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WOOD UTILIZATION OF *Eucalyptus grandis* IN STRUCTURAL ELEMENTS: DENSITIES AND MECHANICAL PROPERTIES

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KEYWORDS

Rose Gum, eucalypt, mechanical properties, bulk density.

ABSTRACT

Over the years, the species of eucalyptus has become a multipurpose raw material. In addition, the most relevant aspect of the use for various purposes is related to the production of a high quality wood, coming from short duration plantations, which is fundamental to the current demand of the industries. However, its use in civil construction has not yet reached a level of importance, due to the low knowledge of many of its resistance properties and the consequent popular fear in the use of reforestation woods, in particular the *Eucalyptus grandis*. This research investigated its main mechanical properties, aiming to reinforce its constructive applications in wood structures. For this, two physical properties and fourteen mechanical properties, in two different moisture conditions of the samples were evaluated, according to the norm NBR 7190 (1997). In the first moisture content, the samples were stabilized at 30%, while the second level considered the content of 12%. It was obtained 3580 determinations for the sixteen properties. From the 14 mechanical properties, only 7 had significant increases with the moisture reduction (30% to 12%), consisting of the rupture modulus in the parallel and normal compressions, normal traction and static bending; modulus of elasticity in normal compression and static bending and in shear strength.

INTRODUCTION

The use of forest resources under the multiple use perspective aims at product diversification, value aggregation and profit maximization, and it has been intensified through the initiative of the sector's entrepreneurs and researches that are the basis for the development of these initiatives (Christoforo et al., 2017).

The man-made forests have increased their area on a global scale in recent decades and are used for productive purposes, such as in timber production, and ecosystem services such as soil conservation and biodiversity (Stephens & Grist, 2014).The reforestation wood has proved to be a promising material for civil construction, because of its relevance in the environmental context and because of its quality (Santos & Aguilar, 2007), so if handled correctly as in reforestation, it must be associated with the good image of a sustainable architectural product (Szücs, 2006: Silva, 2016). Numerous successful applications of reforestation wood in industrialized countries have enabled technological development in the construction sector, which has increased its possibilities in the use of buildings (Santos & Aguilar, 2007). The planted forest can generate a variety of raw materials, such as: essential oils, resins and woods, the lasts ones geared towards multiple uses.

Brazil is one of the countries with the largest forested and reforested area in South America, where, in the south, with the native forest practically extinct, there are reserves of reforestation wood of the eucalyptus or pine type (Szücs, 2006).

The eucalyptus wood presents a number of well-known advantages, such as the consolidated management crop, rapid growth and the great availability of plantations (Peres et al., 2015). The range of potential products that can be generated from eucalyptus wood is broad, such as plywood panels, laminated wood, sawn timber, telephone and electrical poles, building anchors, posts, charcoal, cellulose and paper, buildings structural parts with pliable parts etc. (Lahr et al., 2017).

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From the Myrtaceae family, the *Eucalyptus grandis* is an internationally recognized species by the trade names of Rose Gum or Flooded Gum (Grattapaglia et al., 2012). A native from Australia has proliferated mainly in large forests in the North Coast, New South Wales and Queensland districts, as well as being the most planted forest species in Brazil. Widely planted in the tropics, through the intensive management of short rotation, this species aims to meet the great demand of raw material, for example, the cellulose and paper industry. Under favorable conditions, the *Eucalyptus grandis* can grow from a small seed to a 10 meters high tree or more in two years (Lahr et at., 2017). From tall forests, it usually reaches from 45 to 55 meters of height with a diameter in the height of the breast between 1.2 to 2 meters, revealing a straight trunk. With a core hard to be treated and permeable sapwood, the *Eucalyptus grandis* wood is considered of moderate durability to rotting fungi and termites, as well as being of low durability to soft rot fungi and soil termites.

The wood of *Eucalyptus grandis* is light, fairly hard and easily workable. It has a straight fiber, easily cracks and has a light reddish color, being that its heartwood has dark reddish color and its sapwood presents light color and has susceptibility to *Lyctus* (Christoforo et al., 2015). It consists of a sawmill wood, with good planning, sanding, turning, drilling and finishing characteristics, however, it requires the use of appropriate debris techniques to minimize the effects of growth stresses.

In addition, some studies have focused on the *Eucalyptus grandis* wood for alternative uses, such as cement-wood panels (Iwakiri & Prata, 2008), thermally treated wood (Modes et al., 2013, Cademartori et al., 2015), furniture, small objects (Vieira et al., 2010), composite panel (Iwakiri et al., 2013), sawn lumber for structural applications (Monteiro et al., 2013) (Peres et al., 2015), curved sawn beams (Peres et al., 2015), OSB particulate panels (Okino et al., 2008), LVL laminated panels (Lara Palma & Ballarin, 2011), and so on.

Studies with the aim of evaluating the behavior of post-treatment wood species at high temperatures, such as thermally treated wood, have been the focus of some researches, such as those developed by Araújo et al. (2012), Cademartori et al. (2012), Bal & Bektas (2013), Zanuncio et al. (2014) and Calonego et al. (2016), however, it is important to highlight the lack of information on the physical and mechanical properties of species with potential use in structures, such as the *Eucalyptus grandis* wood evaluated in this research, and which can corroborate to a safer structural design. Yet about the properties of the Eucalyptus wood, among other species, the non-destructive testing techniques have been used in the characterization, as discussed in the studies of Kobori et al. (2013) and Pinto et al. (2014).

The definition of the age at which the species makes the transition from juvenile wood to adult wood has been evaluated in several studies (Bal & Bektas, 2013, Palermo et al., 2015, Zanuncio et al., 2017). Evidently, adult wood is the aim of study of this research. If the definition of the transition age were clearly demonstrated, it would be possible to have adult wood with lower ages than the various ones studied here.

In times of drastic changes in the planet climate, it is the duty of the productive sector to look for certified raw materials that value the forests and, consequently, contribute to the reduction of greenhouse gases (Hamú, 2009). According to Altoé & Alvarez (2011), the environmental movements and popular awareness about the end of natural resources press for constructive activities to adopt less impactful solutions that guarantee the management and use of buildings based on the principles of sustainability.

However, during the search for exotic species and less impacting solutions, the stability of the wood must be observed and assured in the civil construction sector. An example of this is stated by Perstorper et al. (1995), which indicate that the quality of the structural wood must be defined in terms of stability, strength and stiffness.

The changes in timber quality and utilization relate to trends of lower harvesting and logging, new and lower quality timber, widespread use of residual wood, unconventional timber uses, improved forest management and new timber manufacturing techniques (Zobel, 1984). Within these reasons that allow inconsistencies in wood quality, the use of lower quality wood and the unconventional uses of wood are the main possibly negative characteristics to be observed in structural applications, since these can compromise the construction safety if the minimum resistance of certain properties is not ensured. Therefore, it is fundamental to perform physical-mechanical tests, which can help to indicate the most efficient use and for each species of wood. The tests can be carried out according to prescriptions established by normative documents, such as ABNT NBR 7190 (1997) current in Brazil for wood structures.

In this context, this research aimed to evaluate the *Eucalyptus grandis* wood by conducting the main physical and mechanical tests contemplated in the NBR 7190 (1997) standard considering two different moisture contents, one in the green state at 30% and the other at the pattern at 12% indicated by the standard, to ensure its use in constructions with wooden structure, such as houses, sheds, covers, roofs, bridges, silos, etc.

MATERIAL AND METHODS

The wood logs, whose specifications are presented in Table 1, were placed in the premises of the Laboratory of Wood and Wood Structures (LaMEM), School of Engineering of São Carlos (EESC), University of São Paulo (USP).

TABLE 1. Details of wood samples from *Eucalyptus grandis*.

Number of Logs	Number of Beams	Age (year)	Diameter (m)	Region
1	3	34	0.299	Rio Claro
2	2	34	0.295	Rio Claro
3	2	34	0.295	Rio Claro
4	7	8	0.235	Mogi-Guaçu
5	5	8	0.220	Mogi-Guaçu
6	8	41	0.326	Camaquã
7	6	41	0.315	Avaré
8	2	41	0.308	Camaquã
9	4	13	0.220	Itirapina
10	5	13	0.215	Itirapina
11	2	13	0.210	Itirapina
12	3	9	0.252	Jundiaí
13	2	9	0.236	Jundiaí
14	2	9	0.209	Jundiaí
15	2	9	0.230	Jundiaí
16	2	12	0.184	Jundiaí
17	2	12	0.172	Jundiaí
18	2	12	0.184	Jundiaí
19	1	12	0.160	Jundiaí
20	2	14	0.242	Jundiaí
21	2	14	0.231	Jundiaí
22	2	14	0.197	Jundiaí
23	1	14	0.192	Jundiaí
24	1	24	0.289	Restinga
25	3	24	0.286	Restinga
26	2	24	0.285	Restinga
27	6	15	0.278	Lençóis Paulista
28	4	15	0.277	Lençóis Paulista
29	7	15	0.280	Lençóis Paulista
30	4	15	0.275	Lençóis Paulista
31	2	15	0.236	Lençóis Paulista
32	4	13	0.239	Lençóis Paulista
33	6	13	0.255	Lençóis Paulista
34	4	13	0.240	Lençóis Paulista
35	1	13	0.215	Lençóis Paulista
36	4	13	0.235	Lençóis Paulista

The physical and mechanical properties investigated (Table 2) for the *Eucalyptus grandis* wood in the two moisture contents (12, 30%) were obtained according to the recommendations of Brazilian Standard ABNT NBR 7190 (1997).

TABLE 2. Physical and mechanical properties evaluated.

Initials	Denomination
ρ_{bk}	Bulk density
ρ_b	Basic density
f_{c0}	Resistance in parallel compression to fibers
f_{c90}	Resistance in perpendicular compression to fibers
f_{t0}	Resistance in parallel traction to fibers
f_{t90}	Resistance in perpendicular traction to fibers
f_M	Resistance in static bending
f_V	Resistance in Shear
f_{fe}	Resistance in Cracking
f_{H0}	Hardness in the parallel direction to the fibers
f_{H90}	Hardness in the perpendicular direction to the fibers
W	Tenacity
E_{c0}	Modulus of elasticity in parallel compression to the fibers
E_{c90}	Modulus of elasticity in perpendicular compression to the fibers
E_{t0}	Modulus of elasticity in parallel traction to the fibers
E_M	Modulus of elasticity in static bending

This research sought to create a comparison between the 12% moisture (suitable for structural purposes) and the green wood (saturated) to identify the effect of moisture content on the evaluated properties. In total, 3580 determinations were obtained in this study.

The t-test, at the 5% level of significance, was used to investigate the influence of moisture content on each of the evaluated properties. The null hypothesis (H_0) consisted of the equivalence of the two treatments averages (12 and 30%), and no equivalence as an alternative hypothesis. By the hypotheses formulation, P-value (P probability) greater or equal to 5% implies in accepting H_0 (not influence of the moisture in the properties), and to reject it, otherwise (influence of the moisture content).

RESULTS AND DISCUSSION

The results are shown in Tables 3, 4, 5 and 6, which were divided respectively according to their analyzed variables, densities, rupture modulus, elasticity modulus and other resistance properties. The average values of the physical and mechanical properties obtained from this research in the respective moisture content are in accordance with the results of Santos et al. (2003). Wiedenhoeft (2010), Cademartori et al. (2012), Bal & Bektas (2013), Christoforo et al. (2015), Lahr et al. (2017) and also with the Brazilian standard ABNT NBR 7190 (1997).

TABLE 3. Density results of *Eucalyptus grandis* wood specie.

Properties	MC (%)	n	M_D	SD	P-value
Bulk density (g/cm³)	12	118	0.63	0.15	---
Basic density (g/cm³)	30	114	0.51	0.11	0.4699
	12	118	0.50	0.10	

MC: moisture content; n: number of determinations; M_D: mean densities; SD: standard deviation.

Table 3 shows that the basic density of wood was not affected by the moisture content, resulting in equivalent values, which is common in similar studies, such as the one developed by Wiedenhoeft (2010). Table 4 shows the results of the resistance values of the *Eucalyptus grandis* wood in the two moisture contents considered.

TABLE 4. Rupture modulus results of *Eucalyptus grandis* wood specie.

Properties	MC (%)	n	M_{RM}	SD	P-value
Parallel Compression (MPa)	30	109	33.5	7.6	0.0000
	12	113	40.1	11.4	
Normal Compression (MPa)	30	114	3.6	1.6	0.0003
	12	112	4.4	1.7	
Parallel Traction (MPa)	30	105	67.4	28.6	0.4894
	12	109	70.3	32.6	
Normal Traction (MPa)	30	113	2.6	0.9	0.0030
	12	114	3.0	1.1	
Static bending (MPa)	30	110	64.4	14.9	0.0008
	12	110	71.9	17.8	

MC: moisture content; n: number of determinations; M_{RM}: average of the resistance modulus; SD: standard deviation.

Table 4 shows significant increases (P-value <0.05) for all rupture modulus with the reduction of moisture content, being 16.46% in parallel compression (6.6 MPa), 18.18% in normal compression (0.8 MPa), 4.13% in parallel traction (2.9 MPa), 13.33% in normal traction (0.4 MPa) and 10.43% in bending (7.5 MPa), similar behavior was obtained from the research developed by Lahr et al. (2016), showing that the increase in moisture content significantly impacts the reduction of wood resistance properties. Table 5 presents the results of the obtained elastic modulus.

TABLE 5. Elasticity modulus results of *Eucalyptus grandis* wood specie.

Characteristic	MC (%)	n	M_{EM}	SD	P-value
Parallel Compression (MPa)	30	109	12515.5	3725.4	0.7138
	12	113	12696.7	3622.6	
Normal Compression (MPa)	30	114	360.6	161.0	0.0003
	12	112	443.2	174.5	
Parallel Traction (MPa)	30	105	13922.0	4614.3	0.2531
	12	109	14576.3	3663.4	
Static bending (MPa)	30	110	10978.1	3018.8	0.0043
	12	110	12086.4	2758.7	

MC: moisture content; n: number of determinations; M_{EM}: average of elasticity modulus; SD: standard deviation.

From the four values of stiffness investigated, only the results of normal compression and static bending were significantly affected by the moisture content, in which the reduction from 30% to 12% promoted increases in the values of these two properties, the same did not occur with compression and parallel traction (P-value> 0.05). Table 6 shows the results of the other mechanical properties evaluated.

TABLE 6. Results of other mechanical properties of *Eucalyptus grandis* wood specie.

Characteristic	MC (%)	n	M_{OP}	SD	P-value
Shear (MPa)	30	113	9.6	2.0	0.0000
	12	113	11.6	2.8	
Cracking (MPa)	30	113	0.66	0.17	0.9745
	12	117	0.64	0.26	
Normal Stiffness (kN)	30	111	4.55	1.40	0.2307
	12	113	4.84	2.14	
Parallel Stiffness (kN)	30	111	4.03	1.75	0.8681
	12	113	4.07	1.85	
Tenacity (N·m)	30	110	10.7	5.2	0.1952
	12	111	11.7	6.2	

MC: moisture content; n: number of determinations; M_{OP}: average of the other resistance properties; SD: standard deviation.

From Table 6, only the shear strength was significantly affected by the variation in moisture content, as discussed in the study of Lahr et al. (2016), which increased by 17.24% with a reduction from 30% to 12% of moisture, while the other properties were independent of the moisture content. The increase in mechanical properties with the reduction of moisture content was also observed in Santos et al. (2003).

CONCLUSIONS

The results of this research make possible to conclude that:

- the basic density was not significantly affected by the variation of moisture content, as found in correlated research;
- from the 14 mechanical properties evaluated, seven of them suffered significant increases with the reduction of the moisture content, consisting of the rupture modulus in the parallel and normal compressions to the fibers, normal traction to the fibers and static bending; modulus of elasticity in the static bending and in the normal compression to the fibers and shear.

Due to availability, rapid growth and mechanical properties, the *Eucalyptus grandis* wood presents great potential for diverse applications, especially in rural and civil construction.

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