing, Proceedings of IUFRO Conference, The Future of Eucalypts for Wood Products, Launceston, Australia.

Giordano G and Currò P 1973: Unusual methods for reducing damage from growth stresses in Eucalyptus sawn timber, Proceedings of IUFRO V, Cape Town and Pretoria, South Africa.

Gueneau P and Saurat J 1976: Growth stresses in beech. *Wood Science and Technology,* 10:2, 111-123.

Haslett A N 1988: Handling and grade sawing of plantation-grown eucalypts, New Zealand Forest Research Institute Bulletin No 142, Rotorua.

Hillis W E 1984: Wood quality and utilisation. In "Eucalypts for wood production", Ed. Hillis and Brown, CSIRO and Academic Press Sydney, 259-289.

Hillis W E, Hardie A D K and Ilic J 1973: The occurrence of brittleheart in Eucalyptus grandis in Zambia, Proceedings of IUFRO V, 2 485–493,Cape Town and Pretoria, South Africa.

Jacobs M R 1938: The fibre tension of woody stems, with special reference to the genus Eucalyptus, Commonwealth Forestry Bureau Bulletin No 22, Canberra.

Jacobs M R 1945: The growth stresses of woody stems, Commonwealth Forestry Bureau Bulletin No 28, Canberra

Jacobs M R 1965: Stresses and strains in tree trunks as they grow in length and width, Commonwealth of Australia Forestry and Timber Bureau Leaflet no. 96.

Jun Li Yang 2002: Aids to predicting sawlog quality, CSIRO Onwood Newsletter No. 38

Kubler H 1959: Studies on growth stresses in trees, Holz als Roh- und Werkstoff 17(1) 1-9. Studies on growth stresses in trees, Holz als Roh- und Werkstoff 17(2) 44-54.

Kubler H 1988: Silvicultural control of mechanical stresses in trees, Canadian Journal of Forest Research 18 (10) 1215-1225.

Kubler H and Chen T-H 1975: Prevention of crosscut and heating heart checks in log ends, Wood Science and Tech. 9:1 15-24.

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, PhD thesis, University of Stellenbosch, S Africa.

Malan F S 1993: The wood properties of three S African grown eucalypt hybrids, S African Forestry Jour. 167 35-44

Malan F S 1995: Eucalyptus improvement for lumber production, Seminario internacional de utilizaçâo da madeira de eucalipto para serraria, (International seminar on utilising eucalypts wood for sawmilling) Instituto de Pesquisas e Estudos Florestais et al., Sao Paolo-Brazil.

Malan F S and Hoon M 1992: Predicting growth stresses in mature E. grandis from wood property/growth stress relationships in young trees, CSIR Report FOR-1 239.

Mattheck C and Walther F 1992: A new felling technique to avoid end-splitting of deciduous trees, Proceedings of IUFRO V, Nancy, France.

Mayer-Wegelin H 1955: Tensions and tension splitting in standing and felled logs, Mitt der Österreichischen Gesellschaft für Holzforschung 7:2 11-17

Mayer-Wegelin H and Mammen E 1954: Tensions and tension splitting in standing beech-wood, Allg. Forst- und Jagdzeitung, 125:9 287-297.

Muneri A, Leggate W, and Palmer G, 1999: Relationships between surface growth strain and some tree, wood and sawn timber characteristics of Eucalyptus cloeziana, South African Forestry Journal 186:41-49.

Muneri A, Knight J, Leggate W, and Palmer G, 2000: The future of eucalypts for wood products, Paper presented at the IUFRO Conference –Launceston

Nicholson J E, Campbell G S and Bland D F 1972: Association between wood characteristics and growth stress level, Wood Sci. 5 109-117.

Nicholson J E, 1973a: Growth stress differences in eucalypts. Forest Science, 19:3 169-174.

Nicholson J E, 1973b: Effect of storage on growth stress in mountain ash logs and trees, Australian Forestry 36:2, 114-124.

Nicholson J E, Hillis W E, Ditchburne N 1975: Some tree growth-wood property relationships of eucalypts. Canadian Journal of Forest Research 5:3 424-432.

Polge H 1981: Influence des éclaircies sur les contraintes de croissance du hêtre, (Influence of thinning on growth stresses of beech) Ann. Sc. For. 38: 407-423.

Priest D T 1986: Improved yield and utilisation of E. grandis, Journ. Inst. Wood Science 10:6; 235 –240.

Priest D T, Singmin N, van Niekerk J P 1985: Evaluation of PVC rings for retarding the development of end splits in E grandis sawlogs, CSIR Special Report HOUT 374, S Africa.

Robards A W 1965: Tension wood and eccentric growth in crack willow, Ann. Bot. (London) 29 419-431

Schacht L, Garcia J N and Venkovsky R 1998: Variação genética de indicadores de tensão de crescimento em clones de *Eucalyptus urophylla*, (Genetic variation of growth stress parameters in clones of E. urophylla) Scientia Forestalis, Piracicaba, 54: 40-52.

Shwe Thein 1988: Strength grouping of regrowth *Eucalyptus regnans*, PhD thesis, Department of Forestry, Australian National University, Canberra.

Wardrop A B 1964: The reaction anatomy of arborescent angiosperms. In "Formation of wood in forest trees", Ed: M H Zimmerman. Academic Press, New York 405:465.

Washusen R 2002: Tension wood occurrence in Eucalyptus globulus Labill. II, Australian Forestry 65:2 127-134

Waugh G 1972: Growth stresses – genetic and environmental influences, Newsletter 189, FPL, CSIRO.

Waugh G, 1977: Reducing growth stresses in standing trees, Aust. For. Res 7 215-218.

Waugh G, 2000: Use of twin saw systems for young fast-grown eucalypts, Proceedings of IUFRO Conference, The Future of Eucalypts for Wood Products, Launceston, Australia.

Waugh G and Northway R, 2002: Best practice for sawing and drying plantation eucalypts for appearance grade products, Proceedings of the Forest Industry Engineering Association Wood Technology Clinic, Rotorua, New Zealand.

Wilkins A P and Kitahara R (1991a): Silvicultural treatments and associated growth rates, growth strains and wood properties in 12.5 year old Eucalyptus grandis, Australian Forestry 54: 99-104.

Wilkins A P and Kitahara R (1991b): Relationship between growth strain, and rate of growth in 22 year-old *Eucalyptus grandis*, Australian Forestry 54: 95-98.