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FORESTRY SCIENCE

Representativeness of the fiber parallel elasticity modulus value referring to the Brazilian standard C40 strength class in the design of timber structures

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ABSTRACT: *Brazil has the world's second largest forest area, which makes the exploitation and use of varied species in civil construction conducive. One of the traditional uses of wood is to build roofs for different purposes. Considering that the most recurrent pathologies in the roof structures are related to the excessive deformations observed in the structural elements, particularly in those subjected to bending. This study verified the effective representativeness of the stiffness value established by the Brazilian Class wood standard, C40. Batches of eight different tropical wood species were considered, whose framing occurred in the referred Class. Results obtained from the confidence intervals for each evaluated species led to the conclusion that the value of 19500 MPa for the modulus of elasticity is not representative for Class C40 because the value observed in this study was 14467 MPa, which is 26% lower than the normative reference. This observation is an initial indication that the adoption of the value of 19500 MPa by the standard is unfavorable to the safety of the structure, justifying the pathologies observed in the service performance of the roof structures.*
Key words: *timber, native forest, elasticity modulus, strength, strength class.*

Representatividade do módulo de elasticidade na compressão paralela às fibras da classe C40 no projeto de estruturas de madeira

RESUMO: *O Brasil é o segundo maior país em área de florestas no mundo, o que torna propícia a exploração e uso de espécies variadas na construção civil. Um dos usos tradicionais da madeira se dá nos telhados das edificações para as mais diferentes finalidades. Tendo em vista que as patologias mais recorrentes nas estruturas de cobertura estão relacionadas às deformações excessivas verificadas nos elementos estruturais, principalmente nos sujeitos à flexão, o presente trabalho teve como objetivo verificar a efetiva representatividade do valor médio do módulo de elasticidade na compressão paralela estabelecido pela norma brasileira para madeiras da Classe C40. Foram considerados lotes de oito diferentes espécies de madeira tropicais, cujo enquadramento se deu na referida Classe. Os resultados obtidos dos intervalos de confiança para cada espécie avaliada possibilitaram concluir que o valor de 19500 MPa para o módulo de elasticidade não é representativo para a Classe C40, pois o valor encontrado nessa pesquisa foi 14467 MPa, resultado esse 26% inferior à referência normativa. Essa constatação é um indicativo inicial de que a adoção do valor de 19500 MPa pela norma é desfavorável à segurança da estrutura, justificando as patologias observadas no desempenho em serviço das estruturas de cobertura.*
Palavras-chave: *madeira, florestas nativas, módulo de elasticidade, resistência, classes de resistência.*

INTRODUCTION

Wood, one of the most commonly used materials by humans throughout history, is directly related to the solution of problems such as housing, crossing of natural and/or artificial obstacles, construction of vehicles for various modes of transportation, storage of agricultural products, and for building furniture and packaging (ALMEIDA, et al., 2019; COIMBRA et al., 2018).

The versatility of wood has always been fundamental in meeting human needs, including Brazil (SEGUNDINHO et al., 2017; SILVA et al., 2018). Because of the availability of wood, its use has expanded significantly, covering an increasing number of applications in the construction of structures such as roofs, bridges, walkways, silos, falsework, and shoring (GÜNTEKIN & AYDIN, 2016; LAHR et al., 2017; VIEIRA & GESUALDO, 2016).

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Brazil ranks second in terms of forest area, railing only Russia (IBÁ, 2019). The Amazon rainforest has1.26 million hectares of certified land (in Brazil, 6.30 million hectares of forest are certified) (IBÁ, 2017). There is no consensus as to the number of tree species in the Amazon rainforest, the most recent estimate is approximately 16000species (STEEGE et al., 2016). These data showed the importance of Brazil in relation to forest potential and; moreover, highlights the importance of studies for the identification and technological characterization of species from the Amazon rainforest.

In Brazil, the design and dimensioning of timber structures follow the premises and methods of calculation of the national normative document ABNT NBR 7190 (ABNT, 1997), that is, wooden structures project.

The Brazilian standard also specifies the test methods as well as the strength classes in which the batches used in construction are classified. For this classification, the reference property is the compressive strength parallel to the fibers ($f_{c0,k}$). For hardwoods (dicotyledons), the strength classes are C20 ($20 \leq f_{c0,k} < 30$ MPa), C30 ($30 \leq f_{c0,k} < 40$ MPa), C40 ($40 \leq f_{c0,k} < 60$ MPa), and C60 ($f_{c0,k} \geq 60$ MPa).

The standard establishes reference values for the longitudinal modulus of elasticity (E_{c0}) for structural design, which are 9500, 14500, 19500, and 24500 MPa for strength classes C20, C30, C40, and C60, respectively. For this purpose, such property is obtained by installing strain gauges and evaluating the modulus of elasticity in the material under compressive loading. Another property also used is the modulus of elasticity (MOE) obtained in the static flexion test. The MOE is correlated with the E_{c0} using equations (ABNT, 1997).

On the contrary, several authors have reported that the most recurrent pathologies in wood structures for roofing are related to excessive deformations verified in structural elements, particularly those subjected to bending, as highlighted in the literature (BISCAIA et al., 2016; LOURENÇO et al., 2013; METELLI; et al., 2013) with the consequences for the buildings are, in most cases, very expressive.

Overseas, the European Standard EN 338 (CEN, 2009) classifies the species into classes considering the value of static flexural strength, different from that in Brazil, which uses the compressive strength parallel to the fibers as the main parameter for classification.

In this context, this study verified the effective representativeness of the modulus of elasticity value established by the Brazilian standard for Class C40 woods, which presents a wide range of species usually applied in structures (MORANDO et al., 2019; WIERUSZEWSKI & MAZELA, 2017). It was investigated, through statistical analysis with 5% significance level, whether the reference value of the longitudinal MOE (19500 MPa) proposed by the standard for Class C40 is effectively representative of the respective strength class and thus sufficient to ensure structural safety in service limit states.

MATERIALS AND METHODS

Batches of eight species of wood from native forests, as listed in table 1, were used to verify the representativeness of the reference value of 19500 MPa for the longitudinal elasticity module (E_{c0}) of

Table 1 - Popular and scientific names of the wood species evaluated.

Popular Name	Scientific Name
Angelim amargo	*Votairea fusca*
Cafearana	*Andira stipulacea*
Branquilho	*Sebastiania commersoniana*
Canela-parda	*Nectandra* sp.
Canelão	*Ocotea* sp.
Rabo-de-arraia	*Vochysia haenkeana*
Angico-branco	*Anadenanthera colubrina*
Louro verde	*Ocotea* sp.

the batches of wood from class C40, as indicated by ABNT NBR 7190 (ABNT, 1997).

The batches, each one integrated by twelve pieces with nominal dimensions 6 x 12 x 300 cm, were properly stored until they reached a humidity close to 12%, as recommended in Annex B of the Brazilian standard. The assumptions and test methods were followed to obtain the values of strength (f_{c0}) and MOE (E_{c0}) in the direction parallel to the fibers. Twelve specimens (5× 5 × 15 cm) were manufactured and tested in parallel compression (Figure 1) per batch, resulting in 192 experimental determinations.

To determine the moisture content, the samples were placed in an oven at 103 ± 1°C until the difference in mass between the samples was null. After drying, the difference in mass before and after the drying process was compared, and this difference was given by the moisture content in the specimen.

The categorization of wood species in the hardwood group strength classes was performed using Equation 1 (ABNT, 1997), which makes it possible to empirically calculate the characteristic value of compressive strength ($f_{c0,k}$) as well as other mechanical stresses on which the wood was evaluated.

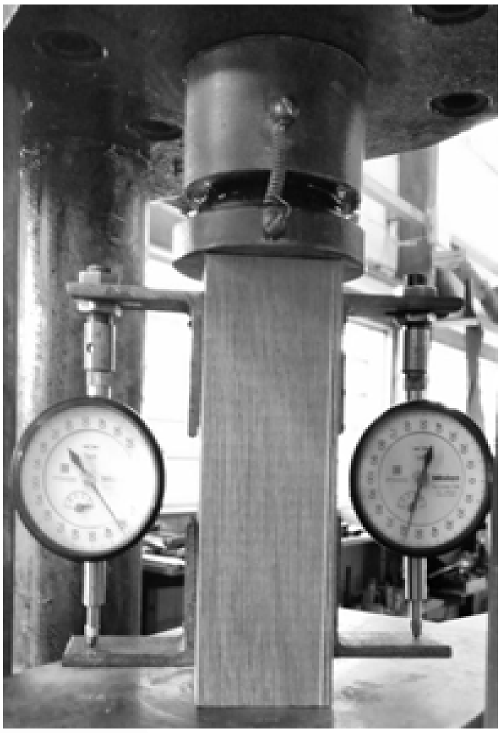

Figure 1 - Specimen tested in compression.

$$f_{c0,k} = 1{,}10 \cdot \left(2 \cdot \frac{f_1 + f_2 + f_3 + \ldots + f_{(n/2)-1}}{(n/2)-1} - f_{n/2} \right) \tag{1}$$

From equation 1, the sample results of the compressive strength in the direction parallel to the fibers (f_i) were placed in increasing order ($f_1 \leq f_2 \leq f_3 \ldots \leq f_n$). The highest strength value was not disregarded because it was an even number (12) of specimens. It should be noted that the characteristic value obtained by equation 1 should not be less than the smallest sample value and not less than 0.70 of the average value of resistance. The lots considered were classified as Class C40, as shown below. The confidence interval of the mean (Equation 2) was used as a criterion for analyzing the representativeness of the value of 19500 MPa proposed by the Brazilian standard for E_{c0}. If the reference value of 19500 MPa is contained in most of the confidence intervals obtained for each wood species, this implies the effective representativeness of this value for class C40 lots (hardwood group). Otherwise, a new average value should be stipulated based on the set involving all species considered in this study, which may be lower or higher than the value stipulated by the standard, implying favorable or unfavorable conditions for the structural project.

$$x_m - t_{\alpha/2,n-1} \cdot S_m / \sqrt{n} \leq \mu \leq x_m + t_{\alpha/2,n-1} \cdot S_m / \sqrt{n} \tag{2}$$

From equation 2, μ represents the population mean of the differences, x_m represents the sample arithmetic mean of the differences, n represents the sample size, S_m represents the sample standard deviation of the differences, and $t\alpha/2_{,n-1}$ represents the value tabulated by Student's t distribution with $n-1$ degrees of freedom and significance level α *(5%)*. For the assumptions made in the normality test (t-test), the p value (probability p) equal to or greater than the significance level implies normality in the distribution E_{c0}, which validates the results obtained from the confidence interval.

To increase the reliability of the results, bootstrap resampling technique was used to simulate the mean confidence intervals (95% reliability), and 100–1000000 simulations were considered.

RESULTS AND DISCUSSION

Table 2 shows the values of the results of strength and MOE in fiber parallel compression for the eight wood species considered in this study.

From table 2, the values of the coefficients of variation (Cv) obtained on the strength values of

Table 2 - Results of strength properties and modulus of elasticity in compression parallel to the fibers.

Property	---Species---							
f_{c0} (MPa)	A	B	C	D	E	F	G	H
$\overline{x}$	63.21	55.15	52.47	53.34	52.50	56.81	44.35	52.95
Cv (%)	12.85	18.20	7.84	15.10	9.66	19.92	8.54	10.71
Min	47.00	41.90	43.00	43.70	44.32	43.80	35.23	45.07
Max	70.00	78.10	54.60	71.70	60.17	76.20	48.46	64.05
$f_{c0,k}$	47.52	44.88	46.20	45.76	46.86	44.88	41.36	49.50
E_{c0} (MPa)	A	B	C	D	E	F	G	H
$\overline{x}$	15023	13772	14263	13334	15544	13402	14962	14649
Cv (%)	12.77	26.06	14.16	20.52	20.78	15.55	19.29	15.92
Min	13291	9727	11394	9416	10198	11103	11683	10577
Max	18740	20777	16595	16850	20614	18620	19016	18929

A - Angelim-amargoso; B - Cafearana; C - Branquilho; D - Canela-parda; E - Canelão; F - Rabo-de-arraia; G - Angico-branco; H - Louro-verde.

the eight wood species evaluated are in compliance with the requirements of the Brazilian standard ABNT NBR 7190 (ABNT, 1997), which establishes a Cv of 18% for resistance to normal stresses.

The characteristic compressive strength values in the direction parallel to the fibers of the wood varied between 41.36–49.50 MPa, which implies that all selected species belong to the C40 class of hardwood group strength by the Brazilian standard ABNT NBR 7190 (ABNT, 1997).

Table 3 presents the average values of the properties of strength and modulus of elasticity in parallel compression to the fibers of some wood species obtained from correlated literature, to evaluate the consistency of the results of f_{c0} and E_{c0} obtained in this study.

The values observed in the study of DIAS & LAHR (2004), which characterized the species according to the Brazilian standard NBR 7190 (ABNT, 1997), presented in table 3 are in agreement

Table 3 - Results of strength properties and correlated modulus of elasticity.

Author	Species	Unit content	E_{c0} (MPa)	f_{c0} (MPa)	$f_{c0,k}$ (MPa)
DIAS and LAHR (2004)	Angelim amargo	12%	15940	60	47.7
DIAS and LAHR (2004)	Cafearana	12%	14185	58	42.4
DIAS and LAHR (2004)	Branquilho	12%	13813	49	45.6
--	Canela-parda	--	--	--	--
--	Cannelon	--	--	--	--
DIAS and LAHR (2004)	Rabo-de-arraia	12%	14411	60	48.7
--	Angico-branco	--	--	--	--
--	Louro verde	--	--	--	--

with the results of strength and elasticity module obtained for some of the wood species evaluated in this study (Table 2) (ABNT, 1997).

Regarding the wood of Canela-parda, Canelão, Angico-branco, and Louro-verde, no physical or mechanical properties were observed in the scientific literature, which indicates the lack of knowledge in terms of physical and mechanical properties of a wide range of wood species, and that should be a focus of research on this subject.

Table 4 presents the confidence intervals of the mean (at 5% significance level) of the modulus of elasticity values for each wood species investigated.

Table 4 shows that the reference value 19500 MPa, indicated by ABNT NBR 7190 (ABNT, 1997) for E_{c0} referring to the hardwood strength class C40, does not belong to any of the confidence intervals obtained for the wood species evaluated in this study, reinforcing that both belong to class C40 of this standard. This implies that the reference value of 19500 MPa is not an adequate representative of the modulus of elasticity values for class C40.

Table 5 presents the mean value for the average modulus of elasticity in parallel compression of the analyzed species and the result of the confidence interval, considering 95% reliability (5% significance) for the averages of the species in table 4. These results are expressed with a sample and through bootstrap, considering up to one million simulations.

Considering the joint values of the modulus of elasticity in parallel compression of the eight wood species, the mean value results in 14467 MPa, presenting a coefficient of variation of 18.92% and a confidence interval of the mean (at 5% significance level) of (13912 MPa; 15021 MPa). The *bootstrap* resampling technique showed that the lowest value obtained for E_{c0} considering class C40 is 13800 MPa, which is much lower than that recommended by NBR 7190 (ABNT, 1997) for this class.

The average value of E_{c0}observedin the group involving the eight wood species is approximately 26% lower than the reference value of E_{c0} established by the Brazilian standard, which indicates that 19500 MPa is unfavorable to the safety of the structure design. This indicated the need for a revision in the next edition of ABNT NBR 7190 (ABNT, 1997), to confirm such value with a larger number of specimens. As the current class C40 includes species with $f_{c0,k}$ between 40 and 59 MPa, these standardized values do not represent the properties of species with $f_{c0,k}$ between 40 and 49 MPa, which can lead to design against the safety of structural elements.

CONCLUSION

Considering the group of eight lots of wood from native forests evaluated in this study, the average value of the elasticity module (14467 MPa) obtained in parallel compression was 26% lower than the value of E_{c0} established by the Brazilian standard (19500 MPa) for hardwoods belonging to the C40 strength class.

This value indicated the need to review this parameter in a future edition of this normative study with a larger number of species because the results of this study indicated that the reference value may be unfavorable to the safety of the structural project. The value of the modulus of elasticity is essential in the design of wooden structures, affecting the calculation of displacements in service.

Table 4 - Confidence intervals (5% significance) of the mean values of E_{c0} for each wood species.

Species	E_{c0} (MPa) - IC
Angelim amargo	(14647; 17234)
Cafearana	(11757; 16422)
Branquilho	(12570; 15056)
Canela-parda	(11595; 15072)
Canelão	(13491; 17596)
Rabo-de-arraia	(12078; 14726)
Angico-branco	(13129; 16796)
Louro verde	(13167; 16131)

Table 5 - Results of the confidence interval for the modulus of elasticity in parallel compression (MPa).

Method	------------------------CI (95% reliability)-------------------------		
	Lower Limit	Average	Upper Limit
t test	12804	14368	16129
Bootstrap - 100 simulations	13857	14367	14754
Bootstrap - 500 simulations	13938	14370	14797
Bootstrap - 1000 simulations	13850	14364	14807
Bootstrap - 5000 simulations	13827	14365	14812
Bootstrap - 10000 simulations	13846	14367	14794
Bootstrap - 50000 simulations	13828	14368	14818
Bootstrap - 100000 simulations	13839	14368	14811
Bootstrap - 500000 simulations	13842	14368	14803
Bootstrap - 1000000 simulations	13838	14368	14818

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DECLARATION OF CONFLICT OF INTEREST

No conflict of interest to declare.

AUTHORS' CONTRIBUTIONS

All authors contributed equally to the conception and writing of the manuscript. All authors critically reviewed the manuscript and approved the final version.

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