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STRUCTURAL CHARACTERIZATION OF NATIVE SPECIES ACCORDING TO THE NEW BRAZILIAN STANDARD ABNT NBR 7190: 2022 – PART 4

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ABSTRACT: Timber is a heterogeneous material with high variability in its physical and mechanical characteristics. Therefore, whenever possible, it is essential to grade timber members using results from tests of structural size specimens that better express its structural quality to meet the design requirements. The Brazilian Standard ABNT NBR 7190: 2022 – Part 4, introduced test methods for mechanical characterization and strength grading of sawn timber in structural sizes. This study aimed to perform these mechanical tests for assign strength class for three native species of the Amazon rainforest obtained from trees under sustainable forest management (Caixeta (*Simarouba amara* Aubl.), Cedrinho (*Erisma uncinatum* Warm.), and Goiabão (*Planchonella pachycarpa* Pires.)). The Goiabão species had the highest characteristic value of bending strength and was graded as D60, Cedrinho D24, and Caixeta D18. Results also showed a high correlation ($R^2 = 0.94$) between modulus of elasticity in dynamic and static bending tests.

KEYWORDS: Structural timber, Strength grading, Mechanical properties, Native species.

1 INTRODUCTION

Wood is one of the most used materials in civil construction and it is essential to know the physical and mechanical properties for the best use of the material in timber structures design, mainly alternative species with potential for use in a rational way.

Extraction of wood in the Amazon rainforest is only allowed through forest management (planning practices and conservation principles which ensures the forest's capacity to continuously supply a product or service plans [1]) and authorization of sustainable exploitation. The awareness of the use and preservation of natural resources from Brazilian tropical forests has been applied with the dissemination of sustainable forest management concepts and the marketing of certified wood.

Several native species from forest management are not recognized for commercialization as raw or engineered timber due mainly to the lack of research on its properties or the correct dissemination of knowledge. The main studies on Brazilian native species can be found in [2-4].

The new Brazilian Standard ABNT NBR 7190 [5] for the design of timber structures, has seven parts and presents new topics and concepts, as mechanical tests for connections and detailed design methods and quality control procedures for engineered wood products (*e.g.* glulam and CLT). Following the initiative of other international standards and trying to express the structural quality of wood better, preconizes mechanical characterization and strength grading of sawn timber using structural size specimens, although, in special situations, allows this characterization using small clear specimens. Part 1 of the standard [5] specifies that strength and stiffness properties of timber are, in general, attributed to batches considered homogeneous – classification by batch - and presents the strength classes. ABNT NBR 7190 - Part 4 [6], based on ISO 13910 [7] details the experimental tests for structural size specimens: density, 4-point bending, tensile and compression parallel to the grain, tensile and compression perpendicular to the grain, shear parallel to the grain and, transversal modulus of elasticity.

This study aimed to characterize and grade three native wood species from Amazon rainforest using this new standard: *Simarouba amara* Aubl., *Erisma uncinatum* Warm., and *Planchonella pachycarpa* Pires.

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2 MATERIALS AND METHODS

2.1 MATERIALS

Three native species from Amazon rainforest were characterized (Figure 1): Caixeta (*Simarouba amara* Aubl.), Cedrinho (*Erisma uncinatum* Warm.) and, Goiabão (*Planchonella pachycarpa* Pires.). These timber boards were obtained from trees under sustainable forest management. Table 1 presents their apparent densities, nominal section and the sample size of the experimental program.

Figure 1 – Species tested

Table 1 – Experimental program - species and sample size (N)

Species	*Scientific names*	Density (kg/m³)	N	Nominal section (cm)
Goiabão	*Planchonella pachycarpa* Pires.	902	57	4x12
Cedrinho	*Erisma uncinatum* Warm.	606	55	4x12
Caixeta	*Simarouba amara* Aubl.	424	62	4x14

2.2 TEST METHODS FOR MECHANICAL CHARACTERIZATION OF STRUCTURAL TIMBER

The characterization was carried out by mechanical tests in structural size specimens according to the new Brazilian Standard NBR 7190 – Part 4 [6], based on ISO 13910 [7]. Additionally, nondestructive test through 3-point bending test was carried out to obtain the reference static modulus of elasticity, as well as the transverse vibration method was used to determine the dynamic modulus of elasticity.

2.2.1 Nondestructive tests

The dynamic modulus of elasticity in bending was obtained for each timber board with a nondestructive grading through Metriguard model 340. The Metriguard Technolgies Inc. provided and calculated the dynamic modulus of elasticity by Equation (1).

$$E_{dyn} = \frac{f_n^2 . W . L^3}{K . b . h^3} \quad (1)$$

Where: E_{dyn} is the dynamic bending modulus of elasticity, f_n is the undamped natural frequency, W is weight of the specimen, L is the span length, K is the constant of equipment, b is the width of specimen, and h is the thickness of the specimen.

The nondestructive bending test was carried out through 3-point static bending test (see Figure 2) to obtain the static modulus of elasticity. The boards was placed in flatwise position and loaded at center-point. The modulus of elasticity was determined in linear elastic regime (normally in 10% to 40% to ultimate load). The deflection measurement was taken at the center point while applying incremental load until the deflection reached 40% of ultimate load. The modulus of elasticity was calculated from Equation (2):

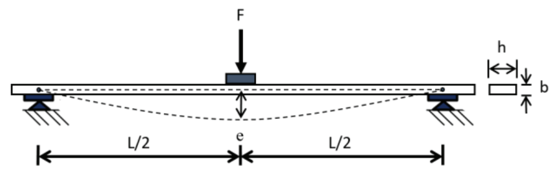

Figure 2 - Non-destructive static bending test [8]

$$E = \frac{1}{4} \cdot \left(\frac{L}{b}\right)^3 \cdot \left(\frac{\Delta F}{\Delta e}\right) \cdot \frac{1}{h} \quad (2)$$

Where, L (mm): span length; h (mm): height of cross-section; b (mm): width of cross-section; F_{ult}: ultimate load; ΔF (N): incremental load; Δe (mm): incremental deflection.

2.2.2 Characterization tests

Mechanical characterization tests were carried out in structural boards according to the new Brazilian standard ABNT NBR 7190 – Part 4: 2022 [6], which was based on ISO 13910: 2005 [7]. The experimental program consists of: 4-point static bending, tension parallel and perpendicular to the grain, compression parallel and perpendicular to the grain and shear parallel to the grain.

4-point static bending

The 4-point static bending test (see Figure 3) was performed to obtain the static modulus of elasticity and bending strength of structural timber boards. The boards were loaded at two points, spaced *6h* between the ends of each support. To determine the modulus of elasticity in bending (E), the deflection measurement at the center-point was taken while applying incremental load until the deflection reached $L/300$. The bending strength (f_m) was determined by increasing the applied load until the maximum load was reached. The modulus of elasticity and bending strength were calculated from Equations (3) and (4):

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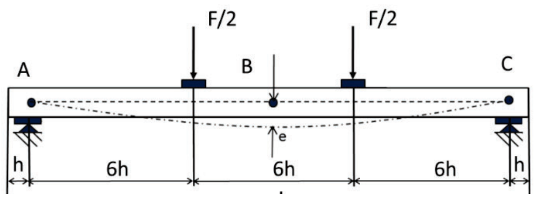

Figure 3 – Bending test [6]

$$E = \frac{23}{108} \cdot \left(\frac{L}{h}\right)^3 \cdot \left(\frac{\Delta F}{\Delta e}\right) \cdot \frac{1}{b} \quad (3)$$

$$f_m = \frac{F_{ult} \cdot L}{b \cdot h^2} \quad (4)$$

Tension parallel to the grain

The tension parallel to the grain test (see Figure 4) was carried out using the Metriguard 422 Tension Proof Testers, which has an 800 kN load capacity. The boards were subjected gradually increasing the applied load until the failure. The tension strength parallel to the grain was determined using Equation (5):

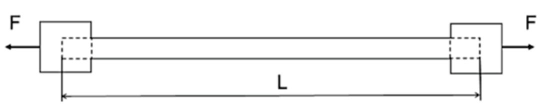

Figure 4 – Tension strength parallel to the grain test [6]

$$f_{t,0} = \frac{F_{ult}}{b \cdot h} \quad (5)$$

Where, $f_{t,0}$ (MPa): tension strength parallel to the grain; F_{ult} (N): ultimate load; h (mm): height of cross-section; b (mm): width of the cross-section.

Tension perpendicular to the grain

The tension perpendicular to the grain test was carried out using alternative method with the EMIC universal testing machine (see Figure 5), which has a load capacity of 30 kN. The specimen was comprised of the full cross-section that was cut the length L_h equal to $h/3$ of the timber board. The specimen was submitted to a 3-point bending test and loaded gradually until it failed. Equation (6) was used to calculate the tension strength perpendicular to the grain:

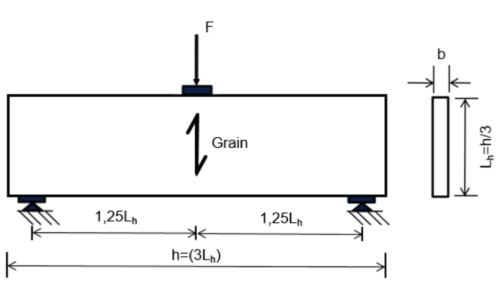

Figure 5 – Tension perpendicular of the grain strength test [6]

$$f_{t,90} = \left(\frac{3{,}75 \cdot F_{ult}}{b \cdot L_h}\right) \cdot \left(\frac{0{,}03 \cdot b \cdot {L_h}^2}{800^3}\right)^{0{,}2} \quad (6)$$

where, $f_{t,90}$ (MPa): tension strength perpendicular to the grain; F_{ult} (N): ultimate load; h (mm): height of cross-section; b (mm): width of cross-section; L_h (mm): length cut from the specimen; $\left(\frac{0{,}03 \cdot b \cdot {L_h}^2}{800^3}\right)^{0{,}2}$: a factor that normalized the tension strength to the equivalent value for a timber cube of side length equal to 800 mm.

Compression parallel to the grain

The compression parallel to the grain test (see Figure 6) was executed using the AMSLER universal testing, which has a load capacity of 25000 kgf. Two specimens with *6b* length were compressed axially until failure. The ultimate load F_{ult} was the lower value of the applied load at failure for the two specimens. The compression strength parallel to the grain was calculated from Equation (7):

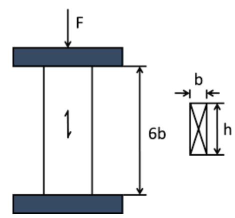

Figure 6 – Compression parallel to the grain test [6]

$$f_{c,0} = \frac{F_{ult}}{b \cdot h} \quad (7)$$

Where, f_{c0} (MPa): compression strength parallel to the grain; F_{ult} (N): ultimate load; h (mm): height of cross-section; b (mm): width of the cross-section.

Compression perpendicular to the grain

The compression strength perpendicular to the grain was obtained using the AMSLER universal and the setup shown in Figure 7. The specimen was cut to a length of *6h*, and then loaded until it either failed or reached a maximum deformation of 0.1 mm. The compression strength perpendicular to the grain was calculated from Equation (8):

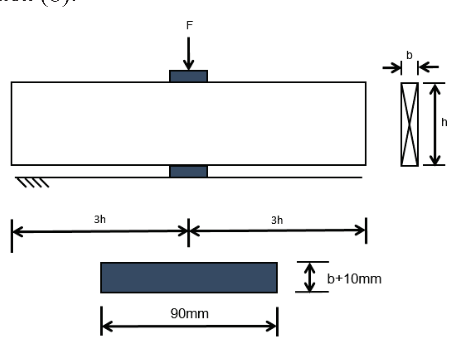

Figure 7 – Compression perpendicular to the grain test [6]

$$f_{c,90} = \frac{F_{ult}}{90 \cdot b} \text{ or } f_{c,90} = \frac{F_{0,1h}}{90 \cdot b} \quad (8)$$

Where f_{c90} (MPa): compression strength perpendicular to the grain; F_{ult} (N): ultimate load; $F_{0,1h}$ (N): load at a deformation of 0.1h mm; b (mm): width of the cross-section.

Shear parallel to the grain

The shear parallel to the grain test was performed according to the setup shown in Figure 8. The specimen was cut to a length of *7h*, and then loaded until it either failed that presented shear failure mode or bending failure mode. However, all results were used to calculate shear strength, regardless of failure mode. The shear strength parallel to the grain was determined from Equation (9):

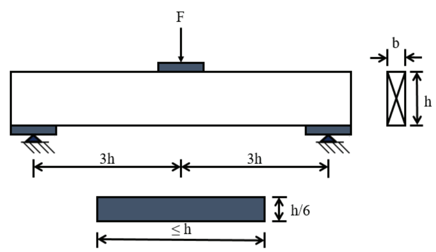

Figure 8 – Shear parallel to the grain test [6]

$$f_v = \frac{0,75 \cdot F_{ult}}{b \cdot h} \quad (9)$$

Where, f_v (MPa): shear strength parallel to the grain; F_{ult} (N): ultimate load; h (mm): height of cross-section; b (mm): width of cross-section.

2.2.3 The characteristic value of the strength

The characteristic value of strength properties of each species was calculated assuming they are logarithmically normally distributed according to EN 14358: 2016 [9]. Thus, the mean value, standard deviation and characteristic value were obtained from Equations (10), (11) and (12), respectively:

$$\bar{y} = \frac{1}{n}\sum_{i=1}^{n} \ln m_i \quad (10)$$

$$s_y = max \begin{cases} \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(\ln m_i - \bar{y})^2} \\ 0,05 \end{cases} \quad (11)$$

$$m_k = \exp(\bar{y} - k_s(n)s_y) \quad (12)$$

Where: $\bar{y}$ is the mean sample value, n is the number of test values, m_i is the individual test value i of stochastic variable m, s_y is the standard deviation, m_k is the 5-percentile value of stochastic variable m, $\bar{y}$ is the sample mean value, s_y is the standard deviation, and $k_s(n)$ is the factor used to determine characteristic value. The factor $k_s(n)$ was calculated from Equation (13):

$$k_s(n) = \frac{6,5\,n + 6}{3,7\,n - 3} \quad (13)$$

Where: n is the number of test values.

3 RESULTS

3.1 Experimental data

Table 2 presents the maximum, minimum and mean value, standard deviation, and coefficient of variation of physical and mechanical properties for "Caixeta".

Table 2 – Density and mechanical properties of Caixeta

Properties	Min.	Max.	Mean	Std.	CoV (%)
ρ_{ap} (kg/m³)	351	498	424	32	7.54
E_{dyn} (GPa)	7.65	13.44	10.62	1.24	11.63
E_{flat} (GPa)	8.02	13.38	10.70	1.22	11.39
E_{edge} (GPa)	8.03	11.78	9.74	1.00	10.23
f_m (MPa)	41.13	80.92	56.80	9.80	17.25
f_{t0} (MPa)	24.07	65.10	40.97	13.72	33.50
f_{t90} (MPa)	0.35	1.13	0.64	0.21	32.35
f_{c0} (MPa)	34.33	50.16	40.59	4.17	10.27
f_{c90} (MPa)	6.54	7.97	7.42	0.68	9.20
f_{v0} (MPa)	3.17	5.42	4.56	0.75	16.55

Table 3 presents the maximum, minimum and mean value, standard deviation, and coefficient of variation of physical and mechanical properties for "Cedrinho".

Table 3 – Density and mechanical properties of Cedrinho

Properties	Min.	Max.	Mean	Std.	CoV (%)
ρ_{ap} (kg/m³)	550	672	606	31	5.19
E_{dyn} (GPa)	7.52	19.76	12.45	2.37	19.01
E_{flat} (GPa)	8.05	15.13	11.97	1.73	14.46
E_{edge} (GPa)	6.91	15.13	12.39	1.90	15.36
f_m (MPa)	29.85	90.31	60.17	18.27	30.37
f_{t0} (MPa)	36.74	64.53	50.93	11.80	23.17
f_{t90} (MPa)	0.33	0.68	0.51	0.11	20.84
f_{c0} (MPa)	35.21	58.10	45.57	5.89	12.92
f_{c90} (MPa)	7.96	11.86	10.00	1.49	14.88
f_{v0} (MPa)	4.89	7.26	5.87	0.83	14.08

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Table 4 presents the maximum, minimum and mean value, standard deviation, and coefficient of variation of physical and mechanical properties for "Goiabão".

Table 4 – Density and mechanical properties of Goiabão

Properties	Min.	Max.	Mean	Std.	CoV (%)
ρ_{ap} (kg/m³)	776	1018	902	56	6.26
E_{dyn} (GPa)	14.53	30.24	20.92	3.41	16.28
E_{flat} (GPa)	13.47	28.15	20.19	3.45	17.09
E_{edge} (GPa)	14.89	22.94	18.55	1.81	9.75
f_m (MPa)	76.68	123.16	99.34	15.24	15.35
f_{t0} (MPa)	50.65	105.00	74.97	19.82	26.44
f_{t90} (MPa)	0.30	1.78	0.67	0.42	62.52
f_{c0} (MPa)	46.98	88.48	70.61	11.14	15.78
f_{c90} (MPa)	20.37	31.54	25.45	4.41	17.32
f_{v0} (MPa)	6.93	9.68	8.44	1.11	13.20

Table 5, 6 and 7 present the characteristics values and a comparison to the properties values of strength class assigned for each species.

Table 5 – Characteristic values and strength class of Caixeta

Properties	Caixeta	D18	Diff (%)
ρ_{ap} (kg/m³)	424	570	-25.6
E_{dyn} (GPa)	10.6		11.8
E_{edge} (GPa)	9.7	9.5	2.5
E_{flat} (GPa)	10.7		12.6
f_m (MPa)	40	18	112.2
f_{t0} (MPa)	18	11	63.6
f_{t90} (MPa)	0.3	0.6	-43.3
f_{c0} (MPa)	33	18	83.3
f_{c90} (MPa)	5.7	7.5	-24.0
f_{v0} (MPa)	3.0	3.4	-11.7

Table 6 – Characteristic values and strength class of Cedrinho

Properties	Cedrinho	D24	Diff (%)
ρ_{ap} (kg/m³)	606	580	4.5
E_{dyn} (GPa)	12.4		24.0
E_{edge} (GPa)	12.4	10.0	24.0
E_{flat} (GPa)	12.0		20
f_m (MPa)	29	24	20.8
f_{t0} (MPa)	26	14	85.7
f_{t90} (MPa)	0.3	0.6	-50.0
f_{c0} (MPa)	35	21	66.6
f_{c90} (MPa)	7.1	7.8	-9,0
f_{v0} (MPa)	4.3	4.0	7.5

Table 7 – Characteristic values and strength class of Goiabão

Properties	Goiabão	D60	Diff (%)
ρ_{ap} (kg/m³)	902	840	7.4
E_{dyn} (GPa)	20.9		22.9
E_{edge} (GPa)	18.6	17.0	9.4
E_{flat} (GPa)	20.2		18.8
f_m (MPa)	72	60	20.0
f_{t0} (MPa)	38	36	5.6
f_{t90} (MPa)	0.2	0.6	-66.7
f_{c0} (MPa)	49	32	53.1
f_{c90} (MPa)	17.5	11.0	59.1
f_{v0} (MPa)	6.1	4.5	35.6

Piter *et al.* (2003) [10] presented mechanical characterization and visual grading of Argentinean *Eucalyptus grandis* with specimens in structural size. The growth characteristics had greater influence reducing strength and stiffness, and obtained different mechanical properties in comparison with strength class system established in EN 338 [11].

When considering the characteristic value of bending strength, mean density, and modulus of elasticity of the "Caixeta" species, the mechanical properties and density of the strength class assigned has significantly lower than the characteristics values of "Caixeta" species. Although the characteristic bending strength was 40 MPa, the low values of modulus of elasticity and density resulted in class D18, which have the lowest strength class in ABNT NBR 7190 [5]. "Cedrinho" species presented characteristics values higher than the properties of the strength class assigned to it, except for the tension strength perpendicular to the grain and shear strength parallel to the grain. It is worth mentioning that "Goiabão" species, with the highest mechanical properties and density, was included in strength classes D60 and also showed characteristics values higher than the mechanical properties of the assigned strength class, except for the tension strength perpendicular to the grain.

Therefore, it is recommended that industries should performed characterization tests for each species they plan to use in their production line, according to well-defined standards. Based on the results of these tests, appropriate strength classes for each species should be established.

3.2 Comparison between dynamic and static modulus of elasticity

Figure 9 shows the association between dynamic and 4-point static modulus of elasticity data for the three species, that the coefficient of determination value (R^2) was 0.9394. Generally, the correlation between the static and dynamic modulus of elasticity is considered high if above 90%. The ABNT NBR 7190 – Part 2 requires that this correlation be above 90%. Morin-Bernard *et al.* (2020) [12] compared the dynamic and static modulus of elasticity of two hardwood species that showed the coefficient of determination for white ash ($R^2 = 0.94$) and yellow birch ($R^2 = 0.87$).

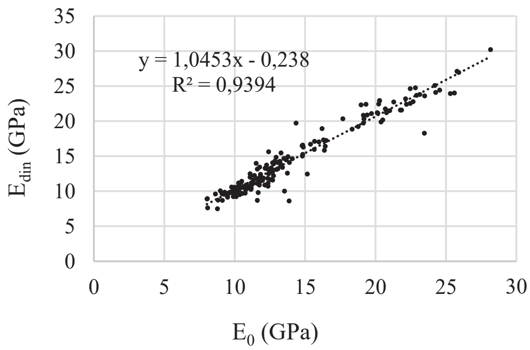

Figure 9 – Dispersion graphic of the static (E_0) and dynamic (E_{din}) modulus of elasticity

Table 8 presents the mean values, the coefficient of variation (%) of the static and dynamic modulus of elasticity for each species and comparative ratios, $\mathbf{E_{flat}/E_{dyn}}$ and $\mathbf{E_{edge}/E_{dyn}}$. The dynamic modulus of elasticity was higher than the static modulus of elasticity for "Cedrinho" and "Goiabão" species. Furthermore, the $\mathbf{E_{edge}/E_{dyn}}$ ratio obtained greater differences, mainly for the "Caixeta" and "Goiabão" species. Sales *et al.* (2009) [13] performed structural grading though nondestructive methods, *i.e*. ultrasound and transverse vibration, and compared to static bending results. The authors evaluated structural members of *Eucalyptus grandis* and *Pinus sp*. The transverse vibration method allowed for modulus of elasticity closer to the values obtained by the static modulus of elasticity that the average percentile variations were 4.42% for *Eucalyptus grandis* and 4.33% for *Pinus sp*.

The modulus of elasticity in flatwise position was closer than edgewise position. The edgewise position is required by ABNT NBR 7190 – Part 4 [5] for the characterization of the 4-point static bending test. However, the dynamic modulus of elasticity through transverse vibration method have been carried out in the flatwise position, the same position required by the Brazilian standard ABNT NBR 7190 – Part 2 [7], for the nondestructive test of the 3-point static bending.

Table 8 – Modulus of elasticity in bending (static and dynamic) and comparison ratio between dynamic and static modulus of elasticity

Properties	Caixeta	Cedrinho	Goiabão
$\mathbf{E_{dyn}}$ **(GPa)**	10.62	12.45	20.92
	11.63%	19.01%	16.28%
$\mathbf{E_{flat}}$ **(GPa)**	10.70	11.97	20.19
	11.39%	14.46%	17.09%
$\mathbf{E_{flat}/E_{dyn}}$	1.01	0.96	0.97
$\mathbf{E_{edge}}$ **(GPa)**	9.74	12.39	18.55
	10.23%	15.36%	9.75%
$\mathbf{E_{edge}/E_{dyn}}$	0.92	0.99	0.87

4 CONCLUSIONS

Mechanical characterization tests were performed in structural size specimens for three native species of the Amazon rainforest obtained from trees under sustainable forest management, *i.e.* Caixeta (*Simarouba amara* Aubl.), Cedrinho (*Erisma uncinatum* Warm.) and, Goiabão (*Planchonella pachycarpa* Pires.). The experimental campaign followed the new Brazilian Standard ABNT NBR 7190 – Part 4 [6] Additionally, non-destructive tests were carried out 3-point static bending test to determine modulus of elasticity and transverse vibration test to determine the dynamic modulus of elasticity. Main highlights are:

- Static and dynamic modulus of elasticity were analysed and the regression presented a high coefficient of determination ($R^2 = 0.9394$).
- The comparison of the static and dynamic modulus of elasticity showed that E_{flat} had closer values to E_{dyn} than E_{edge}, since transverse vibration through Metriguard model 340 requires flatwise position to determine the dynamic modulus of elasticity.
- The species were classified into strength classes by the characteristic value of bending strength and, mean values of static modulus of elasticity and density. "Goiabão" was graded as D60, "Cedrinho" D24, and "Caixeta" D18. However, it was observed that the tension strength perpendicular to the grain and the shear parallel to the grain did not achieve the values presented by the strength classes assigned to these species.

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