

Physical and Mechanical Characterization of *Cedrelinga catenaeformis Ducke* Wood Specie

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Abstract Wood, a natural and sustainable resource, has been used by humankind for several purposes especially in construction and some manufacturing sectors. Due to predatory harvest of well-known wood species and in consequence, possible shortage of these essences, it is indispensable to characterize new wood species. This study intended to determine, under the requirements of Brazilian Code ABNT NBR 7190, the mechanical and properties of Cedroarana wood (*Cedrelinga catenaeformis Ducke*). Besides, with the analysis of variance (ANOVA), testing several regression models, it has hoped to estimate the values of strength and stiffness as a function of apparent density. Thirteen specimens were used for each test, totalizing 195 experimental results. The mechanical properties of *Cedrelinga catenaeformis* obtained demonstrated compatible performance with regular wood species used in temporary civil construction. According the regression models, only two properties were considered significant with apparent density estimation.

Keywords Characterization, *Cedrelinga cateaeniformis Ducke*, Regression model, Analysis of variance (ANOVA)

1. Introduction

Wood is an important and sustainable material employed in several sectors and industries of different segments nowadays and it has been used to quench humankind demands, like store food, construction of shelters and agricultural tools. To use of wood rationally in a large range of possibilities, the knowledge of its anatomical, chemical, physical and mechanical properties is crucial. The use of wood also meets the requirements that the current environmental appeal of products and services provided by man [1-4].

Considering the high-level demand and few options of well-known wood species for structural construction and manufacture purposes, predatory and selective harvesting has reduced market receptivity for new species whose characteristics and properties are not yet known. In consequence, the prices on market were meanly affected and it got confirmed it is indispensable to define new species to replace the traditional ones used in building construction

[1, 3]. Thus, *Cedrelinga catenaeformis Ducke* appears as a very interesting option, especially to Brazilian Amazonian Region, the west and southeast part of Brazilian country, where the occurrence of this wood specie is more noticeable [5].

Brazilian Code ABNT NBR 7190 [6], in its Annex B, defines the tests to proceed wood characterization, i.e., the determination of its physical and mechanical properties for structural purposes. However, it is timely to register the high number of required tests, aspect that causes a high cost for wood characterization (equipment and services). Besides, it must be remembered that some specific testing machines are available only in research centers.

In this context, it seems important to search alternatives to reduce costs and, in this paper, it is intended to correlate all mechanical properties with density. Once demonstrated this possibility, it could generate decrease in costs and in time required to properties estimation.

Density is a physical property of easy experimental determination, defined by the ratio between the mass and volume of the sample at 12% moisture. Considering that density is a fundamental property, its values can endorse determining an appropriate estimate of some wood properties [1, 2, 7, 8, 9]. The estimation of strength and stiffness properties by density via mathematical methods (regression methods) could enable the engineers a better pre-design of the structure.

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Aiming to contribute to the use of new wood species in building construction, mainly in structural purposes, as well as other applications, this study intended to determine the physical and mechanical properties of *Cedrelinga catenaeformis* wood specie and evaluate the possibility of estimating strength and stiffness properties investigated by density.

2. Material and Methods

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

All tests were carried out on the Wood and Timber Structures Laboratory (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 the Brazilian Code ABNT NBR 7190 [6] (Timber Structures Design), provided on its Annex B. It should be noted that 13 values for each one of its physical (3) and mechanical properties (12) were investigated, resulting in 195 experimental values obtained.

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

To estimate $f_{c0,k}$ and mechanical properties (Y), as a function of the apparent density (ρ_{12}) of *Cedrelinga catenaeformis* 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.

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

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

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

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

By ANOVA regression models, 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).

Moreover, 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 capability of the apparent density to explain the estimated dependent variable. This turned

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 *Cedrelinga catenaeformis* Ducke wood specie

Properties	Notation
Apparent density	ρ_{12}
Total radial Shrinkage	RRT
Total tangential 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

3. Results and Discussion

Tables 2 and 3 shows the mean values (\bar{x}), coefficient of variation (C_v), the lowest (Min) and the highest (Max) of the physical and mechanical properties of the *Cedrelinga catenaeformis* Ducke wood, respectively.

Table 2. Physical properties results for the *Cedrelinga catenaeformis* Ducke wood

Stat.	ρ_{12} (kg/m ³)	RRT (%)	RTT (%)
\bar{x}	570	3.49	6.44
C_v	0.08	0.27	0.18
Min	500	2.27	4.37
Max	640	5.20	7.95

The characteristic value of strength in compression parallel to grain, based on Brazilian Code ABNT NBR 7190 [6], classifies *Cedrelinga catenaeformis* Ducke in C20 strength class. The value f_{c0} (41 MPa), when compared with *Toona ciliata* (27 MPa) [10], *Eucalyptus bentamii* Maiden et Cambage (37.34 MPa) [11], *Erismia uncinatum* (34 MPa) [7] and Paricá (24 MPa) [12], is close to these wood species.

Evaluating the apparent density of *Cedrelinga catenaeformis* (0.570 g/cm³), this wood is classified as a moderately heavy wood [13]. Compared with Liquidambar sp. [14], Pinus and Teca [3], *Cedrela fissilis* and *Hovenia dulcis* [15], *Cedrelinga catenaeformis* in the researches of Dias and Lahr [1] and Fernandes et al. [16] and *Pinus caribaea* and *Eucalyptus grandis* [17], *Cedrelinga catenaeformis* wood apparent density (ρ_{12}) is close to these

wood species.

Table 3. Mechanical properties results for the *Cedrelinga catenaeformis* Ducke wood

Stat.	f_{c0} (MPa)	f_{t0} (MPa)	f_{t90} (MPa)	f_{v0} (MPa)
\bar{X}	41	62	3.3	12
Cv	0.24	0.28	0.34	0.28
Min	31	46	1.2	7
Máx	54	93	5.0	17
Stat.	f_{s0} (MPa)	f_m (MPa)	E_{c0} (MPa)	E_{t0} (MPa)
\bar{X}	0.6	60	10252	10937
Cv	0.22	0.19	0.13	0.16
Min	0.4	41	8484	8113
Máx	0.7	85	12913	13304
Stat.	E_m (MPa)	f_{H0} (MPa)	f_{H90} (MPa)	W (N·m)
\bar{X}	10077	58	36	4.50
Cv	0.11	0.33	0.20	0.18
Min	8404	32	27	0.60
Máx	12324	86	45	7.80

Brazilian Code ABNT NBR 7190 [6] establishes the maximum value for the coefficient of variation (Cv) for the characterization to be considered as appropriate, being 18% for strength in normal stresses and 28% for tangential efforts. All stiffness properties met the values of the coefficients of variation required by the standard and all strength properties exceed the limit but hardness normal to the grain (f_{H90}) which attended the limit, showing a Cv equal to 0.20.

Table 4. Regression models for the strength values estimation of the *Cedrelinga catenaeformis* Ducke by the apparent density

	Model	P-value	a	b	R ² (%)
f_{c0}	Geo	0.2635	75.19	1.09	11.21
f_{t0}	Exp	0.2938	179.28	-1.94	9.95
f_{t90}	Exp	0.8522	3.87	-0.52	0.33
f_{c0}	Lin	0.0649	-9.80	38.37	27.65
f_{s0}	Lin	0.7143	0.79	-0.38	1.27
f_m	Exp	0.1435	173.81	-1.89	18.40
f_{H0}	Geo	<u>0.0498</u>	236.77	2.54	30.60
f_{H90}	Lin	<u>0.0397</u>	-17.49	93.52	33.07
W	Exp	0.0792	31.05	-7.68	25.37

Table 5. Regression models for the stiffness values estimation of the *Cedrelinga catenaeformis* Ducke by the apparent density

	Model	P-value	a	b	R ² (%)
E_{c0}	Geo	0.8294	10915.94	0.12	0.44
E_{t0}	Geo	0.1758	17983.97	0.89	15.99
E_m	Exp	0.2979	15775.18	-0.80	9.79

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.

The density was considered significant only in the estimation of hardness parallel to the grain (f_{H0}) [$R^2 = 30.60\%$] and hardness normal to the grain (f_{H90}) [$R^2 = 33.07\%$]. The best fit for the estimation of f_{H0} and f_{H90} were the geometric and linear illustrated in Figure 1.

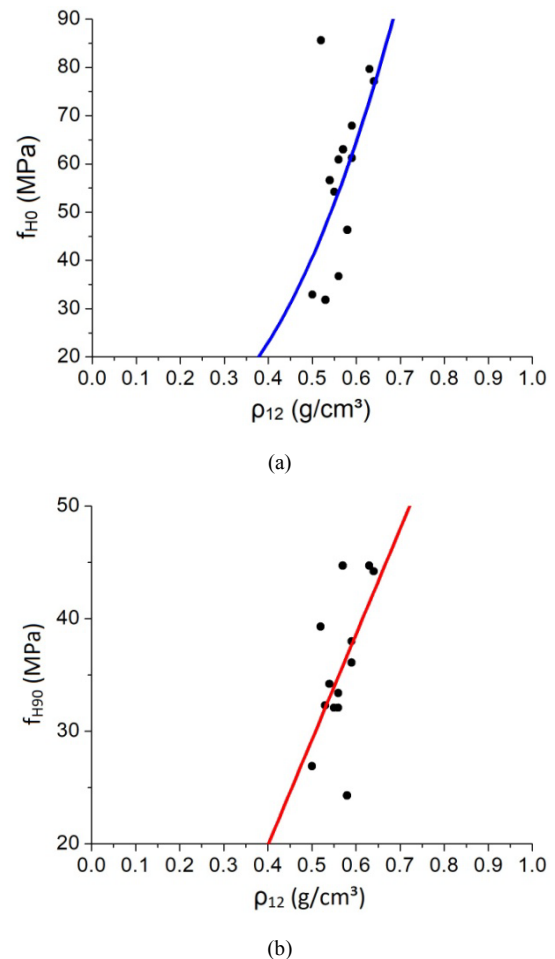


Figure 1. Best fit obtained to estimate the strength values of wood by apparent density - geometric (a) and linear (b) models

Considering the significant adjustment in Table 4 and 5, it demonstrates the representativeness of the apparent density as an estimator of strength and stiffness properties of *Cedrelinga catenaeformis* Ducke wood. Otherwise, none of these adjustments is qualified as a good one, with coefficient of adjustment higher than 70% [7, 18].

4. Conclusions

The results of this study permit us to conclude:

- According to the Brazilian Code, *Cedrelinga catenaeformis* Ducke characterization can be considered adequate, observing the values of the coefficients of variation.
- Following the disposed Brazilian Code, *Cedrelinga catenaeformis* Ducke is classified as C20 strength class

due its characteristic value of strength in compression parallel to grain, implying a potential performance in manufacture and constructions, except for structural purpose.

- According the values of the coefficient of determination reached form the adjustments, the regression models presented significant estimates for: hardness parallel and normal to the grain. It demonstrate the relation between these properties and the apparent density but unable to use them as an estimator of these properties due its poor adjustment.

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