Screening Corewood of Pine for Wood Properties

M. Sharma, J.C.F. Walker and Shakti S. Chauhan

Abstract Conventional breeding requires long breeding cycles which limits selection intensity due to large tree sizes and high costs associated with assessing properties. In contrast very early selection offers a short cycle and assesses corewood which is the poorest wood in the tree. Young *Pinus radiata* trees were deliberately leant to produce separately opposite wood (OW) and compression wood (CW). The two distinct wood types were evaluated for dynamic modulus of elasticity, basic density, longitudinal shrinkage and volumetric shrinkage. A subset was also characterised for microfibril angle and mechanical properties using dynamic mechanical analyser to understand property–structure relationships in OW and CW. The wood properties of the two wood types differ significantly. We observed, for example, higher stiffness and density of CW which implies that selection in a nominally vertical stem would inadvertently result in a biased selection in favour of trees that happened to have abundant CW. This is avoided by focusing on the properties of OW in leant stems.

Keywords Radiata pine · Early selection · Compression wood and opposite wood

Introduction

Conventional tree breeding of radiata pine examines the wood quality in 8–11-year-old trees. Ostensibly this is desired as it gives a high age–age correlation between properties at selection age and at the harvest age. However, outerwood properties are of little concern. Apiolaza et al. (2013) argued that the main problem in radiata pine is the high per cent of poor-quality corewood, formed in the first 5–10 growth rings. Corewood has undesirable properties such as low basic density, high

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microfibril angle (MFA), high longitudinal shrinkage, short tracheids, high lignin and low cellulose content. It is this wood that needs to be improved to an acceptable level. For example, the current price differential between box grade material (the worst of the corewood) and utilitarian grades for framing (MGP10) is much greater than that between utilitarian grades and premium grades for engineering (MGP12) and finishing purposes found in outerwood (Apiolaza et al. 2013). Focusing on corewood permits working with young trees and justifies very early selection (<3 years). Shorter breeding cycles should outweigh any lower accuracy in early selection (Apiolaza 2009). Moreover, it is more practical to, consider whether cost, timescale or logistics, characterise a large population of small-diameter trees at age <3 years than a small population of large-diameter 8–11-year-old trees.

The large variation in stiffness in young radiata pine and its degree of genetic control (Lindström et al. 2004; Dungey et al. 2006) mean that stiffness can be improved by screening at a young age. There is a practical difficulty, namely the intermittent and uncertain presence of compression wood (CW) in young trees (Nakada 2007). Although CW is associated with leaning trees, even vertical stems can have significant amounts of CW, though severity and amount of CW is higher in leaning trees (Donaldson et al. 2004). Burdon (1975) examined 12-year-old *Pinus radiata* on four sites in New Zealand and estimated that 30–45% of the stem volume contained mild to severe compression wood. Deliberately leaning young trees separates the two wood types, resulting in pure CW on the underside and pure opposite wood (OW) on the upper side of the leant stem. These can be assessed separately for range of wood quality parameters.

Non-destructive acoustic testing in 8–11-year-old tree (Kumar et al. 2002; Matheson et al. 2008) is widely used in breeding programs. In young trees, due to their small relative size and poor form, the problem of CW is exaggerated and a non-destructive test will not be ideal, because it is not possible to determine the percentage of CW in an intact tree and the results of screening can mislead. This paper used acoustic resonance to characterise wood properties of CW and OW in short lengths of stemwood cut from leaning trees. The results were referenced against a more fundamental property MFA, which is considered as the main determinant of stiffness and stability (Cave and Walker 1994). At high MFAs, which occur in corewood and CW, the effect of the cell-wall matrix on wood properties was predicted to be particularly pronounced (Yamamoto and Kojima 2002; Xu et al. 2011). Therefore, storage modulus and damping coefficient (tanδ) were studied using DMA to understand the structure–property relationship and explore the possibilities of gathering information about matrix composition and its influence on wood properties.

Materials and Methods

A multi-family radiata pine progeny trial was established at Amberley, Canterbury, New Zealand, on non-irrigated flat land in 2007. In August 2008, all trees were staked and leant at an angle of $\sim 30°$. Trees were low pruned at a regular interval to get a clear bole stem. The trees were harvested in June 2010, and a 300-mm-long clear stemwood sample was extracted immediately above the root collar.

The full experimental procedures are described in Chauhan et al. (2013). First, 120-mm-long bolt from the base of each tree was ripped and trimmed to give two 100 mm long samples (three sides sawn leaving the cambial surface as a slightly curved fourth face): one sample came from the upper side of the lean yielding OW and the other sample from the lower side yielding CW. Samples were dried at 35 °C until they reached constant weight, corresponding to a moisture content (MC) of *ca.* 5%. Density (ρ) was calculated from dry weight ($\sim$5% MC) and volume of the sample. Stiffness (hereafter referred to as $MOE_{dynamic}$) was determined by the product of the resonance acoustic velocity squared (V^2) measured using WoodSpec (developed by Industrial Research Ltd) and the previously determined wood density:

$$MOE_{dynamic} = V^2 \rho \tag{1}$$

A subset of 163 specimens, taken uniformly across the stiffness spectrum, was used in a further study of MFA and dynamic mechanical analysis (DMA). A 10 mm thick strip adjacent to the bark was used to prepare two specimens: one 10 × 5 × 1.5 mm (longitudinal × tangential × radial) for X-ray diffraction and a second 40 × 10 × 1.5 mm (L × T × R) for DMA.

The X-ray diffractometer at the School of Biological Sciences, University of Auckland, comprised of: a Rigaku (Tokyo, Japan) MicroMax-007HF generator outputting 40 kV and 30 mA; a rotating copper anode; an Osmic (Michigan, USA) VariMax-HF mirror and a Mar (Norderstedt, Germany) 345dtb detector. The beam was orientated in the radial direction of the wood samples with exposure set to three minutes. Samples were positioned at a distance of 200 mm from the detector. An open source software "The Area Diffraction Machine Version" was used to integrate the intensity of the diffraction profile of 002 planes of cellulose. Cave and Robinson's method (Cave and Robinson 1998) was used to interpret the integrated diffraction profiles.

For DMA, samples were conditioned in a humidity control box over calcium nitrate (i.e. at 50% relative humidity) at 25 °C which corresponds to 9% moisture content. Density of samples was calculated using mass and dimensions of the sample. A DMA Q800 with a humidity control chamber from TA Instruments with single-cantilever bending mode was used with 17.5 mm distance between the clamping midpoints. Samples were clamped on their tangential face with clamping torque of $\sim$1 Nm. A displacement of 15 µm amplitude was applied at 1 Hz frequency at a constant temperature (25 °C).

Results and Discussion

The two wood types differ significantly in measured wood properties (Table 1). Compression wood is characterised by higher basic density and longitudinal shrinkage and lower acoustic velocity squared and volumetric shrinkage.

The mean basic density at ~5% moisture content was ~544 kg/m^3 for CW and 365 kg/m^3 for OW. Donaldson et al. (2004) reported a mean density 572 kg/m^3 in CW and 477 kg/m^3 in OW in leaning 18-year-old *Pinus radiata* trees. The low density of OW in the present study can be attributed to the juvenile nature of the samples which are characterised by low percentage of latewood, thin tracheid cell walls and large lumens.

The high dry acoustic velocity in OW compared to CW at ~5% moisture content could be attributed to a lower microfibril angle in OW. The difference in their mean acoustic velocities was 6%, so only a small difference in MFAs is to be expected. Indeed the mean MFAs in OW and CW differed by only 5 (Fig. 1). The MFA range in OW was 28°–48° which is consistent with Donaldson (1993). The range for CW was from 36° to 53°. There was good correlation between dry acoustic velocity^2 (V^2) measured on the principal 100 mm sample of OW and the MFA values on the smaller piece taken from the larger sample, although the same relationship was not as strong in CW (Fig. 2). The results not only validate the acoustic technique but also demonstrate that being a bulk measurement it adds further benefits in screening young trees.

The mean dynamic modulus was 3.40 GPa in CW and 3.03 GPa in OW (Table 1) for three-year-old trees. The slightly higher stiffness in CW, arising from its greater density, highlights the necessity to lean the trees as high stiffness in straight trees might be due to randomly distributed CW rather than due to stiffer OW.

Longitudinal shrinkage in OW and CW was comparable to previously reported results (Dadswell and Wardrop 1949; Ying et al. 1993). In this study and previous studies (Harris and Meylan 1965; Wooten et al. 1967) even at comparable MFA,

Table 1 Summary statistics of opposite wood and compression wood properties at 5% moisture content in young three-year-old *Pinus radiata* trees

Variables	Opposite wood		Compression wood	
	Mean	CV%	Mean	CV%
Basic density (kg/m^3)	365	7.1	544	10.4
Dry density (kg/m^3)	419	6.7	591	10.8
Dry acoustic velocity^2 (km/s)^2	7.23	9.7	5.77	8.0
Dynamic modulus (GPa)	3.03	12.3	3.40	10.6
Longitudinal shrinkage (%)	1.01	29.4	3.34	19.1
Volumetric shrinkage (%)	12.7	17.6	8.0	12.75

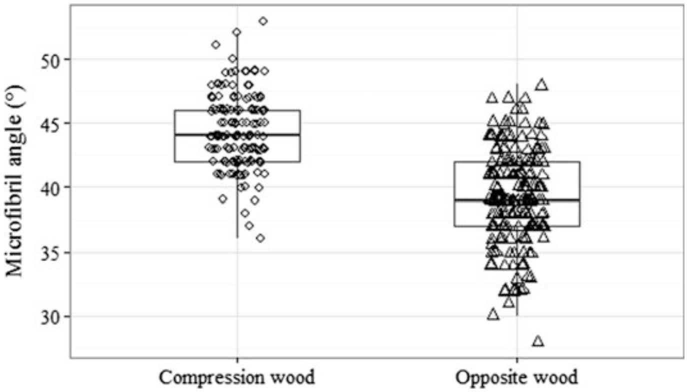

Fig. 1 Boxplot representing variation in MFA in compression wood and opposite wood in young *Pinus radiata*

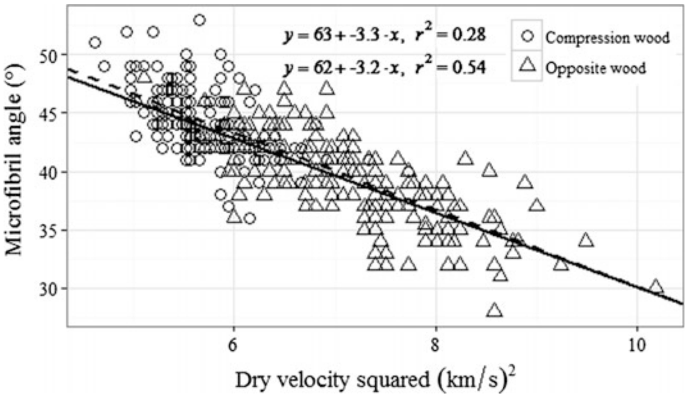

Fig. 2 Relationship between MFA and acoustic velocity squared in compression wood and opposite wood in young *Pinus radiata*

CW shrinkage is three times greater than opposite wood in longitudinal direction. Harris (1977) suggested that in addition to MFA, tracheid wall thickness is also responsible for high longitudinal shrinkage in CW, while Floyd (2005) noted that galactose content correlated with high longitudinal shrinkage. In CW the lignified secondary layer ($S2_{(L)}$) is characterised by a high level of (1-4)-β-galactan content (Altaner et al. 2010). Thus, along with physical and structure factors the galactan content in CW might contribute to the high longitudinal shrinkage in CW.

In opposite wood stiffness ranges from 1.94 to 4.90 GPa, and longitudinal shrinkage ranges from 0.15 to 1.91%, suggesting that there are possibilities to select for stiffness and stability at a young age. Moreover, there was strong negative correlation between stiffness and longitudinal shrinkage in opposite wood ($R = -0.68$). Thus, stiff opposite wood is also dimensionally stable.

The mean volumetric shrinkage for CW was 8%, and for OW it was 12.7%. Theoretically volumetric shrinkage increases with density, but high volumetric shrinkage in OW could be attributed to the fact that the thin walls in OW have collapsed while drying. Collapse was noticed in samples with low density. Comparatively low volumetric shrinkage in denser CW can be explained by its anatomical structure. The absence of S3 wall results in the cell wall shrinking towards the primary cell wall, i.e. increasing the size of the lumen without affecting the outer dimensions of the tracheid (Kelsey 1963; Harris and Meylan 1965).

The DMA analysis revealed that two wood types differed significantly in their damping coefficients (tanδ) (Fig. 3). Lower damping in CW was consistent with an earlier study (Brémaud et al. 2013). As MFA is positively correlated with tanδ, lower damping in CW is likely to be caused by the different proportions or structures of the cell-wall polymers, or the anatomical features of the tracheids. Brémaud et al. (2013) suggested that the abundance and more condensed nature of lignin with fewer methoxy groups in CW could be the reason for its lower damping.

The correlation between mechanical properties measured using DMA and other wood properties is given in Table 2. In OW, there was a significant positive correlation between MFA and tanδ suggesting that chemical composition alone is not the reason for tanδ variation. In CW tanδ did not correlate with MFA. The reason could be the low variation in MFA in CW. Thus, it might be possible to predict chemical composition particularly lignin percentage using tanδ values in CW.

In spite of the modest sample size in the DMA work, there is good correlation between storage modulus measured by DMA and dynamic MOE measured by acoustics (Fig. 4). Therefore, acoustics being faster and a bulk measurement is a better option to screen young wood for stiffness.

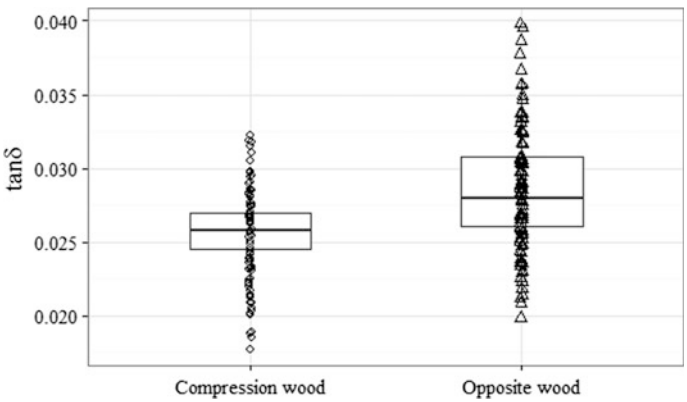

Fig. 3 Boxplots representing variation in tanδ measured at 25 °C, 1 Hz and 9% moisture content in compression wood and opposite wood in young *Pinus radiata*

Table 2 Pearson correlation matrix (with *p* values in parentheses) for wood properties of young *Pinus radiata*

Variable	Basic density (kg/m^3)	Acoustic velocity^2 $(km/s)^2$	Dynamic modulus (GPa)	MFA (°)	tanδ	Storage modulus (GPa)
Basic density (kg/m^3)		0.23 (0.03)	0.68 (<0.01)	−0.02 (0.87)	−0.26 (0.09)	0.55 (<0.01)
Acoustic velocity^2 $(km/s)^2$	−0.36 (<0.01)		0.85 (<0.01)	−0.74 (<0.01)	−0.53 (<0.01)	−0.67 (<0.01)
Dynamic modulus (GPa)	0.73 (<0.01)	0.34 (<0.01)		−0.53 (<0.01)	−0.50 (<0.01)	0.79 (<0.01)
MFA (°)	0.28 (<0.01)	−0.61 (<0.01)	−0.14 (0.17)		0.47 (<0.01)	−0.50 (<0.01)
Tanδ*	0.05 (0.62)	−0.27 (<0.01)	−0.11 (0.29)	0.16 (0.12)		−0.61 (<0.01)
Storage modulus[a] (GPa)	0.42 (<0.01)	−0.24 (<0.01)	0.61 (<0.01)	−0.08 (<0.01)	0.27 (<0.01)	

Opposite wood data above the diagonal, compression wood lies below the diagonal
[a]Measured at 25 °C, 1 Hz and 9% MC; other variables were measured at 20° and 5% MC

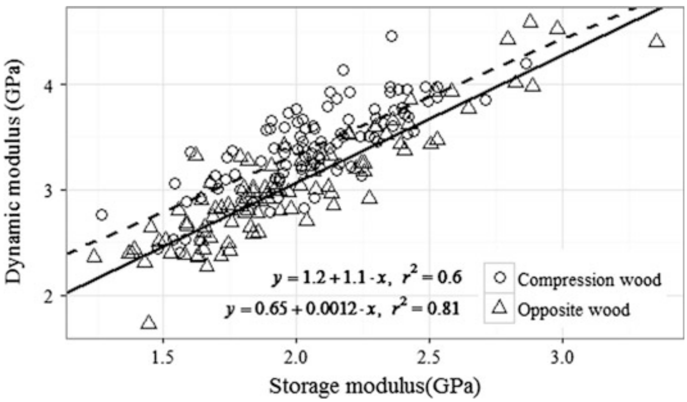

Fig. 4 Relationship between storage modulus measured at 25 °C, 1 Hz and 9% moisture content and dynamic modulus measured at room temperature and 5% moisture content in compression wood and opposite wood of young *Pinus radiata*

Conclusions

The wood types differ significantly in all the measured properties. Large variations in phenotypic stiffness (1.94–4.90 GPa) and longitudinal shrinkage (0.15–1.91%) within opposite wood suggest that it is possible to improve corewood quality by selecting at young age. It can be done much faster and economically by using resonance acoustic technique.

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