Full Characterization of *Vatairea* sp Wood Specie

Francisco A. Rocco Lahr¹, Bruno H. C. Aftimus², Felipe N. Arroyo³, Diego H. De Almeida⁴, André L. Christoforo³*, Eduardo Chahud⁵, Luiz A. M. Nunes Branco⁶

¹Department of Structural Engineering (SET), São Paulo University (EESC/USP), São Carlos, Brazil
²Department of Civil Engineering, University Center of Educational Foundation of Barretos (UNIFEB), Barretos, Brazil
³Centre for Innovation and Technology in Composites - CITeC, Department of Civil Engineering (DECiv), Federal University of São Carlos, São Carlos, Brazil
⁴Department of Engineering, Pitágoras College, Poços de Caldas, Brazil
⁵Department of Civil Engineering, Federal University of Minas Gerais (UFMG), Belo Horizonte, Brazil
⁶Faculty 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 (R²) 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
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

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

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

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

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

ANOVA regression model was considered at confidence level (α) 5%. Null hypothesis formulated consisted in the non-representativeness of the tested models (H₀: β=0) and as alternative hypothesis (H₁: β≠0) was taken their representativeness. P-value upper than significance level adopted implies accepting H₀ (model tested is not representative, i.e. variations in ρ₁₂ 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 (R²) were obtained as way to evaluate the capacity of variations ρ₁₂ 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 | N⁰ Determinations |
|------------|--------------|------------------|
| Density | ρ₁₂ | 12 |
| Total radial shrinkage | RRT | 12 |
| Total tangential shrinkage | RTT | 12 |
| Strength in compression parallel to the grain | f₀₀ | 12 |
| Strength in tension parallel to the grain | f₀₀₀ | 12 |
| Strength in tension normal to the grain | f₀₀₀₀ | 12 |
| Shear strength parallel to the grain | f₀₀₀₁ | 12 |
| Cracking | | 12 |
| Conventional strength in static bending | f₀₀₁ | 12 |
| Longitudinal modulus of elasticity in compression parallel to the grain | E₀₀ | 12 |
| Longitudinal modulus of elasticity in tension parallel to the grain | E₀₀₀ | 12 |
| Conventional modulus of elasticity in static bending | E₀₀₀₀ | 12 |
| Hardness parallel to the grain | f₀₀₀₀₀ | 12 |
| Hardness normal to the grain | f₀₀₀₀₀₀ | 12 |
| Toughness | W | 12 |
| Strength in compression normal to the grain | f₀₀₀₀₀₀₀ | 12 |
| Modulus of elasticity in compression normal to the grain | E₀₀₀₀₀₀₀ | 12 |

3. Results and Discussion

Tables 2 and 3 present means (X̄), variation coefficients (Cv), smallest (Min) and largest (Max) values for physical and mechanical properties, respectively.

The obtained mean value for f₀₀ (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.
According to Brazilian Code, from the obtained value for strength in compression parallel to the grain (fc0), 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 and Tectona grandis [9], whose densities range 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 (ft0) 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 3. Results obtained of mechanical properties of Vatairea sp

| Stat. | f0 (MPa) | f0 (MPa) | f0 (MPa) | W (J) | f0 (MPa) | E0 (MPa) | E0 (MPa) |
|-------|----------|----------|----------|-------|----------|----------|----------|
| 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    |

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

| Models | P-value | a     | b     | R²    |
|--------|---------|-------|-------|-------|
| f0     | Lin     | 0.6262| 0.0008| 67.26%|
|        | Exp     | 0.0013| 0.6805|       |
|        | Log     | 0.6805| 0.0008| 67.26%|
|        | Geo     | 0.6262| 0.0008| 67.26%|

Table 5. Regression models obtained for modulus of elasticity properties of Vatairea sp

| Models | P-value | a     | b     | R²    |
|--------|---------|-------|-------|-------|
| E0     | Lin     | 0.6262| 0.0008| 67.26%|
|        | Exp     | 0.0013| 0.6805|       |
|        | Log     | 0.6805| 0.0008| 67.26%|
|        | Geo     | 0.6262| 0.0008| 67.26%|
Table 5. Regression models obtained for stiffness properties of *Vatairea* sp

| Models | P-value | a          | b          | $R^2$  |
|--------|---------|------------|------------|--------|
| **$E_{c0}$** |         |            |            |        |
| 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          | $R^2$  |
|--------|---------|------------|------------|--------|
| **$E_{c90}$** |         |            |            |        |
| 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% |

P-values obtained for $f_{c0}$, $f_{s0}$, $E_{c0}$, $E_{m}$, $f_{t0}$ and $f_{t90}$ 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 $f_{c0}$, $f_{t90}$ e $f_{c90}$ 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% ($f_{t0}$, $f_{t90}$ 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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