WOOD RESEARCH
e-ISSN 2729-8906
66(4): 2021 582-594 pp.
doi.org/10.37763/wr.1336-4561/66.4.582594

INFLUENCE OF STIFFNESS RELATED TO THE C40 STRENGTH CLASS OF THE HARDWOOD GROUP ESTABLISHED BY THE BRAZILIAN STANDARD IN THE DESIGN OF TIMBER STRUCTURES

FRANCISCO ANTONIO ROCCO LAHR
UNIVERSITY OF SÃO PAULO
BRAZIL

VINICIUS BORGES DE MOURA AQUINO
FEDERAL UNIVERSITY OF SOUTHERN AND SOUTHEASTERN PARÁ
BRAZIL

FELIPE NASCIMENTO ARROYO
FEDERAL UNIVERSITY OF SÃO CARLOS
BRAZIL

HERISSON FERREIRA DOS SANTOS
FEDERAL INSTITUTE OF RONDONIA
BRAZIL

SERGIO AUGUSTO MELLO SILVA
SÃO PAULO STATE UNIVERSITY
BRAZIL

ANDERSON RENATO VOBORNIK WOLENSKI
FEDERAL INSTITUTE OF SANTA CATARINA
BRAZIL

CARLOS MAVIAEL DE CARVALHO
FEDERAL UNIVERSITY OF SOUTHERN AND SOUTHEASTERN PARÁ
BRAZIL

JOÃO PAULO BOFF ALMEIDA, ANDRÉ LUIS CHRISTOFORO
FEDERAL UNIVERSITY OF SÃO CARLOS
BRAZIL

(RECEIVED AUGUST 2020)

ABSTRACT

The Brazilian standard ABNT 7190 (1997) establishes the strength classes C20, C30, C40 and C60 for the proper framework of the different wood types in the group of hardwoods. Associated with the strength class, which is based on the compressive strength characteristic value parallel to the fibers ($f_{c0,k}$), the standard stipulates the respective values representing the stiffness (E_{c0}), with 19500 MPa being the reference value for the class C40, essential variables in structural design. For being the C40 class is the one with the greatest amplitude (20 MPa), it is possible that the value 19500 MPa is not the best representation of stiffness. This work aimed to verify the representativeness the stiffness value established by the Brazilian standard for C40 wood. The result obtained from the average confidence interval indicates the value of 14110 MPa as being the most representative, which may imply structures that are supposedly more rigid than they really are.

KEYWORDS: Wood, native forests, hardwoods, strength classes.

INTRODUCTION

One of the materials most used by man throughout history, wood is directly related to the problems solution such as housing; crossing natural and/or artificial obstacles; the vehicles construction for the different means of transport; agricultural products storage; the manufacture of furniture and packaging, among others (Coimbra et al. 2018, Almeida et al. 2019, Wolenski et al. 2020a).

Wood versatility has always been fundamental for meeting human needs. Similarly, Brazil experiences this situation (Segundinho et al. 2017, Silva et al. 2018, Wolenski et al. 2020b, Jankowska and Kozakiewicz 2014). Wood availability made its employment experience a wide expansion (Guntekin and Aydin 2016), covering more and more new possibilities of application in the structure’s construction: roofs, bridges, walkways, silos, shoring and shoring (Vieira et al. 2016, Lahr et al. 2017, Guntekin and Aydin 2016, Derkowski et al. 2015, Ihnát et al. 2018).

Brazil is the second country in relation to the area of forests in the world, behind only Russia (Beech et al. 2017). The certified areas of the Amazon Forest have 1.26 million hectares (in Brazil, 6.30 million hectares of forests are certified) (Lentini et al. 2012). There is no consensus regarding the number of tree species contained in the Amazon Forest, the most recent estimate being around 16 thousand species (Ter Steege et al. 2016). These data show the importance of Brazil in relation to the forest potential and, in addition, it 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 follows the premises and calculation methods of the normative document ABNT NBR 7190 (1997), which has the strength (f_{c0}) and stiffness (E_{c0}) properties to compression in the parallel direction as the reference for structural design.

The Brazilian standard ABNT NBR 7190 (1997) also specifies the test methods as well as the strength classes, which fit the different wood species based on the characteristic values of the compressive strength in the direction parallel to the fibers ($f_{c0,k}$). For hardwoods, the strength classes are C20 ($20 < f_{c0,k} \leq 30$ MPa), C30 ($30 < f_{c0,k} \leq 40$ MPa), C40 ($40 < f_{c0,k} \leq 60$ MPa) and C60 ($f_{c0,k} > 60$ MPa), as shown in Tab. 1.

Tab. 1: Strength classes of hardwoods. Source: Adapted from ABNT NBR 7190 (1997).

Classes	**$f_{c0,k}$ (MPa)**	**$E_{c0,m}$ (MPa)**	**$\rho_{12\%}$ (kg·m^{-3})**
C20	20	9500	650
C30	30	14500	800
C40	40	19500	950
C60	60	24500	1000

Associated with the strength classes, standard also establishes reference values for the elasticity modulus in the compression parallel to the fibers (E_{c0}) (Tab. 1), it should be noted that the C40 class is the one with the greatest range of values (20 MPa), being the amplitude other classes of 10 MPa.

Due to the greater amplitude related to the C40 strength class, the wood species diversity existing in Brazil and the 23 years since the standard publication, it is possible that the value of E_{c0} = 19500 MPa is not an effective representative of stiffness, which can lead to less secure projects if the most appropriate value is less than 19500 MPa.

This research aimed, with the help of twenty-one species of wood from native forests and categorized in class C40 of hardwoods group, in Brazilian standard ABNT NBR 7190 (1997), of the confidence interval of the average (p = 5%) and the Bootstrap resampling technique for simulating the mean confidence interval (100 to 1000000 simulations), investigate whether the reference value of 19500 MPa proposed by the standard is effectively a representative quantity of the respective strength class, since, with the most representative value being less than that, structural projects can be developed in an unfavorable way to safety.

MATERIAL AND METHODS

The twenty-one species of wood from native forests listed in Tab. 2 were used to verify the representativeness of the reference value of 19500 MPa for the modulus of elasticity (E_{c0}) in the parallel compression to fibers for class C40 wood proposed by the Brazilian standard ABNT NBR 7190 (1997).

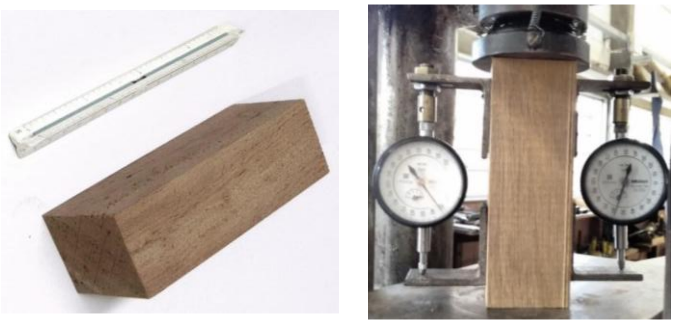
Tab. 2: Names of tropical forest species evaluated.

Common name	**Scientific name**
Angelim-amargoso	*Votairea fusca*
Angelim-araroba	*Vataireopsis araroba*
Angelim-pedra	*Hymenolobium petraeum*
Angelim-saia	*Votairea sp*

Angico-preto	*Piptadenia macrocarpa*
Branquinho	*Sebastiania commersoniana*
Cafearana	*Andira stipulacea*
Canela Sassafrás	*Ocotea odorifera*
Castelo	*Calycophyllum multiflorum.*
Catanudo	*Calophyllum sp*
Copaíba	*Copaifera cf. ret*
Cutiúba	*Goupia paraensis*
Goiabão	*Planchonella pachycarpa*
Guaiçara	*Luetzelburgia sp*
Louro-preto	*Ocotea sp*
Mandioqueira	*Qualea paraensis*
Parinari	*Parinari excelsa*
Piolho	*Tapirira sp*
Rabo-de-arraia	*Vochysia haenkeana*
Tatajuba	*Bagassa guianensis*
Umirana	*Qualea retusa*

The wood from homogeneous lots was properly stored, resulting in a moisture content close to 12%, as recommended by the Brazilian standard ABNT NBR 7190 (1997). The assumptions and test methods of the Brazilian standard were followed to obtain the values of resistance (f_{c0}) and stiffness (E_{c0}) to compression in the direction parallel to the fibers as well as the values of apparent density ($\rho_{12\%}$).

Also as recommended by the Brazilian standard, twelve specimens per species were manufactured and tested in parallel compression (Fig. 1) as well as twelve others for determining apparent density values, resulting in 756 experimental determinations in all.



(a) (b)

Fig. 1: Standardized specimen 5 × 5 × 15 cm according to ABNT NBR 7190 (1997) (a), and the apparatus used to perform the compression tests in the direction parallel to the fibers (b).

When the specimens were broken in the universal testing machine (AMSLER, 25 tons), their moisture content (U) at the time of the tests was obtained using the Marrari M5 contact humidity meter ($10.76\% \leq U \leq 12.96\%$). With the moisture content in the samples, the values of resistance (f_{c0}) and elasticity modulus (E_{c0}) to compression in the direction parallel to the fibers were corrected to the moisture content of 12% ($f_{c0,12}$, $E_{c0,12}$) with the aid of Eqs. 1 and 2 according to ABNT NBR 7190 (1997), resp., in which f_{c0}, U and E_{c0}, U consist of the samples strength and stiffness associated with the moisture content U.

$$E_{c0,12} = E_{c0,U} \cdot \left[1 + \frac{2 \cdot (U - 12)}{100}\right] \text{ (MPa)} \quad (1)$$

$$f_{c0,12} = f_{c0,U} \cdot \left[1 + \frac{2 \cdot (U - 12)}{100}\right] \text{ (MPa)} \quad (2)$$

Based on the corrected values of compressive strength in the direction parallel to the fibers ($f_{c0,12}$), Eq. 3 according to ABNT NBR 7190 (1997) was used to determine the characteristic value ($f_{c0,k}$) for the wood categorization (Tab. 1), where f_1, f_2 to f_n denote the compressive strength values ($f_{c\,0.12}$) in ascending order of the n test specimens tested (n = 12).

$$f_{c0,k} = Max \begin{cases} f_1 \\ 0.7 \cdot \dfrac{\sum_{i=1}^{n} f_i}{n} \\ 1.1 \cdot \left[2 \cdot \left(\dfrac{f_1 + f_2 + f_3 + \ldots + f_{(n/2)-1}}{(n/2) - 1}\right) - f_{n/2}\right] \end{cases} \quad (3)$$

The mean confidence interval (variation inference in the population mean value based on the sample), at the 95% reliability level, was used to calculate the mean value as well as the lower (2.5%) and upper (97.5%), and the Anderson-Darling test (p = 5%) was used to assess the normal distribution of E_{c0} values considering the set of 21 wood species. For the assumptions assumed in the normality test, p-value equal to or greater than the level of significance implies normality in the E_{c0} distribution, which validates the results obtained from the confidence interval. In order to increase the results reliability, the Bootstrap resampling technique was used to simulate the average confidence intervals (95% reliability), with 100 to 1000000 simulations being considered.

Based on the literature (Almeida et al. 2016), the increase in density implies a tendency to increase the wood strength and stiffness. As density is a property of easy experimental determination, it was used as an resistance and stiffness estimator to compression in the direction parallel to the wood fibers by the linear regression model evaluated by analysis of variance (ANOVA), at the level of p = 5%, allowing to judge, in addition to the quality of the fit (adjusted determination coefficient - R^2_{adj}), also the significance of the models, which allows to identify whether increases in apparent density effectively imply increases in the values of mechanical properties.

RESULTS AND DISCUSSION

Tab. 3 shows the average values of apparent density ($\rho_{12\%}$), strength (f_{c0}) and stiffness (E_{c0}) to compression in the direction parallel to the fibers, as well as the characteristic value $f_{c0,k}$ (Eq. 3) of the referred strength property.

Tab. 3: Results of the physical and mechanical properties of the wood species evaluated.

Species	$\rho_{12\%}$ (kg·m^{-3})	f_{c0} (MPa)	$f_{c0,k}$ (MPa)	E_{c0} (MPa)
Angelim-amargoso	772	60	47.7	15940
Angelim-araroba	674	50	45.3	12587
Angelim-pedra	663	58	44.5	11990
Angelim-saia	764	63	51.1	24081
Angico-preto	888	73	55.6	15375
Branquilho	810	49	45.6	13813
Cafearana	678	58	42.4	14185
Casca-grossa	788	57	44.5	17936
Castelo	759	55	54.5	11105
Catanudo	804	51	51.0	13029
Copaíba	695	50	44.1	14012
Cutiúba	1152	79	55.3	18238
Goiabão	938	49	43.1	18717
Guaiçara	995	66	58.9	14027
Louro-preto	680	55	42.1	13536
Mandioqueira	855	71	59.2	19274
Parinari	792	60	56.2	21881
Piolho	828	62	43.7	13404
Rabo-de-arraia	729	60	48.7	14411
Tatajuba	945	79	55.0	18574
Umirana	705	54	52.1	10178

The variation coefficients (CV) for $\rho_{12\%}$, f_{c0} and E_{c0} varied in the ranges from 4.31 to 8.22%, from 10.22 to 16.73% and from 12.73 to 19.15%, respectively, and it is worth noting that the maximum value of CV for f_{c0} (16.73%) was lower than the 18% CV established as a limit for normal requests by the Brazilian standard ABNT NBR 7190 (1997).

As expected, the average property values of some species of wood (Tab. 3) were close to the values obtained in the studies by Nogueira, Nogueira and Lahr (2001), Christoforo et al. (2017), Aquino et al. (2018a,b), Lima et al. (2018) and Morando et al. (2019), it should be noted that the lowest value of E_{c0} obtained (Tab. 3) was equal to 10178 MPa (Umirana wood), about 52% lower than the reference value (19500 MPa) established by ABNT NBR 7190 (1997), and the largest (24081 MPa for Angelim-saia wood) is approximately 23.49% higher than the representative value of the C40 resistance class.

Fig. 2 illustrates the result of the Anderson-Darling normality test for apparent density, fundamental for validating the mean confidence interval. Tab. 4 shows the mean confidence intervals (95% reliability) obtained considering the 21 species (T-test) as well as the confidence intervals extrapolated by the Bootstrap technique.

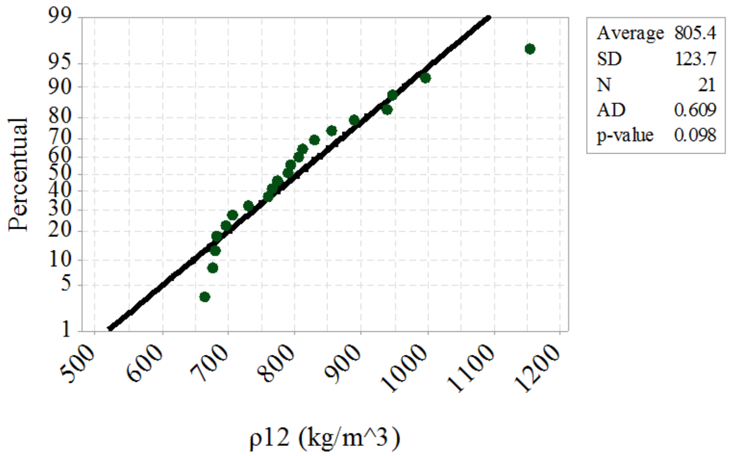


Fig. 2: Result of the Anderson-Darling normality test (p =5%) regarding the apparent density values.

Tab. 4: Confidence intervals results of the mean (CI) for the apparent density (kg·m⁻³).

Methods	CI (95% reliability)		
	Inferior limit	**Average**	**Upper limit**
T-test	749	805	862
Bootstrap - 100 simulations	755	804	850
Bootstrap - 500 simulations	752	805	850
Bootstrap - 1000 simulations	756	805	852
Bootstrap - 5000 simulations	757	805	850
Bootstrap - 10000 simulations	757	806	852
Bootstrap - 50000 simulations	757	805	851
Bootstrap - 100000 simulations	757	805	850
Bootstrap - 500000 simulations	757	805	851
Bootstrap - 1000000 simulations	757	805	851

From Fig. 3, the p-value of the Anderson-Darling normality test was higher than the level of significance adopted (p = 5%), showing the normality in the density values distribution, which validates the results of the mean confidence interval.

By the Bootstrap technique, there was a convergence of both the lateral limits and the average value between 500000 and 1000000 simulations, and for this reason, 805 $kg \cdot m^{-3}$ consists of the representative value of the apparent density for class C40 of the Brazilian standard ABNT NBR 7190 (1997). It should be noted that the reference value for the current standard is 950 $kg \cdot m^{-3}$ (Tab. 1), a value 18% higher than that found in the present study. As there is a tendency for denser woods to show greater resistance and stiffness (Almeida et al. 2016), it is very likely that the wood species used in the generation of resistance classes for the hardwood group by the current Brazilian norm (about 23 years since the last update) presented values of stiffness higher than those found in this work.

The results of the Anderson-Darling normality test and the mean confidence intervals (T-test and Bootstrap simulation) for the compression elasticity module in the direction parallel to the wood fibers are shown in Fig. 3 and Tab. 5, respectively.

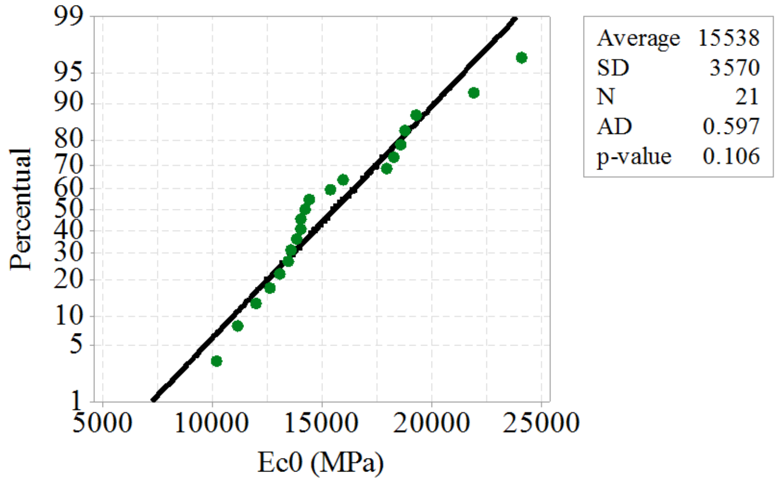


Fig. 3: Result of the Anderson-Darling normality test (p = 5%) for the elasticity modules in parallel compression.

Tab. 5: Confidence intervals results of the mean (CI) for the elasticity modulus in the compression parallel to the fibers (MPa).

Methods	**CI (95% reliability)**		
	Inferior limit	**Average**	**Upper limit**
T-test	13913	15536	17163
Bootstrap - 100 simulations	13848	15642	16881
Bootstrap - 500 simulations	14063	15510	16825
Bootstrap - 1000 simulations	14126	15537	16865
Bootstrap - 5000 simulations	14126	15554	16829
Bootstrap - 10000 simulations	14118	15540	16809
Bootstrap - 50000 simulations	14101	15536	16817
Bootstrap - 100000 simulations	14111	15539	16819
Bootstrap - 500000 simulations	14110	15538	16820
Bootstrap - 1000000 simulations	14110	15538	16820

As the distribution of E_{c0} values is normal, the confidence intervals (CI) results of the mean (95% reliability) are accepted. As in the case of apparent density, there was convergence in the elasticity modulus results in the compression parallel to the fibers between 500000 and 1000000 of simulations. Thus, the E_{c0} average value consisted of 15538 MPa, and the lower and upper limits of the average value by the CI were equal to 14110 and 16820 MPa, respectively.

Based on the average value obtained for E_{c0} with 500000 or 1000000 simulations, the reference value (19500 MPa, class C40) (Tab. 1) established by the current Brazilian legislation ABNT NBR 7190 (1997) is 25.5% higher than the average value obtained of E_{c0} in the present study and 38.2% higher than the lower limit of the average value obtained from the CI, which implies that the reference value stipulated by the aforementioned standard is unfavorable to security for allegedly considering more rigid structures.

For a better understanding of the impact of adopting the modulus of elasticity value to compression in the direction parallel to the fibers (E_{c0} = 19500 MPa) (Tab. 1) of the C40 strength class established by the Brazilian standard ABNT NBR 7190 (1997), be it the beam illustrated in Fig. 4, subject to the action of permanent (g) and accidental (q) distributed forces, span L and b and h measures for the base and the height of the rectangular cross section, respectively.

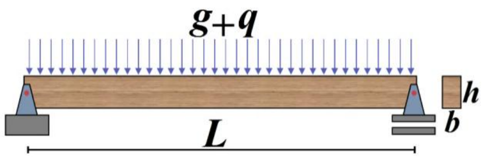


Fig. 4: Structure considered for the analysis of the effects of adopting the value of E_{c0} = 19500 MPa referring to class C40 of the Brazilian standard ABNT NBR 7190 (1997).

For structural scheme illustrated in Fig. 4, the maximum displacement occurs in the middle of the span ($L/2$), and is determined using Eq. 4:

$$\delta_{\max} = \frac{5 \cdot (g+q) \cdot L^4}{32 \cdot E_{c0} \cdot b \cdot h^3} \qquad (4)$$

For the limit state condition of use, the Brazilian standard establishes maximum value of vertical displacement equal to $L/200$. Assuming the values of b = 60 mm, h = 150 mm, L = 3000 mm and E_{c0} = 19500 MPa according to ABNT NBR 7190 (1997), for a maximum displacement of 15 mm (L/200) and making use of Eq. 4, the value resulting from the sum of the distributed forces ($g + q$) is equal to 4.68 $kN \cdot m^{-1}$.

Considering the load of 4.68 $kN \cdot m^{-1}$that meets the service limit state, but now using the values of the confidence interval of the mean (Tab. 5, last line) of the elastic modulus in the direction parallel to the fibers (E_{min} = 14110 MPa, E_{med} = 15538 MPa, E_{max} = 16820 MPa), the maximum displacements result in 20.73 mm, 18.83 mm and 17.39 mm. This implies that the displacements calculated with the E_{c0} of the present work are 38.2%, 25.5% and 15.7% higher than the displacement value of the service condition calculated based on the E_{c0} established in the C40 resistance class of the Brazilian standard. It should be noted that such excessive displacements can promote the manifestation of diverse pathologies in timber structures (Andrade et al. 2014).

Fig. 5 presents the regression models results for the mechanical properties estimates (f_{c0}, E_{c0}) as a function of apparent density.

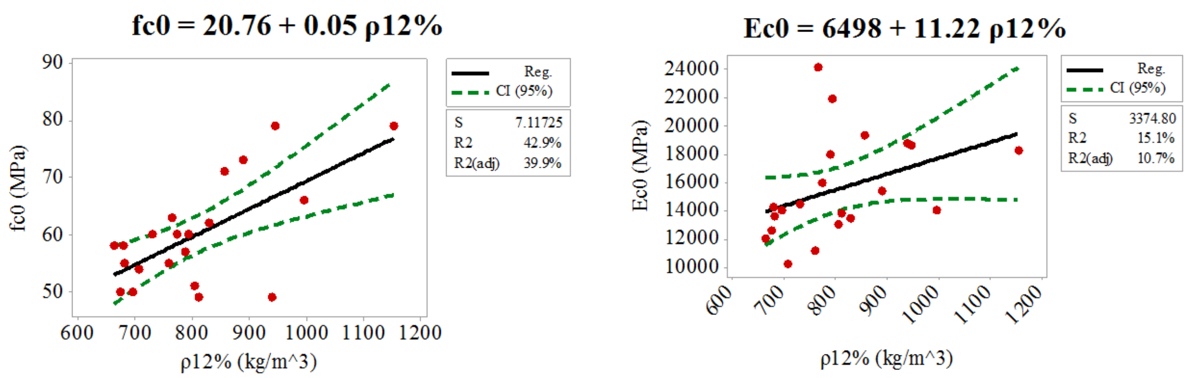


Fig. 5: Regression models.

By the adjusted determination coefficients obtained from the regression models presented in Fig. 4, it is concluded that the apparent density was not a good estimator of the strength and stiffness properties in the direction parallel to the wood fibers, however, for the estimate of the f_{c0}, it is worth noting that the model was considered significant by ANOVA (p = 5%), and this implies that increases in density promote increases in compressive strength in the direction parallel to the wood fibers (behavior trend). Such a result is justified, since the woods are both belonging to the same strength class (40 MPa $\leq f_{c0,k} <$ 60 MPa) and with densities ranging between 663 and 1152 $kg \cdot m^{-3}$ (large amplitude). To obtain more accurate models, other strength classes must be considered together (Almeida et al. 2017) as well as the adoption of chemical constituents of wood (Duarte et al. 2020) also as estimators.

CONCLUSIONS

The results of this research make it possible to conclude that: *(1)* The elasticity modulus value of 19500 MPa in compression parallel to the fibers (E_{c0}) considered by the current Brazilian standard ABNT NBR 7190 (1997) for the C40 resistance class of the hardwood group is 38.2% higher than the lower limit of the value mean (14110 MPa) obtained from the mean confidence interval (CI - 95% reliability) extrapolated by the Bootstrap technique (1000000 simulations). *(2)* From the example of the bi-supported beam under uniform loading, the adoption of the lower limit of the average value of the CI for E_{c0} (extrapolated by the Bootstrap technique) resulted in a displacement 38.2% higher than the value of the limit displacement established for the service condition by Brazilian standard. *(3)* Based on the experimental results of the 21 wood species evaluated, the apparent density ($\rho_{12\%}$) was not a good estimator of the values of resistance and stiffness to compression in the direction parallel to the fibers, which highlights the need for the incorporation of wood species of other resistance classes as well as considering the use of chemical components of wood as estimators in addition to $\rho_{12\%}$.

The results of the present research are important since the structural projects, elaborated on the premises of the Brazilian standard in force ABNT NBR 7190 (1997), may be subject to excessive displacements, which can compromise the structural integrity because it is a potential source of pathologies in the future.

ACKNOWLEDGMENTS

For all the support provided during the production of this research, the authors thank the Coordination for the Improvement of Higher Education (CAPES) and the National Council for Scientific and Technological Development (CNPq).

REFERENCES

1. ABNT, 1997: Projeto de estruturas de madeira ABNT- Técnicas NBR 7190 (Timber structures design). Associação Brasileira de Normas Técnicas.

2. Almeida, T.H., Almeida, D.H., Araujo, V.A., Silva, S.A.M., Christoforo, A.L., Lahr, F.A.R., 2017: Density as estimator of dimensional stability quantities of Brazilian tropical woods. BioResources 12(3): 6579-6590.
3. Almeida, T.H., Almeida, D.H., Arroyo, F.N., Araujo, V.A., Chahud, E., Branco, L.A.M. N., Pinheiro, R.V., Christoforo, A.L., Rocco Lahr, F.A., 2019: Time of exposure at 60^{o}C service temperature: influence on strength and modulus of elasticity in compression parallel to the grain of hardwood species. BioResources 14(1): 207-219.
4. Almeida, T.H., Almeida, D.H., Christoforo, A.L., Chahud, E., Branco, L.A.M.N., Rocco Lahr, F.A., 2016: Density as estimator of strength in compression parallel to the grain in wood. International Journal of Materials Engineering 6(3): 67-71
5. Andrade Jr., J.R., Almeida, D.H., Almeida, T.H., Christoforo, A.L., Rocco, F.A.L., 2014: Avaliação das estruturas de cobertura em madeira de um galpão de estoque de produtos químicos (Evaluation of wood roof structures of industrial shed for chemicals stock). Ambiente Construído 14(3): 75-85.
6. Aquino, V.B.M., Almeida, J.P.B., Almeida, D.H., Almeida, T.H., Panzera, T.H., Christoforo, A.L., Lahr, F.A.R., 2018a: Physical and mechanical characterization of Copaifera sp. wood specie. International Journal of Materials Engineering 8(3): 55-58.
7. Aquino, V.B.M., Panzera, T.H., Magalhães, L.N., Christoforo, A.L., Lahr, F.A.R., 2018b: Physical and mechanical characterization of Ocotea sp. wood specie. Construindo 10(2): 31-40.
8. Beech, E., Rivers, M., Oldfield, S., Smith, P.P., 2017: GlobalTreeSearch: The First complete global database of tree species and country distributions. Journal of Sustainable Forestry 36(5): 454-489.
9. Christoforo, A.L., Arroyo, F.N., Silva, D.A.L., Panzera, T.H., Rocco Lahr, F.A., 2017: Full characterization of *Calycophyllum multiflorum* wood specie. Engenharia Agricola 37(4): 637-643.
10. Coimbra, P.R.S., Almeida, A.S., Almeida, T.H., Almeida, D.H., Chahud, E., Christoforo, A.L., Rocco Lahr, F.A., 2018: Stress distribution in Tauari wood beam. International Journal of Materials Engineering 8(1): 5-11.
11. Derkowski, A., Mirski, R., Majka, J., 2015: Determination of sorption isotherms of scots pine (*Pinus sylvestris* L.) wood strands loaded with melamine-urea-phenol-formaldehyde (MUPF) resin. Wood Research 60(2): 201-210.
12. Duarte, B.B., Rocco Lahr, F.A., Curvelo, A.A.S., Christoforo, A.L., 2020: Influence of Physical and chemical components on the physical-mechanical properties of ten Brazilian wood species. Materials Research 23(2).
13. Güntekin, E., Aydin, T.Y., 2016: Prediction of bending properties for some softwood species grown in Turkey using ultrasound. Wood Research 61(6): 993-1002.
14. Ihnát, V., Lubke, H., Russ, A., Pazitiny, A., 2018: Waste agglomerated wood materials as secondary raw material for chipboards and fibreboards. Part II. Preparation and characterzation of wood fibres in terms of their reuse. Wood Research 63(3): 431-442.
15. Jankowska, A., Kozakiewicz, P., 2014: Comparison of outdoor and artificial weathering using compressive properties. Wood Research 59(2): 245-252.

16. Lahr, F.A.R., Christoforo, A.L, Varanda, L.D., Araujo, V.A., Chahud, E., Branco, L.A.M.N., 2017: Shear and longitudinal modulus of elasticity in wood: relations based on static bending tests. Acta Scientiarum-Technology 39(4): 433-437.
17. Lima, T.F.P., Almeida, T.H., Almeida, D.H., Chritoforo, A.L., Lahr, F.A.R., 2018: Propriedades físicas e mecânicas da madeira Tatajuba (*Bagassa guianensis*) proveniente de duas diferentes regiões brasileiras. Materia 23.
18. Morando, T.C., Christoforo, A.L., Aquino, V.B.M., Rocco Lahr, F.A., Rezende, G.B.M., Ferreira, R.T.L., 2019: Characterization of the wood species *Qualea albiflora* for structural purposes. Wood Research 64(5): 769-776.
19. Nogueira, M.C.J.A., Nogueira, J.S., Rocco Lahr, F.A., 2001: Avaliação da Itaúba e do Angelim Pedra para uso na construção civil (Evaluation of Itauba and Angelim Pedra wood species for use on civil construction). Revista Agricultura Tropical 5(1): 107-115.
20. Segundinho, P.G.A., Carreira, M.R., Regazzi, A.J., Dias, A.A., 2017: Influência do teor de umidade na determinação do módulo de elasticidade de vigas de *Pinus* sp (Influence of moisture content on the determination of the modulus of elasticity of *Pinus* sp. beams). Ambiente Construído 17(3): 319-329.
21. Silva, C.E.G., Almeida, D.H., Almeida, T.H., Chahud, E., Branco, L.A.M.N., Campos, C.I., Lahr, F.A.R., Christoforo, A.L., 2018: Influence of the procurement site on physical and mechanical properties of cupiúba wood species. BioResources 13(2): 4118-4131.
22. Ter Steege, H., Vaessen, R.W., Cárdenas-Lópes, D., Sabatier, D., Antonelli, A., Oliveira, S.M., Pitman, N.C.A., Jorgensen, P.M., Salomão, R.P., 2016: The discovery of the Amazonian tree flora with an update checklist of all known tree taxa. Scientific Reports 6(29549): 1-15.
23. Vieira, M.C.S., Gesualdo, F.A.R., 2016: Efeitos produzidos por entalhes nos terços extremos do vão de vigas estruturais de madeira (Effects produced by notches in the outer thirds of the span of structural timber beams). Ciência & Engenharia 25(1): 66-77.
24. Wolenski, A.R.V., Peixoto, R.G., Fedotova, V., Christoforo, A.L., Lahr, F.A.R., 2020a: Shear strength estimation model for tropical wood species. Wood Research 65(1): 175-182.
25. Wolenski, A.R.V., Peixoto, R.G., Aquino, V.B.M., Christoforo, A.L., Lahr, F.A.R., Panzera, T.H., 2020b: Evaluation of mechanical strengths of tropical hardwoods: proposal of probabilistic models. European Journal of Wood and Wood Products 79: 1-10.

FRANCISCO ANTONIO ROCCO LAHR
UNIVERSITY OF SÃO PAULO
DEPARTMENT OF STRUCTURAL ENGINEERING
SÃO CARLOS, SÃO PAULO
BRAZIL

VINICIUS BORGES DE MOURA AQUINO*
FEDERAL UNIVERSITY OF SOUTHERN AND SOUTHEASTERN PARÁ
TECHNOLOGY FACULTY

SANTANA DO ARAGUAIA, PARÁ
BRAZIL
*Corresponding author: aquino.vini@hotmail.com

FELIPE NASCIMENTO ARROYO
FEDERAL UNIVERSITY OF SÃO CARLOS
DEPARTMENT OF CIVIL ENGINEERING
SÃO CARLOS, SÃO PAULO
BRAZIL

HERISSON FERREIRA DOS SANTOS
FEDERAL INSTITUTE OF RONDONIA
DEPARTMENT OF AGRONOMICAL ENGINEERING
ARIQUEMES, RONDONIA
BRAZIL

SERGIO AUGUSTO MELLO SILVA
SÃO PAULO STATE UNIVERSITY
DEPARTMENT OF CIVIL ENGINEERING
ILHA SOLTEIRA, SÃO PAULO
BRAZIL

ANDERSON RENATO VOBORNIK WOLENSKI
FEDERAL INSTITUTE OF SANTA CATARINA
DEPARTMENT OF CIVIL ENGINEERING
SÃO CARLOS, SANTA CATARINA
BRAZIL

CARLOS MAVIAEL DE CARVALHO
FEDERAL UNIVERSITY OF SOUTHERN AND SOUTHEASTERN PARÁ
TECHNOLOGY FACULTY
SANTANA DO ARAGUAIA, PARÁ
BRAZIL

JOÃO PAULO BOFF ALMEIDA, ANDRÉ LUIS CHRISTOFORO
FEDERAL UNIVERSITY OF SÃO CARLOS
DEPARTMENT OF CIVIL ENGINEERING
SÃO CARLOS, SÃO PAULO
BRAZIL