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Abstract

Wood toughness is a mechanical property of interest in structural design where the load impact must be considered, finding a strong application in bridges, however, not an integral part of the mechanical properties commonly investigated in the characterization of this material. This study aimed to investigate with the aid of variance analysis, the influence of growth ring orientation to obtain toughness for Angelim Saia (*Parkia pendula*), *Eucalyptus grandis, Pinus elliottii* and *Corymbia citriodora* wood species, considering three different positions, so that the orientation causes tensile strength in fibers near the pitch, near the bark, and in the radial direction. The results of the statistical analysis revealed that there was no significance in the orientation of the growth rings to obtain the toughness of the wood species investigated, where the highest values were for *Corymbia citriodora* and the least values were for *Pinus elliottii*.

Keywords: Toughness, wood species, growth ring.

1. Introduction

Wood has long been used by man throughout history, being directly related to the solution of problems such as dwellings; crossing natural or artificial obstacles; manufacturing of vehicles for different types of transport; storage and transport of agricultural products; manufacturing of furniture, and others (ROCCO LAHR, CALIL JR. e DIAS, 2003).

Knowledge of the physical and mechanical properties of wood allows for its better use (FIORELLI e DIAS, 2011; CARREIRA *et al.* 2012; MOLINA *et al.* 2012; CHRISTOFORO, 2013). By reason of the difficulties in performing tests for the characterization of the species, wood is often used without the essential knowledge of its properties, thus leading to material waste (STOLF, 2000).

Special importance is given to the study of wood in relation to its performance when applied to loads that cause impact, particularly in the applications mentioned above, according to Souza et al. (2009), motivating the development of research on this topic.

Pazos *et al.* (2003) investigated the toughness and impact strength of wood *Lysiloma bahamensis*, with density of 0.62 g/cm³, under 12% of moisture content and saturated conditions. The values of toughness or absorbed work (W) obtained from saturated and dry woods were equal to 41.75J and 46.75J, respectively. Among others, the authors concluded that the saturated wood presented the highest toughness and impact strength.

Stangerlin *et al.* (2008a) developed research on wood of the *Eucalyptus dunnii* specie in order to investigate the effect of the orientation of the fiber (radial and tangential) to obtain the toughness and impact strength. Furthermore, the authors concluded that the positioning in the radial direction provided higher values of impact strength and toughness when compared to those obtained from specimens positioned in the tangential direction. The same authors, in another study (Stangerlin *et al.* 2008b) studied the impact strength of *Eucalyptus botryoides* and *Eucalyptus saligna* wood species. The authors concluded that it isn't possible to estimate the toughness of the wood through the bulk density.

Beltrame *et al.* (2012) researched the effect of moisture content (12% and saturated) in the impact strength of nogueira-pecã wood (*Carya illinoinensis*), from two physiographic regions of the Rio Grande do Sul state. Specimens were also prepared and tested for impact strength directions, radial and tangential positions and withdrawal, near the spinal cord and the next shell. As for the energy absorbed or toughness, saturated specimens showed higher (7.774 kg·m) compared the toughness of woods with 12% of moisture content (2.976 kg·m), about 161% higher on average.

Almeida *et al.* (2014) evaluated in their studies the possibility to estimate the toughness with the knowledge of the apparent density of 6 Brazilian tropical wooden species (Angico, Eucalyptus, Jatobá, Paricá, Pine and Teak), by using linear, quadratic and cubic polynomial regression models. The cubic polynomial was the most efficient for estimating the wood toughness, with R^2 = 84.70%.

In addition to moisture content and density, the orientation of growth rings can be influential on the wooden toughness. According to Smith, Lands and Gong (2003), observations at fracture at micro scale indicated that wall thickness has a stronger influence on the fracture of individuals cells than cells size. Fracture in low density wood is usually transwall, while for higher density wood both transwall and intercellular fracture is observed. Consequently, there are different fracture modes in earlywood and latewood cells. Intercellular fracture is observed in thick-walled latewood cells, while transwall fracture is observed in thin-walled earlywood cells. In this sence, the proportion of earlywood to latewood will affect bulk fracture toughness measurements.

In order to generate subsidies to expand the knowledge about the behavior of wood when requested by impact loads, this study aimed to investigate the influence of the orientation of the growth rings in obtaining toughness in the woods: Angelim Saia (*Parkia pendula*), *Eucalyptus grandis, Pinus elliottii* and *Corymbia citriodora*, using analysis of variance (ANOVA) in order to investigate the possible differences.

2. Material and Methods

The toughness tests were performed at the Wood and Timber Structures Laboratory, Department of Structural Engineering, São Carlos School of Engineering, University of São Paulo (LaMEM/SET/EESC/USP) using the Charpy Pendulum test. Tests were performed in equipment developed by Siqueira (1986), based on machine type FPL (developed by Forest Products Laboratory - USA) using a modified Charpy pendulum. The principle of operation is characterized by kinetic energy provided by the pendulum via a flexible current, with a support at its end. Rupture of the specimen is obtained by a single movement of pendulum. Calculations for determination of toughness were performed according to ASTM D143-52 (ASTM 1981).

The woods of Angelim Saia - *Parkia pendula* (AS) came from the northeastern state of Mato Grosso, and *Eucaliptus grandis* (EG), *Pinus elliottii* (PE) and *Corymbia citriodora* (CC) from the Itirapina city (SP). With the aid of a greenhouse, the specimens of the four species had their moisture content adjusted to 12%, according to the premiss of the Brazilian standard ABNT NBR 7190 (1997), using 8 specimens for each wood species evaluated. The Angelim Saia wood attained an average density of 0.72 g/cm³, while for the *Corymbia citriodora*, *Eucalyptus grandis* and *Pinus elliottii* woods, the densities were 0.96 g/cm³, 0.62 g/cm³ and 0.54 g/cm³, respectively.

The specimens for toughness testing (2×2×28cm) were extracted from three pieces of lumber with dimensions of 2×2×100cm. The three specimens (per piece) gave origin to three distinct orientations of growth rings in relation to the direction of impact strength, as illustrated in Figure 1.

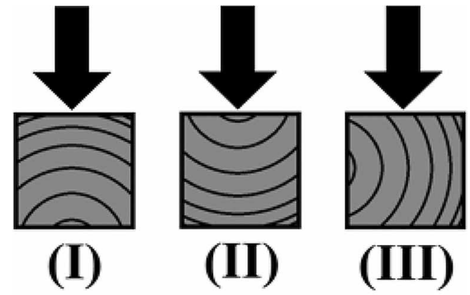

Figure 1
Positioning of growth rings
for toughness evaluation of the woods.

From Figure 1, the impact strength was directed to cause tensile strength in the fibers closest to the core (Position I), in the fibers closer to the shell (position II) and in the radial direction (Position III). In order to ensure that all possible toughness variability results come from only the orientation of the growth rings, the influence of the longitudinal extract position (A; B; C) of the specimens of bars 100 cm long (Figure 2) was evaluated, for obtaining the toughness. It should be noted that the samples to obtain the toughness were extracted from wooden beams and not directly from trees. In this sense, only the position of extraction samples in relation to the longitudinal direction of beams was addressed. For this, we used two pieces of dimensions 2× 2×100 cm per wood species (AS; CC; EG; PE) and shape orientation of growth rings. The influence of the specimen's extraction position to determine toughness was determined with variance analysis (ANOVA), whose basis was the nonparametric Kruskal-Wallis test, at a significance level of 5%, considering equivalence between means as null hypothesis (H_0) and the non-equivalence between means as alternative hypothesis (H_1). P-value of the test greater than the significance level implies acceptance of H_0, otherwise, it is rejected. Statistical analyzes were made by Minitab 16 software.

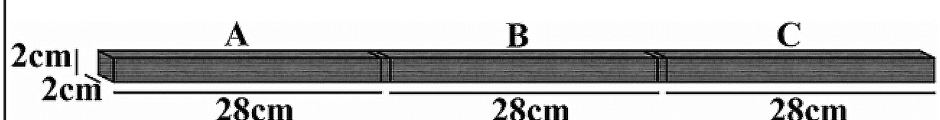

Figure 2
Position of
extraction of specimens.

Once the independence of the extraction position of the specimens was proven, the variance analysis was employed again to investigate the influence of the guidelines of the growth rings in obtaining toughness. Thus, 13 pieces of Angelim Saia, 20 pieces of *Corymbia citriodora*, 32 pieces of *Eucalyptus grandis* and 35 pieces of *Pinus elliottii* wood species, measuring 2×2×100 cm were prepared. From each piece, three specimens (2×2×28 cm) were extracted, oriented in the three positions shown in Figure 1, providing 39 toughness tests for Angelim Saia wood (13 per position), 60 for *Corymbia citriodora* wood (20 per position), 96 for Eucalyptus grandis wood (32 per position) and 105 for the *Pinus elliottii* wood (35 per position), totaling 300 tests.

3. Results and Discussion

Table 1 shows the results for the toughness obtained according to the extraction position (A, B, C) of the specimen (CP) along the length of 100 cm pieces for the three orientations of the growth rings (I, II; III).

Position I			
CP	**W (J) - A**	**W (J) - B**	**W (J) - C**
AS	33.42	33.99	33.38
AS	30.98	30.72	30.34
CC	56.22	55.86	56.09
CC	53.03	53.37	53.21
EG	40.56	39.60	39.74
EG	36.56	36.75	36.31
PE	22.08	23.46	22.86
PE	18.06	17.83	17.47
Position II			
CP	**W (J) - A**	**W (J) - B**	**W (J) - C**
AS	35.94	33.30	34.24
AS	35.14	36.05	37.53
CC	54.26	54.18	54.11
CC	53.32	53.09	53.18
EG	34.27	35.73	34.98
EG	37.54	35.69	37.56
PE	21.25	22.63	23.54
PE	24.61	24.32	23.27
Position III			
CP	W (J) - A	W (J) - B	W (J) - C
AS	40.70	41.35	40.35
AS	31.64	32.58	32.96
CC	56.73	56.42	56.26
CC	54.18	54.06	54.33
EG	37.93	36.57	36.17
EG	38.37	38.56	39.61
PE	21.84	20.56	20.00
PE	20.66	21.81	20.55

Table 1
Toughness obtained from specimens extracted along the bars.

Table 2 presents the results of the variance analysis for nonparametric Kruskal-Wallis toughness tests of the woods for tree orientations of the growth rings. As the P-values found are both higher than the significance level of the test (5%), the null hypothesis should be accepted, implying no significant difference in the extraction position of the specimen bar to obtain the toughness of woods.

Orientation	H	DF	P-value
I	0.0600	2	0.9704
II	0.0650	2	0.9680
III	0.0650	2	0.9680

Table 2
Results of the Kruskal-Wallis test processed with ANOVA for the extraction position of the specimen on the wooden toughness.

Table 3 presents the results of the wood toughness (W) obtained as a function of the orientation of the growth rings, average is the sample mean, Sd is the standard deviation, Vc is the variation coefficient, and Min and Max are the smallest and largest values found.

Angelim Saia **(AS)**			
Values	**W (J) - I**	**W (J) - II**	**W (J) - III**
Average	36.41	34.81	36.33
Sd	3.64	2.98	3.74
Vc	10.00	9.00	10.00
Min	30.18	30.67	29.91
Max	41.84	40.25	43.43
Corymbia citriodora **(CC)**			
Values	W (J) - I	W (J) - II	W (J) - III
Average	57.92	55.56	56.39
Sd	10.13	9.60	8.97
Vc	17.00	17.00	16.00
Min	43.66	40.60	42.65
Max	78.47	75.75	73.60
Eucalipto grandis **(EG)**			
Values	W (J) - I	W (J) - II	W (J) - III
Average	41.52	41.40	41.97
Sd	7.20	7.33	7.30
Vc	17.00	18.00	17.00
Min	29.76	27.48	28.54
Max	55.11	53.99	53.69
Pinus elliottii **(PE)**			
Values	W (J) - I	W (J) - II	W (J) - III
Average	24.45	24.26	24.17
Sd	5.22	5.92	5.00
Vc	21.00	24.00	21.00
Min	18.50	16.51	18.83
Max	36.72	39.54	35.15

Table 3
Results of the wood toughness (W) in joules (J) in terms of growth rings.

The lowest toughness values came from the Pinus elliottii wood species, meanwhile, the lowest density, and highest toughness values came from the Corymbia citriodora wood, which also presented the greatest density amongst those evaluated.

Just as other wood species used in research developed by Pazos *et al.* (2003), Stangerlin *et al.* (2008a), Beltrame *et al.* (2010) and Beltrame *et al.* (2012), the toughness values were close to those obtained from the present study.

Table 4 presents the Kruskal-Wallis/ANOVA results for the orientation of growth rings (I, II, III) on the toughness for the four wood species investigated. In Table 4, H is a partial statistic used in the Kruskal-Wallis ANOVA test, and DF is the degree of freedom of the analysis of variance.

Species	H	DF	P-value
Angelim Saia	2.3588	2	0.3075
Corymbia citriodora	0.4528	2	0.7974
Eucaliptus grandis	0.2418	2	0.8982
Pinus elliottii	0.1087	2	0.9471

Table 4
Results of the Kruskal-Wallis ANOVA factor orientation of growth rings in obtaining wood toughness.

By P-values found in Table 4 were above the significance level for both species, the null hypothesis was accepted, implying no significance in the growth ring orientation for obtaining the toughness of the woods investigated; different from the results presented by Stangerlin *et al.* (2008b), which stated that the impact strength and toughness of *Eucalyptus dunnii* in the radial direction was greater than the impact strength and toughness in the tangential direction.

4. Conclusion

The results of the toughness for the four wood species evaluated showed no significance in growth ring orientation and the *Pinus elliottii* and *Corymbia citriodora* wood species showed the lowest and highest values respectively, emphasizing that these also had the largest and lowest wood densities.

In general, the results of this research contribute to a better understanding of the performance of the woods here investigated when under the impacts upon requested.

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