Relationship among the dynamic and static elastic properties of air-dry *Eucalyptus delegatensis* R. Baker

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Nondestructive impact-induced resonance vibrations and spectral analysis were used to determine the relationships among dynamic longitudinal elastic modulus ($E_L$), wave velocity ($V_L$) in the fibre direction, dynamic flexural elastic modulus ($E_p$), logarithmic decrement (LD) in air-dry specimens of *Eucalyptus delegatensis* R. Baker, measuring 20 × 20 mm transversely and 300 mm long. The dynamic properties were compared with the static elastic modulus (MOE) and the modulus of rupture (MOR) obtained from three point bending tests. $E_L$ was very highly related to $E_p$, MOE, MOR and air-dry density, whereas the relationship between $V_L$ and static moduli was highly significant, but less strong. $V_L$ was related positively to air-dry density, and negatively to static shear modulus (Longitudinal-Tangential and Longitudinal-Radial planes). $E_p$ was the single best predictor of both MOE and MOR. LD was negatively related to MOE and MOR. The association between the dynamic ($G_p$) and static ($G_{ST}$) shear modulus values was only moderately good. The mean dynamic modulus was 3.4 times greater than the mean static value. $E_L$ may be used to estimate the true Young’s modulus in specimens in which shear contributes significantly to bending.

1 Introduction

Nondestructive evaluation (NDE) techniques are used for the assessment of material properties of structural and reconstituted wood products both in research and in the forest products industry (Beall 1996). Increasingly these techniques are being applied to wood quality studies (Kucera 1997). The density of wood and its elastic properties are considered fundamental to the evaluation of wood quality. These properties are usually determined from sample cores, boards, structures *in situ* or sometimes from nondestructive measurements taken directly from standing trees and logs. Elastic properties are usually determined from measurements of the propagation time of elastic waves or from resonant vibrations. The determination of the propagation time usually involves either ultrasonic or stress wave methods. In the case of uniform specimens, including industrial size material, vibration methods have special advantages including simplicity, speed and convenience of use. In this case, the properties depend on the natural resonant frequency, density, and sample dimensions (Hearmon 1958).

The aim of this paper is to examine the potential of a resonance technique for the evaluation of the wood quality of a collapse prone eucalypt. This was carried out by investigating relationships among the dynamic and static elastic properties and wood density. The main objective was to identify the dynamic properties most highly related to static bending MOE and MOR.

2 Materials and methods

Test samples of 1939 regrowth *Eucalyptus delegatensis* were obtained from East Gippsland, Victoria Australia. The material consisted of 52 boards used for ongoing

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experimental work at CSIRO. Each board was cut from a different butt log and taken from either outer or inner heartwood with the aim of obtaining a representative sample of the natural variation in wood properties. Initially the specimens were cut to 20 mm \( \times \) 20 mm and approximately 1200 mm in length. Two 300 mm long specimens (hereafter referred to as 'short specimens') were cut from one end of each board. The short specimens were used for dynamic and static tests. A subset of 35 specimens (hereafter referred to as 'long samples') of the remaining material was cut to 480 mm in length and used for additional static tests. The specimens were conditioned to an equilibrium moisture content (EMC) of 12% in a room set for 25 °C and 65% relative humidity (RH) and allowed to equilibrate to a nominal moisture content of 12%.

2.1 Dynamic elastic modulus

Resonant frequencies were determined from impact induced vibrations in the fibre direction (longitudinal) generated by impacting cleanly crosscut specimens end with a small steel hammer. A Sony microphone, type ECM-T140 was used to convert the audible resonant vibrations to a time varying electrical signal – ‘the transient’. A system was developed for capturing transient data and for the subsequent determination of spectral components. Dynamic elastic constants were calculated from the first mode of the resonant frequencies in the longitudinal direction and the first and second mode of flexural vibrations.

The most convenient way of supporting the specimens was by suspending them with flexible supports, although thin, tightly stretched wire and foam prism supports were also assessed. Resonant frequencies of the lower modes were identical irrespective of the support method. In the method adopted the specimens were hung from their theoretical nodal points for flexural vibration (0.224 of the length) using thick rubber bands stapled to the edge faces.

The detection system consisted of a transient recorder module, an external variable gain (1–50) wide-bandwidth preamplifier, a PCL1800 analogue to digital (A/D) board and DASYLAB software, from DASYTECH, Germany. The preamplifier gain was adjusted to produce voltage output swings between −5 and +5 Volts from the transients generated by tapping the test specimens. The input stage of the recorder was set to respond to a narrow range of voltage levels to ensure that only repeatable impacts were recorded and processed. Each transient was saved as a file and processed separately. A simple spectrum analyser was implemented in the transient recorder module to indicate resonance peaks as the test was performed. A 50 kHz sampling rate producing a frequency resolution of 2.9 Hz was used for all the tests. A separate spectrum analyser module was configured to read files containing the transient signal, perform a fast fourier transform (FFT) and generate output files representing the spectral data. The final step in the analysis was carried out using PEAKFIND, an inhouse program specifically written to identify spectral peak frequencies and use them to calculate \( E_L \), \( V \), \( E_F \) and the dynamic shear modulus \( (G_d) \).

The dynamic longitudinal elastic modulus \( (E_L) \) was calculated from the standard solution of the wave equation for longitudinal vibrations of a slender rod with free-free support condition; using the following equation (Kollman and Krech 1960)

\[
E_L = 4L^2f_m^2\rho / m^2
\]

where \( E_L \) = dynamic longitudinal elastic modulus (Pa), \( L \) = length of the bar (m), \( f_m \) = the resonant frequency (Hz), \( m \) = mode of vibration \((= 1, 2, 3, \ldots)\) e.g. \( f_1 \) = fundamental mode, \( f_2 \) = first harmonic etc., and \( \rho \) = bulk density (kg.m\(^{-3}\)).

The wave velocity in the longitudinal direction, \( V_L \) (m.s\(^{-1}\)) of the natural fundamental mode is given by

\[
V_L = 2Lf_1
\]

and \( V_L \) corresponds to the velocity of sound along a uniform bar.

The dynamic flexural modulus was calculated as:

\[
E_F = 4\rho i^2f^2L^2 / i^2 m^4
\]

When both ends of the beam are free, and where

\( E_F \) = dynamic flexural elastic modulus (Pa),
\( \rho \) = density (kg.m\(^{-3}\)),
\( i \) = the radius of gyration of the cross-section (m) (rectangular beam \( i^2 = h^2/12, h = \) thickness in the plane of bending),
\( f_1 \) = frequency of flexural vibration (Hz),
\( L \) = length of the beam (m),
\( m = 4.73 \) (roots of \( \cos m \cos m = 1 \), for the first mode).

The “Timoshenko correction” for rotatory inertia and shear effects was applied and the dynamic shear modulus \( (G_d) \) was calculated according to Hearmon (1958), only the fundamental frequency and the first overtone were used for the calculations. The results for the flexural moduli were confirmed by application of the procedure described by Chui (1991) for the simultaneous evaluation of bending and shear moduli using the first two natural frequencies of vibrating beams.

2.2 Static properties

Static bending tests were carried out according to the procedure outlined by Mack (1979). In addition, 480 mm long specimens were used for bending tests with varying spans to enable the evaluation of the shear modulus \( (G_ST) \) by solving simultaneously for MOE and \( (G_ST) \). The procedure outlined in ASTM D198–84 was used as a further check.

3 Results and discussion

3.1 Relationships among properties

The mean, 95% probability range and coefficient of variation of the measured properties are summarised in