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# FULL CHARACTERIZATION OF *CALYCOPHYLLUM MULTIFLORUM* WOOD SPECIE

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**ABSTRACT**: Wood is a material that for years has been used by man for a variety of purposes, particularly in rural and civil constructions and furniture industry. The possibility of shortages of some wood species, the characterization of other unfamiliar species is an alternative source for use in civil and rural construction. This study aimed to determine, with the aid of Brazilian standard NBR 7190, physical and mechanical properties of Castelo (*Calycophyllum multiflorum*) wood specie. Twelve determinations were obtained by property, totaling 204 experimental values. In the characterization of wood, regression models were used to estimate the values of timber strength and stiffness as a function of apparent density, being density the physical property more simple to be obtained. The results of mechanical properties showed consistent with the performance of other species used in construction, which highlights the potential use of the Castelo wood in structural design. Regression models, apparent density was considered significant in the estimation of only 4 among the 14 properties for wood strength and stiffness.

**KEYWORDS**: *Calycophyllum multiflorum*, physical-mechanical properties, hardwood, regression model.

## INTRODUCTION

The use of wood in construction is a practice that has been carried out for many years by mankind, from the need to store food, to overcome obstacles to the construction of shelters (Molina et al., 2013, Almeida et al., 2015). The use of wood for a wide range of purposes depends on the knowledge of its properties (physical, chemical, mechanical and anatomical) for a more rational use of this material, which comes from natural sources, perfectly meets the requirements imposed by the current environmental appeal of products and services provided by man (Almeida et al., 2014).

Due to the demand and the few options of known wood species, selective harvesting has become predatory, reducing market receptivity to new species whose characteristics and properties are not yet fully understood (Souza, 1997).

Due to the great demand associated with few options, the prices of commonly used species increased, providing a new moment for the Brazilian timber sector, requiring the exploration of new wood species with the potential to replace those traditionally used in rural and civil construction (Christoforo et al., 2013). In addition, with increasing population awareness of the use of materials that cause the least damage to the environment, wood from planted forests is a resource of great potential (Almeida et al., 2013).

As an alternative to the diversification of wood use, *Calycophyllum multiflorum*, a Rubiácea species known as “palo-branco” in Argentina and “Castelo” in Brazil, presents a great option mainly for the state of Mato Grosso, where its production is more pronounced (Baldin & Marchiori, 2015). However, the physical and mechanical properties of this species have not yet been explored and disseminated.

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The design of a wood structure, as well as other materials, requires the knowledge of the physical and mechanical properties of the species to be used in the project, allowing the best use of the material (Almeida et al., 2013).

The characterization of wood species occurs by determining their physical properties, strength and stiffness through standardized tests. In Brazil, ABNT NBR 7190 (1997) is the document that defines the parameters for the wood characterization as well as the assumptions and methods used for structural design. However, the drawback of many of these tests is the need to use large equipment and high cost, available in research centers.

A physical property of easy experimental determination consists of the apparent density, defined by the ratio between the mass and the volume of the sample at 12% moisture. Since the density is a basic physical property, its values allows determining an adequate estimate of some wood properties (Almeida et al., 2014; Silveira et al., 2013). The estimation of strength and stiffness properties by density via mathematical models (regression models) allows the engineer, known the density of the wood species chosen and determined experimentally, to estimate the values of strength and stiffness to be used in the pre-designing of the structure.

In order to contribute to the use of new wood species in rural and civil construction, as well as in other applications, this research aimed to characterize *Calycophyllum multiflorum* wood and evaluate the possibility of estimating strength and stiffness properties due to the knowledge of the apparent density.

## MATERIAL AND METHODS

The *Calycophyllum multiflorum* wood (Figure 1) was properly stored and tested at the Wood and Timber Structures Laboratory (LaMEM) at the School of Engineering of São Carlos (EESC), University of São Paulo (USP), presenting moisture content around 12%.

FIGURE 1. *Calycophyllum multiflorum* wood specie.

Source: http://cremedemulateiro.xpg.uol.com.br/a_arvore.html.

The physical and mechanical properties, obtained in accordance with the provisions of Brazilian Standard ABNT NBR 7190 (1997) – Design of Timber Structures, provided in Annex B "Determination of wood properties for structural designs", and the number of experimental determinations are presented in Table 1. In total, 3 physical and 14 mechanical properties were obtained, and 204 experimental results were determined.

TABLE 1. Physical and mechanical properties of *Calycophyllum multiflorum* wood specie.

| Properties | Symbol | ND |
|---|---|---|
| Apparent density | $\rho_{12}$ | 12 |
| Total radial shrinkage | RRT | 12 |
| Total tangential shrinkage | RTT | 12 |
| Strength in compression parallel to grain | $f_{c0}$ | 12 |
| Strength in tension parallel to grain | $f_{t0}$ | 12 |
| Strength in tension perpendicular to grain | $f_{t90}$ | 12 |
| Strength in shear parallel to grain | $f_{v0}$ | 12 |
| Cleavage strength | $f_{s0}$ | 12 |
| Flexural strength | $f_m$ | 12 |
| Modulus of elasticity in compression parallel to grain | $E_{c0}$ | 12 |
| Modulus of elasticity in tensile parallel to grain | $E_{t0}$ | 12 |
| Modulus of elasticity in static bending test | $E_m$ | 12 |
| Parallel hardness | $f_{H0}$ | 12 |
| Perpendicular hardness | $f_{H90}$ | 12 |
| Toughness | W | 12 |
| Strength in compression perpendicular to grain | $f_{c90}$ | 12 |
| Modulus of elasticity in compression perpendicular to grain | $E_{c90}$ | 12 |

ND – number of determinations.

The estimation of strength and stiffness properties as a function of apparent density was evaluated with the use of regression models (Equations 1 to 4) based on analysis of variance (ANOVA). In equations 1 to 4, Y denotes the dependent variable (wood strength or stiffness), X consists of the independent variable (apparent density) and a and b are the parameters of the models fitted by Least Squares Methods.

$$Y = a + b \cdot X \quad \text{[Lin - Linear]} \tag{1}$$

$$Y = a \cdot e^{b \cdot X} \quad \text{[Exp - Exponential]} \tag{2}$$

$$Y = a + b \cdot Ln(X) \quad \text{[Log - Logarithmic]} \tag{3}$$

$$Y = a \cdot X^{b} \quad \text{[Geo - Geometric]} \tag{4}$$

By the ANOVA of the regression models, considered at the 5% level of significance (α), the null hypothesis formulated consisted in the non-representativeness of the tested models ($H_0$), and in the representativeness as an alternative hypothesis ($H_1$). P-value higher than the level of significance considered implies accepting $H_0$ (the model tested is not representative - variations of $\rho_{12}$ are unable to explain the variances of the estimated property), refuting it otherwise (the model tested is representative). In addition to the use of ANOVA, which allows or not to accept the representativeness of the models tested, the coefficient of determination ($R^2$) values were obtained as a way of evaluating the capacity of variations in apparent density to explain the analyzed variable, making it possible to choose among the models considered to be significant, the best fit. It should be noted that the apparent density was used to estimate the 14 properties of strength and stiffness with the use of the 4 mathematical models listed in Eq. 1 to 4, totaling 56 adjustments.

## RESULTS AND DISCUSSION

Tables 2 and 3 present the mean values ($\overline{x}$), coefficients of variation (CV) and the lowest (Min) and highest values (Max) for physical and mechanical properties, respectively.

TABLE 2. Results of physical properties.

| Statistics | $\rho_{12}$ (kg/m$^3$) | RRT (%) | RTT (%) |
|---|---|---|---|
| $\bar{x}$ | 770 | 4.02 | 6.64 |
| *CV(%)* | 7 | 14 | 10 |
| *Min* | 690 | 3.17 | 5.72 |
| *Max* | 880 | 4.87 | 7.74 |

TABLE 3. Results of mechanical properties.

| Stat. | $f_{c0}$ (MPa) | $f_{t0}$ (MPa) | $f_{t90}$ (MPa) | $f_{v0}$ (MPa) | $f_{s0}$ (MPa) | $f_m$ (MPa) | $E_{c0}$ (MPa) | $E_{t0}$ (MPa) |
|---|---|---|---|---|---|---|---|---|
| $\bar{x}$ | 55 | 104 | 7.00 | 21 | 1.4 | 103 | 11188 | 12920 |
| *CV(%)* | 5 | 15 | 19 | 18 | 21 | 6 | 11 | 15 |
| *Min* | 50 | 88 | 3.91 | 10 | 1.0 | 89 | 9249 | 10524 |
| *Max* | 59 | 125 | 9.73 | 25 | 2.10 | 112 | 13128 | 16395 |

| Stat. | $E_m$ (MPa) | $f_{H0}$ (MPa) | $f_{H90}$ (MPa) | W (N·m) | $f_{c90}$ (MPa) | $E_{c90}$ (MPa) |
|---|---|---|---|---|---|---|
| $\bar{x}$ | 11457 | 101 | 65 | 14.24 | 12 | 647 |
| *CV(%)* | 12 | 8 | 5 | 15 | 18 | 17 |
| *Min* | 9886 | 91 | 59 | 11.88 | 9 | 502 |
| *Max* | 14471 | 106 | 71 | 18.53 | 17 | 825 |

Based on the sample values (12 samples) of the strength in compression parallel to grain, the characteristic value ($f_{c0,k}$) found according to the Brazilian standard ABNT NBR 7190 (1997) was equal to 55 MPa, which classifies the *Calycophyllum multiflorum* wood belongs to the D40 strength class. The value obtained from $f_{c0}$ (55 MPa) for *Calycophyllum multiflorum* wood is very close to that obtained for Amescla-Aroeira (59.03 MPa) from the research developed by Logsdon et al. (2005), being Amescla-Aroeira a wood used in structures but that is in extinction, evidencing the possibility of the use of *Calycophyllum multiflorum* wood in structures of medium to large dimensions.

The strength in compression parallel to grain (55 MPa) of the *Calycophyllum multiflorum* wood is much higher than the compressive strength values of Paricá wood [24 MPa] (Almeida et al., 2014), *Toona ciliata* [27 MPa] (Braz et al. 2013) and *Eucalyptus benthamii Maiden et Cambage* [37.34 MPa] (Müller et al., 2014), both wood with potential for use in construction.

The mean value obtained from the apparent density [0.770 g/cm³] of *Calycophyllum multiflorum* classifies it as a heavy wood (Melo et al., 1992), being the same classification as *Minquartia guianensis*, *Lecythis poiteaui*, *Mezilaurus itauba*, *Manilkara huberi* and *Brosimum rubescens* (Silveira et al., 2013), however, is still lighter than the species mentioned above, whose densities range from 0.835 to 0.904 g/cm³. It is denser than medium apparent density woods, such as *Liquidambar* sp. (Freitas et al., 2015), *Pinus* and *Teca* (Almeida et al., 2014), *Cedrela fissilis*, Clonal hybrids and *Hovenia dulcis* (Motta et al., 2014), ranging from 0.478 to 0.577 g/cm³. Light wood, such as *Toona ciliata* (Braz et al., 2013), Paricá (Almeida et al., 2013) and *Gallesia integrifólia* (Motta et al., 2014) have a density varying between 0.318 g/cm³ and 0.370 g/cm³.

The Brazilian standard ABNT NBR 7190 (1997) stipulates maximum values for the coefficient of variation for the characterization to be qualified as adequate, being 18% for strength to normal stresses and 28% for tangential stresses, it should be noted that practically all properties have met the requirements of this normative document.

Table 4 shows the best fits (based on the coefficient of determination) obtained from the ANOVA of the regression models for the apparent density as an estimator of the strength and stiffness values, with the significant property adjustments by ANOVA being underlined (P-value < 0.05).

TABLE 4. Regression models for estimating the strength and stiffness values of *Calycophyllum multiflorum* wood by apparent density.

| Properties | Model | P-value | a | b | $R^2$ |
|---|---|---|---|---|---|
| $f_{c0}$ | Geo | 0.0078 | 62.4685 | 28.6092 | 52.09% |
| $f_{t0}$ | Lin | 0.0971 | -2.6904 | 138.4647 | 25.09% |
| $f_{t90}$ | Lin | 0.9743 | 6.7152 | 0.3602 | 0.01% |
| $f_{v0}$ | Lin | 0.2526 | 0.8667 | 26.6667 | 12.84% |
| $f_{s0}$ | Lin | 0.4257 | 2.6159 | -1.6169 | 6.45% |
| $f_m$ | Log | 0.7132 | 105.9627 | 11.1012 | 1.41% |
| $f_{H0}$ | Exp | 0.3094 | 69.7883 | 0.4756 | 10.28% |
| $f_{H90}$ | Lin | 0.1807 | 46.0674 | 25.2107 | 17.15% |
| W | Lin | 0.0745 | -1.2947 | 20.2352 | 28.37% |
| $f_{c90}$ | Log | 0.0000 | 21.3653 | 33.5308 | 85.23% |
| $E_{c0}$ | Log | 0.0088 | 14519.9203 | 12483.8686 | 51.25% |
| $E_{t0}$ | Lin | 0.0040 | -7489.3149 | 26591.7241 | 58.06% |
| $E_m$ | Exp | 0.0002 | 2911.5235 | 1.7773 | 75.48% |
| $E_{c90}$ | Lin | 0.0030 | -569.2238 | 1578.4674 | 60.19% |

The density was considered significant only in the estimation of the strength in compression parallel to grain ($f_{c0}$) [$R^2$ = 52.59%] and in the strength in compression perpendicular to grain ($f_{c90}$) [$R^2$ = 85.23%]. By the values of the determination coefficients obtained from these two models, it is verified that apparent density only provides good precision as an estimator of the $f_{c90}$. The best fit for the estimation of $f_{c0}$ and $f_{c90}$ by $\rho_{12}$ were the geometric and logarithmic, respectively, illustrated in Figure 2.

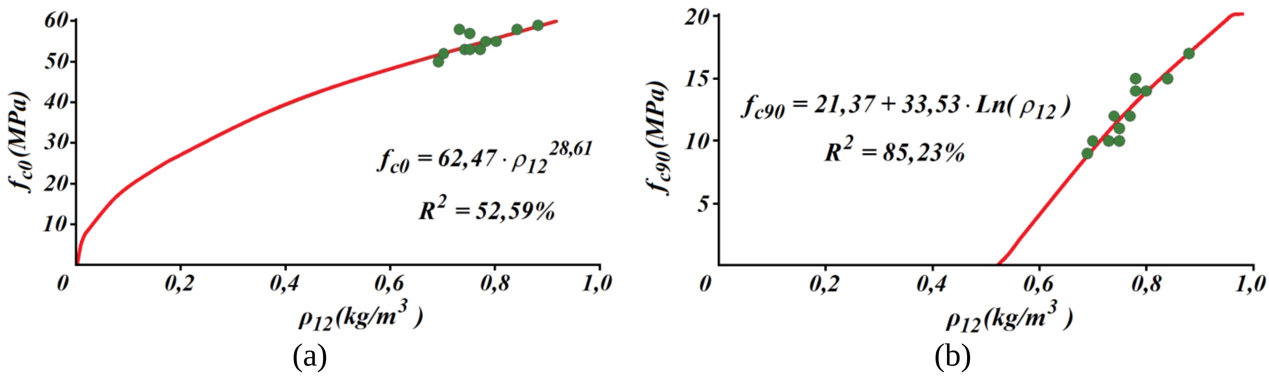


FIGURE 2. Best fit obtained to estimate the strength values of wood by apparent density - geometric (a) and logarithmic (b) models.

The apparent density was considered significant by ANOVA in the estimation of all stiffness properties evaluated (P-value <0.05). The best fit was obtained for the modulus of elasticity in the static bending using the exponential model [$R^2$ = 75.48%] (Figure 3c), followed by the modulus of elasticity in compression perpendicular to grain [$R^2$ = 60.19%] (Figure 3d) with the linear model, by the modulus of elasticity in tensile parallel to grain [$R^2$ = 58.06%] (Figure 3b) with the use of the linear fit and finally by the modulus of elasticity in compression parallel to grain [$R^2$ = 51.25%] (Figure 3a) with the use of the logarithmic fit.

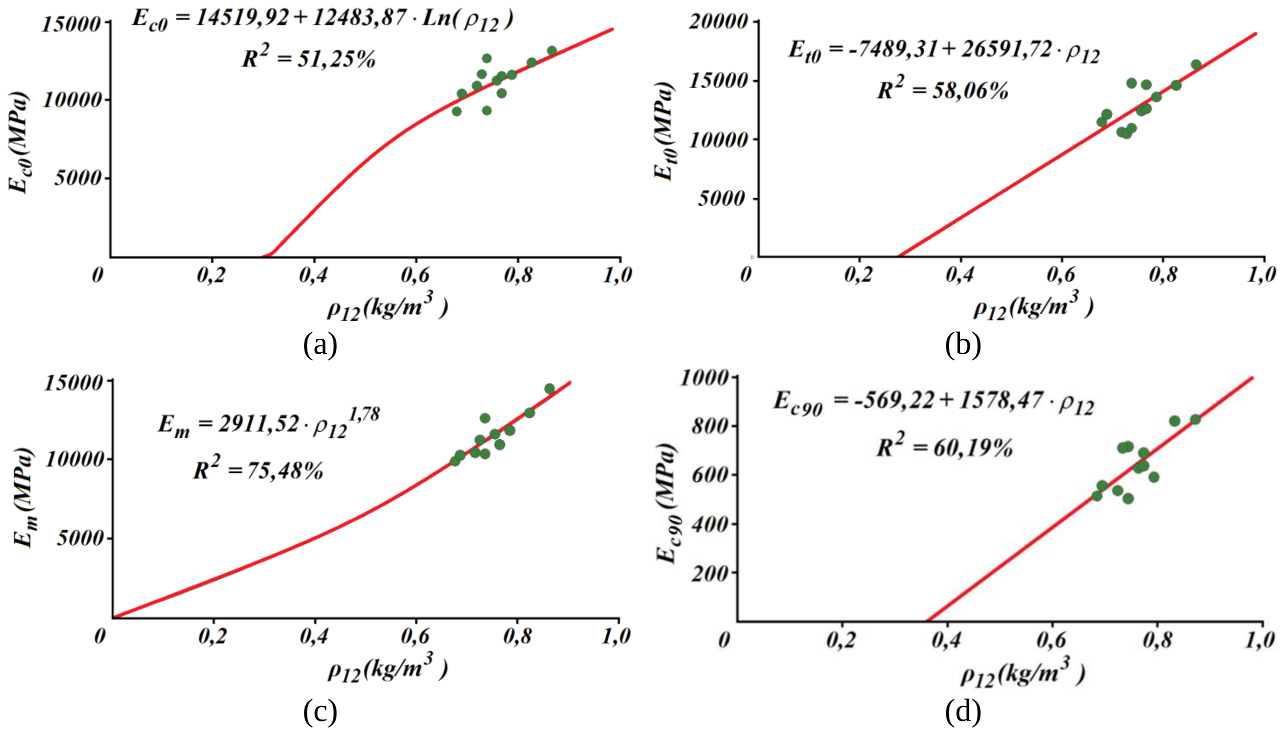


FIGURE 3. Best fit obtained to estimate the stiffness values of wood by apparent density.

From the adjustments considered significant in Table 4, only the strength in compression perpendicular to grain and the flexural modulus of elasticity are effectively considered as good adjustments, since they have coefficients of determination higher than 70%. It should be noted that Almeida et al. (2014) found good regression models ($R^2$> 70%) in the estimation of hardness of the hardwoods group as a function of apparent density, and these results were justified by the use of species of different densities.

## CONCLUSIONS

The results obtained from the present research allow concluding that:

- From the values of the variation coefficient obtained, the characterization of *Calycophyllum multiflorum* wood specie can be considered as required by the Brazilian standard;

- Following the parameters of the Brazilian standard, this wood is classified as belonging to D40 strength classes, because it presents a characteristic value of compressive strength equal to 55.00 MPa, indicating its potentiality of use in rural construction, among other applications, when comparing the results of their mechanical properties with those from other hardwoods already reported;

- By the values of the coefficient of determination obtained from the adjustments, the apparent density showed to be a good estimator only for the strength in compression perpendicular to grain and for the modulus of elasticity in static bending test, evidencing that it is possible to estimate these two properties with the knowledge of the density of *Calycophyllum multiflorum* wood (experimentally measured) to be used in the design, allowing a more precise pre-dimensioning of the structure.

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