

Physical and Mechanical Characterization of *Copaifera* sp. Wood Specie

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Abstract Wood has been used by mankind for many years in many purposes specially in construction and manufacture. It is necessary to characterize unknown species as an alternative for human use due to predatory harvest of well-known wood species; in consequence, possible shortage of this wood. This study intended to determine, under the Brazilian Standard ABNT NBR 7190, the mechanical properties of *Copaiba* wood (*Copaifera* sp.), and with the analysis of variance (ANOVA), handling the regression models, predict the values of strength and stiffness as a function of apparent density. Twelve models were used for each test, totalizing 180 experimental results. The mechanical properties of *Copaifera* sp. presented on tests demonstrated compatible performance with common wood species used in civil construction. According the regression models, any properties were considered significant with apparent density estimation.

Keywords Characterization, *Copaifera* sp., Regression model, Analysis of variance (ANOVA)

1. Introduction

The use of wood in manufacture and construction is a practice performed for many years since human being needed to overcome their want, since store food to construction of shelters. Nowadays it is used in construction, paper manufacture, musical instruments, sports equipment, and wood panels. The use of wood in a large range of view implies the knowledge of its properties (physical, chemical, mechanical and anatomical) for a rational use of this material, which is a natural resource, meeting the requirements that the current environmental appeal of products and services provided by man [1-3].

Despite the fact the high-level demand and few options of known wood species, predatory harvesting has reduced market receptivity for new species, whose characteristics and properties are not well known. This fact had affected the prices on market, being necessary to define which new

species could replace the traditional used in buildings [1, 4]. In consequence, the *Copaifera* sp. becomes a great option, especially to Amazonian part of Brazil, the west and southeast part of Brazilian country, where the production of this wood specie is more noticeable [5].

In Brazil, wood characterization wood (which consists in determining its mechanical and physical properties by standardized tests) is based on ABNT NBR 7190, in its Annex B [6]. Nevertheless, the disadvantage of many tests is the charge to use large and expensive equipment available in research centers.

Otherwise, 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 [1, 7, 8, 9]. The estimation of strength and stiffness properties by density via mathematical methods (regression methods) enables the engineer a better pre-design of the structure.

In order to contribute to the use of new wood species in rural and civil construction, as well as other applications, this study aimed to characterize the *Copaifera* sp. wood specie and evaluate the possibility of estimating strength and stiffness properties investigated by the apparent density.

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2. Material and Methods

The wood samples of the *Copaifera* sp. has been properly stored, with close to 12% moisture content, and this is the moisture balance established by the Brazilian standard [6].

All tests were carried out on the Laboratory of Wood and Wood Structures (*Laboratório de Madeiras e de Estruturas de Madeira - LaMEM*), Department of Structural Engineering (SET), 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 given by ABNT NBR 7190 [6] (Timber Structures Design), provided on its Annex B. It should be noted that 12 values for each one of its physical (3) and mechanical properties (12) were investigated, resulting in 180 experimental values obtained.

In addition to obtaining the physical and mechanical properties listed in Table 1, the wood *Copaifera* sp. has been properly classified in the timber strength classes [6], defined by determining its characteristic value of compressive strength parallel to the grain ($f_{c0,k}$).

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

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

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

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

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

Table 1. Mechanical and physical properties measured for the *Copaifera* 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

By ANOVA regression models, considering 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. Thus, it is 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 best fit.

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 *Copaifera* sp. wood, respectively.

Table 2. Physical properties results for the *Copaifera* sp. wood

Stat.	ρ_{12} (kg/m ³)	RRT (%)	RTT (%)
\bar{X}	700	3.51	7.03
Cv	0.04	0.27	0.18
Min	670	1.78	4.95
Max	780	4.88	9.15

Table 3. Mechanical properties results for the *Copaifera* sp. wood

Stat.	f_{c0} (MPa)	f_{t0} (MPa)	f_{t90} (MPa)	f_{v0} (MPa)
\bar{X}	50	71	3.0	15
Cv	0.12	0.24	0.31	0.18
Min	42	51	1.9	10
Max	61	101	5.4	19

Stat.	f_{s0} (MPa)	f_m (MPa)	E_{c0} (MPa)	E_{t0} (MPa)
\bar{X}	0.6	80	12845	13382
Cv	0.20	0.19	0.18	0.11
Min	0.4	62	9416	10591
Max	0.8	118	16018	15482

Stat.	E_m (MPa)	f_{H0} (MPa)	f_{H90} (MPa)	W (N·m)
\bar{X}	12440	79	47	5.90
Cv	0.10	0.10	0.10	0.40
Min	10164	70	41	3.40
Max	14296	98	57	9.80

With the value of the characteristic compression parallel to grain, based on the Brazilian Standard ABNT NBR 7190 [6], *Copaifera sp.* fits to the C40 strength class. The value f_{c0} (50 MPa) is close to the study developed by Dias and Lahr (50 MPa) [2] for *Copaifera sp.*, and *Amescla-Aroeira* wood (59.03 MPa) [10], indicating the chance of use of *Copaifera sp.* wood in structures of medium dimensions.

Comparing the value obtained (f_{c0}) with *Paricá* wood (24 MPa) [11], *Toona ciliata* (27 MPa) [12] and *Eucalyptus bentamii* Maiden et Cambage (37.34 MPa) [13], *Copaifera sp.* strength in compression parallel to grain (50 MPa) is higher than the species had already described, woods with potential for use in construction [1].

The mean value obtained from apparent density of 0.70 g/cm³ classifies *Copaifera sp.* as a heavy wood [14], in the same class of *Lecythis poiteauii*, *Mezilaurus itauba*, *Minuartia guianensis*, *Manikara huberi* and *Brosimum rubescens* [15] but lighter than the species indicated, with density ranged from 0.835 to 0.904 g/cm³ for the referred species. Comparing with *Liquidambar sp.* [16], Pinus and Teca [7], *Cedrela fissilis* and *Hovenia dulcis* [15], whose density varying between 0.478 and 0.577 g/cm³, *Copaifera sp.* wood apparent density (ρ_{12}) is higher than this wood species. The softwoods, such as *Toona ciliata* [13], *Paricá* [11] and *Gallesia integrifolia* [17] contain density between 0.318 g/cm³ and 0.370 g/cm³.

Brazilian Standard ABNT NBR 7190 [6] defines the maximum value for the coefficient of variation (C_v) 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 the tensile strength normal to the grain (f_{90}), the conventional strength on static bending test (f_m) and toughness (W), which exceed the limit, showing a C_v equal to 0.33, 0.19 and 0.40, 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 *Copaifera sp.* by the apparent density

	Model	P-value	a	b	R ² (%)
f_{c0}	Log	0.8893	47.94	-6.56	0.20
f_{t0}	Geo	0.9609	71.88	0.09	0.03
f_{90}	Geo	0.0540	0.6381	-4.35	32.25
f_{v0}	Log	0.8012	12.25	-5.70	0.66
f_{s0}	Log	0.5376	0.41	-0.60	3.91
f_m	Exp	0.5103	34.07	1.20	4.45
f_{H0}	Exp	0.5379	50.09	0.65	3.91
f_{H90}	Log	0.3615	34.73	-34.09	8.38
W	Exp	0.5251	3.14	-2.50	4.16

Considering the adjustments in Table 4, any property can be estimated by the apparent density, indicating the

non-representativeness of the apparent density as an estimator of strength and stiffness properties. It must be pointed out that Lahr et al. [18] found no relation between apparent density and strength and stiffness properties.

Table 5. Regression models for the stiffness values estimation of the *Copaifera sp.* by the apparent density

	Model	P-value	a	b	R ² (%)
E_{c0}	Log	0.6433	9869.19	-8160.64	2.23
E_{t0}	Lin	0.1546	-1830.32	21887.63	19.16
E_m	Log	0.4747	9861.23	-7074.20	5.23

4. Conclusions

The results of this study permit us to conclude:

- Following the disposed Brazilian Code, *Copaifera 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 adjustments, the regression models were not able to estimate strength and stiffness properties as a function of apparent density.

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