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VARIATION IN ANISOTROPIC SHRINKAGE OF PLANTATION-GROWN PINUS RADIATA WOOD

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ABSTRACT

Anisotropic shrinkage of 27-year old *Pinus radiata* wood was measured from green to oven-dry condition. The samples were prepared from 21 discs cut from seven trees at different stem heights of 0.1m, 5.2m and 10.3m above ground, respectively. Longitudinal shrinkage was found to vary from 0.02% to 2.34%, with peak values near the pith decreasing towards the bark. The variation was more pronounced at the 0.1m height. The longitudinal shrinkage also showed a trend of decrease with the stem height above the ground. Tangential and radial shrinkage was found to increase with growth ring number from the pith, but the variation along the stem height did not show a clear trend.

The results confirmed that the pith-to-bark variation and vertical variation of the anisotropic shrinkage were significant for radiata pine. Large differences were also observed among corewood, transition wood and outerwood. Microfibril angle (MFA) was believed to the main reason for these variations.

Keywords: Anisotropic shrinkage; growth ring number; tree height, *Pinus radiata*

INTRODUCTION

With more and more wood now coming from fast-growing plantation forests, dimensional stability and warp are major concerns in wood processing (drying) and utilization. This problem is believed to be caused by gradients of wood anisotropic shrinkage both in radial and axial directions, as well as spiral grain angle and ring curvature. The patterns of variations in the wood shrinkage and the spiral grain angle, however, can differ widely among genera and species. They can also differ among sites, genotypes and tree ages. The shrinkage variation has been reported to occur from pith to bark (often described in terms of ring number from the pith), along the stem height and within a single ring (earlywood and latewood). Based largely on variation in wood properties, the first few rings from the pith are widely termed as juvenile wood or more appropriately corewood, and the wood outward from the corewood boundary to the bark termed as outerwood (Burdon *et al*. 2004). Transition wood is also used to describe the wood at the boundaries between the corewood and the outerwood. These terminologies are widely used for plantation softwoods in the southern hemisphere.

The purpose of this study was to obtain detailed data and depth of understanding of the patterns of variation in anisotropic shrinkage, which can be crucial to optimize value recovery from the plantation wood.

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MATERIALS AND METHODS

Thirteen 27-year old *Pinus radiata* trees for this study were cut from South Canterbury forests, New Zealand. From the tree stems, 200 mm disks were cut on site at different stem heights of 0.1m, 5.2m and 10.3m from the ground and, during the disc cutting, directions of North, South, East and West of the stems were marked for further use. Then the discs were sent to the Wood Technology Lab at the University of Canterbury for small clear sample preparation. After examining the disks of each tree, 21 disks from seven trees, which had a centralized pith, were selected and used in this project.

From each disk, 50mm-thick boards parallel to the stem axis were cut out through the pith along the directions of North-South and East-West, respectively. The boards were then cut into samples of 120 (longitudinal) × 30 (tangential) × 20 (radial) mm and these samples represented the wood from different growth rings (from pith to bark) and stem heights from the ground. In this project, wood within the first 7 growth rings from the pith was regarded as corewood and wood from the 15 growth rings outward to the bark was termed as outerwood, while the wood between the 8th and 14th growth rings was treated as transition wood. Summary of the samples were shown in Table 1.

Table 1. Sample summary (numbers) based on wood-type and tree height

Height	Corewood	Transitionwood	Outerwood	Total
0.1m	20	45	52	117
5.2m	29	31	27	87
10.3m	31	34	21	86

After the weight and dimensions were measured in green wood, the samples were equalised in a conditioning chamber at a temperature of 30º C with the relative humidity (RH) being decreased from high to low in steps at 80%, 60%, 45% and 35%, respectively, to minimise negative influence of drying stress on the shrinkage. At each step, the samples were conditioned for two weeks when the weight changes in the samples were not detected. After the last step (the lowest RH), the samples were dried at 103°C for 24 hours in an oven to determine the oven-dry weight and dimensions. Shrinkage was then calculated as the dimensional changes from green to oven-dry divided by the green dimensions.

RESULTS

The statistic analysis results from the experiments are given in Table 2 for longitudinal, tangential and radial shrinkage from green to oven-dry condition. From the results, it is found that there were significant variations in the anisotropic shrinkage for the plantation radiata pine used in this project.

Large differences among trees are shown in Figs.1 and 2. Fig.1 illustrates the overall values of the longitudinal, tangential and radial shrinkage (expressed as percentage) in the seven trees averaged over the stem heights (0.1m, 5.2m and 10.3m). The error bars show the data variability at 95% confidence level. The shrinkage variations along the growth ring number from pith to bark at different stem heights are shown in Fig.2(a) for the 0.1m height, in Fig.2(b) for the 5.2m height and in Fig.2(c) for the 10.3m height. Due to the limited number of samples in each growth ring, statistical analysis was impossible and thus the maximum and the minimum values at the measured growth ring are indicated by error bars in Figs. 2(a) to 2(c). From these figures, it is seen that the longitudinal shrinkage had a consistent pith-

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to-bark trend of declining with the growth ring number from the pith and this trend was most apparent for the 0.1m height. At the 0.1m height, the longitudinal shrinkage declined rapidly from 2% at the pith to around 1.1% at the 7th growth ring, approaching a constant value of about 0.8% from the 9th to 14th growth rings, followed by slow decrease outwards. Although a similar pith-to-bark trend was also found for the longitudinal shrinkage at both 5.2m and 10.3m heights, the range of variation was much narrower than that at 0.1m height. From Fig.2, a general pith-to-bark trend is also observed for the tangential and the radial shrinkage which increased from pith to bark although the trend was not as obvious as that for the longitudinal shrinkage.

Table 2. Summary statistics for anisotropic shrinkage (%)

Anisotropic shrinkage	Mean value	Standard deviation	Range
Longitudinal	0.54	0.46	0.02-2.34
Tangential	5.62	0.85	3.34-7.87
Radial	3.21	0.80	1.05-6.60

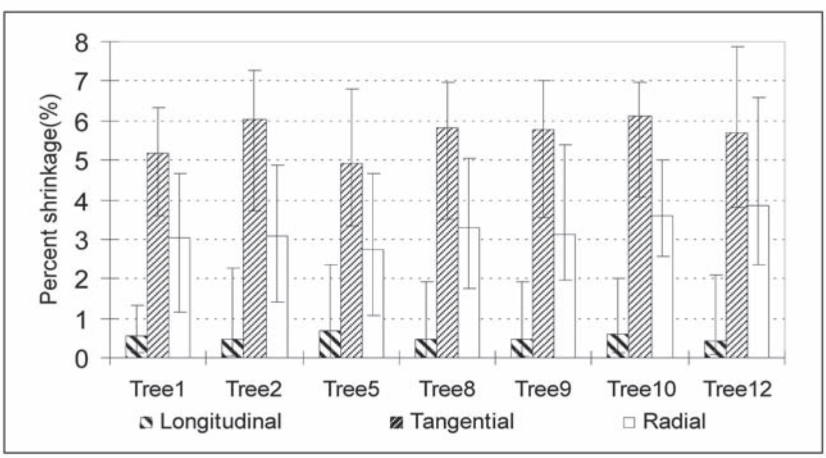

Figure1. Variations in the anisotropic shrinkage among trees. The error bars show the maximum and the minimum values at 95% confidence level.

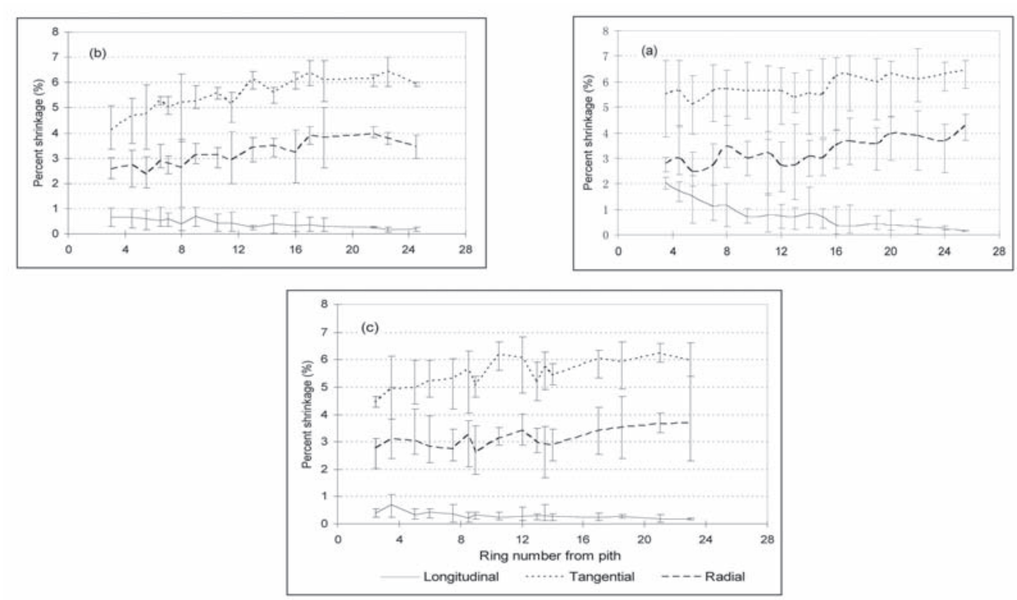

Figure 2. Variation of the anisotropic shrinkage with ring number at different heights of 0.1m (a), 5.2m (b) and 10.3m (c).

Regarding the stem height effect, a trend in the longitudinal shrinkage was observed which decreased with the stem height, average value decreasing from 0.76% at 0.1m, to 0.45% at 5.2m and then to 0.32% at 10.3m. Differences of the tangential and radial shrinkage between stem heights were not consistent although the average values of 0.1m disks tended to be lower than those of disks cut from other stem heights.

Table 3 gives the average values of the anisotropic shrinkage for corewood, transition wood and outerwood. The values with effects of the stem height tree are shown in Fig. 3. From Table 3, it is obvious that there were significant variations of the anisotropic shrinkage between corewood, transition wood and outerwood. As expected, the corewood had the highest longitudinal shrinkage, and the lowest tangential shrinkage and radial shrinkage. On the other hand, longitudinal shrinkage of the outerwood was the lowest, while tangential shrinkage and radial shrinkage were the highest in the outerwood. Anisotropic shrinkage of the transition wood was between those of the corewood and the outerwood.

Table 3. Average anisotropic shrinkage for corewood, transition wood and outerwood*

Shrinkage (%)	Corewood	Transition wood	Outerwood
Longitudinal	0.78 (0.59)*	0.57 (0.42)	0.32 (0.24)
Tangential	5.07 (0.83)	5.55 (0.73)	6.14 (0.68)
Radial	2.84 (0.69)	3.04 (0.65)	3.69 (0.80)

*Note: Numbers in brackets are standard deviation.

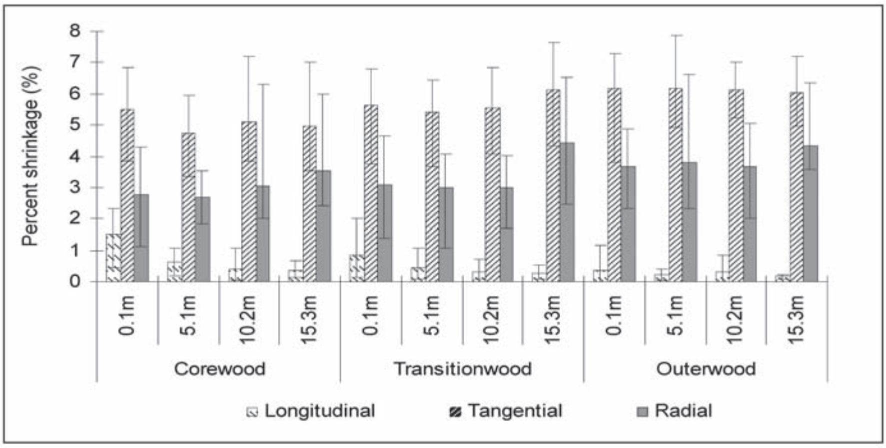

Figure 3. A comparison of average anisotropic shrinkage for corewood, transition wood and outerwood at different height. Sample numbers for each height are given in Table 1, and the error bars show the maximum and the minimum values at 95% confidence level.

Fig.3 also shows a clear trend of the longitudinal shrinkage decreasing with the stem height which is true for all of the corewood, the transition wood and the outerwood. However, effects of the vertical height on tangential shrinkage and radial shrinkage were not as obvious as that for longitudinal shrinkage.

DISCUSSION

The variation of anisotropic shrinkage with growth ring number has been reported in previous studies. Pilura et al. (2005) reported that the tangential shrinkage of young poplar wood increased from pith to mid-radius of the stem disk and then started to decrease outward. In pines, within-tree variation in wood properties is often very pronounced (Donaldson 1992), with pith-to-bark trends being particularly remarkable. Deresse *et al*. (2002) found that longitudinal shrinkage of red pine (Pinus resinosa Ait.) declined significantly with increasing the growth ring number from the pith and the influence of the growth ring number changed significantly at around 15th growth ring, with the longitudinal shrinkage leveling off after that. Herritsch (2007) showed similar trends for radiata pine, although in this study, tangential shrinkage remained relatively constant in the transition wood and the outerwood.

The variation pattern found in this study is consistent with the earlier reported data (Cown and McConchie 1983, Pang 2001, Herritsch 2007). However, it is found that the earlier reported longitudinal shrinkage was lower than the values from the current study as shown in Table 4. This could be due to the tree age and the forest sites in different studies. Younger trees of 25-30 years were used in the work of Pang (2001) and Herritsch (2007), thus higher longitudinal shrinkage was measured compared to the 50 year old trees used in the work of Cown and McConchie (1983).

Table 4. Comparison of longitudinal shrinkage from green to oven-dry between this study and literature data

Source	Cown and McConchie (1983)	Pang (2001)	Herritsch (2007)	This study
Value (%)	0.25	0.38	0.39±0.26	0.54±0.46

It is widely accepted that pith-to-bark variation in longitudinal shrinkage is a key factor for distortion in timber drying. However, Kilger *et al*. (2003) reported that the difference in the longitudinal shrinkage between two faces of the timber explained spring or bow much better when the variation in shrinkage along the timber was considered.

Microfibril angle (MFA) was believed to be the main cause of high variation in longitudinal shrinkage. Meylan (1968) examined the longitudinal and tangential shrinkage in the corewood of *Pinus jeffreyi* where the microfibril angle exceed 40° was found with corresponding longitudinal shrinkage of as high as 7% which was well in excess of the tangential shrinkage in 'normal' samples. In the study on 22-year-old trees of *Pinus radiata*, Donaldson (1992) reported that the mean microfibril angles varied from 9° to 55° with the highest angle occurring in the corewood of the butt log. The results of Donaldson also showed a curvilinear decline of the microfibril angle from pith to bark, which was more pronounced at the butt log of the stem. Herritsch (2007) reported that the tangential shrinkage decreased with the tree height, which followed the same trend as the MFA. However, many other factors including density (Pilura *et al*. 2005), spiral grain, and latewood proportion (Walker 2006) will also affect the variation in shrinkage of the wood, although MFA was believed to be the main cause of the high longitudinal shrinkage in the corewood. Therefore, variation in MFA (Donaldson 1992) together with density (Cown *et al*. 1992) of radiata pine can be able to explain the trend of the shrinkage variation. The high longitudinal shrinkage in the core wood measured in this study is consistent with the trend of MFA as measured by Donaldson (1992). The spiral grain angle may also affect the anisotropic shrinkage, however, this is mainly due to the deviation of the sample length direction (longitudinal) and the actual grain direction. Nevertheless, the high longitudinal shrinkage in the core wood is consistent with the high spiral grain angle observed by Cown *et al*. (1991).

Large radial and axial gradients of the longitudinal shrinkage in the corewood and the transition wood found in this study can strongly influence wood dimensional stability in service and cause wood distortion during kiln drying. The correlation of the wood distortion and the anisotropic shrinkage has also been studied in this project and will be reported separately. From this finding, it is possible to presort the timber based on corewood proportion before drying thus different drying schedule can be used to minimize the timber distortion.

CONCLUSIONS

Pith-to-bark and vertical variations of anisotropic shrinkage were found to be significant for radiata pine with most noticeable variation being observed for the longitudinal shrinkage at 0.1m stem height. An obvious trend was seen for the longitudinal shrinkage which decreases both from pith to bark and with the stem height. The trend of pith-to-bark variation for the tangential and radial shrinkage was also obvious which increases with the growth ring from pith to bark although the variations were less significant in the transition wood and the outerwood. However, the trends of variation with stem height for the tangential and the radial shrinkage were inconsistent. Differences in the anisotropic shrinkage among corewood, transition wood and outerwood are significant with the longitudinal shrinkage showing the most difference.

The results confirmed the pith-to-bark and vertical variation of the anisotropic shrinkage in radiata pine, which is believed to contribute to high distortion in timber drying and dimensional instability in utilisation.

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