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STUDY OF MECHANICAL COMPRESSIVE STRESS PROPERTY OF THE BAMBOO'S SPECIES *BAMBUSA TULDOIDES*

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Abstract. *The purpose of using non-conventional materials brings economic, social and technical advantages. Bamboo can be considered as a non-conventional material, that exhibits fast growth and high yield. Therefore, the main objective of this study is to present to professionals, the possibility of using bamboo as a structural element. This paper presents the results of recent research on bamboo of the Bambusa tuldoides species, performed at Federal Technological University of Paraná, Campus Pato Branco. The moisture content of the samples was around 13%. The study aims to determinate the mechanical compressive stress property of bamboo of the bottom and middle culms. The mean stress determined was 71.39 MPa for the bottom culms and 85.92 MPa for the middle culms. The mean elasticity's modulus was 2512 MPa for the bottom culms and 2640 MPa for the middle culms. These results were distinct to the ones found in the literature, particularly in the elasticity's modulus, verifying the need for further studies about the material.*

Keywords: *Bamboo, Non-conventional material, Compression test*

1. INTRODUCTION

With the industrialization of the products used in civil construction, natural materials have been gradually replaced by industrialized ones, considered as conventional, such as steel and Portland cement (Ghavami and Marinho, 2005).

In addition to the use of industrialized materials, that cost large financial resources and require a centralized process (Ghavami and Marinho, 2005), civil construction is the human activities sector that most consumes natural resources and uses energy intensively, and consequently generates solid, liquid and gaseous waste (Real, 2017).

The substitution of the conventional products by others non-conventional ones, with similar properties, as the bamboo, brings economic, social and technical advantages. Brazil has the greatest diversity and the highest index of bamboo forest in all Latin America, representing 32% of the species and 85% of the genera (Delgado, 2011), allowing the study of this material.

According dos Reis Pereira and Beraldo (2007) bamboo, by combining lightness and flexibility, is one of the most perfect structures in nature. The autor also mentions that bamboo can have several applications, ranging from food to civil construction, has a great availability and easy planting, and can be felled annually without replanting, characterizing an advantage beside it.

The use of structural bamboo has begun over a few decades, despite of its exceptional characteristics. But properties may vary in several aspects. There is a lack of studies such as diversity of species, wall thickness and outer diameter, directly influence physical, mechanical, dynamic and thermal properties, and this data are often not treated in the literature.

In Latin American countries, as Colombia, Venezuela and Peru, bamboo has become the object of research on technologies associated with other materials such as concrete, steel and wood, optimizing its properties and enabling the construction of more resistant and stately structures (Carbonari *et al.*, 2017).

In Brazil, bamboo's research involves the analysis of physical, mechanical and dynamic properties (Chamorro, 2011; Tamayo, 2009; da Rosa, 2005; Ghavami and Marinho, 2005; Armandei *et al.*, 2015), the use on roofs (Sato and Brasil, 2017; More, 2003), analysis of bamboo as Functionally Material Graduate (FGM) (Armandei *et al.*, 2015; Ghavami *et al.*, 2003), as reinforcement in concrete beams (Silva *et al.*, 2007), among others.

Therefore, this paper aims to study the mechanical compressive stress property the bamboo's species *Bambusa tuldoides*, collected in south of Brazil.

2. MATERIALS AND METHODS

The bamboo culms of the *Bambusa tuldoides* species were selected from various clumps located in the city of Campo Largo, Brazil, and were collected on October 2018.

After the felling, the culms were stored in a dark and dry place, protected from rain and sun, and free contact with the soil, until reaching a moisture content close to 12%, recommended by ISO DIS 22157:2019.

The culms were divided into bottom and middle parts, as showed in Fig. 1. ISO DIS 22157:2019 defines the minimum number of test specimens, totalizing 12 samples per specie, per test and per categorization (bottom and middle). Table 1 presents the nomenclature used for sample categorization.

Figure 1. *Bambusa tuldoides*'s samples from a) Bottom of the culm b) Middle of the culm

Table 1. Nomenclature used for sample categorization.

Nomenclature	Description
BTxx B(1)	*Bambusa tuldoides* – Bottom of the culms
BTxx M(1)	*Bambusa tuldoides* – Middle of the culms

(1) where xx is the number of each sample

The length, outer diameter, and wall thickness of each parts were measured. The outer diameter and the wall thickness were obtained from the outer surface.

The outer diameter was measured from two points on either end, and the wall opposite points on thickness from four points, on either end. With the obtained values, the arithmetic averages for each sample was realized.

Bamboo was prepared for the compression test parallel to the axis. The samples were free of any nodes, and the length of the specimen was equal to its outer diameter, as prescribed by ISO DIS 22157:2019. The end planes of the specimen were at right angles to the length of the specimen.

The compression tests were realized in Federal Technological University of Paraná, Campus Pato Branco, with the use of the universal INSTRON/EMIC Test Machine, Model 23300, monitored with the Tesc software. Figure 2 shows the machine used for compression test.

Samples were placed so that the center of the movable head was vertically above the center of the cross-section of the specimen, and a small load of not more than 1000 N was initially applied to set the sample. The load were applied continuously during the test, moving the movable head of the test machine at a constant rate of 1×10^{-5} m per second. Figure 3 shows the sample prepared for compression test.

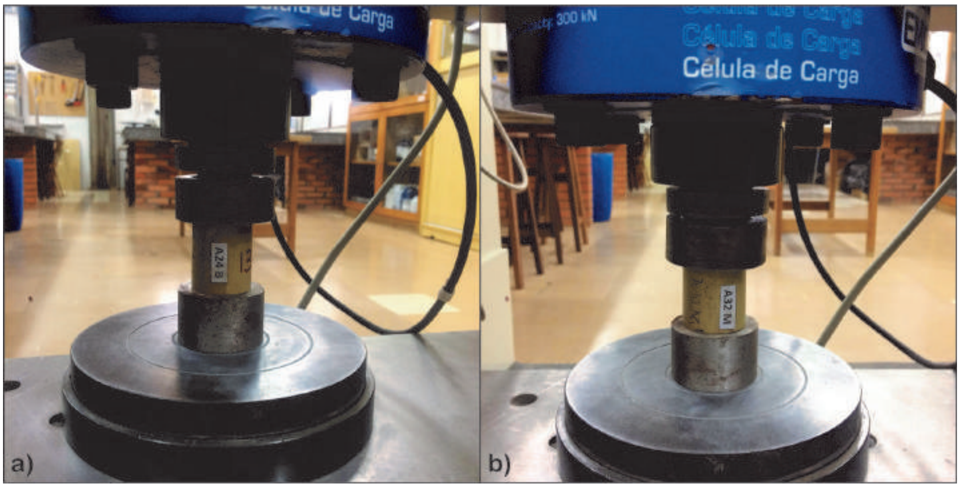

Figure 2. Samples prepared for compression test a) bottom culms b) middle culms

Figure 3. *Bambusa tuldoides*'s samples a) From the bottom of the culm b) Cross sectional from the bottom c) From the middle of the culm d) Cross sectional from the middle

A material property is represented by a 5 percentile property ($R_{0.05}$, in N, was determined in Eq. (1). and estimated from test results, with 75% confidence that it represents the population, this is called the characteristic value (ISO DIS 22157:2019). Characteristic value (R_K) can be obtained from Eq. (2), where f_m is the mean load obtained in the compression tests (in N), *s* is the standard deviation (in N) and *n* is the number of tests, all from the test data.

$$R_{0.05} = f_m - 1.645s \tag{1}$$

$$R_k = R_{0.05}(1 - (\frac{2.7\frac{s}{f_m}}{\sqrt{n}})) \tag{2}$$

Immediately after compression test, the samples were prepared for determination of moisture content *(MC)*. The number of tests pieces was equal to the number of compression tests pieces. The samples were weighed to an accuracy of 1x10^{-5} Kg, and then dried in an oven at a temperature of 103 $\pm$ 2 ^{o}C. After 24 hours, the mass was recorded at regular intervals of not less than 2 hours. The drying was considered completed when the difference between the successive determinations of the weight did not exceed 1x10^{-5} Kg. The moisture content *(MC)* of each test piece is determined by the difference between the mass of the test piece before drying (*m*) and the mass of the test piece after drying (m_0), divided by the mass before drying (*m*). Mass shall be expressed in Kg and the *MC* shall be calculated in percentage. Equation (3) represented *MC*.

$$MC = \left(\frac{m - m_0}{m_0}\right) 100 \tag{3}$$

Equation (4) represented the allowable stress R_{all} of each material, where R_{all} is the allowable stress (expressed in N), R_k is the characteristic value in N, *G* is the modification for the difference between laboratory quality and practice (default value 0.5), *C* is the modification value for duration of load (1.0 for permanent load) and γ is the factor of safety (default value 2.25).

$$R_{all} = \frac{(R_k G C)}{\gamma} \tag{4}$$

The maximum compressive stress (σ_{ult}) was determined by Eq. (5) and expressed in MPa.

$$\sigma_{ult} = \frac{F_{ult}}{A} \tag{5}$$

Where F_{ult} is the maximum load at which the specimen fails (in N), and A is the cross sectional area (in m^2) as represented by Eq. (6).

$$A = \frac{\pi}{4}\left(D^2 - (D-2t)^2\right) \tag{6}$$

Where *D* is the outer diameter, and *t* is the wall thickness, both expressed in m.

The elasticity modulus (*E*), expressed in MPa, was calculated from the mean of the readings, as a linear relationship between stress and strain (20% and 80% of F_{ult}), using Hooke's Law, as described in Eq. (7).

$$\sigma = E\varepsilon \tag{7}$$

Where ε is strain (in microstrain).

3. EXPERIMENTAL RESULTS

Table 2 presents the average of the results for outer diameter, characteristic strength, allowable stress and mean moisture content of *Bambusa tuldoides* species.

Table 2. Average of the outer diameter, characteristc strength, allowable stress and mean moisture.

Nomenclature	Outer Diameter (m)	R_K (KN)	R_{all} (KN)	MC (%)
BTxx B(1)	32.08	32.71	7.27	13.45
BTxx M(1)	26.80	26.80	5.95	13.97

(1) where xx is the number of each sample

The compressive test provides the values of load and displacement of each specimen until failure. With these values, it is possible to plot the stress-strain curves of each sample. Figures 4 and 5 presents the typical stress-strain curves resulting from the compression test of the culms from de bottom and the middle, respectivaly, of *Bambusa tuldoides* species.

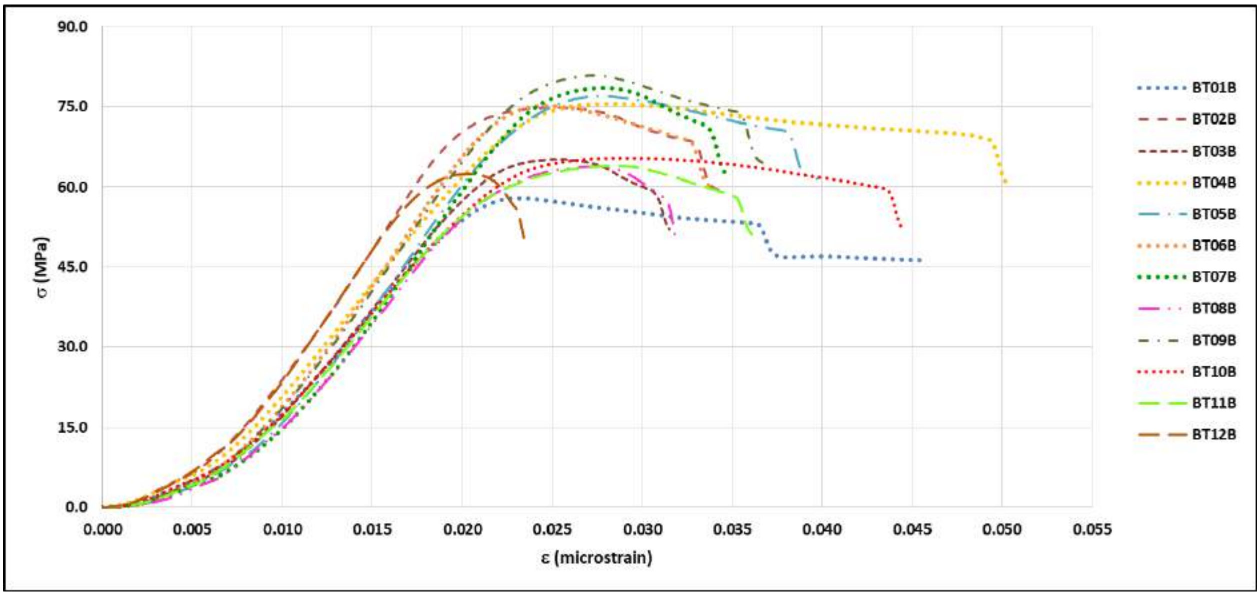

Figure 4. Stress-strain curves from compression test from bottom of the culms

Table 3 presents the average of the results for maximum load (F_{ult}), maximum compressive stress (σ_{ult}) and elasticity modulus (*E*) of *Bambusa tuldoides* species.

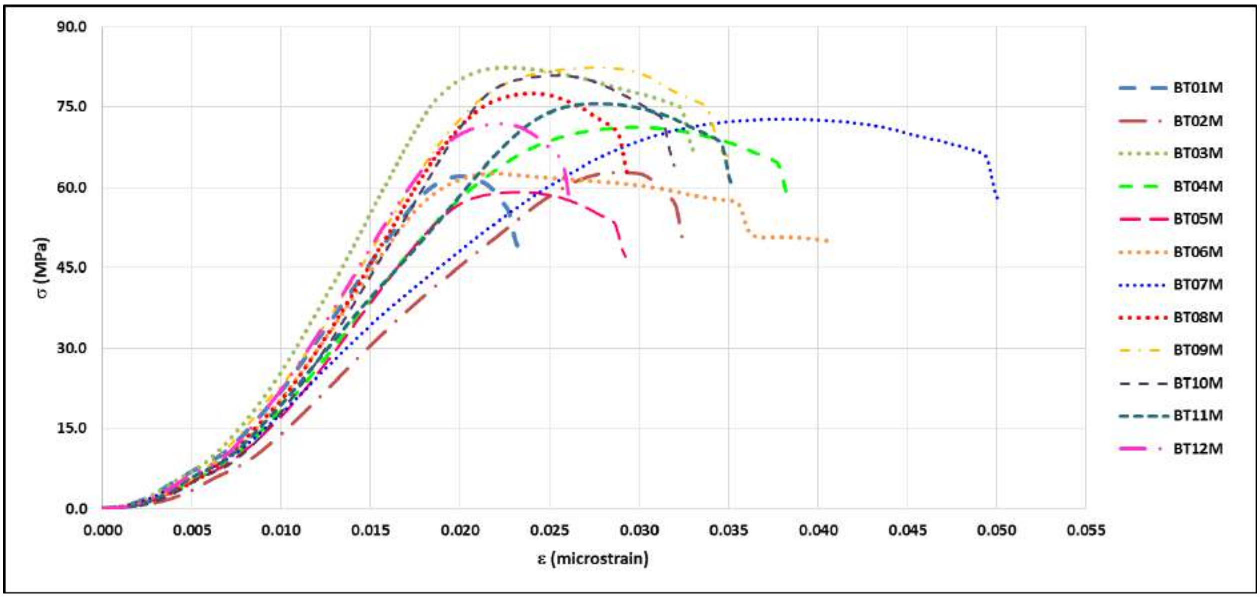

Figure 5. Stress-strain curves from compression test from middle of the culms

Table 3. Nomenclature used for sample categorization.

Nomenclature	F_{ult} (KN)	σ_{ult} (MPa)	E (MPa)
BTxx B$^{(1)}$	48.10	71.39	2511.75
BTxx M$^{(1)}$	39.46	85.92	2640.24

$^{(1)}$ where xx is the number of each sample

4. DISCUSSIONS

With moisture content around 13%, the maximum stress determined was 82.42 MPa for the bottom culms and 84.05 MPa for the middle culms. The mean stress was 71.39 MPa for the bottom culms and 85.92 MPa for the middle culms. Carbonari *et al.* (2017), for the same species, found values for compressive stress around 72.75 MPa. The obtained results in this paper, shown a decrease of 1.87% for the bottom culms and an increase of 15.33% for the middle culms in the compression tests.

Visual inspection on the specimens after compression test also revealed that the failure mode occurred by crushing the bamboo fibers. Figure 6 shows one of the samples from the middle culm after the compression test.

Figure 6. Failure mode

Others previous research carried out by Culzoni (1986); PEREIRA (2001); Nascimento *et al.* (2002), showed compressive stress results of 37.8, 34.0 and 26.8 MPa, respectively. When compared to the values obtained, on average, there was an increase of 53.94%.

The culms of *Bambusa vulgaris* species, that belong to the same genus of *Bambusa tuldoides* species, presented compressive stress results of 66.43 MPa for the bottom culms and 78.67 MPa for the middle culms, with moisture content around 19.10% and 15.10%, respectively (Awalluddin *et al.*, 2017). According to da Mota *et al.* (2017), a mean of 50 MPa for compressive stress for this species.

Regarding the elasticity modulus, there is little data in the literature about this species. Culzoni (1986), found values of 32400 MPa, while Nascimento *et al.* (2002), 16300 MPa. In this paper, the results from elasticity modulus were 2512 and 2640 MPa, from the bottom and middle culms, respectively. These results show the need for further characterization studies of the bamboo mechanical properties, in order to have more convergent values.

5. CONCLUSIONS

In the present paper an analysis of the compressive strength and elasticity modulus of bamboo of *Bambusa tuldoides* species was performed.

The maximum stress determined was 82.42 MPa and 84.05 MPa for the bottom and the middle culms, respectivaly, with moisture content around 13%. The mean stress was 71.39 MPa for the bottom culms and 85.92 MPa for the middle culms. For elasticity modulus the results were 2512 and 2640 MPa, from the bottom and middle culms, respectively.

It was concluded that the methodology used was satisfactory, and allowed to evaluate the mechanical compressive stress properties of the *Bambusa tuldoides* species. The results obtained in this paper were superior to those in the literature, verifying the need for further studies about the material. Based on the obtained results, could be verified that bamboo is an efficient material, with great resistance to compression. Further test needs to be performed to characterize others bamboo properties, such as tensile, bending and dynimic.

6. ACKNOWLEDGEMENTS

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