

# Evaluation of *Eucalyptus triantha* Timber for Structural Applications

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**Abstract.** Eucalypt wood is an important raw material with multiple uses applied for furniture, pulp and paper, charcoal, biomass, and construction. Sixteen tests were performed to evaluate physical and mechanical properties of *Eucalyptus triantha*, which could estimate the possibility of utilization of this woody material in construction. In all, about 267 repeats were realized. Two moisture contents were regarded according to the Brazilian and American standard documents: fiber saturation point (30%) and standard dried point (12%). Results were statistically treated with t-test and demonstrated increases in six mechanical properties from *Eucalyptus triantha* wood species: rupture moduli in perpendicular and parallel compressions and static bending; elasticity moduli in parallel tensile, perpendicular compression, and static bending. Volumetric mass and bulk densities were practically stable. Physical and mechanical properties estimation evinced that *Eucalyptus triantha* wood can be used in structural elements.

**Key words:** Eucalypt; wood; density; moisture content; strength

## Avaliação da Madeira de *Eucalyptus triantha* para Aplicações Estruturais

**Sumário.** A madeira de eucalipto é uma importante matéria-prima de múltiplos usos utilizada em móveis, papel e celulose, carvão vegetal, biomassa e construção. Dezesesseis testes foram realizados para avaliar as propriedades físicas e mecânicas do *Eucalyptus triantha*, os quais puderam estimar a possibilidade de utilização desse material madeirável na construção. Ao todo, aproximadamente 267 repetições foram realizadas. Dois teores de umidade foram considerados segundo os documentos normativos brasileiro e norte-americano: ponto de saturação das fibras (30%) e estado seco padrão

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(12%). Os resultados foram estatisticamente tratados com teste t e demonstraram aumentos em seis propriedades mecânicas da madeira de *Eucalyptus triantha*: módulos de ruptura nas compressões normal e paralela e flexão estática; módulos de elasticidade na tração paralela, compressão normal e flexão estática. As densidades básicas e aparentes ficaram praticamente estáveis. A estimativa das propriedades físicas e mecânicas evidenciou que a madeira de *Eucalyptus triantha* pode ser utilizada em elementos estruturais.

**Palavras-chave:** Eucalipto; madeira; densidade; teor de umidade; resistência

#### **Evaluation du Bois d'*Eucalyptus triantha* pour des Applications Structurelles**

**Résumé.** Le bois d'eucalyptus émerge comme une matière première importante à usages multiples utilisé dans meubles, pâtes et papiers, charbon de bois, biomasse et construction. Seize essais ont été effectués pour évaluer les propriétés physiques et mécaniques d'*Eucalyptus triantha*, ce qui pourrait permettre d'estimer la possibilité d'utilisation de ce matériau ligneux dans la construction. En tout, environ 267 rediffusions ont été réalisées. Deux teneurs en humidité ont été considérées selon les documents standard brésiliens et américains: point de saturation des fibres (30%) et point sec standard (12%). Les résultats ont été traités statistiquement avec le test t et ont montré une augmentation de six propriétés mécaniques du bois d'*Eucalyptus triantha*: modules de rupture en compressions parallèles et perpendiculaires et flexion statique; modules d'élasticité en traction parallèle, compression perpendiculaire et flexion statique. La masse volumétrique et les densités en vrac étaient pratiquement stables. L'estimation des propriétés physiques et mécaniques montre que le bois d'*Eucalyptus triantha* peut être utilisé dans les éléments structuraux.

**Mots-clés:** Eucalypt; bois; densité; teneur en humidité; résistance

## Introduction

Forests are set apart by the fact that carbon is stored long-term in wood (WELLBROCK *et al.*, 2017), and eucalypt wood presents good sequestration potential (DU *et al.*, 2015). *Eucalyptus* genus may almost be said to be peculiar to Australia, and from forestry standpoint is the main characteristic of the woodlands and forests from Australian Commonwealth (JOLLY, 1949). This genus is known by its wide genetic variability, whilst hundreds of species with diverse physical and chemical properties make eucalypt woods suitable for several purposes (PEREIRA *et al.*, 2000), *e.g.*, pulp and paper (GOMIDE *et al.*, 1980; SECA and DOMINGUES, 2006; EIRAS *et al.*, 2008; GOUVÊA *et al.*, 2009), structural panels (CARVALHO *et al.*, 2004; CAMPOS and LAHR 2004; TONOLI *et al.*, 2010; MARTINS *et al.*, 2013), biomass for energy (EUFRADE JUNIOR *et al.*, 2016; ARAUJO *et al.*, 2016), small objects (VIEIRA *et al.*, 2008; VIEIRA *et al.*, 2010), essential oils (SILVA *et al.*, 2006), extracts (NOBAKHT *et al.*, 2014; GOMINHO *et al.*, 2015), among other uses. The outstanding characteristics which made the genus famous were the great strength and durability of the timbers yielded by certain species, but nevertheless the range in quality of the various timbers is very wide (JOLLY, 1949). The eucalypt plantations in Brazil have the highest productivity when compared to other producing countries (MELO *et al.*, 2016). Today, forest industries are looking for multiple uses for eucalypt timber production to improve profitability (VIEIRA *et al.*, 2010).

### *White mahogany: the eucalypt of triantha genus*

Among the multiple eucalypt varieties, triantha emerges as a very interesting genus for timber industrialization, which could also contribute with minimization of the native wood utilization, *e.g.*, from Amazon and/or Atlantic forests.

Considered a honey plant, *Eucalyptus triantha* Link originates from Myrtle family (GUTIÉRREZ, 1976; REUBER, 2015), and is considered a synonym for *Eucalyptus acmenoides* Schauer (JACOBSON, 1975; GUTIÉRREZ, 1976; HILL, 1999), which is also defined as white mahogany (RUDMAN, 1962; WALLIS, 1970; GUTIÉRREZ, 1976; REGIONAL FOREST ASSESSMENTS, 1997).

Then, first white mahogany species recognized was *Eucalyptus acmenoides* Schauer (SCHAUER, 1843). This species has a rounded club-shaped flower bud

with an operculum with short tip, and truncated semi-oval fruits with 7-8 x 6-7 millimeters (KUHLMANN, 1946).

Despite its Australian origin (WALLIS, 1970; GUTIÉRREZ, 1976; STOKOE *et al.*, 2001), *Eucalyptus triantha* is also present in Brazil (KUHLMANN, 1946; TOMAZELLO FILHO, 1985; PEREIRA *et al.*, 2000; CASTELLANO *et al.*, 2013), East Africa (KOKWARO, 1994; VERDCOURT, 2001), India (CHOPRA *et al.*, 2006), Morocco (EL YOUSFI, 1992), etc..

*Eucalyptus triantha* tree has slow growth in its initial phase, but it grows rapidly in some regions as in Brazil (GUTIÉRREZ, 1976). This species can reach up to 40 meter tall and 1.2 meter in diameter (GUTIÉRREZ, 1976; HILL, 1999), and has bark persistent to smaller branches, stringy, grey to red-brown (HILL, 1999), which supports low intensity frosts (MARTINEZ-RUIZ *et al.*, 2006).

*Eucalyptus triantha* wood is a hard wood with interlocked grain, and its colour is light yellowish-beige (GUTIÉRREZ, 1976). Its timber is decay (Rudman 1962) and termite resistant (JACOBSON, 1975). Microscopic description of this species involves numerous rays and ducts, scarce confluent parenchyma, short and tight fiber-tracheid, and visible woody rays (TOMAZELLO FILHO, 1985).

Woods obtained from *Eucalyptus triantha* trees have commercial interest and are used in several applications, *e.g.*, charcoal (BRITO *et al.*, 1983), woodworking (GUTIÉRREZ, 1976), apiculture and honey production (REUBER, 2015), etc. Furthermore, *Eucalyptus triantha* is known as one of the best eucalypt species, and its wood could be used in agglomerate panels, sawn wood for carpentry, telegraph poles, sleepers, wagon and carriage work, and construction parts (WALLIS, 1970; GUTIÉRREZ, 1976), as well as this species is suitable in plywood production (GUTIÉRREZ, 1976; JANKOWSKY and AGUIAR, 1983).

Hence, this paper aimed the physical and mechanical characterization of *Eucalyptus triantha* timber, through the supports of Brazilian ABNT NBR 7190 (1997) and American ASTM D143 (2014) standard documents as well as t-test statistical analysis, to explore the potentiality of this timber in construction for structural purposes.

## **Material and methods**

The focus of this study was to evaluate the utilization of *Eucalyptus triantha* wood for civil construction. Then, this wood species was collected in a Brazilian city at São Paulo State. Table 1 showed the basic information of the wooden logs and the respective beams extracted.

**Table 1** - Information of the *Eucalyptus triantha*

Used Log	Log Age	Beams per Log	Diameter (m)	Region (City)
1	31	2	0.260	Rio Claro, Brazil
2	31	2	0.255	Rio Claro, Brazil
3	31	2	0.240	Rio Claro, Brazil
4	31	2	0.230	Rio Claro, Brazil
5	31	2	0.255	Rio Claro, Brazil

In an efficient wood application on structural purposes, these raw materials must be based on their mechanical and physical characterization with wide repetition, i.e., this construction raw material directly correlate with its structural resistances, limiting and restricting its uses. Here, 267 repeats were realized in the tests according to script followed by LAHR *et al.* (2017) and NOGUEIRA *et al.* (2018 a,b). Therefore, both Brazilian ABNT NBR 7190 (1997) and American ASTM D143 (2014) standard documents prescribe the performance of the following studied physical-mechanical tests: compressive strength parallel to grain ( $f_{c0}$ ), and perpendicular to grain ( $f_{c90}$ ); tensile strength parallel to grain ( $f_{t0}$ ), and perpendicular to grain ( $f_{t90}$ ); shear stress parallel to grain ( $f_{v0}$ ); modulus of elasticity in compression parallel to grain ( $E_{c0}$ ) and perpendicular to grain ( $E_{c90}$ ); volumetric mass density ( $\rho$ ) and bulk density ( $\rho_b$ ) with the specimen at 12% of moisture; charpy impact test ( $f_{bw}$ ) with a Charpy pendulum; cleavage ( $f_S$ ); hardness ( $f_H$ ) necessary resistance for a ball penetration to grain.

For these tests implementations, wood samples were conditioned in two moisture contents: a green state at 30%; and a dried wood state at 12% (ABNT NBR 7190, 1997; ASTM D143, 2014) suitable for structural applications.

Considering that samples were submitted to the moisture contents of 12 and 30%, they are independent due to particular characteristics of this woody material. This is observed by SMITH *et al.* (2003), which evaluated that wood is a natural, heterogeneous, anisotropic, hygroscopic material with high strength and stiffness relative to its weight.

Therefore, through the consideration of the samples independence, the randomization in the sampling process, and the admission of the normality, the t-test was applied to verify the differences among the means according to two conditions of moisture content, 12 and 30%. Statistical hypotheses of interest are established by two circumstances:  $H_0: \mu_1 = \mu_2$  (the means do not differ); and  $H_1:$

$\mu_1 \neq \mu_2$  (the means differ). In this study, we considered the t-test for the different and unknown variances. The decision based on P-value associated with the test is assumed to a significance level of 5%, that is, the equality means hypothesis is rejected,  $H_0$  if the P-value associated is less than 5%, or P-value < 0,005.

## Results and discussion

Results were grouped by property with the two moisture content conditions to enable the analyses of the obtained results for *Eucalyptus triantha* wood species. Table 2 showed the results for physical evaluation on density for this wood.

**Table 2** - Results for densities of *Eucalyptus triantha*

Characteristic	MC (%)	r	M	sd	P-Value
Bulk density (g/cm <sup>3</sup> )	30	9	1.14	0.04	0.0000
	12	8	0.76	0.08	
Volumetric mass density (g/cm <sup>3</sup> )	30	9	0.61	0.06	0.6475
	12	8	0.60	0.02	

MC: moisture content; r: repeats; M: property mean; sd: standard deviation.

Through the Table 2, in the situation of moisture content decreasing studied species, from 30% (fiber saturation point) to 12% (standard point) of Brazilian ABNT NBR 7190 (1997) and American ASTM D143 (2014) standard documents, the bulk density decreased 33.3% in relation to its initial value (or 0.38 g/cm<sup>3</sup> reduction), whereas the volumetric mass density was stable, decreasing just 1.64% (or 0.01 g/cm<sup>3</sup> from its initial stage). According to t-test, the bulk density showed influence with the moisture content reduction (P-value < 0,005). In contrast, the volumetric mass density did not had influence with this decreasing. This situation was similar to expected, which was explored by GLASS and ZELINKA (2010), "where the bulk density of oven-dry wood varies significantly between species, as well as within a given species, this density varies because of anatomical character such as the ratio of earlywood to late wood and heartwood to sapwood".

Tables 3 to 5 referred to the results from mechanical evaluation performed for *Eucalyptus triantha* wood species.

Through moisture reduction from 30% to 12%, the evaluated rupture moduli showed by Table 3 an increasing of 23.75% (in order to 12.8 MPa) in parallel compression, 5.5% (or 78.57 MPa) in perpendicular compression, 14.87% (or 15 MPa) in parallel tensile, and 60.94% (or 135.6 MPa) in static bending. Meanwhile, the perpendicular tensile property revealed a decrease of 15.63% (0.5 MPa). Through the t-test, the rupture moduli which presented influence with the moisture content reduction were (P-value < 0,005): static bending, perpendicular and parallel compression tests. In contrast, the perpendicular and parallel tensiles did not have any influence with moisture content.

**Table 3** - Results for rupture moduli of *Eucalyptus triantha*

Characteristic	MC (%)	r	M	sd	P-Value
Parallel Compression (MPa)	30	9	41.1	5.7	0.0022
	12	7	53.9	7.0	
Perpendicular Compression (MPa)	30	10	1.5	0.5	0.0013
	12	7	7.0	2.6	
Parallel Tensile (MPa)	30	9	85.9	30.5	0.3245
	12	8	100.9	30.1	
Perpendicular Tensile (MPa)	30	7	3.2	0.7	0.4544
	12	4	2.7	1.1	
Static Bending (MPa)	30	9	86.9	9.6	0.0002
	12	7	222.5	46.4	

MC: moisture content; r: repeats; M: property mean; sd: standard deviation.

All of the elasticity moduli shared increases in their properties (Table 4) with moisture reduction. Such increases were 64.84% (452.1 MPa) for perpendicular compression, 13.91% (2032.7 MPa) for parallel compression, 22.79% (3541.4 MPa) for parallel tensile, and 19.81% (3171.1 MPa) for static bending. In this case, the wood drying affected positively in the evaluated properties. Then, t-test indicated the elasticity moduli which suffered influence with moisture reduction were: perpendicular compression, parallel tensile, and static bending (P-value < 0,005). Parallel compression did not show influence with this moisture change.

In the aforementioned moisture reduction, the other last strength properties (Table 5) presented increasing and decreasing in their values. In the case of shear stress, and perpendicular hardness, the results revealed an increasing of 18.95% (2.9 MPa), and 13.94% (1050 N), respectively. But, in this moisture

reduction, the properties of cleavage, parallel hardness, and toughness decreased 28.99% (0.2 MPa), 11.80% (800 N), and 43.48% (8.0 N.m), respectively. In the t-test evaluation was verified only a property exceptionally suffers influence with the moisture content reduction: the toughness (P-value < 0,005). Then, the other four properties did not have influence with moisture reduction.

**Table 4** - Results for elasticity moduli of *Eucalyptus triantha*

Characteristic	MC (%)	r	M	sd	P-Value
Parallel Compression (MPa)	30	9	12584.6	2356.0	0.1615
	12	7	14617.0	2930.1	
Perpendicular Compression (MPa)	30	10	245.2	259.3	0.0033
	12	7	697.3	254.5	
Parallel Tensile (MPa)	30	9	12000.6	3484.3	0.0428
	12	8	15542.0	2586.7	
Static Bending (MPa)	30	9	12837.9	2576.7	0.0073
	12	7	16009.0	1292.8	

MC: moisture content; r: repeats; M: property mean; sd: standard deviation.

**Table 5** - Results for other strength properties of *Eucalyptus triantha*

Characteristic	MC (%)	r	M	sd	P-Value
Shear stress (MPa)	30	8	12.4	1.8	0.1506
	12	7	15.3	4.5	
Cleavage (MPa)	30	8	0.69	0.19	0.0596
	12	8	0.49	0.20	
Perpendicular Hardness (N)	30	9	6820.0	1620.0	0.1600
	12	7	7870.0	1210.0	
Parallel Hardness (N)	30	9	7580.0	2010.0	0.3291
	12	7	6780.0	1100.0	
Toughness (N.m)	30	17	18.4	3.2	0.0000
	12	10	10.4	3.7	

MC: moisture content; r: repeats; M: property mean; sd: standard deviation.

In short, the moisture content reduction of *Eucalyptus triantha* wood species contributed - as it expected and revealed by BERGMAN (2010) that stated "the most of wood strength properties increases with drying processes, that is, with



the moisture loss" – to a real improvement of its mechanical properties, enabling its efficient application on structural applications.

## Conclusions

Through the moisture content reduction of *Eucalyptus triantha* wood from 30% to 12%, ten strength properties showed an increasing, propitiating an improvement of the most studied mechanical properties. The improved properties were: four rupture moduli (perpendicular and parallel compressions, parallel tensile, and static bending); four elasticity moduli (perpendicular and parallel compressions, parallel tensile, and static bending); and two other strength properties (shear stress, and perpendicular hardness). Statistically, t-test indicated fifty percent of the mechanical properties suffered influence with the moisture content reduction, that is, three rupture moduli (static bending, parallel and perpendicular compressions); three elasticity moduli (perpendicular compression, parallel tensile and static bending); and one other strength property (toughness). In these seven aforementioned properties, only six evinced increased their values, and only the toughness decreased in this studied condition.

Seven properties did not suffer any influence with moisture decreasing: two rupture moduli (parallel and perpendicular tensile); one elasticity moduli (parallel compression); and four other strength properties (cleavage, shear stress, and perpendicular and parallel hardnesses).

In relation to the physical properties of *Eucalyptus triantha*, its bulk density at 12% decreased comparing to its initial value at 30% of moisture content, and the volumetric mass density was stable such as it was expected. The t-test verified the bulk density had influence with the moisture content reduction, and the volumetric mass density of *Eucalyptus triantha* did not have influence in this condition.

Additionally, these obtained results indicated the *Eucalyptus triantha* is suitable for structural applications, due to the improvement of its mechanical resistance and stability after the moisture content reduction.

## Acknowledgments

We are grateful to the Structural Engineering Department (SET) and Laboratory of Wood and Timber Structures (LaMEM) from Engineering College of São Carlos, both in the University of São Paulo (EESC/USP).

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