ICSV14
Cairns • Australia
9-12 July, 2007

14th International Congress on Sound & Vibration

ACOUSTIC DETECTION OF TENSION WOOD IN EUCALYPTS

Jun Li Yang[1], Voichita Bucur[1] and Dung Ngo[1]

[1]Ensis, Private Bag 10, Clayton South, Victoria 3169, Australia
junli.yang@ensisjv.com

Abstract

The occurrence and distribution of tension wood in trees can result in major defects in manufactured wood products. The nondestructive detection and location of tension wood in trees and logs is a major interest for hardwood industry in Australia. This paper proposes a combined acoustic method using ultrasonic waves and stress waves for 2D imaging of the presence of tension wood in transversal section of logs.

Five discs of 10 cm thickness cut from *Eucalyptus delegatensis* logs from regrowth forests and one disc from an *E. nitens* log from Hancock Victorian Plantations were selected. As wood material has an orthotropic structure, velocities were measured on the three primary symmetry axes. It was demonstrated that on the transverse section of discs, the presence and the location of tension wood may be determined. In the same time, the opposite wood, the lateral wood and the juvenile wood zones may also be detected. These methods show potential for use in sawmills for the inspection of defective features in cross sections of logs and also in standings trees of commercial forests, parks and public gardens.

Keywords: ultrasonics, stress wave, tension wood, imaging

1. INTRODUCTION

Tension wood occurs in hardwood species. It refers to the type of wood fibres that are characterized by the presence of gelatinous layers (G layer) in the cell wall of the fibres. The cellulose microfibrils in the G layer are much thicker [1] than the normal wood fibres, and are laid at very small angle to the fibre axis [1, 2]. Tension wood therefore differs considerably from normal wood in several wood properties such as density and shrinkage. In a perfectly shaped tree, the cross section of the stem is round and the pith is located in the centre. The real trees in reality, however, have varying degrees of irregularity in the shape of stem cross sections. Tension wood is often found at the wider side of eccentric cross sections or the upper side of a leaning stem or tree branch.

Tension wood can cause severe internal checking and board distortion during drying and result in subsequent downgrade of sawn boards that otherwise would have met the appearance grade. Severe drying distortion has been observed in *Eucalyptus globulus* Labill. sawn boards [3,4] and tension wood is considered to be a major cause. As *E. globulus* is the most widely planted eucalypt species in Australia and there is a growing interest in value-adding this resource, nondestructive methods capable of detecting and locating tension wood in trees and logs would therefore be very useful to both eucalypt growers and the wood processing industry in Australia.

Tension wood has been reported to have longitudinal shrinkage 5 times as high as normal wood [5]. When normal wood and unevenly distributed tension wood both exist in a board, the difference in longitudinal shrinkages across the board could be enormous. This level of differential can result in severe bend (spring or bow) during drying and lead to subsequent downgrade or even rejection of the board from being used in making value-added products. Since straightness is a key criterion for appearance grade product, it is therefore logical to grow trees that are less prone to tension wood formation. It will also be very useful to make tools available to tree growers and sawmilling industry to enable nondestructive detection and quantification of tension wood in standing trees and/or logs.

Breeding and resource evaluation often involves sampling a large number of stems and requires nondestructive sampling. The samples taken from tree stems are most likely to be increment cores. In order to keep costs and tree injury down, the sampling intensity is often limited to no more than two radial cores or one diametrical core per stem. This approach suits the assessment of some wood properties but its effectiveness is questionable with regard to tension wood detection. This is because the cores may miss tension wood entirely and/or information collected from the cores (assuming the cores have gone through tension wood zone and tension wood in the cores has been quantified correctly) is not sufficient to indicate the distribution of tension wood across the stems. A recent study on *E. globulus* logs (most of them contained conspicuously eccentric pith) is a good example of how easy it was to miss potential tension wood [4]. To improve detection, a large number of cores will be needed per height. Unfortunately, such sampling intensity will have little appeal to tree breeders and tree owners because of severe injury to the trees and because the labour and lab running costs will also multiply. Therefore there is a real need to develop practical methods/tools that are able to nondestructively map tension wood in tree stems/logs, are useable in the field and are economical.

The aim of this research was to assess the potential of acoustic methods for the detection and location of tension wood in eucalypts.

2. MATERIALS AND METHODS

2.1 Materials

Six wood discs showing various degrees of pith eccentricity were used in this study. The discs were removed from 5 regrowth eucalypt logs at Black Forest Timbers (one disc per log) and one *E. nitens* plantation log (Hancock Victoria Plantations). Three discs were eccentric (DiscA, Disc1, Disc2) and three were more or less concentric (DiscB, Disc3, Disc4). The average thickness was 100 mm. The cross-sectional surfaces were coated with sealant soon after the discs were cut. The discs were then wrapped in the plastic and stored in a cool room.

2.2 Methods

Two acoustic tests were conducted, ultrasonic measurements of velocities in the longitudinal anisotropic direction of wood and measurements of stress wave velocities in the radial and tangential directions.

2.2.1 Velocity Measurements in the Longitudinal Direction – Ultrasonic test

The velocity measurements in the longitudinal direction were made using ultrasonic testing equipment which operates with a centre frequency of 1 MHz, and using a direct transmission technique. Fifteen rays (pith-to-periphery lines) were drawn on DiscA. Then on each line, locations were marked at 20 mm increments starting from the disc periphery (Fig. 1) without trying to match the rings between locations from different rays. The time of flight of the transmitted longitudinal wave along the wood grain at each pre-marked location was measured and the longitudinal velocity (V_{LL}) was calculated.

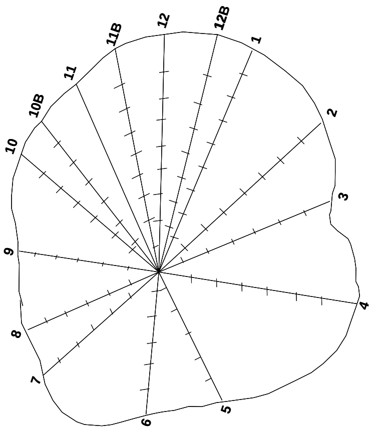

Figure 1. 15 rays and a various number of locations at each ray were marked on DiscA for ultrasonic measurements of the time of flight of the longitudinal wave using direct transmission ultrasonic technique.

2.2.2 Stress Wave velocity Measurements in the Radial Direction

A FAKOPP 8-channel microsecond timer [6] was used in this study. With this method, eight transducers were inserted in the radial direction into the surface of the wood discs along the disc periphery, the spatial information of the transducers was collected and entered into the computer program, the transducers were actuated one by one (via tapping with a hammer), the acoustic signals (i.e. the transit time of the stress wave) were measured, the radial stress wave velocity matrix was determined, then a radial stress wave velocity 2D map was generated for the cross section of the discs.

2.2.3 Surface Stress Wave Measurements in the Tangential Direction

The time of flight of surface tangential stress waves (the transducers were in the tangential plane), with the transducers being perpendicular to the transverse surface of the discs, were measured on three eccentric discs and two concentric discs (one was clear and the other contained a knot). For each disc, up to 10 sets of measurements were measured. Each set of measurements covered a different proportion of the transverse surface area of the disc and were used to produce one 2D velocity map. The purpose of these experiments was to investigate the level of variation in surface tangential stress wave velocity within the disc cross section.

3. RESULTS AND DISCUSSOIN

3.1 Ultrasonic Results

To demonstrate longitudinal velocity variations in the disc and to avoid cluttering, rays 1 (the wider side of the disc), 6 (the opposite wood), 4 and 9 (the lateral wood) were selected and the velocity data were plotted. It can be clearly seen in Fig. 2 that the longitudinal velocities are highest along ray 1 (average 3847 m/s), lowest along ray 6 (average 3187 m/s), and are in between along ray 4 and 9 (the lateral wood area, average 3500 m/s). These results agree with the findings by Bucur *et al*. [7] that the velocity was highest in tension wood (beech samples). Coutand *et al*. [8] found that tension wood (poplar samples) had higher Young's modulus and this difference was more accounted for by smaller cellulose microfibril angles in the second layer and the G layer of the secondary wall of the fibres rather than by differences in density. As the stiffness modulus measured by acoustic method is calculated by multiplying V_{LL} squared with density, Coutand *et al*. [8] would have observed higher acoustic velocities along wood grain in their tension wood samples if they measured them. Based on the results of ours and others, the longitudinal velocity shows prospect in detecting tension wood in a broad sense.

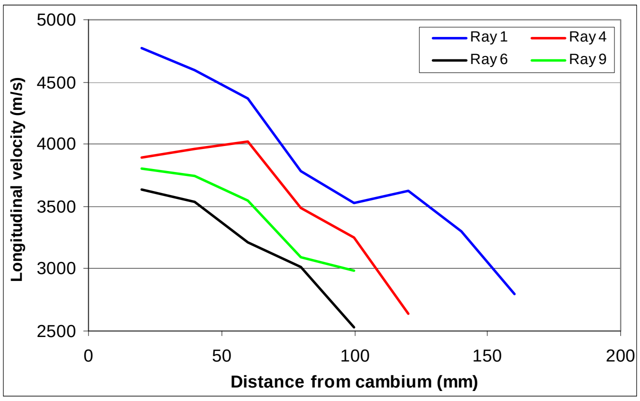

Figure 2. Longitudinal velocities measured with ultrasonic method along 4 rays that correspond to the ray positions in Fig. 1.

3.2 Bulk Radial Stress Wave Velocity Results

The bulk radial stress wave velocity maps of two eccentric discs and one concentric disc are shown in Fig. 3 together with the disc photographic images.

The radial stress wave velocity maps for the two eccentric discs (Fig. 3 DiscA, Disc1) show regions of considerably lower velocities on the wider side of the discs (where tension wood is likely to be present) than on the opposite side. In comparison, the velocity map for the concentric disc (Fig. 3 DiscB) was far more uniform in colour. This clearly indicates that the FAKOPP multi-channel timer has the potential to map the wider side of eccentric cross sections of tree stems, and hence to detect tension wood.

The radial stress wave velocity map of the other clear concentric disc and the knotty concentric disc each shows a region of lower velocity in correspondence to the pithy area (the 2D velocity maps are not shown in this paper due to restrictions on the paper length). This indicates that the FAKOPP multi-channel timer has potential in locating the pithy area and the juvenile wood zone. These two maps also show regions of low radial stress wave velocity in the mature wood zone. This would have resulted from experimental errors (possibly inadequate contact between the transducers and the wood or uncertainty in the transducers' time of flight delays) as it is against the normal pattern of wood property distributions within a cross section.

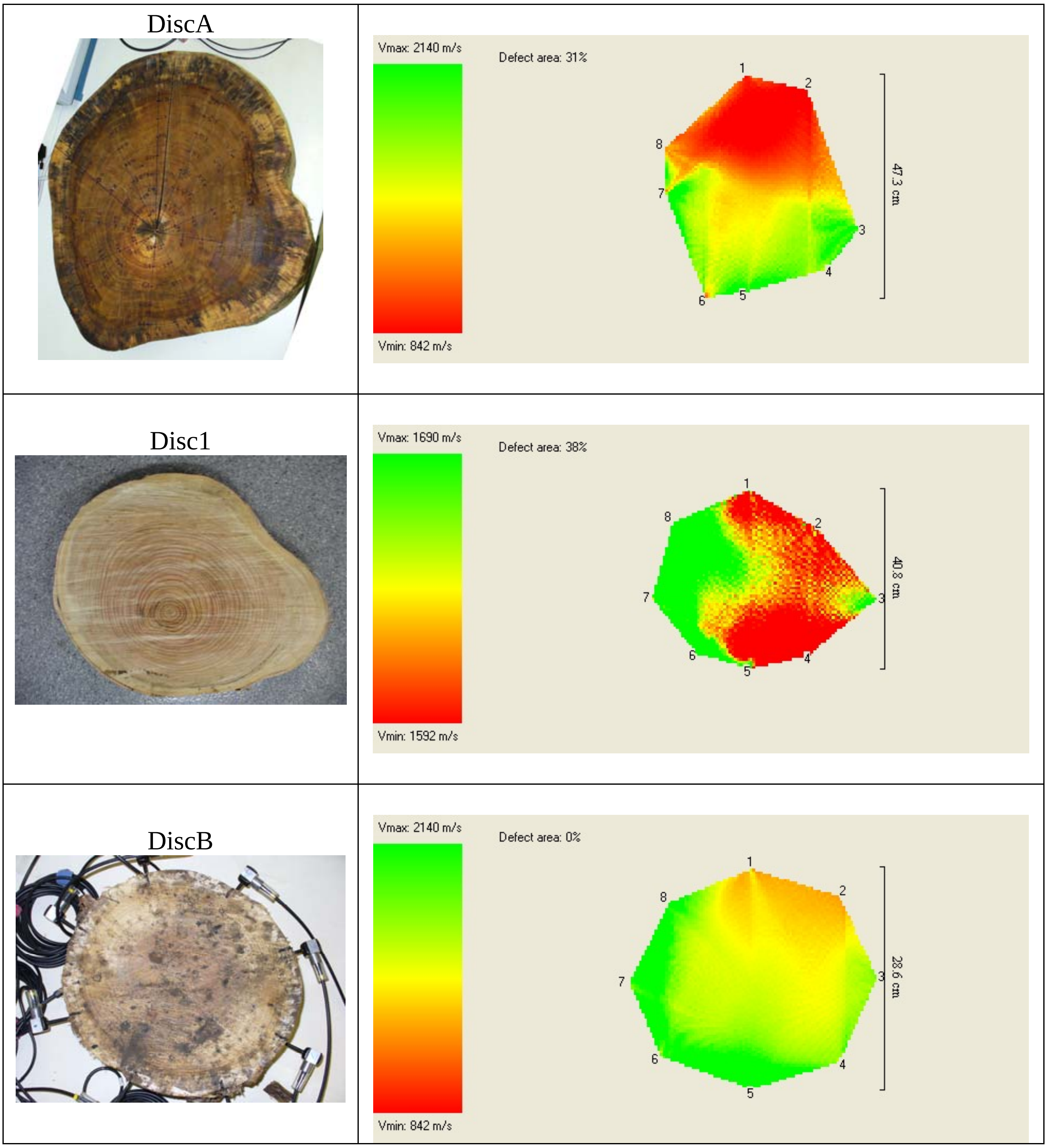

Figure 3. Radial stress wave velocity maps of two eccentric discs (DiscA, Disc1) and one concentric disc (DiscB).

The knotty disc contained a surface knot (as the other surface was clear) and a kino pocket (crescent-shaped cavities filled with liquid or solid extraneous materials). However, these two features did not readily stand out in the radial stress wave velocity maps. We think this is because, (1) the knot might be very much limited to the surface, and (2) as far as the kino pocket is concerned, an 8-channel timer could not produce sufficient velocity resolution for our large disc; also, the wave length of the stress waves needs to be smaller than the dimension of the kino for it to be detected.

3.3 Tangential stress wave velocity results

Tangential stress wave velocity maps were used to inspect the variation in different cross sectional zones of 5 discs. As results were similar for the eccentric discs and for the concentric discs, only the velocity maps of eccentric DiscA that presumably contained a considerable proportion of tension wood and concentric DiscB are presented in this paper.

Fig. 4 shows two tangential stress wave velocity maps for DiscA. As we have seen in the radial stress wave velocity maps of the same disc (Fig. 3), low stress wave velocity values were again observed in the zone between ray 3, 1 and 8 (the upper half of the disc). This was confirmed in every map on this disc with reference to different transducer positions (maximum distances: 40.5 and 16.3 cm).

In map 2 in Fig. 4 (maximum distance 16.3 cm), the velocity resolution was much higher because the zone being inspected was the smallest. Differences in tangential stress wave velocities were observed not only between tension wood and lateral wood, but also between tension wood and juvenile wood (the zone surrounding the pith, which is in orange colour in the map). This again points out that more transducers as well as accurate time-of-flight measurements are required in order to obtain higher resolution velocity maps.

Fig. 5 shows a tangential stress wave velocity map for the concentric disc DiscB, which virtually did not contain tension wood. The map is overall uniformly coloured and correspond to an average velocity value of 1200 m/s and a range of 941 m/s to 1432 m/s.

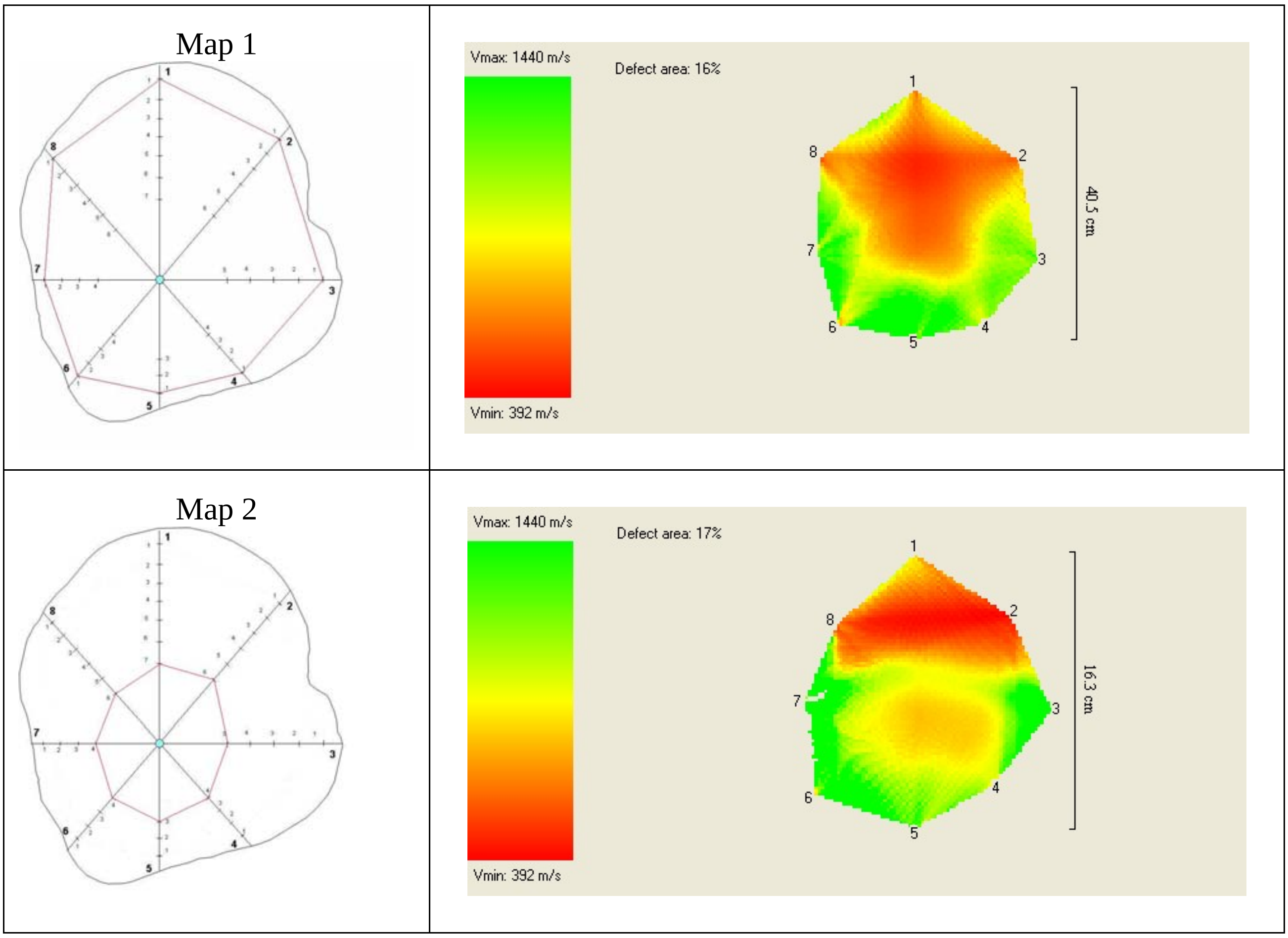

Figure 4. DiscA - Transducers were positioned perpendicular to the disc transverse surface.

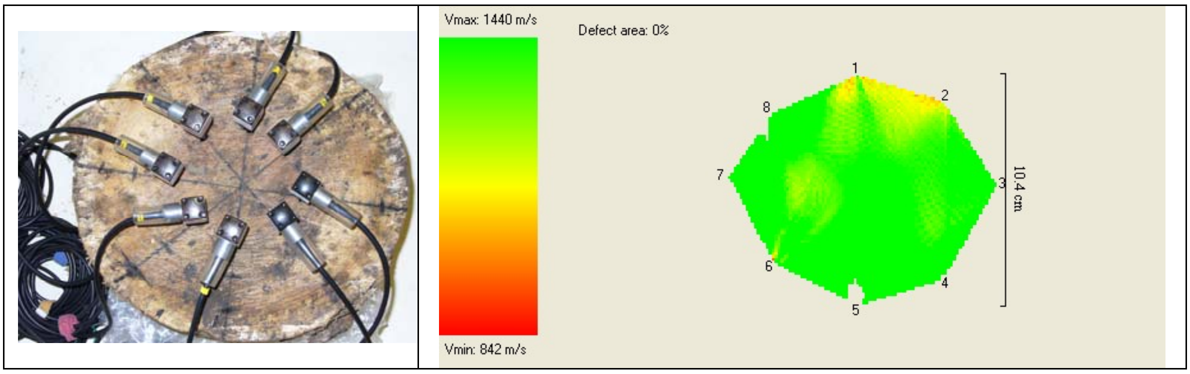

Figure 5. DiscB - Transducers were positioned perpendicular to the disc transverse surface.

4. CONCLUSIONS

- The longitudinal velocity V_{LL} (measured with ultrasonic longitudinal waves), in the L direction, was considerably higher on the wider side of the eccentric disc (DiscA) than on the opposite side. V_{LL} will be essential for the calculation of acoustic invariants in the detection and location of tension wood.
- The radial stress wave velocity maps for the 3 eccentric discs show measurements made using a multi-channel timer has potential in mapping the wider side of eccentric cross sections of tree stems, hence potentially tension wood. These results can also be interpreted as that the multi-channel timer has good potential in revealing large variation in wood properties within a cross section.
- The radial stress wave velocity maps of the concentric discs and the knotty disc indicate that a multi-channel timer has potential in locating the pithy area and potentially the juvenile wood zone. This observation was supported by the results with surface tangential stress wave velocities.
- Improvement in the resolution of the velocity maps could be achieved by using a multi-channel timer with 16 or 32 transducers in order to produce more precise radial velocity maps so that the variation in wood can be more precisely determined. Such multi-channel instruments are available.
- Based on the radial stress wave testing results on discs in this study, the multi-channel timer is expected to show similar potential in nondestructively detecting moderate to severe tension wood in standing trees and logs.
- It was observed that surface tangential stress wave velocities were lower in tension wood zones than in the opposite wood, the lateral wood and the juvenile wood.
- The experimental configuration for surface tangential stress wave velocity measurements can be applied to log ends to inspect within-cross-section wood property variation, in conjunction with the use of conventional radial stress wave velocities.

ACKNOWLEDGEMENTS

The wood discs were provided by Hancock Victoria Plantations and Black Forest Timbers. We thank Drs Grant Emms and Roger Meder of Ensis for their various help during this study and their valuable comments on this manuscript.

REFERENCES

[1] M. Müller, M. Burghammer and J. Sugiyama, "Direct investigation of the structural properties of tension wood cellulose microfibrils using microbeam X-ray fibre diffraction", *Holzforschung* **60**, 474-479 (2006).

[2] D. Fengel and G. Wegener, *Wood - Chemistry, Ultrastructure, Reactions*, De Gruyter, Berlin, 1984.

[3] J.L.Yang, D. Fife, G. Waugh, G. Downes and P. Blackwell, "The effect of growth strain and other defects on the sawn timber quality of 10-year-old *Eucalyptus globulus* Labill.", *Australian Forestry* **65**(1), 31-37 (2002).

[4] J.L. Yang, "The impact of log-end splits and spring on sawn recovery of 32-year-old plantation *Eucalyptus globulus* Labill.", *Holz als Roh- und Werkstoff* **63**(6), 442-448 (2005).

[5] A.J. Panshin and C. de Zeeuw, *Textbook of Wood Technology*, McGaw-Hill Book Company, New York 1980, page 319.

[6] FAKOPP Multi-channel Timer, *User's Guide*. FAKOPP Enterprise www.fakopp.com

[7] V. Bucur, G. Janin, C. Herbe and J.M. Ory, "Ultrasonic detection of reaction wood in European species", *Proc. 10th Congress Forestier Mondial*, Paris, 17-26 Sept. 1991.

[8] C. Coutand, G. Jeronimidis, B. Chanson and C. Loup, "Comparison of mechanical properties of tension and opposite wood in *Populus*", *Wood Sci. Technol.* **38**, 11-24 (2004).