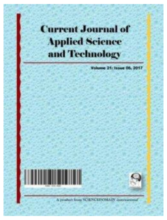

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Evaluation of the Number of Load Cycles to Determine Some Wood Stiffness Properties

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Authors' contributions

All authors contributed equally. Authors EAMM and FARL designed the study, wrote the protocol and managed the analyses of the study. Author ALC wrote the protocol and statistical analysis. Authors DHA and THP managed the analyses of the study, wrote the first draft of the manuscript and managed the literature review. All authors read and approved the final manuscript.

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ABSTRACT

For fiber accommodation in tests to obtain wood strength and stiffness properties, some standards codes provide two or more load cycles, such as the Brazilian Standard ABNT NBR 7190, which establishes a number of three cycles (two previous and the final load cycle). However, reducing the number of load cycles provides savings in energy and manpower in the operation and maintenance of the testing machines, which motivates the development of research on this topic. This study

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aimed to investigate, according to Brazilian Standard Code and analysis of variance (ANOVA), the influence of the number of load cycles (1, 2, 3) to determine the modulus of elasticity in compression (E_{c0}) and tension (E_{t0}) in parallel direction to the grain, in normal compression (E_{c90}) and in static bending (E_m) for the native Brazilian species Cambará Rosa, Cupiúba, Envira, Angico and Champagne woods, allowing, with the use of wood evenly distributed on strength classes, the results to be extended to other wood species. Results of the Tukey test show that only the first load cycle presented different stiffness values, with the second and third load cycles giving equivalent results of modulus of elasticity. This implies that the third load cycle can be disregarded, and stiffness properties can be obtained after only with the second load cycle.

Keywords: Brazilian wood specie; hardwood; mechanical properties; standard code; wood.

1. INTRODUCTION

The study of wood and its mechanical characterisation, as well as its engineered products [1-3], is of fundamental importance in order to achieve better use of this material together with those whose properties are widely known, regardless of the industrial segments involved [4-8].

Several studies have been conducted with the aim of characterising and evaluating the performance of wood of different tree species [9-12], but the subject is still far from being exhausted [13-15]. In particular, in Brazil, to update Brazilian Standard Code ABNT NBR 7190 [16], some tests for physical and mechanical characterisation, such as perpendicular and parallel compression to the grain, parallel tension to the grain and static bending, were carried out with two and the final cycle, from which the values of the strength and the corresponding modulus of elasticity are determined.

There are several Standard Codes used to obtain physical and mechanical properties of wood specie, such as: AFNOR B51-007 [17] of the French Association of Normalization, ASTM D143 [18] of the American Society for Testing and Materials, Pan American Commission on Standards (COPAN) [19-22], International Organization for Standardization (ISO) [23-27] and EN408 [28] of the European Committee for Standardization among others [29,30]. Among the mentioned standards, only ISO and AFNOR recommend carrying out more than one loading cycle in the tests to determine some strength and stiffness properties of the wood. On the other hand, in most of them, more than one test is necessary for the determination of the longitudinal modulus of elasticity.

Several researches have been carried out, using the premise and methods of calculation of the normative documents to characterise wood, however, with regard to the study of the influence of the number of cycles on the strength and stiffness properties, few research have been done [31,32].

This work aims to investigate the influence of the number of load cycles (1, 2, 3 cycles) needed to obtain stiffness properties of five Brazilian native hardwood species. The species were conveniently separated in the strength classes for hardwood species group, according to ABNT NBR 7190 [16], that would allow us to evaluate if with less than 3 cycles, the stiffness properties could be obtained in an equivalent way to the results of the adoption of three cycles. This would imply positively reducing the operating time of the test machines, which in turn could provide reduction of expenses in electricity and labor.

2. MATERIALS AND METHODS

Wood species used in this work were Cambará Rosa (*Erisma* sp.), Cupiúba (*Goupia glabra*), Envira (*Xylopia* sp.), Angico (*Anadenanthera* sp.) and Champagne (*Dipteryx odorata* (Aubl.) Willd). It should be pointed out that the wood species were classified in the strength classes of the hardwood group according to characteristic values (Equation 1) obtained from the compression parallel to the grain strength [16].

In Equation 1, f_{wk} is the characteristic strength, n is the number of specimens and f_i = specimen strength. It should be emphasised that strength results must be placed in increasing order ($f_1 \leq f_2 \leq f_3 ... \leq f_n$), neglecting the highest strength value for a number of specimens is odd and not taken for f_{wk} value less than f_1 and not less than 0.70 of the average value of the strength.

$$f_{wk} = \left(2 \times \frac{f_1 + f_2 + f_3 + ... + f_{(n/2)-1}}{(n/2)-1} - f_{n/2} \right) \times 1.10 \qquad (1)$$

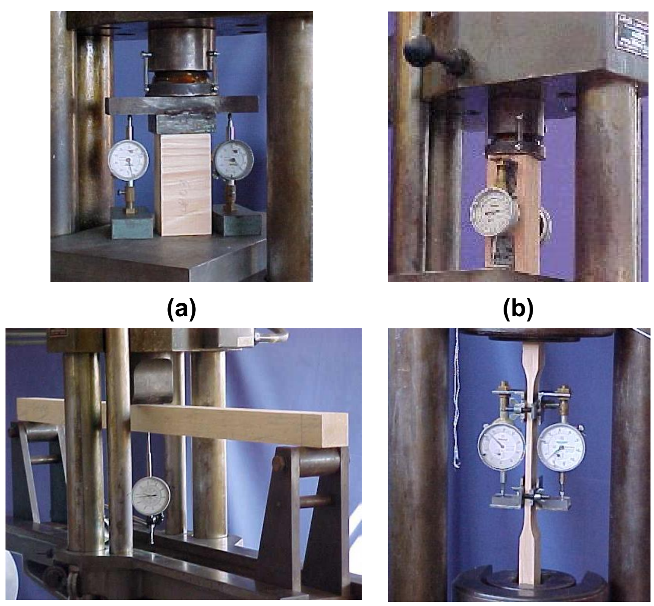
According to Brazilian Standard ABNT NBR 7190 [16], 12 specimens for each wood specie were used to obtain the values of compressive strength and also the apparent density at 12% moisture content. Table 1 shows the classification of the wood species in the strength class (SC), apparent density (ρ_{ap}) and the wood specie provenance.

Modulus of elasticity in compression (E_{c0}) and tension (E_{t0}) parallel to the grain, modulus of elasticity in compression perpendicular to the grain (E_{c90}) and modulus of elasticity in static bending (E_m) were obtained by following the assumptions and calculation methods in Brazilian Standard Code ABNT NBR 7190 [16], for each hardwood species. However, the stiffness values were obtained for each of the three load cycles investigated. By test type and for each hardwood species were manufactured 12 specimens, totaling 240 specimens and 720 results. Experimental procedures (Fig. 1) were carried out at the Laboratory of Wood and Wood Structures (LaMEM), Department of Structural Engineering, School of Engineering of São Carlos, University of São Paulo (USP), in a universal machine AMSLER, capacity 250 kN.

In order to investigate the influence of the number of loading cycles on the stiffness properties, the analysis of variance (ANOVA), evaluated with the software Minitab® version 14, was used. ANOVA was considered at the significance level (α) of 5% (H_0) and non-equivalence as an alternative hypothesis (H_1). Thus, P-value higher than the level of significance implies in accepting H_0, refuting it otherwise. For validation of ANOVA, the Anderson-Darling (AD) and Bartlett (Bt) variance homogeneity tests were used, both at a significance level of 5%. By the formulation of both tests, P-value higher than the level of significance implies that the distributions by response present normal distribution and equivalence of variances, thus validating the

Table 1. Strength classes, apparent density and provenance of Brazilian native hardwoods

Wood specie	SC	ρ_{ap} (g/cm^3)	Provenance
Cambará Rosa	C20	0.67	North of state of Mato Grosso
Cupiúba	C30	0.83	South of state of de Roraima
Envira	C40	0.90	North of state of Mato Grosso
Angico	C40	0.86	South of state of Roraima
Champanhe	C60	1.11	North of state of Mato Grosso



(a) (b) (c) (d)

Fig. 1. Mechanical tests: (a) compression perpendicular to the grain; (b) compression parallel to the grain; (c) static bending; (d) tension parallel to the grain

ANOVA model. Tukey test, also at the significance level of 5%, was used to group the levels of the factor number of loading cycles, making it possible to identify the groups considered equivalent or different in each value of stiffness investigated.

3. RESULTS AND DISCUSSION

Tables 2 to 6 present the mean values (x_m) and coefficients of variation (CV) of the stiffness properties investigated by hardwood species in each load cycle.

Table 2. Mean values and coefficients of variation of stiffness properties related to the three load cycles for Cambará Rosa wood specie

Stiffness		Load cycle numbers		
		1	2	3
E_{c90}	x_m (MPa)	994	901	891
	CV (%)	16	16	14
E_{c0}	x_m (MPa)	13,140	12,709	12,708
	CV (%)	18	18	18
E_m	x_m (MPa)	11,275	11,624	11,564
	CV (%)	20	20	20
E_{t0}	x_m (MPa)	12,870	12,474	12,509
	CV (%)	14	15	14

Table 3. Mean values and coefficients of variation of stiffness properties related to the three load cycles for Cupiúba wood specie

Stiffness		Load cycle numbers		
		1	2	3
E_{c90}	x_m (MPa)	581	515	514
	CV (%)	46	46	48
E_{c0}	x_m (MPa)	20,398	19,104	19,088
	CV (%)	23	22	23
E_m	x_m (MPa)	16,667	15,702	15,845
	CV (%)	29	28	29
E_{t0}	x_m (MPa)	17,486	16,351	16,565
	CV (%)	20	21	20

Mean values obtained from the Envira wood specie (*Xylopia* sp.) in this work were relatively close to those found in Christoforo et al. [33], whose elastic modulus values in compression parallel, tension parallel, static bending and perpendicular compression were equal to 18,328, 18,022, 14,973 and 620 MPa, respectively.

Tables 7 to 11 present the ANOVA results for the five investigated wood species, DF being the degrees of freedom of ANOVA and AD and Bt the Anderson-Darling normality and homogeneity between variances Bartlett, respectively (ANOVA validation). It should be noted that, from the Tukey test, equal letters imply factor levels with equivalent means, A being the highest average group, B the second highest average group, etc.

Table 4. Mean values and coefficients of variation of stiffness properties related to the three load cycles for Envira wood specie

Stiffness		Load cycle numbers		
		1	2	3
E_{c90}	x_m (MPa)	1,083	1,302	1,310
	CV (%)	14	15	14
E_{c0}	x_m (MPa)	17,159	18,387	18,328
	CV (%)	18	16	17
E_m	x_m (MPa)	15,241	14,822	14,605
	CV (%)	19	17	15
E_{t0}	x_m (MPa)	17,842	18,131	18,051
	CV (%)	6	7	6

Table 5. Mean values and coefficients of variation of stiffness properties related to the three load cycles for Angico wood specie

Stiffness		Load cycle numbers		
		1	2	3
E_{c90}	x_m (MPa)	680	683	619
	CV (%)	18	18	17
E_{c0}	x_m (MPa)	10,725	11,013	11,435
	CV (%)	15	10	9
E_m	x_m (MPa)	12,344	11,794	11,177
	CV (%)	9	11	9
E_{t0}	x_m (MPa)	13,570	12,754	13,131
	CV (%)	10	22	12

Table 6. Mean values and coefficients of variation stiffness properties related to the three load cycles for Champagne wood specie

Stiffness		Load cycle numbers		
		1	2	3
E_{c90}	x_m (MPa)	1,424	1,695	1,678
	CV (%)	19	17	17
E_{c0}	x_m (MPa)	25,395	27,118	26,758
	CV (%)	13	14	14
E_m	x_m (MPa)	21,799	21,600	21,840
	CV (%)	11	11	11
E_{t0}	x_m (MPa)	21,555	21,258	21,332
	CV (%)	32	31	31

Table 7. Results of ANOVA for the factor number of loading cycles for Cambará Rosa wood specie

Stiffness	DF	ANOVA validation		ANOVA	Tukey test		
		AD	Bt	P-value	1 Cycle	2 Cycles	3 Cycles
E_{c0}	35	0.653	0.732	0.019	B	A	A
E_{t0}	35	0.060	0.989	0.043	B	A	A
E_m	35	0.262	0.982	0.001	B	A	A
E_{c90}	35	0.676	0.993	0.006	B	A	A

Table 8. Results of ANOVA for the factor number of loading cycles for Cupiúba wood specie

Stiffness	DF	ANOVA validation		ANOVA	Tukey test		
		AD	Bt	P-value	1 Cycle	2 Cycles	3 Cycles
E_{c0}	35	0.533	0.931	0.022	B	A	A
E_{t0}	35	0.165	0.935	0.000	B	A	A
E_m	35	0.951	0.951	0.000	B	B	A
E_{c90}	35	0.118	0.982	0.003	B	A	A

Table 9. Results of ANOVA for the factor number of loading cycles for Envira wood specie

Stiffness	DF	ANOVA validation		ANOVA	Tukey test		
		AD	Bt	P-value	1 Cycle	2 Cycles	3 Cycles
E_{c0}	35	0.723	0.756	0.000	B	A	A
E_{t0}	35	0.217	0.995	0.145	A	A	A
E_m	35	0.320	0.658	0.015	B	A	A
E_{c90}	35	0.267	0.959	0.001	B	A	A

Table 10. Results of ANOVA for the factor number of loading cycles for Angico wood specie

Stiffness	DF	ANOVA validation		ANOVA	Tukey test		
		AD	Bt	P-value	1 Cycle	2 Cycles	3 Cycles
E_{c0}	35	0.156	0.856	0.000	B	A	A
E_{t0}	35	0.381	0.932	0.000	B	A	A
E_m	35	0.714	0.961	0.019	B	A	A
E_{c90}	35	0.269	0.748	0.000	B	A	A

Table 11. Results of ANOVA for the factor number of loading cycles for Champagne wood specie

Stiffness	DF	ANOVA validation		ANOVA	Tukey test		
		AD	Bt	P-value	1 Cycle	2 Cycles	3 Cycles
E_{c0}	35	0.574	0.989	0.019	B	A	A
E_{t0}	35	0.330	0.846	0.068	A	A	A
E_m	35	0.165	0.991	0.000	B	A	A
E_{c90}	35	0.212	0.990	0.021	B	A	A

From Tables 7 to 11, it was observed that the distributions by response were normal and that the variances of the groups were homogeneous, which validated the ANOVA model (P-value > 0.05). Regarding the number of cycles, the equivalence of the stiffness results between the second and third loading cycles, both higher than the stiffness values from the first loading cycle, is predominant, implying that the calculated stiffness values can be obtained with one or two loading cycles, not three as predicted by the Brazilian Standard Code ABNT NBR 7190 [16].

4. CONCLUSIONS

Results of the statistical analysis revealed that the calculated stiffness values can be obtained with the use of only two loading cycles instead of the three cycles defined by the Brazilian Standard Code ABNT NBR 7190 [16]. Since the results of the evaluated properties were equivalent to two and three loading cycles and both higher than the results from the use of a cycle, implying a reduction in the test time as savings in the energy and labour.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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