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PHYSICAL AND MECHANICAL CHARACTERIZATION OF OCOTEA SP WOOD SPECIE

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ABSTRACT

Wood, a sustainable and renewable resource, has been used by mankind for many years in several purposes, especially in construction and manufacture. Considering the predatory harvesting, it is necessary to characterize unknown species as an alternative for human use. In consequence, there are a considerable risk of shortage of this woods. This research aimed to determine, following the Brazilian Standard ABNT NBR 7190, physical and mechanical properties of *Louro Preto* wood (*Ocotea sp*), and with the analysis of variance (ANOVA), handling the regression models, estimate the values of strength and stiffness in function of apparent density. Twenty-one models were used for each test, totalizing 315 experimental results. The mechanical properties of *Ocotea sp* presented on tests demonstrated compatible performance with common wood species used in civil construction. According the regression models, only one property were considered significant with apparent density estimation.

Keywords: Characterization, *Ocotea sp*, Regression model, Analysis of variance (ANOVA)

1. INTRODUCTION

The use of wood, an important and sustainable resource on manufacture and construction, is a practice carried out since ancient times, when human being demanded to fulfill their need, and in present time, it is used on construction, paper manufacture, musical instruments, sports equipment, wood panels and furniture. The use of wood in a large range of view implies the knowledge of its physical and mechanical properties for a rational use of this material (Dias e Lahr, 2004; Christoforo et al., 2017; Almeida et al., 2014; Komariah et al., 2015).

Considering the elevated demand for wood products and few options of common wood species on market, predatory harvesting led to a decrease on market receptivity for new species, impacted the prices on market. It is indispensable to define new species to substitute traditional woods used in buildings and manufacture. This unknown wood species should be characterized to turn out to be an alternative for use on civil construction (Dias e Lahr, 2004; Almeida et al., 2014, Aquino et al., 2018). Hence, the wood Ocotea sp. appears a great option, especially to Amazonian, south eastern and western region of Brazil, where the production of this wood specie is more noticeable (IPT, 2018).

In Brazil, wood characterization is regulated by the Brazilian Code ABNT NBR 7190 (1997), which consists in determining its mechanical and physical properties by standardized tests. Though, the harm of several tests is the charge to use large and expensive equipment available only in research centers.

Analyzing this scenario, it is necessary to discover new forms to reduce costs on wood market and characterization. A physical property of easy experimental determination is the apparent density, defined by the ratio between the mass and volume of the sample at 12% moisture. Considering that density is a basic physical property, its values endorse determining an appropriate estimate of some wood properties (Dias and Lahr, 2004; Lahr et al., 2016a; Dadzie e Amoah, 2015; Machado et al., 2013).

The estimation of strength and stiffness properties by density via mathematical methods (regression methods) provides the engineer a better pre-design of the structure and meets with demand for cost reduction on wood use.

Aiming to contribute to the use of new wood species in rural and civil construction, as well as other applications, focusing on structural purposes, this study intended to characterize

the *Ocotea sp.* wood specie and evaluate the possibility of estimating strength and stiffness properties investigated by the apparent density.

2. MATERIAL AND METHODS

The wood samples of the *Ocotea sp.* has been properly stored, with close to 12% moisture content, and this is the moisture balance established by the Brazilian standard ABNT NBR 7190 (1997).

All tests were executed on the Laboratory of Wood and Wood Structures (*Laboratório de Madeira e de Estruturas de Madeira - LaMEM*), at the São Carlos Engineering School (EESC), University of São Paulo (USP).

The physical and mechanical properties (Table 1) were obtained according to the assumptions and calculation methods disposed on the Brazilian Code ABNT NBR 7190 (1997) (Wooden Structures Project), provided on its Annex B. It should be pointed out that 21 values for each one of its physical (3) and mechanical properties (12) were investigated, resulting in a total of 315 experimental values obtained.

In addition to obtaining the physical and mechanical properties listed in Table 1, the wood *Ocotea sp.* has been properly classified in the timber strength classes (ABNT, 1997), defined by determining its characteristic value of compressive strength parallel to the grain ($f_{c0,k}$).

For strength and the stiffness properties estimation (Y) as a function of the apparent density (ρ_{12}) of the *Ocotea sp* wood specie, regression models were used (Equations 1 to 4) based on analysis of variance (ANOVA), tested in a form to define the best fit for estimated property.

$$Y = a + b \cdot \rho_{12} \quad \text{[Lin - linear]} \quad (1)$$

$$Y = a \cdot e^{b \cdot \rho_{12}} \quad \text{[Exp - exponential]} \quad (2)$$

$$Y = a + b \cdot Ln(\rho_{12}) \quad \text{[Log - logarithmic]} \quad (3)$$

$$Y = a \cdot \rho_{12}{}^{b} \quad \text{[Geo - geometric]} \quad (4)$$

By ANOVA regression models, it was considered the 5% level of significance (α), the formulated null hypothesis consisted by the non-representativeness of the tested models

(H_0: $\beta = 0$), and the representativeness as an alternative hypothesis (H_1: $\beta \neq 0$). P-value greater than the significance level implies in the accepting H_0 (the model tested is not representative - ρ_{12} variations are unable to explain the variation in strength and stiffness property), refuting it otherwise (the model tested is representative).

Besides the use of ANOVA, which allows to accept or not the representativeness of the tested models, the coefficient of determination values (R^2) were obtained as a way to evaluate the variation capability in the apparent density to explain the estimated dependent variable, making it possible to determine, among the considered significant models (4 models for each of the 12 strength properties and estimated stiffness – resulting in 48 adjustments), the ones with the best fit.

Table 1: Mechanical and physical properties measured for the *Ocotea sp* wood specie

Properties	**Notation**
Apparent density	ρ_{12}
Total radial Shrinkage	RRT
Total tangencial Shrinkage	RTT
Compressive strength parallel to the grain	f_{c0}
Tensile strength parallel to the grain	f_{t0}
Tensile strength normal to the grain	f_{t90}
Shear strength parallel to the grain	f_{v0}
Splitting strength	f_{s0}
Conventional strength on static bending test	f_m
Modulus of elasticity in parallel directions to the grain	E_{c0}
Modulus of elasticity in tension parallel to the grain	E_{t0}
Conventional modulus of elasticity on static bending test	E_m
Hardness parallel to the grain	f_{H0}
Hardness normal to the grain	f_{H90}
Toughness	W

Source: Elaborated by the Authors

3. RESULTS AND DISCUSSION

Tables 2 and 3 shows the mean values ($\bar{x}$), coefficient of variation (*Cv*), the lowest (*Min*) and the highest (*Max*) of the physical and mechanical properties of the *Ocotea sp* wood, respectively.

Table 2: Physical properties results for the Ocotea sp wood

Stat.	ρ_{12} (kg/m^3)	RRT (%)	RTT (%)
$\bar{x}$	680	4.11	7.95
Cv	0.05	0.13	0.12
Mín	630	2.73	5.39
Máx	760	5.15	8.87

Source: Elaborated by the Authors

Table 3: Mechanical properties results for the Ocotea sp wood

Stat.	f_{c0} (MPa)	f_{t0} (MPa)	f_{t90} (MPa)	f_{v0} (MPa)	f_{s0} (MPa)	f_m (MPa)	E_{c0} (MPa)
$\bar{x}$	57	70	3.3	15	0.6	93	14271
Cv	0.15	0.22	0.34	0.22	0.23	0.35	0.22
Mín	40	41	1.4	10	0.4	55	7594
Máx	69	100	6.2	22	0.9	195	18955

Stat.	E_{t0} (MPa)	E_m (MPa)	f_{H0} (MPa)	f_{H90} (MPa)	W (N·m)
$\bar{x}$	13411	13993	86	51	6.90
Cv	0.17	0.28	0.09	0.13	0.35
Mín	8567	8097	69	40	3.00
Máx	16884	24323	98	67	12.80

Source: Elaborated by the Authors

Analyzing the characteristic value of compressive strength parallel to the grain and according the Brazilian Code ABNT NBR 7190 (1997), *Ocotea sp.* can be classified in the C40 strength class. The value f_{c0} (57 MPa) is close to the study carried out by Dias and Lahr (55 MPa) (2004), *Goupia glabra* (Silva et al., 2018) and *Calycophyllum multiflorum* (Christoforo et al., 2017) wood species, indicating the possibility of *Ocotea sp.* wood in structures of medium dimensions.

When compared the f_{c0} value obtained with *Paricá* wood (24 MPa) (Almeida et al., 2013), *Erisma uncinatum* (34 MPa) (Lahr et al, 2016a), and *Eucalyptus benthamii* Maiden et Cambage (37.37 MPa) (Muller et al., 2014), *Ocotea sp.* compressive strength parallel to the

fibers is higher than those wood species already exposed, woods which could be used on civil construction (Christoforo et al, 2017).

When comparing the obtained apparent density value of *Ocotea sp.* (0.68 g/cm³), it is in the same class of *Protium heptaphyllum* (Logsdon et al, 2005), *Pouteria sp.* (Almeida et al, 2015), all being classified as heavy wood (Melo et al., 1992). Analyzing the *Cedrela fissilis* and *Hovenia dulcis* (Motta et al, 2014), and *Pinus caribaea* and *Eucalyptus grandis* (Amorim et al, 2013), whose density varying between 0.46 and 0.577 g/cm³, *Ocotea sp.* density is higher than these wood species.

Brazilian Standard ABNT NBR 7190 (1997) establishes the maximum value for the coefficient of variation (*Cv*) for the characterization to be considered as adequate, being 18% for strength in normal stresses and 28% for tangential efforts. All properties met the values of the coefficients of variation required by the standard, but tensile strength parallel to the grain (f_{t0}), tensile strength normal to the grain (f_{t90}), conventional strength on static bending test (f_m) and toughness (W), which exceed the limit, showing a *Cv* equal to 0.22, 0.34, 0.34 and 0.35, respectively.

Tables 4 and 5 shows the best fits (by property) obtained using regression models for apparent density in the estimation of the values of strength and stiffness, respectively.

Table 4: Regression models for the strength values estimation of the *Ocotea sp* by the apparent density

	Model	**P-value**	**a**	**b**	**R^2 (%)**
f_{c0}	Geo	0.1683	84.97	1.08	9.74
f_{t0}	Geo	0.2397	115.02	1.34	7.19
f_{t90}	Geo	0.5467	4.68	1.05	1.94
f_{v0}	Log	0.0112	29.82	39.08	29.34
f_{s0}	Lin	0.8448	0.80	-0.22	0.21
f_m	Geo	0.7976	102.84	0.40	0.35
f_{H0}	Lin	0.0052	-9.12	138.70	34.39
f_{H90}	Geo	0.0354	84.50	1.34	21.25
W	Geo	0.5415	1.00	1.16	1.99

Source: Elaborated by the Authors

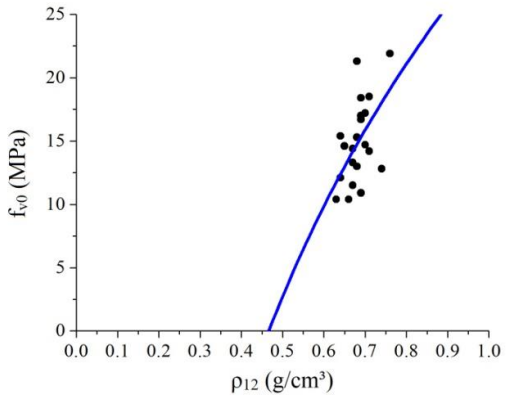
Table 5: Regression models for the stiffness values estimation of the *Ocotea sp* by the apparent density

	Model	P-value	a	b	R^2 (%)
E_{c0}	Log	0.0453	25813.86	30323.93	19.44
E_{t0}	Geo	0.0516	25056.74	1.68	18.50
E_m	Geo	0.0993	31050.51	2.18	13.64

Source: Elaborated by the Authors

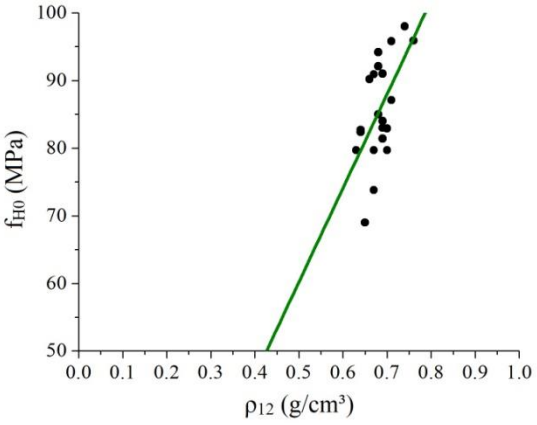
The density was considered significant only in the estimation of shear strength parallel to the grain (f_{v0}) [R^2 = 29.34], hardness parallel to grain (fH0) [R^2 = 34.39], hardness normal to the grain (f_{H90}) [R^2 = 21.25]. The best fit for the estimation of f_{v0}, f_{H0} and f_{H90} were the logarithmic, linear and geometric, illustrated in Figure 1, 2 and 3, respectively. The best fit for the estimation of E_{c0} was the logarithmic, illustrated in Figure 4.

Figure 1: Best fit obtained to estimate the strength values of wood by apparent density - logarithmic



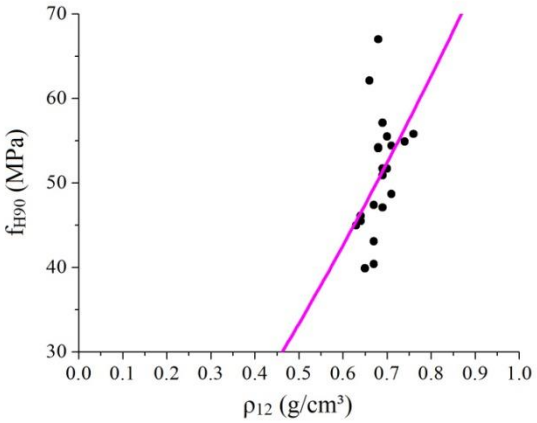
Source: Elaborated by the Authors

Figure 2: Best fit obtained to estimate the strength values of wood by apparent density - linear



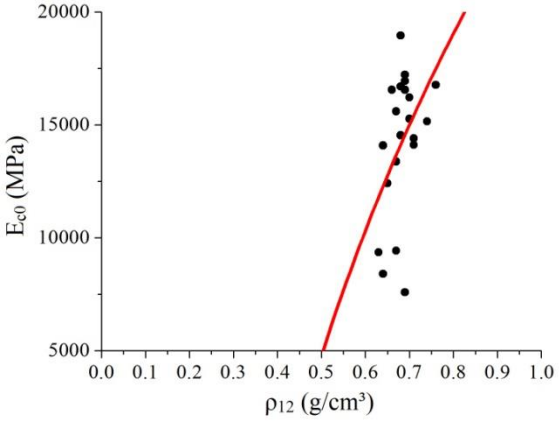
Source: Elaborated by the Authors

Figure 3: Best fit obtained to estimate the strength values of wood by apparent density - geometric



Source: Elaborated by the Authors

Figure 4: Best fit obtained to estimate the stiffness values of wood by apparent density - logarithmic



Source: Elaborated by the Authors

Analyzing the significant adjustment on Tables 4 and 5, it displays the non-representativeness of apparent density as an estimator of strength and stiffness properties, with no properties qualified as good adjustment, with coefficient of determination (R^2) higher than 70% (Christoforo et al, 2017; Lahr et al, 2016b).

4. CONCLUSIONS

The results of this study permit us to conclude:

- According to the Brazilian standard, *Ocotea sp* characterization can be considered adequate, observing the values of the coefficients of variation.

- Following the disposed Brazilian standard, *Ocotea sp* is classified as C40 strength class due to its characteristic value of compressive strength, implying a potential performance in manufacture and constructions, including structural performance.
- According the values of the coefficient of determination reached form the adjustments, the regression models presented any significant estimate. It demonstrate the impossibility of use the apparent density as an estimator of strength and stiffness properties due its low reliability.

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