Full Characterization of *Vatairea* sp Wood Specie

Francisco A. Rocco Lahr[1], Bruno H. C. Aftimus[2], Felipe N. Arroyo[3], Diego H. De Almeida[4], André L. Christoforo[3,*], Eduardo Chahud[5], Luiz A. M. Nunes Branco[6]

[1]Department of Structural Engineering (SET), São Paulo University (EESC/USP), São Carlos, Brazil
[2]Department of Civil Engineering, University Center of Educational Foundation of Barretos (UNIFEB), Barretos, Brazil
[3]Centre for Innovation and Technology in Composites - CITeC, Department of Civil Engineering (DECiv), Federal University of São Carlos, São Carlos, Brazil
[4]Department of Engineering, Pitágoras College, Poços de Caldas, Brazil
[5]Department of Civil Engineering, Federal University of Minas Gerais (UFMG), Belo Horizonte, Brazil
[6]Faculty of Engineering and Architecture, FUMEC University, Belo Horizonte, Brazil

Abstract   In Brazil, wood is a material which has been used for years in different purposes. The variety of Brazilian tropical wood species is expressive, nonetheless only a few of them are considered in structural design. Taking in account possibility of eventual shortages of these well-known wood species, characterization of alternative essences is presented as fundamental for maintenance of wood supply for civil construction. In Brazil, the structural dimensioning and timber characterization are specified by ABNT NBR 7190:1997 (Timber structures design), in its Annex B. This work aimed, with the aid of Brazilian Code, determining physical (4) and mechanical (13) properties of Angelim Saia (*Vatairea* sp.). Besides, with regression model (linear, exponential, geometric and logarithmic) based in analysis of variance (ANOVA), it was aimed to estimate resistance values and stiffness in function of the density, once this is an easy-obtainable property for wood. From a set of twelve aleatory pieces, twelve specimens were produced for each test type, totalizing 204 experimental measurements. Results of mechanical properties showed compatible performance with other species already established for use in structure, which shows the potential of Angelim Saia for structural purposes. From regression models for estimate strength and stiffness values, it was possible conclude that not all properties can be estimate by density. Better results were showed by the geometric model in estimation of hardness parallel to grain, who provided determination coefficient (R^2) close to 70%.

Keywords   *Vatairea* sp., Characterization, Density, Regression model

1. Introduction

Employing wood in construction is a practice carried out for many years by humanity, since the necessity of store food, overcoming obstacles, until the construction of shelters [1].

Initially, exploration of Amazon Tropical Forest was selective and predatory, once demand concentrated once only a few well-known wood species were extracted. This undesirable exploitation led those species (already completely characterized) to almost exhaustion, imposing to the market improve receptivity for new species not yet with a wide application [2].

Due to this high demand and few options, the prices of used species increase, give a new moment to Brazilian timber sector, being necessary define which new species can substitute the traditional used species in construction [3, 4]. In addition, with the growing awareness of population the use of materials which cause the minimum damage to the environment, timber originates from planted forests becomes also a building material to be widely considerable [5].

As such, *Vatairea* sp. is an interesting possibility, once this species occurs in several Brazilian regions, including Tocantins, Goiás and Bahia until São Paulo states. It is a very tall tree, with middle-heavy wood and potential satisfactory mechanical properties [6, 7].

However, before the using of a new species in any situation, be in roofs, bridges, silos or any others, it is necessary to determine its physical and mechanical properties, thus promoting a better condition to use [5].

Full characterization of wood species involves determination of their physical and mechanical properties, obeying requirements of normative Codes. In Brazil, is the NBR 7190 [8] who sets parameters for this characterization. However, the inconvenience of several of these tests and necessity of using heavy equipments, increase costs and make fundamental rely this work to research centers [8].

By other side, a physical property easily determined in usual experimental procedures is the apparent density (or simply density), set by ratio between mass and volume a 12% of moisture content (as referenced in Annex B, NBR 7190:1997). As density is a basic physical property, their

* Corresponding author:
alchristoforo@gmail.com (André L. Christoforo)

values can, eventually, allow establish an adequate estimate of the mechanical wood properties [9, 10].

Therefore, the aim of this work is determinate the physical and mechanical properties of *Vatairea* sp. according to pre-defined indications of Brazilian Code, as well as research the possibility of estimating of mechanical properties in function of density.

2. Material and Methods

In order to reach proper conditions to get the specimens, *Vatairea* sp wood pieces were duly stored, until showing moisture content by 12%, reference adopted by NBR 7190:1997 [8].

Mechanical tests were carried out in Wood and Timber Structures Laboratory (LaMEM), Department of Structural Engineering (SET), School of Engineering of São Carlos (EESC), University of São Paulo (USP). Physical tests were conducted in Federal University of Minas Gerais (UFMG) and FUMEC University laboratories. Statistical procedures were processed in Federal University of São Carlos (UFSCar).

Physical and mechanical properties were obtained under the requirements of test methods proposed by the Brazilian Code [8], in its Annex B (Determination of timber properties for structural purposes). The number of experimental determinations is introduced in Table 1, for each property, and it should be noted that, in total, 204 determinations were made.

To estimate mechanical properties by density, regression models (Expressions 1 to 4), reasoned on analysis of variance (ANOVA), have been tested in order to establish best fit between and each mechanical property investigated, in a way to establish mathematical reasons among them

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

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

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

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

ANOVA regression model was considered at confidence level (α) 5%. Null hypothesis formulated consisted in the non-representativeness of the tested models (H_0: β=0) and as alternative hypothesis (H_1: β≠0) was taken their representativeness. P-value upper than significance level adopted implies accepting H_0 (model tested is not representative, i.e. variations in ρ_{12} are unable to explain variations of the property), refuting it to otherwise (tested model is representative), being Y the dependent variable (value of properties studied).

Beyond use of ANOVA, that allows accepting or not the representativeness of models tested, the values of determination coefficient (R^2) were obtained as way to evaluate the capacity of variations ρ_{12} to explain the variable analyzed. This enables, among the models considered

significant, elect the one of better fit.

Table 1. Physical and mechanical properties of *Vatairea* sp

Properties	Abbreviation	Nº Determinations
Density	ρ_{12}	12
Total radial shrinkage	RRT	12
Total tangential shrinkage	RTT	12
Strength in compression parallel to the grain	f_{c0}	12
Strength in tension parallel to the grain	f_{t0}	12
Strength in tension normal to the grain	f_{t90}	12
Shear strength parallel to the grain	f_{v0}	12
Cracking	f_{s0}	12
Conventional strength in static bending	f_m	12
Longitudinal modulus of elasticity in compression parallel to the grain	E_{c0}	12
Longitudinal modulus of elasticity in tension parallel to the grain	E_{t0}	12
Conventional modulus of elasticity in static bending	E_m	12
Hardness parallel to the grain	f_{H0}	12
Hardness normal to the grain	f_{H90}	12
Toughness	W	12
Strength in compression normal to the grain	f_{c90}	12
Modulus of elasticity in compression normal to the grain	E_{c90}	12

3. Results and Discussion

Tables 2 and 3 present means ($\bar{x}$), variation coefficients (*Cv*), smallest (*Min*) and largest (Max) values for physical and mechanical properties, respectively.

The obtained mean value for fc0 (64.2 MPa) is very close to that of *Protium heptaphyllum* (59 MPa) [11]. According to the authors, this permits utilization in all kinds of structures, for their high strength, far larger than obtained to the Paricá (Schizolobium amazonicum) - 24 MPa [9], Toona ciliate (27 MPa) and Eucalyptus benthamii (37 MPa) [13], proper for light structures.

Table 2. Results obtained of physical properties of *Vatairea* sp

Stat.	ρ_{12} (kg/m³)	RRT (%)	RTT (%)
$\bar{x}$	760	4.24	8.20
Cv	0.08	0.19	0.11
Mín	0.68	3.19	6.15
Máx	0.88	5.50	8.90

Table 3. Results obtained of mechanical properties of *Vatairea* sp

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)
$\overline{x}$	64.2	96	3.0	15	0.8	113	19748	20214
Cv	0.14	0.22	0.21	0.12	0.16	0.20	0.16	0.14
Mín	46.7	33	1.9	12	0.6	76.6	13274	16037
Máx	76.3	152	4.3	17	1.0	137	25713	24555

Stat.	E_m (MPa)	f_{H0} (MPa)	f_{H90} (MPa)	W (J)	f_{c90} (MPa)	E_{c90} (MPa)
$\overline{x}$	18561	86.4	60.5	43	1.8	93.6
Cv	0.11	0.11	0.15	0.13	0.13	0.12
Mín	14357	68	49	33	1.4	76.4
Máx	22527	102	76	51	2.1	114.9

According to Brazilian Code, from the obtained value for strength in compression parallel to the grain (f_{c0}), Vatairea sp be categorized as class C40 (dicotyledonous), presenting characteristic value 51 MPa for that property.

The mean density (0.760 g/cm³) classifies *Vatairea* sp. as a heavy timber [14], same characteristic of *Minquartia guianensis, Lecythis poiteaui, Mezilaurus itauba, Manilkara huberi* e *Brosimum rubescens* [10]. However, it must be pointed out that density of these wood species varies between 0.835 to 0.904 g/cm³, and they are widely applied in heavy structures.

Density of *Vatairea* sp. is higher comparing with *Liquidambar* sp. [15], *Tectona grandis* [9], *Cedrela fissilis* and *Hovenia dulcis* [16], whose densities range between 0.478 to 0.577g/cm³; and naturally more dense that *Toona ciliata* [12], *Schizolobium amazonicum* [5] e *Gallesia integrifolia* [16], which presented density varying between 0.318 to 0.370g/cm³ and, under certain conditions, can be employed in light structures.

Brazilian Code NBR 7190:1997 stipulates maximum values for variation coefficient, so that the characterization be qualified as compatible, being 18% for normal strengths and 28% for tangential efforts. All properties attended these parameters, except strength in tension parallel to the grain (f_{t0}) that exceeded the limit, presenting Cv 32%. Despite this point, this characterization can be here considered as obeying the normative requirements.

Table 4 and 5 show ANOVA results of the regression models.

Table 4. Regression models obtained for strength properties of *Vatairea* sp

	Models	P-value	a	b	R^2
	Lin	0.0024	-22.5178	0.1119	61.74%
	Exp	0.0031	15.1567	0.0019	60.01%
f_{c0}	Log	0.0019	-512.1278	87.2739	63.57%
	Geo	0.0023	0.0042	1.4483	62.15%

	Models	P-value	a	b	R^2
	Lin	0.5216	169.7591	-0.0965	4.23%
	Exp	0.6808	167.9310	-0.0008	1.76%
f_{t0}	Log	0.5156	595.2275	-75.2330	4.35%
	Geo	0.6653	6768.8975	-0.6497	1.95%

	Models	P-value	a	b	R^2
	Lin	0.800	3.6277	-0.0008	0.67%
	Exp	0.8284	3.5100	-0.0002	0.49%
f_{t90}	Log	0.7920	7.4599	-0.6746	0.73%
	Geo	0.8203	10.5414	-0.1934	0.54%

	Models	P-value	a	b	R^2
	Lin	0.1788	4.7696	0.0128	17.29%
	Exp	0.1725	7.1856	0.0009	17.75%
f_{v0}	Log	0.1742	-51.5459	9.9656	17.62%
	Geo	0.1680	0.1299	0.7102	18.09%

	Models	P-value	a	b	R^2
	Lin	0.0432	-0.1546	0.0013	34.85%
	Exp	0.0388	0.2352	0.0017	36.09%
f_{s0}	Log	0.0403	-5.8843	1.0136	35.66%
	Geo	0.0360	0.0002	1.2841	36.94%

	Models	P-value	a	b	R^2
	Lin	0.5497	161.0765	-0.0673	3.69%
	Exp	0.5657	172.3715	-0.0006	3.41%
f_m	Log	0.5803	427.3822	-47.8819	3.16%
	Geo	0.5942	2001.7127	-0.4406	2.94%

	Models	P-value	a	b	R^2
	Lin	0.0009	-8.7266	0.1218	68.20%
	Exp	0.0009	27.4957	0.0015	68.54%
f_{H0}	Log	0.0008	-541.2850	94.2800	69.20%
	Geo	0.0007	0.0460	1.1315	69.74%

	Models	P-value	a	b	R^2
	Lin	0.0014	-27.1222	0.1168	65.38%
	Exp	0.0014	14.2239	0.0019	65.81%
f_{H90}	Log	0.0011	-542.3691	91.1028	67.28%
	Geo	0.0010	0.0030	1.4954	67.77%

	Models	P-value	a	b	R^2
	Lin	0.6467	34.3649	14.5716	2.18%
	Exp	0.6584	35.1095	0.3274	2.03%
W	Log	0.6212	48.7810	12.0624	2.53%
	Geo	0.6345	48.5297	0.2703	2.35%

	Models	P-value	a	b	R^2
	Lin	0.1817	0.7530	0.0013	17.08%
	Exp	0.1825	0.9714	0.0008	17.02%
f_{c90}	Log	0.1655	-5.3329	1.0724	18.29%
	Geo	0.1658	0.0278	0.6262	18.26%

Table 5.   Regression models obtained for stiffness properties of *Vatairea* sp

	Models	P-value	a	b	R^2
E_{c90}	Lin	0.1572	1055.7369	-1.1937	18.95%
	Exp	0.1399	2838.0686	-0.0042	20.45%
	Log	0.1410	6452.3906	-950.7389	20.35%
	Geo	0.1255	6452.25E+8	-3.3742	21.84%
	Models	**P-value**	**a**	**b**	R^2
E_{c0}	Lin	0.0095	-8594.3112	37.0888	50.58%
	Exp	0.0095	4228.4203	0.0020	50.60%
	Log	0.0074	-173640.0982	29143.3296	52.87%
	Geo	0.0072	0.5677	1.5738	53.08%
	Models	**P-value**	**a**	**b**	R^2
E_{t0}	Lin	0.1593	6137.6575	18.4202	18.78%
	Exp	0.1496	9830.1373	0.0009	19.58%
	Log	0.1512	-75390.5941	14407.4663	19.45%
	Geo	0.1415	157.8448	0.7301	20.30%
	Models	**P-value**	**a**	**b**	R^2
E_m	Lin	0.0353	3625.5189	19.5447	37.15%
	Exp	0.0352	8094.3915	0.0011	37.20%
	Log	0.0315	-82802.3614	15275.3311	38.42%
	Geo	0.0310	67.9929	0.8445	38.59%
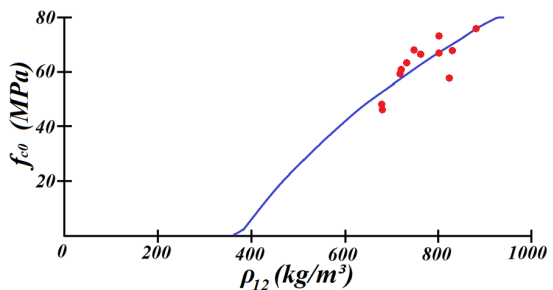
(a)
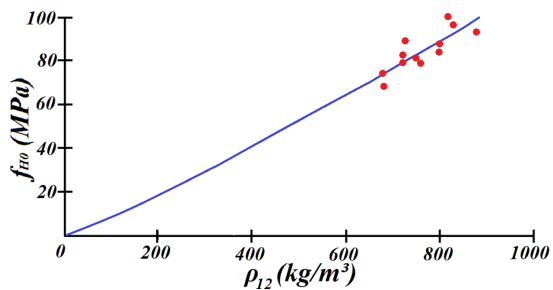
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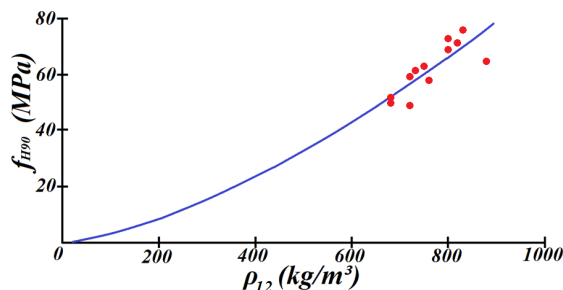
(c)

Figure 1.   Regression models: relation between density and strength in compression parallel to the grain (a); density and hardness parallel to the grain (b); density and hardness normal to the grain (c)

P-values obtained for f_{c0}, f_{s0}, E_{c0}, E_m, f_{H0} and f_{H90} were lower than 0.05. This implies that the obtained settings for these properties are significant. The determination coefficients (R^2) vary from 34 to 69%. Estimative of f_{H0}, f_{H90} e f_{c0} in function of density reached R^2 upper than 60%, what implies a satisfactory quality of the proposed adjustments [17].

The geometric model provided the higher values of R^2, emphasizing that to fourteen of the mechanical properties estimated by density, only 6 provided significant adjustments, and of these six properties, only three showed coefficient R^2 higher to 60% (f_{H0}, f_{H90} and f_{c0}).

Figure 1 presents the better settings of tested models (Table 4).

4. Conclusions

The results obtained of this research allow concluding that:

- Based on the variation coefficient, *Vatairea* sp. characterization can be considered according to the required by Brazilian standard;
- Following the premises of Brazilian Code, *Vatairea* sp. is categorized as C40 (dicotyledonous), by presenting a characteristic value of strength in compression parallel to the grain ($f_{c0,k}$) 51 MPa, indicating a potential good performance for light and heavy structures;
- The regression models presented significant estimates and good quality in adjusting (R^2 bigger than 60%) only for three among the fourteen mechanical properties investigated: strength in compression parallel to the grain, hardness parallel to the grain and hardness normal to the grain;
- The regression models geometric presented the better settings, followed by logarithmic models.

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