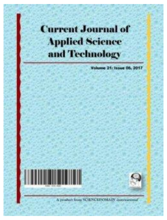

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Evaluation of Stiffness in Compression Perpendicular to Grain of Brazilian Tropical Wood Species

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Authors' contributions

This work was carried out in collaboration between all authors. Authors ASA and FARL designed the study, wrote the protocol and managed the analyses of the study. Author ALC wrote the protocol and statistical analysis. Authors TLSL and JAC managed the analyses of the study, wrote the first draft of the manuscript and managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

It is essential to have full knowledge of wood properties, such as strength and stiffness, for the preparation of reliable structural designs. The Brazilian Code ABNT NBR 7190 (1997) establishes that the modulus of elasticity in compression perpendicular to grain (E_{c90}) can be obtained in a

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simplified way, in the absence of experimental determination, by means of a correlation with the modulus of elasticity in the direction parallel to grain (E_{c0} = 20 E_{c90}). In order to verify the adequacy of this expression, the results obtained for five species of wood, covering the strength classes assumed by the mentioned Code were analyzed: Cambará Rosa (*Erisma* sp.), C20; Cedro Amazonense (*Cedrella* sp.), C30; Cupiúba (*Goupia glabra*), C40; Itaúba (*Mezilaurus itauba*), C50; Roxinho (*Peltogyne* sp.), C60. For each species, from the tests prescribed by ABNT NBR 7190, the elastic moduli were obtained in the directions parallel and normal to grain. In the evaluation of the precision of the proposed estimation, the least squares method was used to determine the coefficient α of the investigated relation. For the data set involving the five species studied, the coefficient resulted in α = 20.64. This value is compatible with the correlation proposed by the Brazilian standard, evidencing its reliability.

Keywords: Wood properties; wood stiffness; compression parallel to grain; compression normal to grain; simplified equation.

1. INTRODUCTION

Since the beginning of civilization, wood has been used for many purposes because of its versatility and facility to obtaining. These characteristics made wood indispensable for industrial, military and technological evolution [1,2,3,4]. Among these characteristics, it is worth mentioning that wood is a renewable material, aesthetically attractive for civil constructions, has good thermal and electrical insulation, which contributes to the energy efficiency of a building [1,5].

Wood presents variability in its structure due to the biological origin, an aspect that causes variations in physical-mechanical properties within the same species [6,7,8]. Recent research estimates the existence of 16,000 tree species in the Amazon Forest [9,10,11], many of them still not cataloged and whose properties are unknown. This limits its technological potential [10] and demonstrates that its characterization is essential to disseminate its rational use [9].

It is essential to have full knowledge of wood strength and stiffness for the preparation of reliable structural designs [8]. One of the most important parameters, related to wood structural employment, is the strength in compression parallel to grain [12], adopted as a reference by NBR7190/1997: Timber Structures Design, Brazilian Association of Technical Standards, ABNT [13].

This document, in its Annex B, provides the guidelines for obtaining said properties through laboratory tests. If the simplified characterization of the stiffness of little-known species is adopted, the relation must be respected:

$$E_{c0} = 20\ E_{c90} \tag{1}$$

Where:

- E_{c0}: Modulus of Elasticity in the normal direction to grain.
- E_{c90}: Modulus of Elasticity in the direction parallel to the grain.

Researches such as those by Ferro et al. [14]; Lopes et al. [15]; Silva et al. [16]; Mohd-Jamil and Khairul [17]; Machado et al. [18] and Carradine and Gonzalez [19] have been developed in order to verify if the relations between the properties obtained obeying test methods recommended by NBR7170/1997 are appropriate for estimating properties based on parameters of strength and stiffness in compression parallel to grain. In cases where the relationships are not confirmed, adjustments are suggested for the appropriate revisions of the Code [15].

In this context, this work aims to confirm that the simplified relation provided by NBR7190/1997 to estimate E_{c90} is proper. Five wood species, seeking to cover all strength classes established by ABNT NBR 7190/97 [13] were select: Cambará Rosa (*Erisma* sp.), C20; Cedro Amazonense (*Cedrella* sp.), C30; Cupiúba (*Goupia glabra*), C40; Itaúba (*Mezilaurus itauba*), C50; Roxinho (*Peltogyne* sp.), C60. All these species come from tropical forests and are widely used in construction.

2. MATERIALS AND METHODS

Five Brazilian tropical wood species were chosen, seeking to cover all strength classes assumed by ABNT NBR 7190 (1997): Cambará Rosa (*Erisma* sp.), C20; Cedro Amazonense (*Cedrella* sp.), C30; Cupiúba (*Goupia glabra*), C40; Itaúba (*Mezilaurus itauba*), C50; Roxinho (*Peltogyne* sp.), C60.

Tests were carried out to determine the modulus of elasticity in compression parallel to grain [E_{c0}] and normal to grain [E_{c90}], according to the premises of ABNT NBR 7190 (1997). Based on Christoforo et al. [20] and Lahr et al. [21], usually the number of twelve replications per species is adopted according to what ABNT NBR 7190 (1997) prescribes [13], since it is known that the values of the properties of the same species of wood may show differences, and thus more representative results are obtained. Thus, for each species 12 samples were confectioned, resulting in 120 determinations. Tests followed in the universal test machine AMSLER with the capacity of 250 kN.

Fig 1. AMSLER universal testing machine

In order to evaluate the accuracy of the E_{c0} = $20E_{c90}$ ratio proposed by the Brazilian Code, the least squares method (Equation 2) was used to determine the coefficient α ($E_{c0} = \alpha \cdot E_{c90}$) according to the minimum residue criterion [22].

$$f(\alpha)=\frac{1}{2}\sum_{i=1}^{n}(E_{c0_i}-\alpha\cdot E_{c90_i})^2 \tag{2}$$

The coefficient α obtained by Equation 2, for each species and also for the set involving the five species considered, aimed to verify the possible difference between the values of the coefficients to the one recommended by the Brazilian Code (20).

(a)

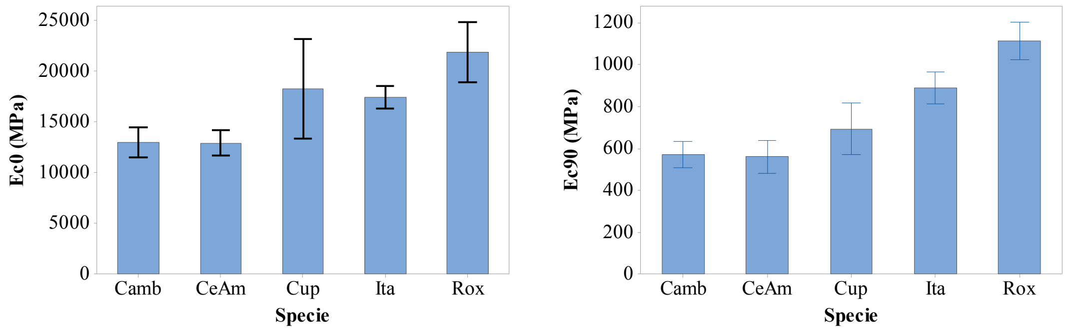
(b)

Fig 2. Compression test: (a) parallel to grain; (b) normal to grain

3. RESULTS AND DISCUSSION

Fig. 3 shows the mean values and confidence intervals (95% reliability) of the modulus of elasticity in the parallel compression E_{c0} (a) and perpendicular E_{c90} (b) to grain of the wood.

As for the modulus of elasticity in normal compression to grain of Cambará (Camb), the mean value is around 600 MPa, varying approximately 500 to 650 MPa, close to those obtained by Morales and Lahr [23].



(a) **(b)**

Fig. 3. Mean values and confidence intervals (95% reliability) of Ec0 (a) and E_{c90} (b)

Cambará presented modulus of elasticity in the compression parallel to grain about 13,000 MPa, with variations of 11,000 to 15,000 MPa. The mean value attests the results found by Ferro et al. [14], Morales and Lahr [23] and Duarte [24], 13,867, 12,708 MPa and 13,267 MPa, respectively.

Amazonian Cedar (CeAm) exhibited E_{c0} near 13,000 MPa, with variations of 11,000 to 14,500 MPa. In a recent study, Ferro et al. [14] show a mean value of E_{c0} equal to 11,368 MPa, contemplated in the range of values obtained in this study.

As for E_{c90}, Cedro Amazonense showed mean value of 560 MPa, varying from 450 to 650 MPa. The recent literature does not registers values of this property based on the specific test, due to the usual relation to E_{c0} proposed by the normative and analyzed in the present study.

Cupiúba (Cup) showed E_{c0} of approximately 18,300 MPa, ranging from 13,000 to 24,000 MPa. Note that the high variation in these values obtained is justified by the singularity of the analyzed specie, which usually exhibits great variations due to the presence of reverse grain, that is, which are not parallel to the axis of wood [24]. The range of values presented contemplates the Brazilian Code ABNT NBR 7190 (1997) [13], of 13,627 MPa. Furthermore, it covers the results obtained by da Silva [25], Dias and Lahr [5], Duarte [24], Ferro et al. [14] and Oliveira e Sales [26], 15,976, 14,125, 14,500, 16,187 and 15,439 MPa, respectively.

For E_{c90} to Cupiúba, the mean value is close to 700 MPa, ranging from approximately 600 to 900 MPa, including the result obtained by Duarte [24], of 900 MPa.

Itaúba (Ita) exhibited mean E_{c0} approximately 17,500 MPa, with variations of 16,000 to 18,000 MPa. The range of values presented contemplates the results obtained by Jesus, Logsdon and Finger [27], Morales [28] and Stangerlin et al. [29], 17,187, 17,443 and 16,606 MPa, respectively. For E_{c90}, Itaúba exhibited mean value of 900 MPa, with variations from 800 to 1,000 MPa.

Finally, Roxinho (Rox) presented mean E_{c0} about 22,000 MPa, with variations of 18,000 to 25,000 MPa. The mean value is equivalent to that obtained by Duarte [24]. As for E_{c90}, Roxinho species showed mean value of 1120 MPa, varying from 1,000 to 1,200 MPa. The range includes the one shown by Duarte [24], equal to 1,000 MPa.

The mean values obtained experimentally were calculated based on the 95% confidence interval as stipulated in ABNT NBR 7190, with a 5% level of significance. This shows that the obtained results were representative according to NBR 7190 and the average values found are according to each resistance class to which each species belongs.

The use of the 5 wood species to estimate the precision of the simplified equation was based on the attempt to arrive at a more precise result since at the time NBR 7190 was made, these data were collected based on the species of wood available and known at the time. Today, there is more research in this area, and more species of wood are known, being possible a better understanding of their resistance classes and consequently, we have a greater help in the choice of wood species for our research. Comparisons with the values found in the literature serve to demonstrate that the results obtained are within the expected range and are representative.

Table 1 presents the results of the coefficients α obtained from equation 1 for each wood species and for the set involving the five species.

Table 1. Coefficents results α

Species	$\alpha\ [E_{c0} = \alpha \cdot E_{c90}]$
Cambará Rosa (*Erisma* sp.)	22.13
Cedro Amazonense (*Cedrela* sp.)	22.04
Itaúba (*Mezilaurus itauba*)	19.26
Cupiúba (*Goupia glabra* Aubl.)	24.40
Roxinho (*Peltogyne* sp.)	19.52
All species	20.64

Due to the originality of the work (which deals with wood species coming from Brazilian tropical forests), there is no international bibliography in the area that mentions results discussed in this paper. From the use of equation 1, the coefficient α of the least squares method for the set involving all species resulted in 20.64, evidencing the good precision of the relation proposed by the Brazilian Code ABNT NBR 7190 (1997) [13] $[E_{c0} = 20\ E_{c90}]$. By species of wood, the most significant difference in the coefficient values came from the wood of Cupiúba (24.40). This difference is justified by the higher dispersion of the results around the mean for E_{c0}, as evidenced by the larger amplitude of the confidence interval shown in Fig. 2a.

4. CONCLUSION

According to the results obtained, the good precision of the simplified relationship, when there is a lack of specific experimental determination, is evidenced for the estimation of the modulus of elasticity E_{c90} proposed by Brazilian Code ABNT NBR 7190 (1997). It is suggested that this study is continued for other wood species, tropical or planted forests, to increase the degree of reliability of the normative parameters adopted.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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