SORTING LOGS AND LUMBER FOR STIFFNESS USING DIRECTOR HM200

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(Received July 2004)

ABSTRACT

Acoustic tools such as the Director HM200 are able to sort logs and boards according to their intrinsic stiffness. Here, some uses of such tools are demonstrated. First, six logs are analyzed before sawing into cants and individual boards. Second, the same approach is reconsidered from basic principles, emphasizing the variety of investigative projects to match the species-specific responses to acoustics and the need to match local resources to local markets. In both instances, correlations between acoustic properties measured in logs are related to those from cants and boards. The offsetting effects of changes in stiffness and density in determining acoustic velocity are discussed. The intention is to emphasize future possibilities for commercial application.

Keywords: Director HM200, acoustic velocity, density, stiffness, radiata pine.

INTRODUCTION

Traditionally, it has proved relatively simple to develop rules that allow visually similar material—whether trees, timber, or lumber—to be segregated into various categories or grades. This is preferable to selling "run of forest" or processing "run of mill" logs. This may be adequate for segregating broadly between sawlogs and pulplogs, when considering diameter, sweep, branch sizes, etc. However, visual grading fails to look inside the tree, log, or board, which means that within visually segregated material there still is an enormous natural variation. Thus in practical terms, a sawmill that buys a particular grade of logs will find that the between-log variation—however defined—varies by at least a factor of two.

In assessing intrinsic wood quality, an important requirement is the ability to ensure good representation of the desired property throughout the whole volume of the object. For this reason, there has been considerable interest in commercializing nondestructive tools to capture the intrinsic wood quality characteristics of whole stems, logs, and lumber for their rational utilization. For the wood processing industry, knowledge of final wood properties prior to processing would be of considerable economic importance in selecting appropriate wood resources and processing strategy. For structural purposes, wood stiffness is the most important property. The use of acoustic technology to estimate the stiffness of logs or lumber and to segregate them according to their processing characteristics has gained significant commercial importance (Pellerin and Ross 2002; Addis Tsehaye et al. 2000; Wang et al. 2000), and is subject to a number of patents relating to stiffness measurement tools and methodologies.

There have been many studies in which log stiffness has been determined from the acoustic velocity (Arima et al. 1990; Ross et al. 1997), and subsequently, when these logs have been batch processed, excellent correlations have been observed between the batched logs and the corresponding lumber stiffness and grades. Generally, acoustic tools based on the resonance technique have an edge over transit-time tools in terms of their accuracy in the velocity measurement in logs and lumber (Andrews 2000, 2002; Harris and Andrews 1999). Significant savings are possible in lumber processing if the dried lumber stiffness can be assessed effectively when the boards are in the green condition prior to processing. This study examines the association between green log velocity, and green and dried lumber stiffness as determined from the acoustic velocity measured by a resonance tool "Director HM200." It also investigates the usefulness of using only acoustic velocity to segregate lumber according to stiffness.

MATERIALS AND METHODS

Six radiata pine butt logs, aged ca. 24 years, were selected for this study. The logs were of different diameters ranging from 28 cm to 64 cm. First, acoustic velocity in the logs was measured using Director HM200 (ca. one week after felling). Then a 90-mm-thick diametral cant was cut from each of the logs, and the acoustic velocity was remeasured in these diametral cants (ca. 2 weeks after felling). Subsequently, 40-mm-thick boards were sawn from each of the diametral cants together with a pair of unedged, waney sapwood boards (Fig. 1).

A total of 42 boards were obtained from these six diametral cants. Green density (green weight over green volume) and moisture content were determined from clearwood blocks cut from these boards (ca. 3 weeks after felling). Acoustic velocity in the boards was measured while green and after air-drying, as was the air-dry density.

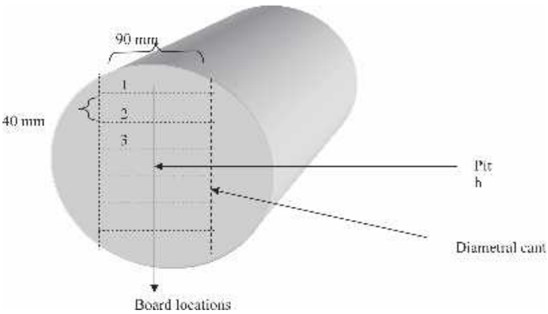

FIG. 1. Sawing pattern of logs showing location of the diametral cants and boards.

The Director HM200 acoustic tool was developed by Carter Holt Harvey fibre-gen, in New Zealand. Technical specifications and examples of use can be found at <http://www.fibre-gen.com> by referring to 'Products'. Director HM200 provides a means of segregating wood according to its nonvisible, intrinsic properties—whether one is segregating for sawlogs or pulpwood. Director-derived velocities can be used to sort whole stems before merchandizing or cut-to-length stacked logs. An individual stem can be assessed by one person in less than 30 s. The essential feature is that it analyzes the log as it resonates when tapped by a hammer. The acoustic reverberation of the hammer impulse moves as a plane wave back and forth along the length of the log, and by incrementally amplifying the signal as it decays, it is possible to observe many passes, in some instances over a hundred reflections (Harris et al. 2002). The Director HM200's accelerometer that is pressed in contact with the log end detects the acoustic signal, which is subsequently analyzed to derive the resonant frequencies of the reverberation. The tool derives the acoustic velocity for logs and lumber from the recorded resonant frequencies. The tool and its operation are shown in Fig. 2.

Knowing the fundamental frequency (f) and the fact that its wavelength (λ) is two times the

FIG. 2. When lightly tapped, the reverberation of the acoustic pulse along the log provides a spectral signature that is captured by Director HM200. The instrument provides a visual display of the acoustic velocity and the predicted log velocity class that is predetermined by the operator. The data are stored and can be uploaded.

length of the log (L), i.e. $\lambda = 2L$, then the acoustic velocity is easily calculated from the equation $V = f\lambda$:

$$V = f\lambda = 2Lf, \quad (1)$$

and for the n^{th} harmonic $V = f_n \lambda_n = (2L/(n))\, f_n$.

In practice, the acoustic velocity reported by Director HM200 is derived from the second harmonic frequency.

Dynamic modulus of elasticity (MOE) is calculated from the acoustic velocity and nominal density (density at the time of velocity measurement) of the material using the following equation:

$$E_{dyn} = \rho V^2 = \text{nominal density} * (\text{acoustic velocity})^2 \quad (2)$$

RESULTS AND DISCUSSION

Acoustic velocity in logs and boards

The acoustic velocity data for logs and diametral cants, and the mean of the acoustic velocities in boards sawn from the diametral cants are shown in Table 1.

The acoustic velocity in green condition in the butt logs ranged from 2.34 to 3.71 km/s. The average acoustic velocity of all the green boards within each diametral cant was similar to that for the diametral cant itself and for the original butt log. The relationships between acoustic velocity in logs with the mean board velocity in green and dried conditions are shown in Fig. 3.

The individual acoustic velocities for the boards taken from a particular diametral cant varied depending on the position of the board within the diametral cant. The variation in acoustic velocity in the boards is shown in Fig. 4.

The acoustic velocity measured by the resonant frequencies obeys the Law of Mixtures. Thus the acoustic velocity of the diametral cant should be the volume-weighted average velocity for all the boards from the diametral cant (Chauhan 2004). Since all the boards sawn from a diametral cant were of the same dimensions, the volume-weighted average of acoustic velocity should be the simple arithmetic mean of the acoustic velocities. From Table 1, it is evident that the average acoustic velocity of boards is close to the measured acoustic velocity in the corresponding diametral cant with a coefficient of determination of 0.98. The acoustic velocity determined by Director HM200 for logs and dia-

TABLE 1. *Acoustic velocity in butt logs and diametral cants, and the mean velocity for all boards in the green and air-dry conditions.*

Log No. and No. of boards per log	Log diameter (cm)	Acoustic velocity in log (km/s)	Acoustic velocity in diametral cant (km/s)	Mean acoustic velocity of all boards from the diametral cant and standard deviation (km/s)	
				Green	Air-day
1–4	28.0	3.29	3.35	3.26 (0.13)	4.24 (0.27)
2–5	30.0	3.71	3.51	3.39 (0.19)	4.11 (0.32)
3–6	32.5	3.13	3.15	3.15 (0.14)	3.77 (0.22)
4–7	35.0	2.34	2.32	2.35 (0.31)	3.18 (0.13)
5–9	54.5	2.51	2.53	2.54 (0.26)	3.29 (0.46)
6–11	64.0	2.48	2.51	2.69 (0.20)	3.26 (0.51)

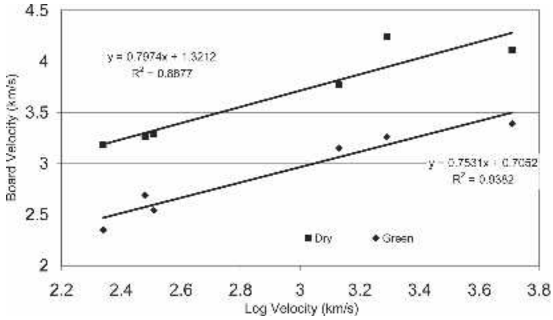

FIG. 3. Comparison of acoustic velocity for the log versus that for the green and air-dry boards cut from the cant. The data for the log versus the green cant (not shown) closely overlie those for the green boards, $y = 0.9053x + 0.2606$; $R^2 = 0.9755$.

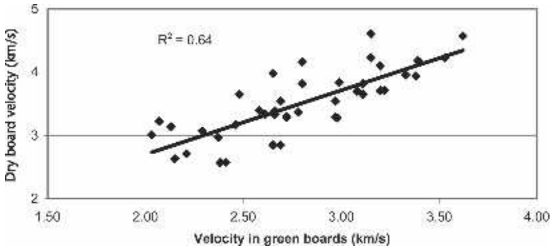

FIG. 5. There is only a modest correlation between the velocity of sound in the boards when green and after air-drying.

metral cants and the volume-weighted average velocity for the entire cross-section are interrelated through the application of Eq (2).

Comparison of acoustic velocity and stiffness in green and air-dry conditions

The main aim of this study was to evaluate the efficiency of acoustic velocity measurements in green condition to segregate lumber according to its MOE in air-dried condition. The acoustic velocities for the boards in the green and air-dry condition are shown in Fig. 5.

The moderate nature of association is due to the fact that the acoustic speed depends on both moisture content and the MOE of the board. The butt logs were from a mature stand and had a proportion of dry heartwood (Fig. 6). When sawn, the wet sapwood will produce boards with high moisture content (ca. 120% MC), while the heartwood boards from near the pith would be much drier (ca. 40% MC). The variation in Fig. 4 is partly a reflection of the variation in moisture content of the green boards at the time of sawing. It is evident that the acoustic velocity in boards cut from the stiff sapwood can be lower than that in the dry heartwood wood around the pith (Fig. 4): the lower velocities follow logically from Eq (2).

As the center of the tree is gradually transformed from sapwood to heartwood, the modulus of elasticity remains unchanged, but because the green density declines by about 50%, it follows that the acoustic velocity must increase by

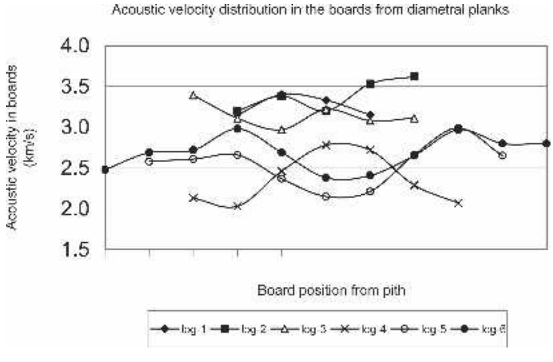

FIG. 4. The acoustic velocity changes little across the diametral plank from cambium to pith to cambium. The higher stiffness of the sapwood is offset by its higher green density; while the lower stiffness in the heartwood is compensated for by its lower green density (*refer* Eq. 2).

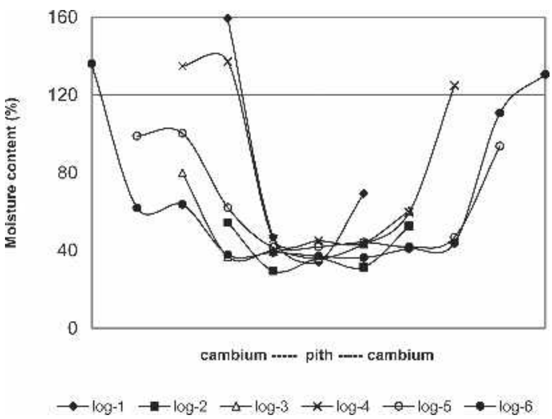

FIG. 6. Moisture content of boards is higher in the sapwood and lower in the heartwood.

22% to compensate (Eq 2). Thus the dry heartwood can have a higher acoustic velocity than the green sapwood, despite the heartwood being less stiff than the sapwood. For the same reason, during drying the acoustic velocity in the sapwood boards increases substantially as compared to the acoustic velocity in the boards from the heartwood zone: there is a larger density change.

The high variability in moisture content values in boards has resulted in only a moderate association between air-dried and green acoustic velocity in boards (Fig. 5).

The acoustic MOE in the green and air-dried condition can be calculated using the density and acoustic velocity of each board in the corresponding state and plotted against the acoustic velocity (Fig. 7). In the green condition, the acoustic MOE of the individual boards sawn from the logs had only a moderate association with acoustic velocity: again this is attributable to the large moisture content variation in the green boards. In case of air-dried boards, where all the boards were at the same moisture content, acoustic velocity alone explains 91% of the variation in stiffness despite the air-dry density ranging from 360 to 504 kg/m^3. This observation is interesting as it implies that Director HM200 can effectively assess the stiffness of kiln-dried lumber without taking account of density.

A strong positive relationship was observed between green and air-dry stiffness in the boards (Fig. 8). Above the fiber saturation point, ca. 30% MC, the acoustic MOE remains essentially constant so high green density is compensated

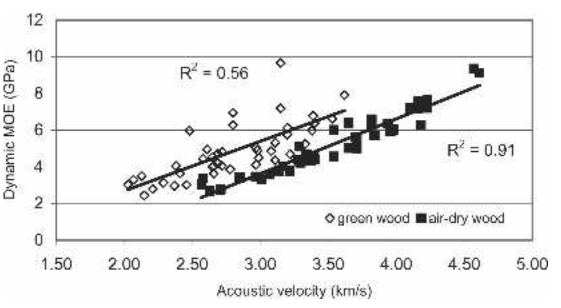

FIG. 7. The correlation between acoustic velocity and stiffness is much better in air-dry wood because there is less variation in wood density at 12% MC than when the wood is green.

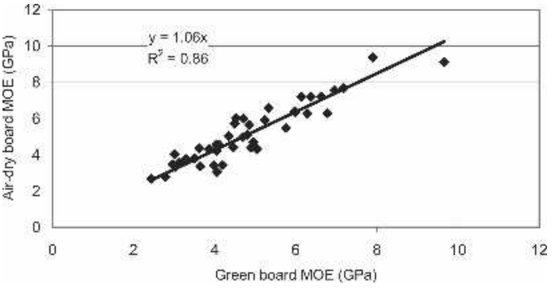

FIG. 8. Relationship between dynamic MOE in air-dried and green condition.

by the proportionate decrease in acoustic velocity. Thus, unlike the comparison between green and air-dry velocities (Fig. 5), there is a much superior relationship between green and air-dry stiffness. The air-dried stiffness was found to be about 6% higher than the green stiffness.

The results suggest that when dealing with green sawn wood e.g. lumber from mature old trees with a significant amount of heartwood, it is necessary to know the actual wet density of the individual piece for computing its MOE. Then, the stiffness of boards in green condition can be used to predict the stiffness at the dried condition with a reasonable accuracy. However, when the boards are at the same moisture content e.g. air-dried or kiln-dried boards, acoustic velocity measurement alone is sufficient to segregate boards according to their stiffness.

A thought exercise

There can be dissonance between what one expects to see and what one observes, especially with relatively small data sets. Further, one should be cautious in applying the outcomes for one species to another or even to trees of different ages. We have taken an old data set of stiffness and density for 25-yr-old radiata pine growing in Canterbury in which 48 trees were separated into stiffness groups (Addis Tsehaye et al. 1995). Here, we consider only the stiffest and least stiff trees (top and bottom 10%). In the case of radiata pine, one might expect the green densities of sapwood and heartwood to be around 1000 and 600 kg/m^3 respectively. The stiffness values are for air-dried wood and so could be 6%

TABLE 2. *The acoustic velocity in wood depends on the local stiffness, which increases from pith to cambium, and on the green density. In the latter case, green density is lower with the onset of heartwood formation, resulting in a corresponding increase in the acoustic velocity, see Eq (2).*

	Stiffest 10% of trees				Least stiff 10% of trees			
	Sapwood		Heartwood		Sapwood		Heartwood	
	Outer	Inner	Outer	Inner	Outer	Inner	Outer	Inner
Green MOE	11.5	10.5	8.5	6.0	7.5	6.5	4.5	3.0
Green density	1000	1000	600	600	1000	1000	600	600
Acoustic velocity in old tree	3.4	3.25	3.75	3.15	2.75	2.55	2.75	2.25
Green thinnings		1000	1000	1000		1000	1000	1000
Acoustic velocity, in thinnings		3.25	2.9	2.45		2.55	2.1	1.73

high (*see* Fig. 8). The radial acoustic velocity profile can be estimated (Table 2). In a mature tree with heartwood, the acoustic velocity would be expected to increase to the outer heartwood boundary, decline in the inner sapwood before rising again in the outer sapwood. However, in the same tree at a younger age before the onset of heartwood formation, the acoustic velocity would increase steadily from pith to cambium (Table 2). This same profile will be observed higher in stems in older trees, where heartwood has yet to form. In practice, when a log is sawn, the boards are rarely inner/outer of the heart/sapwood but some mix either in cross-section or along the board length as was the case in Fig. 4.

CONCLUSIONS

Acoustic resonance tools average the stem cross-section, giving an excellent estimate of the mean MOE of the lumber that can be cut from the log.

Correlations between green board acoustic velocity and dry board MOE are more problematic due to the uncertain and variable green moisture content. However, the air-dry acoustic velocity is a good estimator of air-dry MOE. In practice, that gives the smaller mill the opportunity to select out higher grade material, for example, for glue-laminating.

Most of the applications and interpretations will be species-specific. Thus Director HM200 offers an endless variety of investigative projects to match local resources to local markets.

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