WOOD STIFFNESS OF *Corymbia* AND *Eucalyptus* species

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Abstract: Because it is a low-cost, simple and fast the analysis of transverse vibration has been applied in various materials, including wood for determining their elastic properties. This study evaluated the variation in dynamic elastic of wood by means of resonance analysis. 338 wood specimens (defects free) cut from 37 year-old trees were submitted to dynamic tests for determining the modulus of elasticity (E) as a function of the first frequency of flexural vibration. *Eucalyptus cloeziana*, *Corymbia citriodora* and *E. dunni* were the stiffer species (E > 22 GPa) while *E. deglupta* presented the lower E (16 GPa). *Eucalyptus microcorys*, *E. saligna, E. pilularis* and *E. urophylla* showed intermediate values for their elastic moduli. The stiffness slightly increased toward the bark, especially for *E. deglupta*, *E. pilularis* and *E. microcorys*. In short, our findings indicate that there are alternative species that could be implanted in Brazil for supplying biomass with adequate wood properties.

Keywords: acoustic, mechanical strength, mature wood, stiffness, transverse vibration

1. INTRODUCTION

The use of a wood species for building construction and structures depends on its mechanical properties, specially the modulus of elasticity (Madsen, 1992). According to Record (2004) stiffness is the property by means of which a body acted upon by external forces tends to retain its natural size and shape, or resists deformation. Thus a material that is difficult to bend or otherwise deform is stiff; one that is easily bent or otherwise deformed is flexible. That is why the wood stiffness, as indicated by its elastic modulus, is one of the most commonly studied mechanic property (Yang and Evans, 2003).

Destructive tests for determining wood stiffness and strength are based on the application of a uniform force on the specimen until it fails: the stress to strain plot, the maximum force until fail and the distance displaced are recorded and elastic constants can be calculated (Kollmann and Cote, 1968). Mechanical testing determines the static modulus of elasticity (E) using a universal testing machine, an expensive equipment that demands high maintenance costs, requires an average 5 to 15 minutes per sample depending on the species and test conditions (Hein et al., 2009). Therefore, the use of faster alternative methods for determining elastic properties takes on critical importance within the context of wood science and technology (Leite et al., 2012).

The modulus of elasticity of materials also can be determined by nondestructive, acoustic methods, such as ultrasound, stress waves and transverse vibration. In wood, many studies have demonstrated the potential of those techniques for timber classification by applying ultrasound (Vun et al., 2004; Ballarin and Nogueira, 2005), stress waves (Calegari et al., 2008; Stangerlin et al., 2010) or transverse vibration (Hein et al., 2012). According to

Brancheriau and Baillères (2002) the analysis of flexural vibrations has been considered the simplest, most inexpensive and effective method of determining wood elastic constants.

Wood stiffness is a key parameter for many applications. For instance, modulus of elasticity is important in designing products which can only be allowed to deflect by a certain amount. In regard to living plantations, many forest-based companies are facing a new problem: tree breaking under storms, especially in Brazil (Rosado et al., 2013). The genetically improved *Eucalyptus* clones present high growth rate (IBA 2014) but low mechanical properties. According to Hein et al. (2010) these varieties of tree present optimal performance for pulp and paper production; However they can be a major problem in the field, because of their fragility that makes them susceptible to breaking. Therefore these industries may search for new species producing stiffer wood in order to overcome problems with tree breaking in field. In this study, we hypothesize that there are unknown species of *Eucalyptus* with potential to commercially produce wood adequate for pulp, energy and sawn timber production from a mechanical point of view.

Thus, the aim of this study was to evaluate the variation in dynamic elastic wood properties of *Corymbia citriodora* and a range of *Eucalyptus* species by means of resonance analysis.

2. MATERIAL AND METHODS

2.1 Wood samples

Wood samples of *Corymbia citriodora* and several *Eucalyptus* species at 37 years old were obtained at the campus of Universidade Federal de Lavras, southern Minas Gerais state, Brazil. The campus is located at an average altitude of 900 meters, lying in a transition zone between the Cerrado and Atlantic Rainforest biomes (21°14’ S and 45°00’ W), and the local climate falls under the Cwb category according to Köppen classification. The list of investigated wood species are listed in Table 1.

Three hundred and thirty eight (338) samples were cut from central board (one meter in length) which had been taken from the first log. The defect-free specimens used in bending tests were 410 x 25 x 25 mm in size and had well defined tangential and radial surfaces. The specimens were kept in a temperature-controlled room at 21°C and 65% relative humidity. Under these conditions, the moisture of wood samples is expected to stabilize at 14%.

2.2 Resonance analysis

The transverse vibration of wood specimens was evaluated in time and frequency domain using Sonelastic equipment (ATCP Engenharia Física, São Carlos, SP, Brazil), as illustrated in Figure 1.

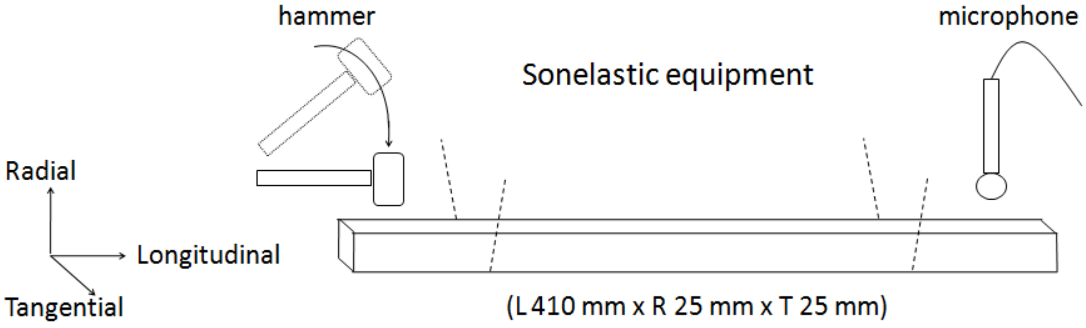

Figure 1 – Experimental device used for measuring time and frequency of transverse vibration in wood samples through the resonance system.

The samples were placed in supports in order to generate free vibrations. Vibration is produced by lightly taping a wood-tipped hammer on one end of the specimen. The specimen emits an acoustic response which depends on its elastic properties, dimensions and mass, and the elastic. Input and output signals were transmitted using a low-pass filter and a data acquisition card coupled to a computer and then recorded.

The elastic moduli are calculated from the natural frequencies of vibration extracted from the acoustic response by Fast Fourier Analyses using the following formula:

$$E = 0.9465\left(\frac{m f_f^{\,2}}{w}\right)\left(\frac{L}{t}\right)^3 T \qquad \text{and} \qquad T = 1 + 6.858\left(\frac{t}{L}\right)^2$$

where *m* is the mass, *ff* the fundamental resonance frequency in flexure, *L* the length, *w* the width, *t* the thickness and *T* the correction factor.

The descriptive statistics, analysis of variance and multiple comparison between means were calculated using SPSS statistics software (SPSS Inc., version 17.0, Chicago, IL).

3. RESULTS AND DISCUSSION

Fast and reliable methods for wood classification are important for wood-based industries which may evaluate the quality of their raw material. Thus, many studies have shown high correlation between the destructive (using a universal testing machine) and the nondestructive method (resonance) for determination of stiffness in wood specimens (Brancheriau and Baillères, 2003; Calil Junior and Miná, 2003; Haines et al., 1996; Ilic, 2003; Ohsaki et al., 2007; Targa et al., 2005). For instance, Ilic (2001) has evaluated wood stiffness in *Eucalyptus* and found a strong correlation (r=0.99) between the dynamic modulus and the static modulus of elasticity. Targa et al. (2005) have evaluated three *Eucalyptus* species reporting correlations between the dynamic and the static moduli of elasticity, with an R^2 of 0.87 for *E. citriodora* and *E. grandis;* and 0.76 for *E. saligna*. Considering the high correlation between dynamic and static modulus, here it was considered only the dynamic modulus of elasticity.

3.1 Wood stiffness variability among species

Table 1 provides results of dynamic modulus of elasticity obtained by transverse vibration tests in wood specimens of *Eucalyptus* and *Corymbia*.

Table 1 - Descriptive statistics of modulus of elasticity (MPa) of the species investigated in this study.

Species	Mean	Min	Max	CV (%)	N
Eucalyptus cloeziana	25,552	19,300	29,940	10.0	48
Corymbia citriodora	24,408	18,590	27,060	08.2	33
Eucalyptus urophylla	21,186	14,020	24,600	13.1	22
Eucalyptus saligna	19,606	12,760	28,600	17.2	87
Eucalyptus dunnii	22,165	19,440	24,440	05.2	14
Eucalyptus pilulares	19,716	11,560	24,980	13.6	81
Eucalyptus microcorys	19,675	11,650	27,150	22.6	43
Eucalyptus deglupta	15,612	11,080	18,350	16.7	10
Total	21,045	11,080	29,940	18.5	338

Wood stiffness, as indicated by the dynamic modulus of elasticity, presented wider variation for *Eucalyptus microcorys* (CV higher than 20%), but low variability for *Eucalyptus dunnii and Corymbia citriodora (*CV lower than 10%) as shown in Table 1. The mean dynamic modulus of elasticity of the total sampling was 21,045 MPa, varying from 11,080 to 29,940 MPa. There were significant differences in modulus of elasticity between species and radial positions according to analysis of variance (not shown).

Figure 2 shows the averaged values of modulus of elasticity (MPa) showing that there was a significant difference between species in terms of elastic properties of their wood (Tukey test). As the growing conditions were the same for all trees, that difference in Elastic moduli can be attributed by genetic factors.

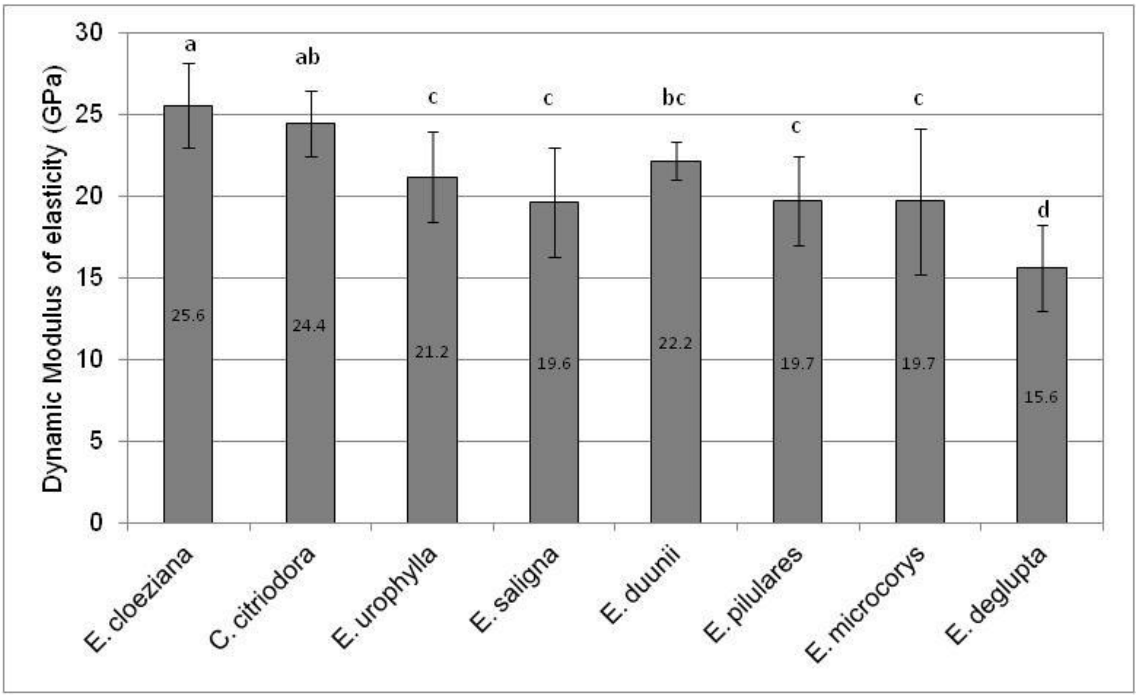

Figure 2 - Mean Modulus of elasticity of wood of several *Eucalyptus* species and *Corymbia citriodora*. Means were compared by Tukey test at 5%.

3.2 Radial variation

Numerous studies have reported similar patterns of radial or longitudinal variation for wood stiffness in many wooden species (Bendtsen and Senft, 1986; Cruz et al. 2003; Ishikura et al., 2012). In short, patterns in pith to cambium variation of the wood traits themselves have been known for many decades: wood density and stiffness generally increases towards the bark (Zobel and Van Buijtenen, 1989).

In this study, clearwood specimens were cut from central boards taking into account the radial variation of each tree. The modulus of elasticity increased towards the bark for most *Eucalyptus* species, as indicated in Figure 3. There was no significant variation from pith to bark for *E. cloeziana*, *E. dunnii* and *C. citriodora* whereas stiffness slightly increased toward the bark, especially for *E. deglupta*, *E. pilularis* and *E. microcorys*. *Eucalyptus deglupta* and *E. dunnii*, linear trends are shown because only samples from two radial positions could be taken: near pith and cambium. The species *Eucalyptus dunnii* showed decrease of 3% in the elastic modulus of wood from pith to bark, but not statistically significant.

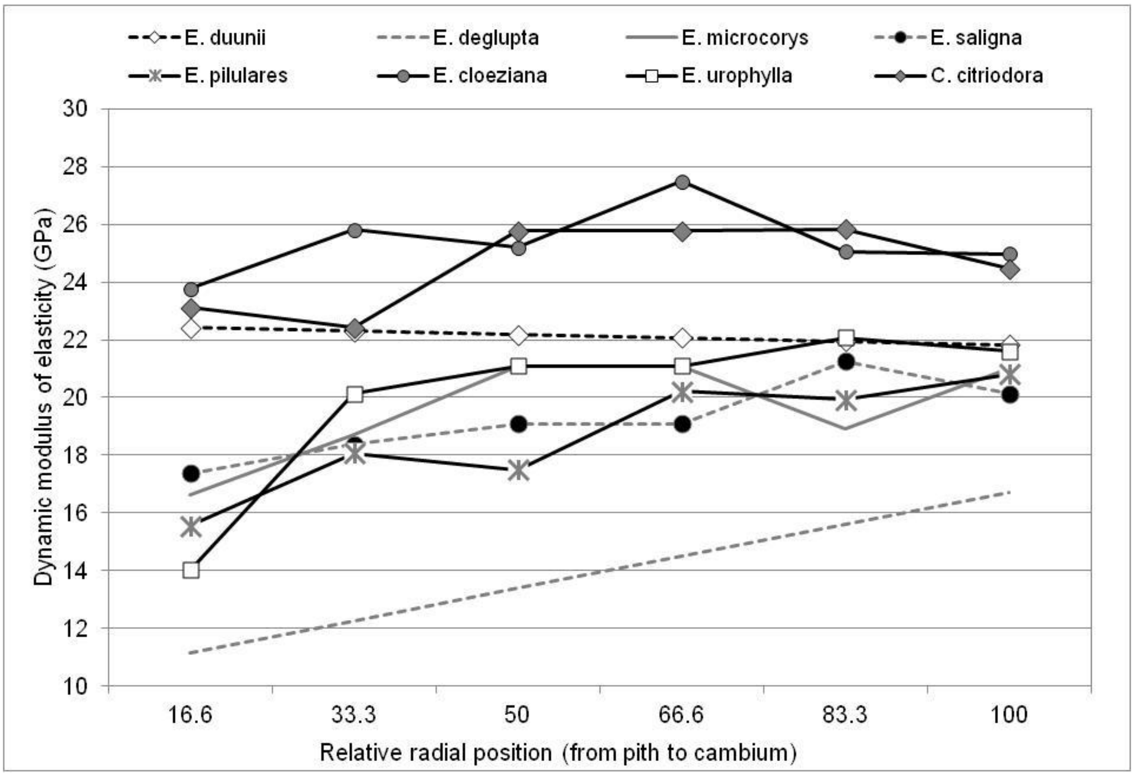

Figure 3 - Radial variation of modulus of elasticity (MPa) for several wood species

The higher increases in dynamic E from pith to bark were showed by *Eucalyptus urophylla* (57%) and *E. deglupta* (50%). *Eucalyptus pilularis*, *E. microcorys* and *E. saligna* had intermediate radial increase (from 34 a 22%) towards the cambium.

3.3 Performance of the species

While *Eucalyptus saligna*, *E. cloeziana*, *E. urophylla* and *Corymbia citriodora* has been commercially cultivated in Brazil for providing material raw for many applications (IBA, 2014), the industrial performance of some alternative species deserves further investigation. For instance, although *Eucalyptus pilularis* is one of the most important hardwoods in Australia (McMahon et al., 2010), this species is not commercially cultivated in Brazil. According to McMahon et al. (2010) *E. pilularis* is prone to wind throw and stem damage when young due to a dense canopy and shallow root system; prone to weed competition in plantations due to slow initial growth rates. *Eucalyptus dunnii* has the reputation of beeing a poor sawlog mainly due to problems during dry. This species present problems for sawn timber such as end splitting and high shrinkage (Smith and Henson, 2007) and cupping (Harwood et al., 2005). Relatively few studies have been performed for *E. microcorys* wood, even around the world. According to Sun and Dickinson (1997), *E. microcorys* trees presented rapid height and branch growth and were considered highly suitable for windbreaks. According to Little and Skolmen (1989) the wood of this species presented adequate wood density (570 kg.m^{-3}) for many applications, but many young plantation-grown timber has severe growth stresses that causes end splitting, spring, and brittleheart in logs and lumber.

4. CONCLUDING REMARKS

The modulus of elasticity obtained by transverse vibration tests in wood samples of *Corymbia citriodora* and *Eucalyptus* species showed that *Eucalyptus cloeziana*, *Corymbia citriodora* and *E. dunnii* were the species producing the stiffer wood (E > 22 GPa) while the samples taken from *E. deglupta* trees presented the lower modulus of elasticity (E < 16 GPa). The wood from *Eucalyptus microcorys*, *E. saligna*, *E. pilularis* and *E. urophylla* showed intermediate values for their elastic moduli ranging from 19 to 21 GPa.

In regard to the radial variation, there was no significant variation from pith to bark for *E. cloeziana*, *E. dunnii* and *C. citriodora* whereas stiffness slightly increased toward the bark, especially for *E. deglupta*, *E. pilularis* and *E. microcorys*.

In short, this study indicates that there are alternative species that could be implanted in Brazil for supplying biomass with adequate wood properties. The resonance technique can be used in order to rapidly and reliably provide a large data set of the elastic properties of these woods.

5. ACKNOWLEDGMENTS

The authors wish to thank the Departamento de Ciências Florestais, Universidade Federal de Lavras, for providing equipment and measuring instruments with which to carry out this study. This project was funded by CNPq (Conselho Nacional de Desenvolvimento Científico e Tecnológico, Brazil), CAPES (Coordenação de Aperfeiçoamento de Pessoal de Nivel Superior) and FAPEMIG (Fundação de Amparo à Pesquisa do estado de Minas Gerais).

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