SIXTEEN PROPERTIES OF *Eucalyptus tereticornis* WOOD FOR STRUCTURAL USES

DEZESSEIS PROPRIEDADES DA MADEIRA DE Eucalyptus tereticornis *PARA USOS ESTRUTURAIS*

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ABSTRACT: Forest Red Gum eucalypt provides a versatile wood and is converted into different purposes. However, such wood is somewhat limited in structural ends, which highlights the need to exploit this gap through diffusion of mechanical properties of such timber. This study aimed to evaluate the effect of moisture content reduction, from 30 to 12%, in physical and mechanical properties of *Eucalyptus tereticornis*, using Brazilian and American documents, to reinforce the structural potential wood and assisting engineers and architects in decision-making for its best building application. We evaluated two physical and fourteen mechanical properties of *Eucalyptus tereticornis* at two different moisture contents, following the prescriptions of Brazilian (ABNT NBR 7190: 1997) and North American (ASTM D-143-14: 2014) standards. Thus, 1091 repeats were carried out for all properties. By a moisture reduction, the bulk density and eleven strength properties statistically showed changes such as modulus of rupture (static bending, parallel and perpendicular compressions), modulus of elasticity (perpendicular compression and static bending), shear stress, tangential cleavage, and parallel and perpendicular hardnesses. Then, the *Eucalyptus tereticornis* timber could be better usable if is further applied for structural construction uses.

KEYWORDS: Eucalypt. Timber. Moisture content. Density. Strength.

INTRODUCTION

Forest Red Gum is standard trade name for *Eucalyptus tereticornis* Smith (WALLIS, 1970; RAO et al., 2002; PAYNE; CHALMERS; LAXTON, 2012). Its trees occur in the Australian regions of New South Wales, Queensland, and Victoria (WALLIS, 1970; BEAN, 2013), having the most extensive latitudinal distribution of its genus (BOLAND et al., 2006). Also, such species is found in the United States (FOELKEL; BARRICHELO; MILANEZ, 1975; ROCKWOOD, 2012), Mexico (FOROUGHBAKHCH et al., 2017), Brazil (SILVA et al., 2007; QUEIROZ et al., 2010; MENTONE et al., 2011; SEGUNDINHO et al., 2015), Argentina (VILLAS BÔAS et al., 2009), Colombia (LÓPEZ; BARRIOS; TRINCADO, 2015), India (SHARMA et al., 2005; VARGHESE et al., 2008; CHEZHIAN et al., 2010), and Nigeria (ADEGBEHIN; OKOJIE; NOKOE, 1988) as well as in Ecuador, Uruguay, Chile, Guyana, South Africa, Portugal and Turkey (FAO/UN, 1981). Greater preferences in plantations are due to its fast growth, wide adaptability to varied weather conditions, and high drought resistance (RAO et al., 2002), being among the main cultivated eucalypts in Brazil (QUEIROZ et al., 2010).

Eucalyptus tereticornis is a medium-sized to tall tree (Figure 1a), from 20 to 50 meters in height and up to 2 meters in diameter, with a generally straight and clear trunk (BOLAND et al., 2006), thin barks (GAVA et al., 1995), being versatile member (AGGARWAL et al., 2012) and an important forest crop plant, whereas is used for wide purpose range such as shade and shelter, agroforestry, and industry (DORAN; BROPHY, 1990). Tereticornis leaves are used to produce coolant extracts (BADRUNNISA; VINITHA, 2017), larvicidal oils (NATHAN, 2007), and medicinal oils (DORAN; BROPHY, 1990; NAGPAL et al., 2010; GUILLÉN et al., 2015).

Hard and heavy, *Eucalyptus tereticornis* timber has dark red colored heartwood (WALLIS, 1970; FAO/UN, 1981) with moderately fine texture and interlocked grain (Figure 1b). Its sapwood is pale, yellowish, and susceptible to attack by *Lyctus* (BOLAND et al., 2006), whose heat modification reduces such borer attacks (POONIA; TRIPATHI, 2016). This timber is durable and has been used for poles, sills, paving blocks, flooring, and bearings in

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windmills (WALLIS, 1970). Also, tereticornis wood is weather-resistant and could present 25-year soil-exposure durability as suggested by the Australian Standard (AS 5604:2005).

(a)   (b)

Figure 1. *Eucalyptus tereticornis*: (a) tree (Source: Noosa's Native Plants, 2007), and (b) flattened surface of its timber after machining process (Source: Hurford Hardwood, 2020).

Also, this wood is applied for construction (GUTIÉRREZ, 1976; SEGUNDINHO et al., 2015), solid wood products (CHAUHAN; AGGARWAL, 2011), railway sleepers (FAO/UN, 1981), fuelwood (AHIMANA; MAGHEMBE, 1987; GREWAL; SINGH; JUNEJA, 1993; DHANDA; SINGH; GILL, 2005), posts, drawers, stanchions for mining (ALVARADO; ALVARADO; MENDOZA, 2003), plywood and fiberboard (GUTIÉRREZ, 1976), rayon (SUGAVANAM; UDAIYAN; DEVARAJ, 2000), pulp and paper (FOELKEL; BARRICHELO; MILANEZ, 1975; GUTIÉRREZ, 1976; DORAN; BROPHY, 1990; VILLAS BÔAS; MAX; MELO, 2009; DASGUPTA; CHEZHIAN; YASODHA, 2010; UMADEVI; AVUDAINAYAGAM, 2013).

Due to extensive studies for pulp and paper and the lack of timber characterization for structural purposes, this study aimed to evaluate the effect of moisture content reduction, from 30 to 12%, in sixteen physical and mechanical properties, using Brazilian and American documents, to reinforce the structural potential of *Eucalyptus tereticornis* wood.

MATERIAL AND METHODS

Thirteen *Eucalyptus tereticornis* trees were harvested in five cities at São Paulo state, Brazil, whose timber was obtained from log conversion into sawn wood (beams). Table 1 indicated this information as well as the age of each harvested tree and its respective diameter at breast height.

Two physical properties were the bulk and volumetric mass densities, which were tested using the standard prescriptions from the Brazilian ABNT NBR 7190:1997 document. By means of American ASTM D-143-14:2014 and Brazilian ABNT NBR 7190:1997 documents, the following mechanical properties were studied at 30% moisture condition: modulus of rupture in static bending, parallel and perpendicular compressions to grain, parallel and perpendicular tensiles to grain; modulus of elasticity in static bending, perpendicular and parallel compressions to grain, parallel tensile to grain; and, shear stress, tangential cleavage, tangential toughness, parallel and perpendicular hardnesses.

Table 1. Specific details of *Eucalyptus tereticornis* wood samples.

Log number	Beam amount by log	Age (year)	Diameter (m)	Region of Origin
1	2	39	0.240	Rio Claro
2	2	39	0.230	Rio Claro
3	1	39	0.235	Rio Claro
4	1	28	0.200	Corumbataí
5	1	28	0.185	Corumbataí
6	1	28	0.220	Corumbataí
7	1	28	0.210	Corumbataí
8	3	40	0.295	Rio Claro
9	2	40	0.275	Manduri
10	2	40	0.250	Rio Claro
11	9	46	0.310	Pradópolis
12	4	46	0.295	Pradópolis
13	9	28	0.253	Restinga

Eucalyptus tereticornis wood samples were produced and standardized in shape and dimensions with respect to prescriptions from these respective standard documents, and submitted in a predrying stage to regularize their moisture content in a stable green point at 30%. Half of samples were dried at 12%. All samples were tested in both moisture contents (30 and 12%), together with a universal testing machine. This research inquired the influence of these two moisture contents for two physical and fourteen mechanical properties, comparing their progresses by means of testing of *Eucalyptus tereticornis* wood, such as were followed by Lahr et al. (2017) and Nogueira et al. (2018a,b,c). In total, 1091 repeats were performed.

Due to the consideration of sampling independence, randomization of sampling process, and the normality admission, the t-test was utilized to verify statistical differences among results at both moisture conditions of 30 and 12%, similarly to those analyses from Lahr et al. (2017) and Nogueira et al. (2018a,b,c). For this, statistical hypotheses of interest were established, where in the first condition (H_0: $\mu_1 = \mu_2$) there is no statistical differences, and in the second one (H_1: $\mu_1 \neq \mu_2$) these means do differ. This test considered distinct and unknown variances, and the decision was based on the P-value associated to a significance level of 5%. Lastly, the hypothesis of average equality is rejected if the P-value associated is less than 5%.

RESULTS

This research was based on physical and mechanical properties evaluation of *Eucalyptus tereticornis* species because of lack of information about this timber characterization for construction. In short, this gap has not been filled, because recent studies only have evaluated its timber properties essentially for decay resistance, weather resistance, and/or natural durability such as revealed Carvalho et al. (2016), Delucis et al. (2016a; 2016b), Lazarotto et al. (2016). Then, this present research is necessary for better utilization of this species in timber industry.

Tables 2, 3, 4 and 5 respectively refer to results for properties of densities, modulus of rupture, modulus of elasticity and other mechanical properties for *Eucalyptus tereticornis* wood species. Information described in each table involves moisture content (MC), number of repeats (n), and standard deviation (sd). The average of each studied property was described as M_D for densities, M_R for modulus of rupture, M_E for modulus of elasticity, and M_O for other properties.

In the analyzed condition of moisture reduction from 30% to the standard point at 12% (ABNT NBR 7190: 1997), bulk density notably decreased 18.92% (0.21 g/cm^3), as well as volumetric mass density was 0.70 g/cm^3, being stable as expected for this property (Table 2).

Table 2. Densities of *Eucalyptus tereticornis*.

Characteristic	MC	n	M_D	sd	P-value
Bulk Density (g/cm³)	30	29	1.11	0.09	0.0000
	12	26	0.90	0.10	
Volumetric Mass Density (g/cm³)	30	29	0.70	0.07	–
	12	26	0.70	0.07	

MC: moisture content (%); n: number of repeats; M: property average; sd: standard deviation.

Table 3. Modulus of rupture properties of *Eucalyptus tereticornis*.

Characteristic	MC	n	M_R	sd	P-value
Parallel Compression (MPa)	30	37	45.4	8.9	0.0000
	12	36	57.7	9.7	
Perpendicular Compression (MPa)	30	38	4.4	1.7	0.0395
	12	32	5.7	3.1	
Parallel Tensile (MPa)	30	38	81.6	35.9	0.0014
	12	30	116.0	45.8	
Perpendicular Tensile (MPa)	30	39	3.1	1.3	0.0000
	12	32	4.6	1.4	
Static Bending (MPa)	30	35	81.1	15.6	0.0001
	12	33	131.0	65.4	

MC: moisture content (%); n: number of repeats; M: property average; sd: standard deviation.

Tables 3 to 5 demonstrated increases in all mechanical properties: modulus of rupture such as 21.32% (12.3 MPa) in parallel compression, 22.81% (1.3 MPa) in perpendicular compression, 29.66% (34.4 MPa) in parallel tensile, 32.61% (1.5 MPa) in perpendicular tensile, and 38.09% (49.9 MPa) in static bending; modulus of elasticity such as 7.59% (1311.8 MPa) in parallel compression, 26.21% (156.3 MPa) in perpendicular compression, 11.11% (2057.0 MPa) in parallel tensile, and static bending 16.10% (2811.8 MPa); and in other five studied strength properties such as 20.99% (3.4 MPa) in shear stress, 28.00% (0.28 MPa) in tangential cleavage, 25.61% (2.53 kN) in perpendicular hardness, 24.04% (2.18 kN) in parallel hardness, and 19.44% (2.8 N.m) in tangential toughness.

Table 4. Modulus of elasticity properties of *Eucalyptus tereticornis*.

Characteristic	MC	n	M_E	sd	P-value
Parallel Compression (MPa)	30	37	15973.5	4779.6	0.2812
	12	36	17285.3	5503.0	
Perpendicular Compression (MPa)	30	38	440.1	175.1	0.0142
	12	32	596.4	307.8	
Parallel Tensile (MPa)	30	38	16451.6	6570.4	0.1778
	12	30	18508.6	5858.7	
Static Bending (MPa)	30	35	14652.6	3643.9	0.0031
	12	33	17464.4	3880.0	

MC: moisture content (%); n: number of repeats; M: property average; sd: standard deviation.

Table 5. Other properties of *Eucalyptus tereticornis*.

Characteristic	MC	n	M_O	sd	P-value
Shear Stress (MPa)	30	39	12.8	1.7	0.0000
	12	36	16.2	2.7	
Tangential Cleavage (MPa)	30	37	0.72	0.19	0.0000
	12	33	1.00	0.25	
Perpendicular Hardness (kN)	30	29	7.35	0.90	0.0000
	12	36	9.88	1.65	
Parallel Hardness (kN)	30	38	6.89	1.06	0.0000
	12	36	9.07	1.96	
Tangential Toughness (N.m)	30	37	11.6	6.4	0.1067
	12	31	14.4	7.5	

MC: moisture content (%); n: number of repeats; M: property average; sd: standard deviation.

DISCUSSION

Through this observed moisture content reduction from 30% to 12%, only bulk density has decreased its value, and volumetric mass density remained stable such as was fully expected for this test (Table 2).

In analysis of these results by t-test, we observed that, for bulk density, there was a rejection of the null hypothesis of mean equality (Table 2), *i.e.*, moisture content indicated a significant difference in the averages when moisture content of the *Eucalyptus tereticornis* was reduced from 30 to 12% (P-value<0.05).

Volumetric mass density (Table 2) is within the range – from 0.55 to 1.0 g/cm^3 – established by Alvarado, Alvarado and Mendoza (2003), Gutiérrez (1976), and Pereira et al. (2000).

In relation to mechanical testing, all five modulus of rupture properties rejected the null hypothesis of mean equality (Table 3) by t-test, *i.e.*, moisture content had significant difference in these averages when the moisture content was reduced from 30 to 12% (P-value<0.05). For modulus of elasticity, parallel tensile and compression did not reject the null hypotheses of mean equality (Table 4), considering that static bending and perpendicular compression tests had visible average differences with moisture reduction (P-value<0.05). However, shear stress, tangential cleavage, perpendicular and parallel hardnesses properties rejected the null hypothesis of mean equality (Table 5), *i.e.*, the moisture content indicated a significant difference in the averages when the moisture content is reduced (P-value<0.05). Only tangential toughness did not reject the null hypothesis, which revealed the non-significant average difference from cited reduction.

Comparing these results to ones found to *Eucalyptus umbra* (NOGUEIRA et al., 2018a), *Eucalyptus camaldulensis* (NOGUEIRA et al., 2018b), *Eucalyptus maidenii* (NOGUEIRA et al., 2018c), and *Eucalyptus urophylla* (LAHR et al., 2017), the *Eucalyptus tereticornis* timber is efficient from the structural point of view (Tables 3 to 5), being interesting for heavy and light buildings and rural uses due to result similarities. In addition, this study reinforced that tereticornis species could be useful in these purposes, testifying Gutiérrez (1976) and Boland et al. (2006) similar affirmations from their eucalypt "encyclopedic studies", despite their non-specification of any numerical value for *Eucalyptus tereticornis* mechanical properties.

CONCLUSIONS

Bulk density presented a visible decrease with the moisture content reduction from 30 to 12%, while volumetric mass density remained obviously stable in accordance to the expected;

All mechanical properties increased significantly their values when the moisture content was reduced. However, statistically, eleven strength properties showed changes in this analysis: modulus of rupture in static bending, and parallel and perpendicular compressions, modulus of elasticity in perpendicular compression and in static bending, shear stress, tangential cleavage, parallel and perpendicular hardnesses.

Most of mechanical properties showed significant increases with the moisture reduction and, similarly to other studied eucalypt wood species, *Eucalyptus tereticornis* could also be better usable if is further applied for structural solid elements and parts for construction.

RESUMO: Eucalipto de goma vermelha prove uma madeira versátil e é convertido para diferentes propósitos. Porém, essa madeira é um pouco limitada para fins estruturais, o que destaca a necessidade de explorar essa lacuna mediante à difusão das propriedades mecânicas de tal madeira. Os resultados obtidos deverão auxiliar os engenheiros e arquitetos na tomada de decisão para a sua melhor aplicação construtiva. Esse artigo estudou a avaliação de duas propriedades físicas e catorze propriedades mecânicas do *Eucalyptus tereticornis* em dois teores de umidade, seguindo as prescrições dos documentos normativos brasileiro (ABNT NBR 7190: 1997) e norte-americano (ASTM D-143-14: 2014). Assim, 1091 repetições foram conduzidas para todas essas propriedades. Pela redução de umidade de 30% para 12%, a densidade aparente e onze propriedades de resistência demonstraram estatisticamente mudanças, tais como módulos de ruptura (flexão estática e compressões paralela e perpendicular), módulos de elasticidade (compressão perpendicular e flexão estática), cisalhamento, fendilhamento e as durezas perpendicular e paralela. Então, a madeira de *Eucalyptus tereticornis* poderia ser melhor utilizável se for também aplicada para usos construtivos estruturais.

PALAVRAS-CHAVE: Eucalipto, Madeira, Teor de umidade, Densidade, Resistência.

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