

# Relationships between static and dynamic modulus of elasticity for a mixture of clear and decayed eucalypt wood

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## Summary

Static bending and dynamic resonance tests (flexure and longitudinal) were used to determine modulus of elasticity (MOE) of 167 wood specimens from clear and decayed regrowth Tasmanian oak (mostly *Eucalyptus obliqua* L'Hérit.). Strong relationships were found between static and dynamic MOE for both the clear and decayed wood specimens. The type of wood (clear or decayed) did not affect the closeness of the relationships, nor did it cause noticeable differences between the regression equations.

**Keywords:** wood strength; strength testing; modulus of elasticity; decayed wood; *Eucalyptus*

## Introduction

Dynamic modulus of elasticity (MOE) is increasingly being used for the evaluation of wood quality because it enables a rapid and convenient assessment (Tanaka *et al.* 1994; Beall 1996; Haines *et al.* 1996; Kucera 1997; Ross *et al.* 1997b, 1998; Yamamoto *et al.* 1998). Ilic (2001) demonstrated excellent relationships between static and dynamic tests for *Eucalyptus delegatensis* and possibly other species which make the dynamic test highly suitable for the rapid evaluation of stiffness-related properties for a wide range of specimens potentially of different size.

Overall, fungal decay has a significant adverse effect on strength properties of wood, particularly toughness and impact bending (Wilcox 1978). Yang *et al.* (2000) showed that increasing decay had little effect on MOE (static bending), but modulus of rupture (MOR) was more likely to be reduced. Ross *et al.* (1997a) suggested that non-destructive evaluation (NDE) using stress waves had significant promise for predicting the strength of wood members exposed to biological attack. Wang *et al.* (1980) found that a dynamic flexural test in *Pinus strobus* was more sensitive to early signs of decay than loss of mass, and that the NDE test could be repeatedly applied to the same sample during the progress of decay.

Close relationships between static and dynamic MOE have been shown in a number of reports using clear wood specimens; some

of these were summarised by Ilic (2001) and Macheck *et al.* (2001). Following the study by Yang *et al.* (2000), an evaluation was made to determine the extent to which dynamic MOE would be affected by decay and whether such a test might be potentially useful as an early indication of decay. The results are reported in this paper.

## Materials and methods

Wood specimens (167) of regrowth Tasmanian oak<sup>1</sup>, mostly consisting of *E. obliqua*, were used in this study. Of them, 68 were prepared from clear wood and the rest from a range of decayed material that was classified as 'discoloured', 'pencil streak', 'decay pocket' or 'rot' (Wardlaw 1996; Yang *et al.* 2000). The dimensions of the specimens were 20 mm x 20 mm x 300 mm and the nominal moisture content was 12%. About 10% of the specimens had true flat-sawn (back-sawn) growth ring orientation, but in the remaining specimens the growth ring orientation varied by up to 45°. Additional details about the origin of the wood, the specimen preparation and decay classification can be found in Yang *et al.* (2000). Mass density at 12% moisture content was determined from the weight and dimensions of the specimens.

Dynamic modulus of elasticity was determined for each specimen using resonance flexure and longitudinal modes as described by Ilic (2001). In resonance tests, the specimen was suspended on a pair of soft springs (rubber bands) with radial face facing up. The distance from each end of a specimen to its nearest support was 0.224 times the specimen length. The specimen was tapped once on its radial face at mid-length point, using a small metal rod, to determine the flexural resonance. The resonance was detected using a microphone and the resonance frequency determined with a spectrum analyser. One or sometimes two major peaks would occur. The primary peak with the highest magnitude (the fundamental peak) corresponded to the resonance induced from vibrations in the tangential direction. The secondary peak corresponded to the vibration induced from the direction at right angles. In the longitudinal test, the specimen was supported in the same way as in the flexure test, but in this instance the specimen was tapped once on one end. The primary peak was determined and the corresponding frequency recorded.

The resonance flexure MOE ( $MOE_{flexure}$ ) and the resonance longitudinal MOE ( $MOE_{longitudinal}$ ) were calculated respectively using Equations 1 and 2 (Kollmann and Krech 1960),

<sup>1</sup> Tasmanian oak is a trade name used in Australia that represents a mixture of *Eucalyptus regnans* F.Muell., *Eucalyptus delegatensis* R.Baker and *Eucalyptus obliqua* L'Hérit.

**Table 1.** Average static ( $MOE_{static}$ ) and resonance flexure modulus ( $MOE_{flexure}$ ) (in GPa) of clear and decayed specimens of regrowth Tasmanian oak (standard deviation in brackets)

Specimen type	$MOE_{static}$	$MOE_{flexure}$	Difference (%)
Clear wood ( $n = 68$ )	13.5 (2.2)	15.6 (2.7)	14.9
Decayed wood ( $n = 99$ )	12.8 (2.3)	14.5 (2.8)	13.5
Combined specimens ( $n = 167$ )	13.1 (2.3)	14.9 (2.8)	14.2

**Table 2.** Relationships between static ( $MOE_{static}$ ) and resonance flexure modulus ( $MOE_{flexure}$ ) of regrowth Tasmanian oak using simple linear regression, and the corresponding coefficients of determination ( $r^2$ )

Specimen type	Regression equations	$r^2$
Clear wood ( $n = 68$ )	$MOE_{static} = 0.77 + 1.53 MOE_{flexure}$	0.94
Decayed wood ( $n = 99$ )	$MOE_{static} = 0.80 + 1.14 MOE_{flexure}$	0.94
Combined specimens ( $n = 167$ )	$MOE_{static} = 0.79 + 1.32 MOE_{flexure}$	0.94

**Table 3.** Average static ( $MOE_{static}$ ) and longitudinal resonance modulus ( $MOE_{longitudinal}$ ) (GPa) of clear and decayed specimens of regrowth Tasmanian oak (standard deviation in brackets)

Specimen type	$MOE_{static}$	$MOE_{longitudinal}$	Difference (%)
Clear wood ( $n = 68$ )	13.5 (2.2)	18.8 (3.3)	39
Decayed wood ( $n = 99$ )	12.8 (2.3)	17.4 (3.4)	36
Combined specimens ( $n = 167$ )	13.1 (2.3)	18.0 (3.4)	37

**Table 4.** Relationships between static ( $MOE_{static}$ ) and longitudinal resonance modulus ( $MOE_{longitudinal}$ ) of regrowth Tasmanian oak using simple linear regression, and the corresponding coefficients of determination ( $r^2$ )

Specimen type	Regression equations	$r^2$
Clear wood ( $n = 68$ )	$MOE_{static} = -1.05 + 1.46 MOE_{longitudinal}$	0.94
Decayed wood ( $n = 99$ )	$MOE_{static} = -0.95 + 1.46 MOE_{longitudinal}$	0.94
Combined specimens ( $n = 167$ )	$MOE_{static} = -0.90 + 1.44 MOE_{longitudinal}$	0.94

$$MOE_{flexure} = 0.946\rho f^2 L^4 / h^2, \quad (1)$$

$$MOE_{longitudinal} = 4\rho f^2 L^2, \quad (2)$$

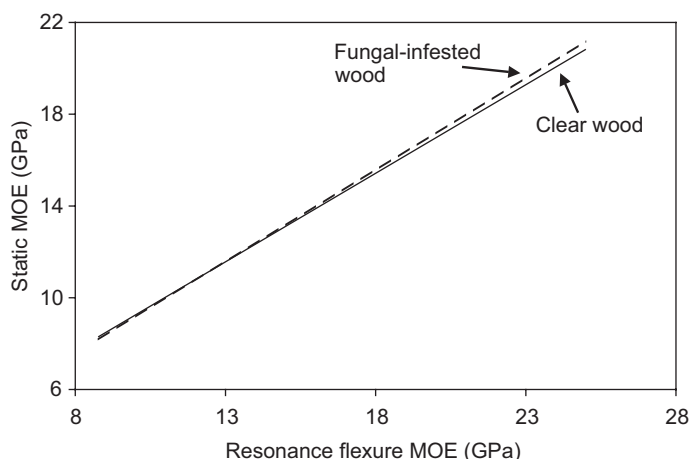
where  $\rho$  = mass density of the specimen ( $\text{kg m}^{-3}$ ),  $f$  = fundamental frequency corresponding to the primary peak (Hz),  $L$  = specimen length (0.3 m), and  $h$  = specimen thickness (0.02 m).

The static bending test (centre-point-loading) was then performed on the specimens to obtain static MOE ( $MOE_{static}$ ) and modulus of rupture ( $MOR_{rupture}$ ) using the Australian standard method for testing small clear specimens (Mack 1979). In this method, the load is applied to one radial face of the specimens in the tangential direction.

## Results and discussion

### Flexural resonance tests

In the resonance flexure tests, it was observed that the closer the specimens were to true flat-sawn state, the more likely it was that only one resonant peak would be induced. The presence of more than one peak, however, did not preclude determination of the appropriate primary peak. Various growth ring orientations in the specimens did not affect the objective of this study because the static and dynamic tests were conducted on the same specimens. Growth ring orientation would have been important for assessing the mechanical properties of the wood (Panshin and de Zeeuw 1980).



**Figure 1.** Simple linear regressions between static and dynamic resonance flexure MOE

The resonance flexure MOE was significantly higher than the static bending MOE for both clear and decayed specimens ( $P < 0.001$ ). On average, the  $MOE_{flexure}$  was 15% and 14% higher than the  $MOE_{static}$  of the clear and decayed specimens respectively (Table 1). This agreed with the findings of Ilic (2001), who obtained a mean difference of 11% for *E. delegatensis*, a eucalypt species similar in anatomical structure to *E. obliqua*.

Strong linear relationships between static and resonance flexure MOE were found for the clear specimens, the decayed specimens, and combined data (Table 2). The regression equations for the clear and decayed wood were very similar. The prediction lines start to diverge only at the extremes of the MOE values (Fig. 1). Macheck *et al.* (2001) obtained similar relationships for clear and decayed wood for five European and tropical hardwoods and three European softwoods, although their correlations were marginally better. Interestingly, the slope of the regression line they obtained for keruing (*Dipterocarpus* spp.), a tropical hardwood having wood structure that was more like the eucalypt in this study than the other hardwood species, was also 1.14, with the intercept about half that obtained here.

In this study, as in that by Macheck *et al.* (2001), the flexural dynamic MOE was found to be more sensitive to the early stages of decay than the loss of mass indicated by changes in basic density.  $MOE_{flexure}$  of the discoloured wood specimens was 14.1 GPa, being 9% lower than that of the matching clear-wood specimens. Density of the discoloured wood specimens, however, was  $597 \text{ kg m}^{-3}$ , only 5% lower than that of the matching clear-wood specimens (Yang *et al.* 2000).

### Longitudinal resonance tests

The magnitude of the longitudinal resonance MOE was also significantly higher than the static bending MOE of both clear and decayed specimens ( $P < 0.001$ ). On average, the  $MOE_{longitudinal}$  was 39% and 36% higher than the  $MOE_{static}$  of the clear and decayed specimens respectively (Table 3). This is in keeping with findings for clear wood by Smulski (1991) and Ilic (2001), who obtained mean differences ranging from 22% to 32% for five North American hardwoods and 29% for *E. delegatensis*, respectively.

Strong linear relationships between static and longitudinal resonance MOE were found for the clear specimens, the decayed specimens, and the pooled data (Table 4); the regression equations for the clear and decayed wood were almost identical.

It was also found that the  $MOE_{flexure}$  was closely related to the  $MOE_{longitudinal}$  for both the clear and decayed specimens, with the respective coefficients of determination being 0.95 and 0.97. Longitudinal testing, however, is less likely to be as good an indicator of the progress of decay as flexural testing, because in the former case surface effects are less important. It should be pointed out that any individual evaluation of dynamic MOE alone would be unlikely to be a reliable indicator of decay, because low values of MOE can be due to other intrinsic factors such as larger microfibril angle (MFA) and lower density. Thus wood exhibiting the early stages of decay (e.g. discolouration) could still have higher MOE than clear wood if it also had lower microfibril angle and higher density. Yang *et al.* (2000) showed that although clear wood and decayed wood constituted separate populations, the density, MOE and MOR ranges of clear wood overlapped those of wood with incipient decay. Dynamic resonance testing of a given sample, nevertheless, should be sensitive to the changes of stiffness accompanying changes in wood soundness.

### Conclusions

Very strong relationships were found between static and resonance (flexure and longitudinal) MOE for both clear and decayed wood. The type of wood (clear versus decayed) did not appear to affect the closeness of the relationships nor the differences between the regression equations. Dynamic resonance testing is unlikely, on its own, to indicate decay, but it has the potential to monitor changes in the soundness of a given piece of wood in service and in durability evaluation.

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