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PHYSICO-MECHANICAL CHARACTERIZATION OF THE *Anadenanthera colubrina* WOOD SPECIE

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ABSTRACT: In Brazil, the characterization of wood is carried out in accordance with the premises established by ABNT NBR 7190standard; however, the determination of wood properties requires the use of equipment, which hinders the wood characterization for the construction professional. To circumvent this problem, the properties of wood strength and stiffness can be estimated through regression models using the apparent density as estimator, being the density a physical property of easy determination. This study aimed to determine 4 physical and 13 mechanical properties of "Angico Branco" wood (*Anadenanthera colubrina*), and with the aid of regression models based on analysis of variance, estimate the strength and stiffness properties as a function of apparent density. Twelve samples were produced for each test, resulting in a total of 204 experimental determinations. The results of mechanical properties showed consistent performance with other wood species studied, demonstrating their potential use in various applications. From the regression models, only the longitudinal modulus of elasticity in parallel compression to the grain showed a significant result, and the best were obtained with the linear model, which provided determination coefficient (R^2) equal to 56.32%.

KEYWORDS: *Anadenanthera colubrina*, physico-mechanical characterization, apparent density, regression models, analysis of variance (ANOVA).

INTRODUCTION

With the growing awareness of the population to use materials that cause the least damage to the environment, wood from planted forests is a potential material for several sectors of the economy, especially construction, where it is used as a structural element for making forms and other purposes (ALMEIDA et al., 2013; LAHR et al., 2016).

Popularly known as "angico-branco", the *Anadenanthera colubrina* (Vell.) species *Brenan* of the *Mimosaceae* family can be found in several regions of Brazil (CARVALHO, 2002), as in the Atlantic slope of the States of Rio de Janeiro and São Paulo (LORENZI, 2002), Minas Gerais, Mato Grosso, Mato Grosso do Sul, Bahia, Paraná, Espírito Santo and the Federal District (CARVALHO, 2002).

The *Anadenanthera colubrina* can reach a height of 10 to 20 m, it is widely used in the planting of mixed forests and in the afforestation of parks (GOMES et al., 2004;ORTOLANI et al., 2010), due to its moderate to rapid growth (CARVALHO, 2002), and it can be used to control erosion and soil improvement (SANTOS, 1987). Because it is a dense, smooth and lustrous wood, with good resistance and great durability (CARVALHO, 2002; ORTOLANI et al. 2010), this is indicated for use in planks, bats, carpentry, debris, internal works, slats, implements, packaging, shipbuilding and civil construction (CARVALHO, 2002).

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However, to be used in the construction of wood structures, as in the case of other materials, it is necessary to have adequate knowledge of the physical and mechanical properties of the species, thus allowing a more rational use of the material, which contributes to a structural sizing with greater security and economy.

In Brazil, the design of wood structures is developed using the resistance classes defined by the Brazilian standard ABNT NBR7190 (1997) or through the results of physical-mechanical characterization tests, which are also specified by this standard. The use of test results is more appropriate because strength class values are generally overestimated and do not exhibit the characteristics of all species available in nature (LOGSDON et al., 2008a, LOGSDON et al., 2008b).

However, due to the difficulties in carrying out the tests for the determination of the various physical and mechanical properties of the wood of interest, alternatives are proposed, such as the use of other properties as an estimation factor (CHRISTOFORO et al., 2014; LAHR et al., 2016), and since density is a basic physical property and easy to determine, it is a possible estimator of the mechanical properties of the wood (DIAS & LAHR, 2004), highlighting that the Brazilian standard itself establishes relations between properties with the purpose of estimating values for a pre-sizing.

The aim of this study was to characterize the wood species of *Anadenanthera colubrina*, and also, for a more precise structural pre-sizing to estimate, with the use of regression models, the possibility of estimating the strength and stiffness properties investigated according to the density, since the density can be easily determined by the construction professional interested in the use of this kind of wood.

MATERIAL AND METHODS

The wood of the *Anadenanthera colubrina* species came from timber companies located in the city of São Carlos (SP).The wood pieces were properly stocked, with moisture content close to 12%, consisting of equilibrium moisture for wood established by the Brazilian standard.

All the tests were carried out at the Laboratory of Wood and Wood Structures (LaMEM), at the School of Engineering of São Carlos (EESC), University of São Paulo (USP).The carried out experiments followed all the assumptions and methods indicated by the Brazilian Standard ABNT NBR 7190 (1997), provided in its Annex B, "Determination of wood properties for structural projects".

Table 1 show the physical and mechanical properties evaluated in this study.12 samples were manufactured per type of test, in which 3 physical properties and 14 mechanical properties were analysed, resulting in 204 experimental determinations.

TABLE 1.Physical and mechanical properties of *Anadenanthera colubrina* wood specie.

Properties	Abbreviation
Apparent density	ρ_{12}
Total radial retraction	TRR
Total tangential retraction	TTR
Strength to the parallel compressive to fibres	f_{c0}
Strength to the normal compressive to fibres	f_{c90}
Strength to the parallel traction to fibres	f_{t0}
Strength to the normal traction to fibres	f_{t90}
Strength to the parallel shearing to fibres	f_{v0}
Strength to the cracking	f_{s0}
Conventional strength in the static bending test	f_m
Parallel hardness to fibres	f_{H0}
Normal hardness to fibres	f_{H90}
Modulus of longitudinal elasticity in parallel compression to fibres	E_{c0}
Modulus of elasticity in normal compression to fibres	E_{c90}
Modulus of longitudinal elasticity in parallel traction to fibres	E_{t0}
Modulus of conventional elasticity in the static bending test	E_m
Tenacity	W

The classification of *Anadenanthera colubrina* wood in the wood strength classes of the hardwood group was done using Equation 1, where f_k consists of the strength characteristic value and n is the number of test pieces used. From [eq. (1)], the strength results should be placed in ascending order $f_1 \leq f_2 \leq \ldots \leq f_n$, neglecting the highest value if the number of pieces is odd, and not taking f_k values less than f_1 and nor at 0.70 of the average value.

$$f_k = \left(2.\frac{f_1 + f_2 + \ldots f_{\frac{n}{2}-1}}{\frac{n}{2}-1} - f_{\frac{n}{2}}\right).1{,}1 \quad (1)$$

The [eq. (1)] was also used to investigate the accuracy of relations: $f_{c0,k}/f_{t0,k}=0.77$; $f_{c90,k}/f_{c0,k}=0.25$ and $f_{v0,k}/f_{c0,k}=0.12$, expressions established by the Brazilian standard.

For the estimation of the wood strength and stiffness properties according to the apparent density (ρ_{12}), regression models (Equations 2 to 5) based on analysis of variance (ANOVA) were used in order to establish the best fit between the apparent density and each one of the 14 mechanical properties (Y) investigated, which resulted in the generation of 56 mathematical models.

$$Y = a + b.\rho_{12} \text{ [Lin - linear]} \quad (2)$$

$$Y = a.e^{b.\rho_{12}} \text{ [Exp - exponential]} \quad (3)$$

$$Y = a + b.\ln(\rho_{12}) \text{ [Log - logarithmic]} \quad (4)$$

$$Y = a.\rho_{12}{}^{b} \text{ [Geo - geometric]} \quad (5)$$

By the ANOVA of the regression models, considered at the 5% level of significance (α), the null hypothesis formulated consisted in the non-representativeness of the tested models (H_0: β=0), and in the representativeness as an alternative hypothesis (H_1: $\beta \neq 0$).

RESULTS AND DISCUSSION

Tables 2 and 3 show the average values ($\overline{x}$), coefficients of variation (CV), the lowest (Min) and the largest (Max) values of the physical and mechanical properties investigated.

TABLE 2. Results of physical properties of *Anadenanthera colubrina* wood specie.

Estat.	ρ_{12} (kg/m^3)	TRR (%)	TTR (%)
$\overline{x}$	710	3.12	5.14
CV	0,03	0.14	0.33
Min	670	2.56	4.67
Max	750	4.00	6.31

TABLE 3. Results of mechanical properties of *Anadenanthera colubrina* wood specie.

	f_{c0} (MPa)	f_{t0} (MPa)	f_{t90} (MPa)	f_{v0} (MPa)	f_{s0} (MPa)	f_m (MPa)	E_{c0} (MPa)	E_{t0} (MPa)
$\overline{x}$	44	89	6.1	15	1.1	89	14962	14745
CV	0.09	0.12	0.21	0.15	0.16	0.09	0.19	0.16
Min	35	54	3.1	8	0.9	77	11683	10437
Max	48	85	8.9	17	1.5	105	19016	19451

	E_m (MPa)	f_{H0} (MPa)	f_{H90} (MPa)	W (J)	f_{c90} (MPa)	E_{c90} (MPa)
$\overline{x}$	15776	70	61	38.50	8	948
CV	0.18	0.10	0.09	0.17	0.11	0.12
Min	11941	56	52	28.50	6	826
Max	19859	79	70	53.42	9	1151

The coefficients of variation (*Cv*) values obtained from the strength and stiffness properties of *Anadenanthera colubrina* were lower than the limits established by the Brazilian standard (18% for strength for normal stresses and 28% for tangential stresses), highlighting the good representativeness of the properties by their average values.

The results of the apparent density (710 kg/m³) for *Anadenanthera colubrina* classify it as a dense wood (CARVALHO, 2002), resembling to the density of the *Angelim Araroba* wood (CHRISTOFO et al., 2016; ALMEIDA et al., 2016) and higher than the "Cedro Doce" (CHRISTOFO et al., 2016), but much lower than the density of Pariri wood (ALMEIDA et al., 2015) and other species already researched (LOGSDON et al., 2008a; CHRISTOFO et al., 2016; ALMEIDA et al., 2016).

The radial retraction is smaller than the tangential retraction, results that are in agreement with affirmations made by some authors such as MELO et al. (2010); DURLO & MARCHIORI (1992) and DEL MENEZZI (2006).Comparing the results obtained with other species (LAHR et al., 2016; CHRISTOFORO et al., 2016; MELO et al., 2010), it is possible to verify that denser wood species have greater dimensional variation, as affirmed in the researches of CHRISTOFORO et al. (2016), VITAL & TRUGILHO (1997) and TSOUMIS (1991).

The strength in the parallel compression to the fibers obtained of 44MPa for the *Anadenanthera colubrina* wood is very close to the strength in the parallel compression (42.98MPa) of *Araucaria angustifolia* (MELO et al., 2010), values that are reasonable when compared with those coming from species reported in the researches of ALMEIDA et al. (2013) and CAVALHEIRO et al. (2016), but very low when considering species such as *Vatairea sp* and Pariri showed in the studies of ALMEIDA et al. (2015) and LAHR et al. (2016).

The results of the tensile strength in the parallel direction (89MPa) to the fibres of the *Anadenanthera colubrina* wood are close to the values of the tensile strength in the parallel direction to the wood fibres of *Vatairea sp* [96MPa] (LAHR et al., 2016), "Cedro marinheiro" [111.18MPa] (LOGSDON et al., 2008b) and "Peroba-mica" [87.63MPa] (LOGSDON et al., 2008a).

The average value of the strength to the shear in the parallel direction to the fibres (15MPa) of the *Anadenanthera colubrina* wood is equal to f_{v0} of the "Pariri" and *Vatairea sp* species (ALMEIDA et al., 2015; LAHR et al., 2016), and are larger than the strength values to shear of the

"Peroba-mica", "Cedro marinheiro" and "Paricá" species (LOGSDON et al., 2008a; LOGSDON et al., 2008b; CAVALHEIRO et al., 2016).

Table 4 shows the characteristics values of the strength properties determined using [eq. (1)].

TABLE 4. Characteristic values of the strength properties for *Anadenanthera colubrina* wood specie.

Properties	Unit (MPa)
Characteristic resistance to parallel compression to fibres	41.36
Characteristic resistance to parallel traction to fibres	53.24
Characteristic resistance to normal compression to fibres	6.16
Characteristic strength to parallel shear to fibres	13.20

The characteristic value of the strength in parallel compression in Table 4 fits the *Anadenanthera colubrina* wood belonging to the strength class C40 for the hardwood group according to the Brazilian standard.

The relation obtained between $f_{c0,k}/f_{t0,k}$ was equal to 0.78, a value very close to the relation established by the Brazilian standard (0.77).However, the investigated relations $f_{c90,k}/f_{c0,k}$ and $f_{v0,k}/f_{c0,k}$ resulted in coefficients equal to 0.12 and 0.32, respectively, values very different from those indicated by the standard ($f_{c90,k}/f_{c0,k}$=0.25; $f_{v0,k}/f_{c0,k}$=0.12), as well as obtained by other authors (LOGSDON et al., 2008a; LOGSDON et al., 2008b), which indicates the need to revise ABNT NBR 7190 standard in these relations.

Tables 5 and 6 express the ANOVA results of the regression models.

TABLE 5. Regression models for estimating the strength properties of *Anadenanthera colubrina* wood specie.

	Models	P-value	a	b	R^2
f_{c0}	Lin	0.5185	21.1451	32.7343	4.29%
	Exp	0.5895	27.7657	0.6550	3.01%
	Log	0.5312	52.1061	22.5157	4.04%
	Geo	0.6028	51.5460	0.4480	2.81%
	Models	P-value	a	b	R^2
f_{t0}	Lin	0.4858	-0.4121	95.5071	4.98%
	Exp	0.4981	24.8882	1.3874	4.71%
	Log	0.4878	90.5190	67.4060	4.93%
	Geo	0.5007	93.2003	0.9776	4.65%
	Models	P-value	a	b	R^2
f_{t90}	Lin	0.2028	-13.6169	27.9461	15.66%
	Exp	0.2470	0.2435	4.5092	13.13%
	Log	0.2016	13.0368	19.8572	15.74%
	Geo	0.2473	17.8970	3.1943	13.12%
	Models	P-value	a	b	R^2
f_{v0}	Lin	0.0668	54.4685	-55.3273	29.70%
	Exp	0.0601	436.2216	-4.7593	30.98%
	Log	0.0719	1.9402	-38.6239	28.81%
	Geo	0.0651	4.7600	-3.3206	30.02%
	Models	P-value	a	b	R^2
f_{s0}	Lin	0.6996	0.4846	0.8601	1.55%
	Exp	0.7041	0.6441	0.7333	1.50%
	Log	0.6854	1.3148	0.6396	1.71%
	Geo	0.6904	1.3072	0.5450	1.65%
	Models	P-value	a	b	R^2
f_m	Lin	0.9534	93.0231	-6.2901	0.04%
	Exp	0.9658	91.5299	-0.0517	0.02%
	Log	0.9551	87.0827	-4.3008	0.03%
	Geo	0.9664	87.1513	-0.0360	0.02%
	Models	P-value	a	b	R^2
f_{H0}	Lin	0.1397	-25.7035	135.9435	20.46%
	Exp	0.1504	17.4439	1.9663	19.52%
	Log	0.1443	103.5302	95.3817	20.05%
	Geo	0.1548	113.1150	1.3802	19.14%
	Models	P-value	a	b	R^2
f_{H90}	Lin	0.7491	44.6906	23.1065	1.07%
	Exp	0.7149	44.8146	0.4317	1.39%
	Log	0.7421	66.8767	16.8428	1.13%
	Geo	0.7086	67.7938	0.3130	1.46%
	Models	P-value	a	b	R^2
W	Lin	0.5436	80.8752	-60.0334	3.80%
	Exp	0.6925	77.6527	-1.0183	1.63%
	Log	0.5233	22.9127	-44.6782	4.19%
	Geo	0.6713	28.8899	-0.7739	1.87%
	Models	P-value	a	b	R^2
f_{c90}	Lin	0.9285	6.9345	1.1553	0.08%
	Exp	0.8650	6.2783	0.2880	0.30%
	Log	0.9387	7.9950	0.7023	0.06%
	Geo	0.8755	8.2158	0.1882	0.26%

TABLE 6. Regression models for estimating the stiffness properties of *Anadenanthera colubrina* wood specie.

	Models	P-value	a	b	R^2
E_{c90}	Lin	0.9852	888.9191	-27.9846	0.00%
	Exp	0.8312	1106.2986	-0.3520	0.48%
	Log	0.9775	858.6556	-30.1248	0.01%
	Geo	0.8247	788.2551	-0.2593	0.51%
	Models	P-value	a	b	R^2
E_{c0}	Lin	0.0049	-47962.8588	89150.4493	56.32%
	Exp	0.0069	247.8024	5.7856	53.46%
	Log	0.0050	36986.5079	63121.2320	56.20%
	Geo	0.0069	61480.5671	4.0989	53.41%
	Models	P-value	a	b	R^2
E_{t0}	Lin	0.0548	-24253.5982	55251.7330	32.07%
	Exp	0.0514	952.7800	3.8638	32.83%
	Log	0.0532	28484.8971	39379.0493	32.43%
	Geo	0.0494	38128.1579	2.7575	33.29%
	Models	P-value	a	b	R^2
E_m	Lin	0.0895	-25564.2542	58569.1913	26.11%
	Exp	0.0672	880.5272	4.0674	29.63%
	Log	0.0838	30483.8973	42153.5955	26.92%
	Geo	0.0626	43114.8523	2.9239	30.48%

Analysing the results from Tables 5 and 6, we observed that among the 14 mechanical properties estimated by the apparent density with the use of the regression models, only the elastic modulus estimation in the parallel compression to the fibres (E_{c0}) was significant (P-value <0.05), consisting in the linear model (E_{c0} = -47962.8588 + 89150.4493·ρ_{ap}) as the best fit (R^2 = 56.32%).This implies the low representativeness of the apparent density as estimator of the strength and stiffness properties of *Anadenanthera colubrina* wood.

Some authors have found significant relations between the apparent density and the strength to compression in the parallel direction to the fibres for some wood species such as Canafístula [R^2=48.57%] and Castelo [R^2 = 52,84%] (ALMEIDA et al.,2016) and *Vatairea sp* (LAHR et al., 2016), and non-significant relations between the apparent density and the strength in parallel compression to the fibres for the *Angelim Araroba* wood (ALMEIDA et al., 2016), as well as obtained with the *Anadenanthera colubrina* of this research. As well as the *Anadenanthera colubrina*, the *Vatairea sp* (LAHR et al., 2016) also provided a significant adjustment for the longitudinal elastic modulus in parallel compression to the fibres, with a determination coefficient around 50%.

CONCLUSIONS

From the results of this research, the following can be concluded:

- From the coefficient of variation values obtained, the characterization of the *Anadenanthera colubrina* species can be considered according to the requirements of the Brazilian standard, and the averages of the physical and mechanical properties obtained can be accepted as representative values of the sample sets by property:

- According to the assumptions of the Brazilian standard, the *Anadenanthera colubrina* wood is categorized as belonging to resistance class C40, because it presents a characteristic value of compressive strength ($f_{c0,k}$) equal to 41.36MPa, indicating a good performance for using in wood structures;

- From the 3 relationships explored between the characteristic resistance values, only the relation between the compressive strength (f_{c0}) and th**e** tensile strength (f_{t0}) in the parallel direction to the fibres provided a result (0.78) close to that established by the Brazilian standard ($f_{c0,k}/f_{t0,k}$ =0.77);

- The regression models used in the estimation of the 14 strength and stiffness properties in function of the apparent density were significant only in the estimation of the modulus of elasticity values in the parallel compression to the fibres, consisting the linear model as the one that provided the best adjustment (E_{c0}=-47962.8588+89150.4493$\cdot\rho_{ap}$; R^2=56.32%).

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