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Evaluation of the Potential Use of Oiticica-Amarela Wood for Structural Applications

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Abstract In relation to other materials such as concrete, plastic, steel and aluminum, wood has a number of advantages, such as beauty, high mechanical resistance to mass, good thermal insulation and easy workability. Still, wood presents environmental advantages when compared to other building materials (cement, concrete, steel and aluminum), beause it is recyclable, renewable, biodegradable and requires low energy needs for its processing. Taking so many advantages of the wooden use, it's necessary to aim a rational use for this raw material, as an example, there are the physical and mechanical properties, which are important for the structural use of the species in the design of wood structures. This work aimed to characterize the wood species *Clarisia racemosa* (Oiticica-Amarela), objectifying its viable use for structural purposes. The tests to obtain the physical and mechanical properties were carried out according to the recommended established by Brazilian Standard ABNT NBR 7190 (1997), allowing the classification of such species in strength class C60 (hardwoods), as well as evaluating the possibility of estimation (linear, exponential, geometric and logarithmic models) of the physical and mechanical properties in function of the apparent density. The results obtained from the regression models implied the possibility of estimating only the mechanical property of compressive strength parallel to the fibers (f_{c0}) as a function of the apparent density ($\rho_{ap,\ 12\%}$).

Keywords Physical and Mechanical characterization, Apparent density, Structures of wood, *Clarisia racemosa*

1. Introduction

The use of wood in its various purposes, the knowledge of its physical, chemical, mechanical and anatomical properties, so that one can make the rational use of this material, being a wood, a material derived from natural sources that perfectly meet as requirements conferred by the environmental damage of goods and services performed by man [1].

In Brazil wood is destined for various purposes such as residences, bridges, churches, warehouses, structures, electric power transmission lines, walkways, furniture industry and, mainly, buildings that are contoured by environments that have a high degree of corrosion, as in the chemical industries, by the sea, etc. However, the Brazilian society carries a high level of doubt regarding the use of wood material, due to the lack of knowledge and the lack of specific projects, being in charge of carpenters to elaborate projects of wood structures, culminating in the vulnerability of the works to the different types of problems [7-8,14].

Regarding to structures, the use of wood is mostly in roofing, especially in residential buildings, so it is not apparent that there are small gaps. On the other hand, when it comes to steel and concrete structures, which are more culturally accepted by the Brazilian user, the use of these materials is not restricted to coverings, as it is the case of wood [14].

The execution of tests with national species cataloged or not in Annex E of the Brazilian standard ABNT NBR 7190 (1997) expands the knowledge about the native species and reforestation, being possible a better understanding of its potential for application in projects, encouraging the use of a natural and renewable material [7].

Brazil is a country with a vast biodiversity, which provides a wide diversity of wood species throughout the country. The application of wood for structural purposes presents a certain bias, due to its low valorization, lack of knowledge by professional designers of structures and other cultural aspects, making the wood a less competitive material compared to other materials commonly used in design of structures [13,14].

Oiticica-amarela wood (*Clarisia racemosa*) (Figure 1), is an alternative for using in civil construction due to the low amount of species on the market. This tree develops in clayey, hardwood forests that occur frequently throughout

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the Amazon, as well as in the north of the state of Espírito Santo, in the southern state of Bahia, in the forest area of the state of Minas Gerais and in the valley of the sweet river. Its wood is significantly heavy and its mechanical strength is rated between medium and low. This tree is described as dioecious reaching heights of 25 to 30 m and it can still reach diameters between 60 and 100 cm.

Figure 1. A trunk of *Clarisia racemosa*

The estimation of strength and stiffness characteristics from a readily determinable physical property (apparent density) provides the non-performance of some tests indicated in the Brazilian standard ABNT NBR 7190 (1997), if all mechanical properties has to be determined, it is necessary to have some equipment, which may not be available because of the high cost of installation. The estimation of the mechanical properties aims to ensure a more efficient pre-sizing by the designers and to make the wood a more competitive material. Through regression models with good mathematical adjustments on the given species, it allows easy access to other mechanical properties, aiming the use of native species and reforestation available in the regions in question, contributing to the variety of wood species that can be applied in woodworking projects [3].

2. Material and Methods

The recommendations indicated in Annex B - Determination of wood properties for structural designs - Brazilian Standard ABNT NBR 7190 (1997) were used to obtain the physical and mechanical properties of the investigated species, the tests were carried out in the Laboratory of Timber and Structures of Wood (LaMEM), University of São Paulo (USP), with moisture content of 12% for the selected samples.

The direct analysis of lots of homogeneous sawn wood occurs for lots with a volume of 12 m³. Test specimens were removed from remote regions in the ends of the pieces at least five times the smallest cross-sectional dimension of the piece, but never less than 30 cm and the same should be free of defects. For a minimum characterization of resistance of the species it is necessary to use at least 12 specimens for each characterization.

Table 1 shows the physical and mechanical properties obtained experimentally in the analysis of a total of 12 specimens for each of the 15 studied properties, giving a total of 225 results.

Table 1. List of symbols and abbreviation

Properties	Abbreviation
Apparent Density	$\rho_{ap,12\%}$
Total Radial Shrinkage	**TRR**
Total Tangencial Shrinkage	**TTR**
Compressive Strength in the direction Parallel to the Fibers	f_{c0}
Tensile Strength in the direction Parallel to the Fibers	
Tensile Strength in the direction Normal to the Fibers	f_{t0}
Shearing Strength in the direction Parallel to fibers	f_{t90}
Cracking Strength	f_{v0}
Conventional Strength in the Static Bending Test	f_{s0}
Longitudinal Modulus of Elasticity in Compression Parallel to the Fibres	f_M
Modulus of elasticity in traction Parallel to the Fibres	E_{c0}
Conventional Modulus of Elasticity in the Static Bending Teste	E_{t0}
Hardness parallel to the Fibers	E_M
Hardness normal to the Fibers	f_{H0}
Tenacity	f_{H90}
	W

The characteristic strength values (f_{wk}) of the wood are given by Equation 1 according to the Brazilian Standard ABNT NBR 7190 (1997).

$$f_{wk} = \left(2 \bullet \frac{x_1 + x_2 + \ldots + x_{\frac{n}{2}-1}}{\frac{n}{2}-1} - x_{\frac{n}{2}} \right) \bullet 1{,}1 \qquad (1)$$

The results were arranged in ascending order ($f_1 \le f_2 \le \cdots \le f_n$), discarding the highest value if the number of specimens is odd, with no value of resistance less than f_1 and less than 0,7 multiplied for the average value of the strength (f_m).

In order to obtain an estimation of the mechanical properties, rigidity and some physical properties of wood species *Clarisia racemosa* as a function of apparent density, it is performed by means of regression models (Equations 2 to 5) based on analysis of variance (ANOVA) with the help of free software BioEstat 5.3.

$$Y = a + b \bullet (\rho_{ap,12\%}) \qquad (2)$$

$$Y = a \bullet e^{\left(b \bullet \rho_{ap,12\%}\right)} \qquad (3)$$

$$Y = a + b \bullet \ln\left(\rho_{ap,12\%}\right) \qquad (4)$$

$$Y = a \cdot \left(\rho_{ap,12\%}\right) \quad (5)$$

Based on the ANOVA of the regression models, established at the 5% level of significance (α), the formulated hypotheses of the tested models consist of the representativity, null hypothesis (H_0: $\beta = 0$), and non-representativity, alternative hypothesis (H_1: $\beta \neq 0$). For P-value lower than the level of significance considered, it implies acceptance of H_0, so the model tested is representative, the variations of $\rho_{ap,\ 12\%}$ are able to explain the variations of the property analyzed, in the case of P-value higher than the level of significance considered, the model tested is not representative.

Besides the use of ANOVA, which makes it possible to accept or not the representativeness of the tested models, the coefficient of determination (R^2) is a way of investigating the reliability of apparent density variations and elucidating the estimated variable, thus selecting the best adjustment, among the significant models considered.

3. Results and Discussion

The Table 2 shows the physical and mechanical characteristics of the wood species *Clarisia racemosa*, obtained in the laboratory for a total of 12 specimens, considering that they were extracted from a homogeneous lot. If (x') is the mean value, (Cv) is the coefficient of variation, (CI) is the confidence interval of the mean value (95% confidence), (Min) is the smallest value, (Max) the highest value and (f_{wk}) the characteristic values.

Table 2. Descriptive statistics of laboratory values for wood of the species *Clarisia racemosa* (Oiticica-amarela)

Properties	x'	CV(%)	Mín	Máx	f_{wk} (MPa)
$\rho_{ap,12\%}$(g/cm³)	0,76	2,61	0,73	0,78	---
TRR (%)	2,47	9,93	2,0	2,87	---
TTR (%)	6,21	3,83	5,9	6,74	----
f_{c0} (MPa)	70,3	9,76	58,0	79,0	63,62
f_{t0} (MPa	85,8	14,94	53,3	106,5	75,0
f_{t90} (MPa)	3,9	29,26	2,1	5,7	2,74
f_{v0} (MPa	17,8	11,82	13,8	21,4	16,06
f_{s0} (MPa)	0,65	28,97	0,4	1,0	0,40
f_M (MPa)	107,5	15,05	71,6	134,6	---
E_{c0} (MPa)	14718,8	9,25	11993,8	16888,6	---
E_{t0} (MPa)	148025,5	9,61	124656,0	166607,0	---
E_{M0} (MPa)	14491,3	8,52	12280,7	16871,1	---
f_{H0} (MPa)	95,7	5,41	86,7	103,7	95,83
f_{H90} (MPa)	58,9	8,88	52,7	67,8	55,77
W (N.m)	13,4	22,96	7,54	19,17	---

When analyzing the values obtained in Table 2 and they are compared to the values established in Annex E of ABNT NBR 7190 (1997), it is observed that the values found are consistent with those already tabulated and any differences can be attributed to the different locations of extraction. For the physical property, an average density of 0,76 g/cm³ was obtained, being the same value presented by the Brazilian Standard.

Based on [10] wood species *Hymenolobium spp.* (Angelim-stone) has values of apparent density ($\rho_{ap,\ 12\%}$), conventional strength in the static bending test (f_M) and compressive strength parallel to the fibers (f_{c0}) are close to the respective values of the wood species *Clarisia Racemosa* obtained experimentally, and can be used in civil construction in the most diverse purposes as beams, rafters, slats, linings, props, concrete forms, scaffolding, among other forms of applications for which wood is indicated.

Based on [11] for a referential moisture content of 12% of *Clarisia racemosa* wood, the value found out for the characteristic strength in compression parallel to the fibers ($f_{c0,k}$) was iqual to 59,14 MPa, similar to that obtained experimentally (63,62 MPa).

[7] Found out for the same wood species the value of $f_{c0,k}$ equals to 73,5 MPa classifying such wood species as strength class C60.

The [9] presents the physical and mechanical characteristics of the wood species *Clarisia racemosa*, however, few results can be compared with those obtained in this work, since the test methods used are based on the old Brazilian standard ABNT MB26 (1985).

ABNT NBR 7190 (1997) assigns maximum values for the coefficient of variation (Cv) so that the characterization is considered adequate, with limit values for strength in normal and tangential stresses of 18% and 28%, respectively. It is observed in Table 2 that most of the coefficients of variation (Cv) are in accordance with the recommendations required by ABNT NBR 7190 (1997).

Table 3. Results of the (P-values) ANOVA of the regression models

Propertie	Model	a	b	P-Value	R^2 (%)
TRR	Logarithmic	0,718	0,043	0,496	4,75
TTR	Geometric	1,134	-0,223	0,308	10,36
fc0	Exponential	0,603	0,003	0,001	70,70
ft0	Linear	0,823	-0,001	0,090	26,18
ft90	Geometric	0,706	0,052	0,036	37,04
fv0	Linear	0,740	0,001	0,786	0,78
fs0	Exponential	0,741	0,,029	0,511	4,44
fM	Exponential	0,949	-0,041	0,287	11,23
Ec0	Exponential	0,714	0,000	0,536	3,94
Et0	Geometric	0,563	0,025	0,777	0,84
EM0	Logarithmic	1,217	-0,048	0,522	4,22
fH0	Exponential	0,750	0,000	0,964	0,02
fH90	Exponential	0,668	0,002	0,177	17,39
W	Linear	0,752	0,003	0,896	0,18

Table 3 presents, the best models obtained for the wood species *Clarisia Racemosa* through apparent density, where

(a) and (b) are the coefficients adjusted by means of the Minimum Squares Method, (R^2) represents the coefficient of (P-value<0,05) or the non-representativeness (P-value>0,05) of the evaluated models. It is worth emphasizing that the adjusted models are investigated for the apparent density, whose range of values are between 0,73 and 0,78 g/cm³.

For the *Clarisia racemosa* species, the compressive strength (f_{c0}) and the tensile strength (f_{t90}) was obtained P-values of 0,001 and 0,036, respectively, it's considered significant by the ANOVA (P-value <0,05) but only for the compressive strength (f_{c0}), the exponential model resulted in a good approximation because it exhibits a coefficient of determination (R^2) approximately to 70%, which implies the possibility of strength property estimation as a function of apparent density.

In [2], the regression models were tested using the apparent density as independent variable and it was found out a good adjustments in the estimation of compressive strength (f_{c0}) for the wood of Cassafferula (*Cassia ferrugínea*) and Castle (*Gossypiospermum sp.*). The best model obtained for both species was the geometric with a coefficient of determination (R^2) of 48,57% and 52,84% for Canafístula and Castelo, respectively.

In [12] for wood Angelim Saia (*Vatairea sp*.) The P-values obtained for the compressive strength parallel to the fibers (f_{c0}), hardness parallel to the fibers (f_H), hardness normal to the fibers (F_{H90}) were significant, and the best model used was the geometric, providing a coefficient of determination (R^2) greater than 60% for the 3 strength properties.

Other work in the scientific literature evidenced a varied behavior (representative or not) of the use of density as an estimator of physical and mechanical properties, in the works [1] and [6], significant results were obtained in the estimation of wood tenacity as a function of apparent density, which can not be observed in [4] and [5].

4. Conclusions

In this work the physical and mechanical characteristics of the wood species *Clarisia racemosa* were determined according to the assumptions established in ABNT NBR 7190 (1997) classifying according to the strength class C60 (hardwoods) because it presents characteristic strength in compression parallel to the fibers ($f_{c0,k}$) equals to 63,2 MPa, indicating a good potential for applications in light and heavy structures.

Among the regression models tested for a total of 12 mechanical properties and 3 physical properties, only the compressive strength parallel to the fibers (f_{c0}) presented the possibility of estimation as a function of the apparent density ($\rho_{ap,\ 12\%}$), providing a coefficient of (R^2) of 70,7% for the exponential model.

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