

Pre-processing prediction of wood quality in peeler logs grown in northern New South Wales

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Summary

Pinus elliottii (slash pine), *P. taeda* (loblolly pine) and *Eucalyptus saligna* (Sydney blue gum) logs grown in northern New South Wales were acoustically sorted into three wood stiffness classes. Veneers were peeled from the class-designated nine log batches and plywood boards then manufactured. In all species, the stiffness of the plywood boards was found to be closely related to the average recorded acoustic velocity of log batches. The average stiffness ranking of the plywood boards across species was *E. saligna* > *P. elliottii* > *P. taeda*. Regardless of species, sound velocity along logs reflected sound velocity measurements of corresponding peeler cores, suggesting that the average log acoustic signature may be a means towards managing problematic corewood stiffness. Mill studies confirmed the robustness of the mathematical relationship between sound velocity and wood stiffness. The implications are that acoustic tools have the potential to minimise yield of low-quality product during plywood manufacture. In turn, forest growers have the opportunity to use wood quality information, from both non-destructive stress wave (acoustic) technology and micro-processing studies on the current crop, to assist with silvicultural decisions for future new or replacement crops. Growers and processors should explore ways to integrate wood quality data into forest management information systems, linked to differential pricing arrangements, to maximise economic returns.

Keywords: log grade; wood properties; wood density; wood strength; juvenile wood; quality; grading; outturn; instruments; acoustic properties; plywood; *Pinus elliottii*; *Pinus taeda*; *Eucalyptus saligna*

Introduction

Wood quality information, particularly stiffness, is becoming increasingly important for both growers and processors. It has major effects on (a) total recovery and grade recovery in sawlogs; (b) pulp fibre recovery; and (c) plywood face veneer quality and plywood board strength. Non-destructive acoustic sorting of logs with a propensity to yield unacceptable products may offer a

means to improve the value recovery of current plantation crops in some parts of northern New South Wales (NSW).

In order to address environmental concerns regarding mixed native forests whilst satisfying the demand for wood products, Forests NSW (FNSW) is increasing the volume of both hardwood and softwood plantation-grown timber supplied to its plywood and sawmill customers. Species of interest include softwoods such as *Pinus elliottii* and *P. taeda*, and hardwoods such as *Eucalyptus saligna*, from intensively-managed planted forests with reasonably short rotations of about 30 y. These logs, however, tend to be smaller than those from traditional sources and include greater proportions of corewood. The properties of the corewood cause product down-grade during manufacture. For example, it is thought that corewood with low stiffness causes plywood manufacturing problems, such as buckling and splitting of veneer during drying. When the volume of corewood in logs is a small fraction of total volume, yields are not obviously affected; but when the fraction approaches 10–20%, both the yield and the quality of the final product declines (Zobel and Sprague 1998). It is proposed that the segregation of logs comprising high proportions of corewood, using acoustic tools, may improve grade yields within mills.

New knowledge is becoming available on the variability of corewood and outerwood within softwood trees (Burdon *et al.* 2004; Grabianowski *et al.* 2004). To some extent, this has been made possible by the development of acoustic tools (amongst other technologies) which are capable of measuring the average wood stiffness of logs, including that of the inner cylinder of juvenile wood. Research indicates acoustic tools are able to reliably predict the stiffness of wood in logs and particularly the stiffness and to some extent the warp properties of corewood (Walker and Nakada 1999; Downes *et al.* 2002). FNSW has actively collaborated with a number of its mill customers in processing studies to gather information on the application of acoustic log sorting tools. This collaborative effort has also improved understanding of the impact of species and silviculture on the quality of timber and fibre products (structural timber,

plywood, pulp and paper) produced by mills. The outcomes further our understanding of the effect of forest management practices on the performance of timber products (Bunn 1981).

This paper provides an overview of the outcomes of recent micro-processing studies on two sites of FNSW customers in northern NSW, in which the effectiveness of non-destructive tools for sorting logs according to wood quality specifications for producing structural plywood was evaluated. This work has continued to build technical linkages with processors and in turn improve forest cultural practices.

Materials and methods

Log selection and sound velocity measurement

Logs were randomly selected at two plywood mills in northern NSW for two mill studies. Ninety-six *P. elliotii* logs were sampled at the Norply mill, and both *P. taeda* (99 logs) and *E. saligna* (83 logs) were sampled at the Big River Timbers mill. The exact age of the *P. elliotii* logs was not known at the time of sampling as these were run-of-mill logs which may have come from more than one plantation, but they were from mature clearfell operations and hence the age would have been ≥ 30 y. The *P. taeda* logs were from a 33-y-old plantation in Clouds Creek State Forest (Cpt 38) near Dorrigo, and the *E. saligna* logs from a 37-y-old plantation in Pine Creek State Forest (Cpt 50) near Urunga. A mixture of butt and upper logs was used in both mill studies. The small- and large-end diameters over bark and the length of each log were measured. The sound velocity along the grain of each log was measured using the *Director HM200* tool (a Carter Holt Harvey product). *Director* determines the metric from many hundreds of reverberations of the acoustic signal within a log, providing a highly accurate measurement of the plane wave acoustic velocity. Acoustic velocity readings were taken by holding the unit firmly against the log end, with the sensor in good contact, and then hitting the log end with a hammer. As the position of the tool on the end section did not affect the reading, only a single reading was taken. For both mill studies, logs were segregated into three sound velocity classes: slow, medium and fast. The break points between classes are presented in Table 1.

To provide an estimate of basic wood density (oven-dry mass divided by green volume) and other wood properties, a disc of wood 50 mm thick was taken from both ends of five logs in each of the sound velocity classes (15 logs per species). The logs selected for this covered the range of Pilodyn readings of wood density (not reported here) within each sound velocity class. Basic density was determined gravimetrically on the whole disc, and

basic density for the log was then estimated by averaging the densities from either end, weighted by the area of the cross section of each disc. Moisture content (difference between green and oven-dry mass expressed as a percentage of oven-dry mass) was also determined on the whole disc, and estimated for the log in the same way as for basic density.

To identify log classes during conversion, each log was painted on both ends with a colour unique for each of the sound velocity classes.

Peeler log conversion

The logs in each sound velocity class were then debarked, heated for 12 hours and cut into billet lengths prior to peeling. At Norply, the *P. elliotii* logs were cut into billets 2.4 m long for both long- and cross-band veneers¹. At Big River Timbers, the *P. taeda* and *E. saligna* logs were cut into billets 1.8 m and 2.6 m long respectively for the long bands, and billets 1.3 m long for the cross bands. The logs in each sound velocity class were rotary peeled to produce continuous veneer 2.4 mm (Norply) or 3.0 mm (Big River Timbers) thick, which was subsequently clipped every 1.2 m and batched. The veneer batch from each log class was quarantined from others and identified with a paint colour that corresponded to the log class from which it was peeled. The veneers were dried in a 'piece drier', sorted, repaired and finally laid up to manufacture plywood panels either 2.4 m \times 1.2 m (*P. elliotii* and *E. saligna*) or 1.8 m \times 1.2 m (*P. taeda*). The *P. elliotii* panels were 12 mm thick, whilst both the *P. taeda* and *E. saligna* panels were 15 mm thick. All panels were of 5-ply construction. The veneers were laid up as they came off the stack and no attempt was made to place them in any specific location within the plywood. All veneers used were of Quality 'D' or better, which is normally required to produce structural plywood. The plywood was manufactured to comply with Australian and New Zealand Standard AS/NZS 2269:1994 (Standards Australia 1994) for structural plywood.

In addition, a subset of the peeler cores (the small cylinders of wood remaining at the completion of peeling) was tracked to the original logs and measured for acoustic velocity to examine how corewood properties may affect plywood stiffness. The diameters of these peeler cores were about 12.5 cm for *P. elliotii*, and 14 cm for both *P. taeda* and *E. saligna*. In total, 192 peeler cores (two per log) were tracked to the 96 logs peeled for *P. elliotii*, 100 peeler cores were tracked to 44 logs for *P. taeda* and 50 peeler cores to 25 logs for *E. saligna*. As there were two or more peeler cores from each log, the acoustic measurements were averaged for each log prior to the later analysis and regressions.

Plywood grading

All the plywood panels produced from each log class were then stress-graded on site at the mills using PAA stress grading machines. In this process, panels were manually fed individually into the machines, which bent the panel by applying a centre

Table 1. The acoustic velocity^a break points for each of the log batches

Species	Sound velocity (km sec ⁻¹)		
	Fast class	Medium class	Slow class
<i>P. taeda</i>	> 2.95	2.75–2.95	< 2.75
<i>P. elliotii</i>	> 3.70	3.40–3.70	< 3.40
<i>E. saligna</i>	> 4.05	3.85–4.05	< 3.85

^aVelocity determined by the *Director* tool

¹At Norply, the cross-band veneers were derived from the long bands by clipping them in half.

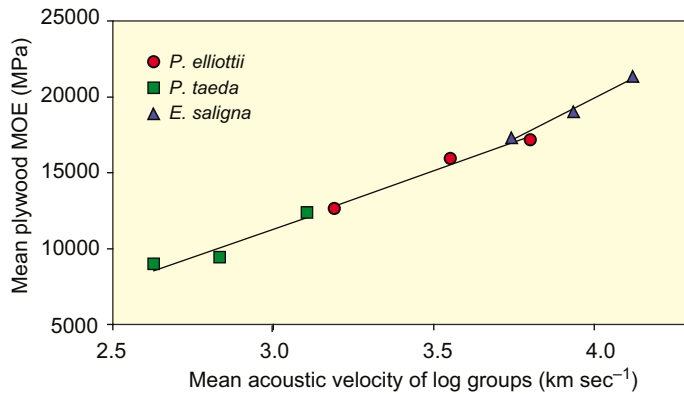


Figure 1. Relationship between mean acoustic velocity of log groups and mean stiffness of resulting plywood board, for *P. taeda*, *P. elliotii* and *E. saligna*

load over a test span of 900 mm (Norply) or 1200 mm (Big River Timbers). The resultant bending deflection, along with the known applied force, was then used by the machine to calculate modulus of elasticity (MOE) and assign an F-grade (Standards Australia 1994) to the panel.

Data analysis

Analysis of variance (ANOVA) was used to establish whether the overall stiffness of the plywood and other properties were significantly different among logs in the three sound flight classes. If the analysis indicated statistically significant differences, an *a posteriori* test (Tukey HSD multiple comparisons) was used to

establish where the differences existed. Correlation between the acoustic measurements and wood stiffness was estimated to examine the strength of the relationship and its predictive potential.

Results and discussion

The relationship between average plywood panel stiffness and log acoustic velocity is shown in Figure 1. The acoustic velocity was positively correlated ($r = 0.99$) with mean plywood stiffness, regardless of species. There is some data smoothing in this graph as each point on the graph represents a batch of logs in each of the three sound classes in the individual mill studies. The log acoustic measurements ranked the species in the following stiffness order: *E. saligna* > *P. elliotii* > *P. taeda*. This ranking is consistent with mill managers' observations that veneers peeled from *P. taeda* logs have a higher propensity to buckle and split during drying than those peeled from *P. elliotii* logs, and that panels made up from *P. taeda* generally produce poorer grade yields. These effects may be due to the corewood of *P. taeda* having poorer intrinsic characteristics such as lower density, higher microfibril angle (MFA) and more compression wood (Zobel 1975; Zobel and Sprague 1998; Walker and Nakada 1999).

The logs of each species segregated reasonably evenly across the three sound classes. Within each species, logs in the high-velocity sound class had the densest wood, although the differences in wood density between sound classes were species dependent (Table 2). For *P. elliotii*, the basic density of logs in the low-velocity class was 65 kg m^{-3} lower than of logs in the medium-velocity class and 136 kg m^{-3} lower than of logs in the

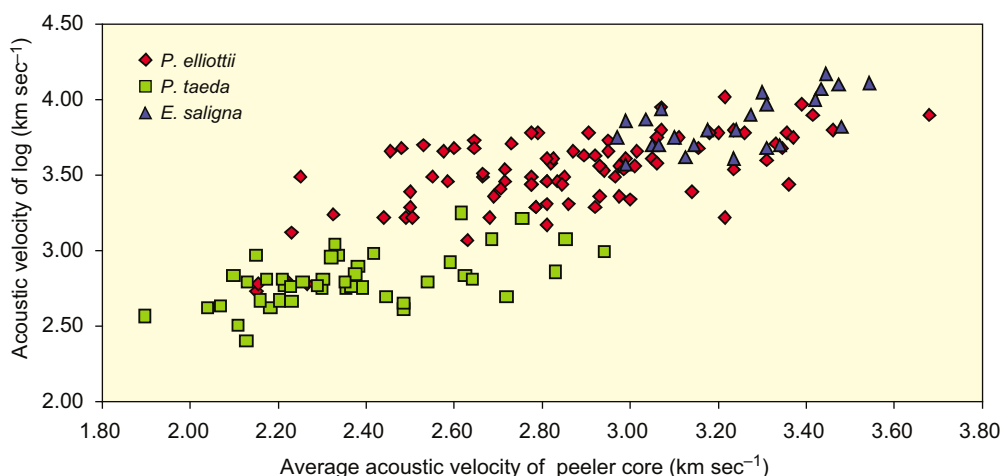
Table 2. Mean values (and standard deviations) of log and wood properties for *P. elliotii*, *P. taeda* and *E. saligna*

Species	Variable	Units	Stiffness class		
			Low	Medium	High
<i>P. elliotii</i>	No. logs		25	48	23
	SED ^a	(cm)	24.5 (2.9)	24.6 (2.3)	23.6 (2.5)
	Volume	(m ³)	7.8	15.2	6.4
	Heartwood	(%)	—	—	—
	Basic density	(kg m ⁻³)	487 (37)	552 (72)	623 (29)
	Moisture content	(%)	59 (12)	48 (7)	36 (2)
	Board stiffness	(MPa)	12659 (2009)	15897 (1617)	17190 (1428)
<i>P. taeda</i>	No. logs		27	42	30
	SED	(cm)	40.6 (7.3)	39.6 (4.7)	37.4 (4.6)
	Volume	(m ³)	18.5	26.7	19.1
	Heartwood	(%)	4.7 (1.9)	3.5 (3.4)	3.1 (1.6)
	Basic density	(kg m ⁻³)	427 (59)	440 (19)	449 (25)
	Moisture content	(%)	113 (30)	104 (12)	97 (6)
	Board stiffness	(MPa)	8927 (1581)	9394 (829)	12309 (1020)
<i>E. saligna</i>	No. logs		26	34	23
	SED	(cm)	35.7 (3.3)	33.9 (2.7)	32.8 (2.7)
	Volume	(m ³)	20.3	26.5	15.9
	Heartwood	(%)	71 (3.2)	71 (4.2)	69 (3.0)
	Basic density	(kg m ⁻³)	590 (24)	604 (20)	625 (18)
	Moisture content	(%)	74 (6)	69 (4)	63 (4)
	Board stiffness	(MPa)	17292 (1088)	18982 (1682)	21372 (1349)

^aSED = small-end diameter

Table 3. Recovery of plywood boards, by grade, from billets across log classes of 37-y-old plantation-grown *E. saligna* at the Big River Timbers mill, Grafton NSW

Acoustic velocity class	Log volume harvested (m ³)	Recovery (%)	Merchantable volume recovered by grade (%)			
			F17	F22	F27	F34
Slow	20.3	36.7	21	50	29	—
Medium	26.5	39.6	7	14	79	—
Fast	15.9	37.7	—	—	60	40

**Figure 2.** The relationship between mean acoustic velocity of peeler cores and the acoustic velocity of the logs from which the cores were derived, for *P. taeda*, *P. elliottii* and *E. saligna*

high-velocity class. For *P. taeda* and *E. saligna* the differences in average basic density for the same comparisons were 13 kg m⁻³ and 22 kg m⁻³, and 14 kg m⁻³ and 35 kg m⁻³, respectively. This variation across species is consistent with a recent finding that basic wood density of radiata pine does not predict wood stiffness well (Lindstrom *et al.* 2002). It is generally thought that MFA is associated with wood stiffness and that acoustic measurements are related to MFA (Downes *et al.* 2002).

The mean stiffness values for both the *P. elliottii* and *P. taeda* plywood boards were higher than those previously reported for the same species grown in Australia (Bolza and Kloot 1963; Bootle 1983). The stiffness of the *E. saligna* plywood boards was similar to values reported for mixed native hardwood (Bootle 1983). Essentially, the stiffness of the logs (as determined from plywood average MOE for logs) in the medium- and high-velocity sound classes was comparable to published data for the species tested. However, the stiffness of the logs in the low-velocity class was generally lower than published values.

The varying stiffness of the manufactured plywood boards across each of the sound velocity classes was reflected in the machine stress grade values (Table 2). For example, in the case of *E. saligna*, most of the grades were F22 or below for logs in the low-velocity class, F27 for logs in the medium-velocity class and F27 or above for logs in the high-velocity class (Table 3). The log dimensions across the three sound velocity classes were similar (Table 2). This suggests that the intrinsic wood properties (e.g. wood stiffness) of the hardwood logs are not well assessed

by the current visual log grading rules, which are largely a function of log size and visual (external) characteristics. This, in part, may account for the varying levels of product degrade within mills during manufacture and the impact of corewood.

Pith-to-bark changes in wood stiffness

In softwood, corewood generally refers to a cylinder consisting of the first 10–15 y of growth layers nearest to the pith. Corewood at the base of the tree extends further in a radial direction than it does in the logs from higher in the tree. In planted forests, cultural treatments such as fertiliser, irrigation, site preparation, stocking and thinning alter tree growth rates and, in turn, radial growth patterns. These treatments change the proportion of corewood harvested at any given age. Accelerated growth, together with reduced harvest ages, produce higher proportions of corewood in the timber supply. Timber from *P. elliottii* plantations 20–30 y old has been found to have low strength and stiffness properties that failed to attain the required design values for visually-graded structural material (MacPeak *et al.* 1990).

The relationship between acoustic velocity in logs and stiffness of plywood may be associated with corewood, regardless of species (Fig. 2). Regression analysis indicated that the acoustic velocity in individual logs was fairly strongly related to acoustic velocity measured along their corresponding peeler cores ($r^2 = 0.33$ – 0.43). In this relationship there were few outliers that would have indicated unexplained variation. This finding indicates that the acoustic velocity measurement of logs reflects the stiffness

properties of the corewood. It is known that the acoustic velocity measured in a log is the average for the log, and that it indicates the typical radial stiffness profile (Dickson *et al.* 2004). Thus, acoustic assessment of logs offers the opportunity to detect logs that have corewood of low stiffness. Figure 2 also indicates that there were peeler cores within the log population of each species that were stiffer than others. This result supports the view of Walker and Nakada (1999) that there is value in identifying, within the population, logs whose corewood has properties satisfactory for a particular end use. The ranking of peeler cores in stiffness, based on acoustic velocity, was the same as that of the logs, with *P. taeda* cores generally returning a lower acoustic velocity than *P. elliotii* and *E. saligna* cores, in that order. Not surprisingly, the hardwood cores were some of the stiffest.

Key outcome of the mill studies

Growers of new and replacement plantations must pursue research and improvements to silvicultural operations that lead to superior wood qualities as well as optimum tree growth (Bunn 1981). We suggest that acoustic tools offer a means for understanding important characteristics (e.g. problems with juvenile wood) of the ever-changing wood resource at manufacturing sites. Further, acoustic measurements, amongst other wood quality measurements, are critical in the feedback loop to enable silviculturalists to better match cultural regimes to the end products envisaged from future tree crops.

Implications of variation in wood properties

Routine surveys of the wood quality of forests, and the segregation of logs with non-destructive tools in order to improve mill grade yields, seem logical steps for a forest owner. Some large integrated companies have partly adopted these measures. There are, however, some logistical issues that may compromise the desired outcomes. These include the availability of log tracking systems and the effective implementation of differential pricing. These issues are likely to be more challenging in forestry enterprises where the participating businesses are not vertically integrated.

There is little doubt that measurements of wood properties in standing trees may greatly assist tree breeding and improve silvicultural decisions regarding wood stiffness (Wang *et al.* 2000). Indeed, broad-scale maps of wood stiffness may be instructive at the forest and regional level. However, it is less obvious how — in a broad-acre harvesting operation — acoustic information on trees or logs (an indication of wood quality) can be effectively carried along the merchandising chain from the forest to the processing mill, and be reflected in differential pricing for the grower. The inherent variation in wood quality, both within and amongst trees within stands, would require a sophisticated chain-of-custody system so that individual logs can be tracked through to milling. If wood quality is measured at the stand level, how will individual trees be assigned a unique identifier? If growers were to measure wood quality of trees, where and when would the technology be used (e.g. after felling and before processing)? And for what products would the lower-quality logs be processed? Is it feasible to introduce an additional sorting step into already complex operations? Perhaps a way forward would be to incorporate acoustic instruments into

mechanical harvester heads so that logs can be sorted according to stiffness as trees are felled and logs are bucked. Again, this may not be simple because of complexities in log tracking and log sorting.

The market arrangements of some growers do not now offer differential prices for wood from stands with differing proportions of corewood and mature wood, due for example to varying growth patterns or cutting age (e.g. felling at 22 y compared to 35 y). Notwithstanding, it is important that both foresters and millers continue to work closely together to develop and implement technical solutions to improve industry profitability. Agreed differential pricing based on objective wood quality measures on standing trees and logs will go part of the way towards improving value recovery from plantations.

Conclusion

This study confirmed that non-destructive acoustic assessment of hardwood and softwood logs provides valuable information on wood stiffness. The use of acoustic tools may be an appropriate way to manage the impact of corewood on product out-turn during manufacture.

Micro-processing studies such as the one reported here are a valuable means of evaluating wood properties to assist the better silvicultural management of future tree crops.

The integration of routine measurements of wood quality in the forest into management requires both software for information systems and market developments to more clearly link the forest data to resulting products. There is a critical need for growers and processors to continue to work closely in order to integrate and realise the value of wood quality information in their businesses.

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