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Wood characterization of *Eucalyptus paniculata* Smith species

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ABSTRACT

Eucalypts have not been well accepted for construction use by civil societies in different nations. For the elimination of these cultural barriers, there is the demand for better knowledge of the physical-mechanical properties of these silvicultural species. Thus, the research carried out a wide characterization of the Eucalyptus paniculata Smith wood species. Based on the Brazilian standard document ABNT NBR 7190, 14 mechanical properties and 2 physical properties were evaluated. Two moisture contents were adopted to compare the wood samples in different conditions: above the fiber saturation point and dried point. Results of properties were treated statistically with a t-test. In total, 1384 repeats were reached. Only two mechanical properties did not show changes in their resistance values to moisture reduction: tangential cleavage and modulus of rupture in the perpendicular tensile to grain. Further properties showed differences in the resistances from t-test for the studied moisture reduction.

Keywords: Density. Grey Ironbark. Moisture. Resistance. Wood properties.

Caracterização da madeira de espécies de *Eucalyptus paniculata* Smith

RESUMO

Os eucaliptos não têm sido bem aceitos em usos na construção pelas sociedades civis em diferentes nações. Para a eliminação dessas barreiras culturais, existe a demanda por mais conhecimento das propriedades físico-mecânicas dessas espécies silviculturais. Assim, a pesquisa conduziu uma ampla caracterização da madeira da espécie Eucalyptus paniculata Smith. Foram avaliadas 14 propriedades mecânicas e 2 propriedades físicas com base na norma brasileira ABNT NBR 7190. Dois teores de umidade foram adotados para comparar as amostras de madeira em diferentes condições: acima do ponto de saturação das fibras e no ponto seco. Os resultados das propriedades foram estatisticamente tratados com teste t. No total, 1384 repetições foram alcançadas. Somente duas propriedades mecânicas não indicaram mudanças em seus valores de resistência com a redução da umidade: fendilhamento tangencial e módulo de ruptura na tração perpendicular às fibras. As outras propriedades mostraram diferenças nas resistências a partir do teste t para a redução de umidade estudada.

Palavras-chave: *Eucalipto casca-de-ferro. Umidade. Propriedades da madeira. Densidade. Resistência.*

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1 Introduction

Given mechanical and aesthetical features, wood is widely used in several industrial contexts, being inserted in the "building" culture of some Brazilian regions (BISSOLI-DALVI *et al.*, 2017), particularly, in southern and southeastern states, despite the absence of domestic policy to promote timber-based housing (DE ARAUJO *et al.*, 2019a; DE ARAUJO *et al.*, 2019b).

Even with different studies and trends for a better wood utilization in engineered beams and panels (DIAZ; ALVAREZ, 2017; IWAKIRI *et al.*, 2012; LIMA *et al.*, 2013; MALONEY, 1996; SEGUNDINHO *et al.*, 2013; TENORIO; MOYA; CAMACHO, 2012; TEUBER *et al.*, 2016; WEBER *et al.*, 2017, and others), including those initiatives about eucalypt varieties (BAL; BEKTAS, 2014; GUIMARÃES JÚNIOR *et al.*, 2011; LARA PALMA; BALLARIN, 2011; MENDES *et al.*, 2014; PIERRE *et al.*, 2014), lumber parts have been used widely for different housing techniques worldwide, even in modern examples (DE ARAUJO *et al.*, 2016; DE ARAUJO *et al.*, 2019a). Also, fiber-based resources have been considered useful alternatives to replace other materials (WEBER *et al.*, 2017).

Still, sawn wood is a cheaper and simpler way to use timbered materials in buildings. Apart from composite benefits, historical buildings with timbered structures have been preserved over time, essentially using lumber parts (ABREU *et al.*, 2013; SU *et al.*, 2019).

In contrast, Clement and Higuchi (2006) stated Brazilian lumber is mostly internally marketed, although not popular in noble applications.

A domestic example is silvicultural species that have been applied intensively for pulp and paper and bioenergy purposes, despite the potential of some species for construction.

Eucalypt wood is an example of that condition variability since species of the same genus could present different degrees of decay resistance (DELUCIS *et al.*, 2016) as well as several ranges in quality and character (JOLLY, 1948). Diversified species, varieties, and properties enable the eucalypt to become an important source of lumber, especially replacing native woods (MÜLLER *et al.*, 2017). Eucalypts have revealed greater financial returns for construction when compared to energy (COELHO *et al.*, 2016). But, eucalypt varieties still need more studies to promote their uses in higher added value goods (NOGUEIRA *et al.*, 2019b). Structural parts for construction could be a way of its application.

Due to the advantages of eucalypts, this present study aimed to evaluate physical and mechanical properties for paniculata species, respecting values and prescriptions cited by Brazilian standard ABNT NBR 7190 (1997).

2 Grey Ironbark

Grey Ironbark is the commercial nomenclature of the *Eucalyptus paniculata* Smith, Myrtaceae family and Angiospermae subphylum (CABI, 2019; LAW; CHIDEL, 2007). Popular in Australia, grey ironbark wood is also found in Brazil (CASTELLANO; CAMARINHO, 2019; DELUCIS; GATTO, 2017; GARCIA *et al.*, 2014; MATTEI; LONGHI, 2001; OLIVEIRA; TOMAZELLO FILHO; SILVA, 2005; PIZZOL; NOGUEIRA; LOMBARDI, 2011; RESENDE; FERREIRA, 2009).

Grey ironbark is a subtropical and warm humid to sub-humid climate species, which has proven to be a good plantation, combining quick growth and good coppicing ability with adaptability to a wide range of soil conditions, and some tolerance of drought and light frost (CABI, 2013). If there is an initial condition to favor seed germination and plant development, natural regeneration by paniculata seeds could be a viable alternative for good quality forest stands (MATTEI; LONGHI, 2001). Grey ironbark is a medium-sized tree with 18 to 24 meters tall or more (Figure 1a) and a trunk diameter of 0.6 to 1.2 meters (LITTLE JUNIOR; SKOLMEN, 1989), whose shape is long and straight with a furrowed, hard or corky, light grey ironbark persistent to the small branches (CABI, 2019).

Paniculata has prime importance to nectarivorous wildlife, timber industry, and beekeepers (LAW; CHIDEL, 2007), provides bark tannins for adhesives and leather (TRUGILHO *et al.*, 2003), offers a log-based environment for shiitake cultures (ANDRADE *et al.*, 2010), and allow the production of essential oils (SILVEIRA *et al.*, 2012), fuelwood (CABI, 2013), and charcoal (ZANUNCIO *et al.*, 2013).

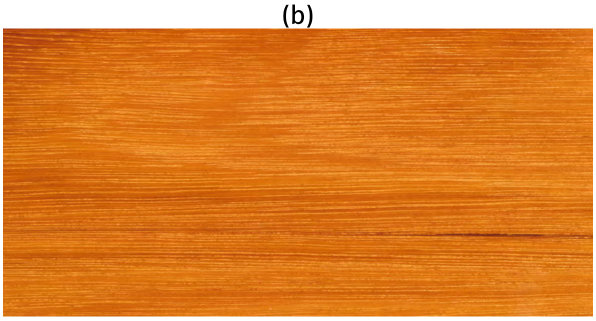
Eucalyptus paniculata wood has a reddish-brown color (Figure 1b), with a high content of yellow pigment in the tangential sections (GARCIA *et al.*, 2014). Its interlocked grain and fine texture are the main attributes of *Eucalyptus paniculata* wood, which is extremely hard, heavy, strong and durable, and has complex workability with checks from drying (LITTLE JUNIOR; SKOLMEN, 1989).

Figure 1 – *Eucalyptus paniculata*: (a) tree and (b) timber

(a)

Source: National Register of Big Trees (2011)

(b)



Source: Wood Solutions (2013)

This wood species usually has vivid coloration (DELUCIS *et al.*, 2015), showing low weight loss in weather exposure (OLIVEIRA; TOMAZELLO FILHO; SILVA, 2005). The Australian Standard AS 5604 (2006) suggested that its wood durability can overcome 25 years in contact with the soil.

Eucalyptus paniculata timber is considered of high quality, being valued for railway sleepers and poles (KARSTEDT; GLOGER, 1978; LAW; CHIDEL, 2007), and spacers for storage of steel plate stacks (PIZZOL; NOGUEIRA; LOMBARDI, 2011). This wood is also applied largely for bridges and wharf timbers, piles, and lumber for ships and construction (LITTLE JUNIOR; SKOLMEN, 1989).

Due to these applications, the expansion of new possibilities to this eucalypt species is necessary, e.g., industrialized components for construction. Thus, this paper studied sixteen physical-mechanical properties of the *Eucalyptus paniculata* wood in two moisture contents, according to the ABNT NBR 7190 (1997) prescription and the statistical support of t-test, enlarging its use as structural timber.

3 Materials and methods

Eucalyptus paniculata trees were obtained from three São Paulo state cities: Rio Claro, Lençóis Paulista, and Camaquã. Different conditions were considered for a randomized representation of forest origin, age of trees, log amount, and the number of beams extracted by log (Table 1).

Table 1 – Details of *Eucalyptus paniculata* wood samples

Log	Beam	Age	Diameter (m)	City Region
1	3	33	0.390	Rio Claro
2	3	33	0.392	Rio Claro
3	3	33	0.346	Rio Claro
4	16	41	0.520	Camaquã
5	3	33	0.295	Rio Claro
6	3	33	0.290	Rio Claro
7	3	33	0.268	Rio Claro
8	3	33	0.253	Rio Claro
9	3	33	0.275	Rio Claro
10	5	20	0.195	Lençóis Paulista
11	5	20	0.195	Lençóis Paulista

Source: elaborated by the authors

The method was supported by the properties and prescriptions of wood characterization described on the Brazilian standard document ABNT NBR 7190 (1997). Just as the studies of Lahr *et al.* (2017, 2018), and Nogueira *et al.* (2018a, 2018b, 2018c, 2019a, 2019b, 2020), the study script considered the evaluation of the same sixteen properties.

Wood samples were obtained, prepared, and sequentially conditioned analysis of moisture contents at green (30%) and standard points (12%). The 12%

level was prescribed to be stable in dry conditions by this standard document.

Thereby, the verification of property progress or regression was done. In the wood characterization for structural purpose, the ABNT NBR 7190 (1997) standard document prescribed the following testing; compressive strength parallel (f_{c0}) and perpendicular to the grain (f_{c90}); tensile strength parallel (f_{t0}) and perpendicular to the grain (f_{t90}); shear stress parallel to the grain (f_{v0}); modulus of elasticity in compression parallel (E_{c0}) and perpendicular to the grain (E_{c90}); cleavage (f_S); hardness (f_H); volumetric mass density (ρ) and bulk density (ρ_b) at 12% moisture content.

By the standard test is obtained the characteristic resistance of defect-free parts to standard moisture content at 12% and compared to green point at 30%. After the mechanical properties variation, the values of resistant efforts are obtained to use in the future structural design of wood for construction.

Statistical analysis occurred about the influence of moisture content reduction from 30 (green) to 12% (standard point) for each investigated physical and mechanical property. Thus, the t-test was applied to accept independent sample conditions and randomization of admissions in the sampling process and its normality.

Using the strategy of Nogueira's and Lahr's studies cited, two hypotheses were regarded: where the means do not differ (H_0: $\mu_1 = \mu_2$), and they differ from each other (H_1: $\mu_1 \neq \mu_2$). The variances are different and unknown. The decision was based on the P-value associated with this test and was taken at the 5% significance level. Thereby, the hypothesis of mean equality is rejected, and H_0 whether P-value is less than 5% (P-value < 0.05).

All data about physical, rupture and elasticity parameters obtained in the performed tests were grouped to enable the analysis of results. After this ordination, green and air-dried conditions were regarded to get the mean values for each studied physical-mechanical property.

Results were demonstrated in four tables (2 to 5), which included the following variables, number of repeats or determinations (n), means of numerical values for each property (M), standard deviations of these means (sd), and those respective P-values.

4 Results

The results of physical properties, bulk density, and volumetric mass are in Table 2.

Table 2 – Densities of paniculata wood

Characteristic	mc (%)	n	M	sd	P-value
Bulk Density (g/cm³)	30	46	1.20	0.06	0.0000
	12	42	1.09	0.15	
Volumetric Mass Density (g/cm³)	30	46	0.84	0.00	–
	12	42	0.84	0.00	

mc: moisture content; n: repeat; M: mean; sd: standard deviation

Source: elaborated by the authors

While the volumetric mass density property does not change with humidity variation (Table 2), only the bulk density of *Eucalyptus paniculata* samples showed a decrease in its mean value when the wood moisture was decreased from the fiber saturation point (30%) to standard point – which is stable and dried at 12% prescribed by the ABNT NBR 7190 (1997).

The mechanical properties are in Tables 3 to 5. About modulus of rupture values, four out of five properties demonstrated increases in their means as the moisture content was decreased. Furthermore, only perpendicular tensile slightly was reduced.

Table 3 – Modulus of rupture of paniculata wood

Characteristic	mc (%)	n	M	sd	P-value
Parallel Compression (MPa)	30	43	53.4	5.5	0.0000
	12	39	73.6	13.3	
Perpendicular Compression (MPa)	30	46	6.5	2.4	0.0006
	12	40	8.8	3.4	
Parallel Tensile (MPa)	30	41	104.8	36.2	0.0000
	12	39	149.4	44.0	
Perpendicular Tensile (MPa)	30	43	4.6	2.1	0.8171
	12	39	4.5	1.8	
Static Bending (MPa)	30	47	99.7	23.8	0.0000
	12	37	133.5	36.0	

mc: moisture content; n: repeat; M: mean; sd: standard deviation

Source: elaborated by the authors.

The results of modulus of elasticity are in Table 4. All properties were increased with the moisture reduction in the paniculata species.

In the last five strength properties (Table 5), all values presented increases in their means according to the moisture content reduction at the stable point prescribed by the ABNT NBR 7190 (1997) standard document.

Therefore, this contribution was efficient in the determination of the main physical and mechanical properties of *Eucalyptus paniculata* wood. In fact, a representative sampling was obtained through these multiple results (Tables 2 to 5) to materially endorse the utilization of this species for structural purposes.

Table 4 – Modulus of elasticity of paniculata wood

Characteristic	mc (%)	n	M	sd	P-value
Parallel Compression (MPa)	30	43	19213.8	4409.6	0.0078
	12	39	22886.0	7197.0	
Perpendicular Compression (MPa)	30	46	606.7	242.7	0.0001
	12	40	878.2	341.0	
Parallel Tensile (MPa)	30	41	19404.0	6299.5	0.0039
	12	39	23719.0	6648.6	
Static Bending (MPa)	30	47	15896.1	4406.1	0.0000
	12	37	20494.4	4768.7	

mc: moisture content; n: repeat; M: mean; sd: standard deviation

Source: elaborated by the authors

Table 5 – Other strength properties of paniculata wood

Characteristic	mc (%)	n	M	sd	P-value
Shear Stress (MPa)	30	47	15.6	2.1	0.0000
	12	42	20.5	3.5	
Tangential Cleavage (MPa)	30	45	0.85	0.18	0.0812
	12	42	0.94	0.28	
Perpendicular Hardness (kN)	30	45	10.12	1.83	0.0000
	12	41	12.79	2.60	
Parallel Hardness (kN)	30	45	10.72	2.15	0.0000
	12	41	13.28	2.15	
Tangential Toughness (N.m)	30	45	16.5	5.4	0.0183
	12	39	19.8	6.9	

mc: moisture content; n: repeat; M: mean; sd: standard deviation

Source: elaborated by the authors

5 Discussion

Given the lack of specific studies about a broad characterization of the *Eucalyptus paniculata* wood, the importance of this paper became expanded about physical-mechanical properties.

This fact was confirmed by the single comparison with another similar research for this species, which studied few properties. A final comparison regarded other studies focused on different eucalypt varieties.

In the condition of wood moisture reduction from 30% to 12% established by the ABNT NBR 7190 (1997), the bulk density of *Eucalyptus paniculata* at a standard point of 12% decreased 0.11 g/cm^3 about the initial value at the green point at 30%. Of course, the volumetric mass density was stable as expected, reaching a value of 0.84 g/cm^3 (Table 2). Applying the t-test analysis for the bulk density, we observed that their means rejected the null hypothesis of mean equality, that is, the moisture content showed a significant difference in the means when it was decreased from 30% to 12% (P-value < 0.05).

Being stable to moisture content, volumetric mass density has not revealed changes. In short, this eucalypt variety could be classified as high-density wood according to the prescriptions from Coradin *et al*. (2010), Silva, Vale e Miguel (2015), and Silveira, Rezende e Vale (2013).

Concerning the modulus of rupture properties of *Eucalyptus paniculata wood*, only the perpendicular tensile decreased (0.1 MPa) in this studied condition of moisture reduction. The other four properties evinced increases of 20.2 MPa in parallel compression, 2.3 MPa in perpendicular compression, 44.6 MPa in parallel tensile, and 33.8 MPa in static bending (Table 3).

The t-test for moduli of rupture showed only the property of perpendicular tensile to the grain did not reject the null hypothesis of mean equality, *i.e.*, the moisture content did not present a significant difference in the means when it was changed from 30 to 12% (Table 3). The other four properties indicated visible differences (P-value < 0.05). But, Pizzol, Nogueira e Lombardi (2011) found a greater modulus of rupture in perpendicular compression.

In the studied moisture reduction for the modulus of elasticity of *Eucalyptus paniculata* wood, all properties showed increases compared to their initial values (Table 4): perpendicular compression (271.5 MPa), parallel compression (3672.2 MPa), parallel tensile (4315.0 MPa), and static bending (4598.3 MPa). The t-test for the moduli of elasticity indicated that all these four properties rejected the null hypothesis of mean equality. In other words, the moisture content presented significant differences in their means with its reduction (P-value < 0.05). But, Pizzol, Nogueira e Lombardi (2011) reached a lower modulus of elasticity in perpendicular compression.

In Table 5, for the same observed moisture reduction, all properties showed increases compared to their initial values: shear stress (4.9 MPa), parallel hardness (2.56 kN), perpendicular hardness (2.67 kN), tangential cleavage (0.09 MPa), and tangential toughness (3.3 N.m). The t-test identified only tangential cleavage did not reject the null hypothesis of mean equality, that is, without significant difference in the means with moisture content reduction from 30% to 12%. Then, shear stress, parallel and perpendicular hardness, and tangential toughness indicated a rejection of this null hypothesis (P-value < 0.05), being the opposite way.

Therefore, *Eucalyptus paniculata* wood could be efficiently applied for civil construction because the obtained mechanical properties were similar to properties prescribed by the Brazilian standard ABNT NBR 7190 (1997).

In general, the properties were superior to other eucalypts such as urophylla, grandis, umbra, maidenii, camaldulensis, saligna, and alba studied, respectively, by Lahr *et al*. (2017, 2018) and Nogueira *et al*. (2018a, 2018b, 2018c, 2019a, 2019b).

Formerly, timber-based buildings were developed from local forestry resources (ZANI, 2013). For example, *Araucaria angustifolia* was the main native species applied for clapboard-and-wainscot housing construction as identified by Imaguire Junior and Imaguire (2011). However, legal restrictions and slow propagation decreased the use of araucarias. In the *Araucaria angustifolia* characterization studied by Melo *et al*. (2010), this species was notably less resistant than *Eucalyptus paniculata* wood regarding the elasticity and rupture moduli, shear stress, and cleavage properties. This result also confirmed the relevant potentiality of paniculata wood as structural lumber for construction.

6 Conclusion

From the 14 mechanical properties evaluated of the *Eucalyptus paniculata*, two properties did not change their resistance to the moisture reduction: modulus of rupture in perpendicular tensile to grain and tangential cleavage.

The other properties indicated significant differences in their resistances, according to the t-test. Moduli of rupture of parallel and perpendicular compression and static bending increased their resistance in this study, with moisture decreasing from 30% to 12%. In this similar condition, all moduli of elasticity and the properties of shear stress, parallel and perpendicular hardness, and tangential toughness also increased their respective properties. Bulk density also decreased with this moisture content reduction. In a confrontation with similar studies for other eucalypt species, Eucalyptus paniculata wood also achieved good mechanical performance, being very useful as structural lumber-based elements for construction ends.

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