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EXPERIMENTAL STUDY ON FULL-SCALE GLULAM BEAMS MANUFACTURED WITH *Eucalyptus urograndis*

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ABSTRACT

Engineered wood products need alternatives of raw materials to their production. The hybrid *Eucalyptus urograndis* has great potential to supply the demand of this industrial sector. In this context, the present paper aims to analyse the feasibility of using *Eucalyptus urograndis* in glued laminated timber (glulam) production. To this end, four groups with ten glulam beams each, were produced and tested. An extensive experimental program was performed in order to determine: the stiffness and bending strength of the beams; and the compression strength parallel to grain of the beams. The performance of structural adhesives was verified based on shear tests of glue lines. The experimental mean of stiffness was higher than 14675 MPa and the characteristic value of compression strength parallel to grain achieved a value above 40 MPa. Nevertheless, failure mode of the glulam beams showed that finger-joints reduced bending strength. The glulam beams produced with *Eucalyptus urograndis* proved to be a feasible alternative due to their mechanical properties. However, this material presents difficulties in finger-joints adhesion.

Keywords: *Eucalyptus urograndis*, finger-joints, glued laminated timber, hardwood, timber structures.

INTRODUCTION

In Brazil, forest plantations with exotic species have been increasing significantly every year. The plantation area of *Eucalyptus* genus, throughout the country, has grown 15,77 % between 2010 and 2016 (IBÁ 2017). The hybrid *Eucalyptus urograndis*, obtained from *Eucalyptus urophylla* and *Eucalyptus grandis* species, was developed in Brazil (Wright 1997) and already represents an expressive percentage of the planted forest areas of *Eucalyptus* spp. in this country (Negrão *et al.* 2014). In addition, cultivation of *Eucalyptus urograndis* can already be seen in China, Southeast Asia (Booth *et al.* 2017), in India (Sharma *et al.* 2015), South Africa, Congo, Mexico, Colombia and Venezuela (Wright 1997).

Brazilian glued laminated timber (glulam) industries employ species from planted forests in their production line. Due to its continental dimensions, Brazil has a significant extension of native forests, which may be exploited through sustainable management, and planted forests with potential to supply the demand of timber companies. Still, the search for alternative raw materials is always necessary in order to guarantee full attendance of wood demand in glulam production.

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Glulam is a structural product produced from joining sawn lumber pieces. Widely, softwoods are preferred in glulam production due to better interaction with structural adhesives (Serrano 2003). Therefore, several research studies were developed, aiming to increase raw material alternatives for the glulam market (López and Correal 2009, Nadir and Nagarajan 2014, Tran *et al.* 2016, Moya *et al.* 2019). In addition, adhesives need to be tested following normative parameters in order to verify their adhesion capacity with different wood species (Knorz *et al.* 2014, Clerc *et al.* 2018). The main challenge to using hardwoods in glulam production is the lamellae adhesion (Lehmann *et al.* 2016), once their anatomical characteristics are different from softwoods (Kamke and Lee 2007).

Lumber pieces (lamellae) present smaller lengths than glulam structural members. Therefore, connections between lamellae ends (finger-joints) should be performed to produce the desired glulam beam length. Nowadays, finger-joint is the most usual type of connection used to join lamellae ends in glulam industries (Stark *et al.* 2010). Finger-joints strength depends on wood density, finger length (Ahmad *et al.* 2017) and adhesive type (Özçifçi and Yapici 2008). Moreover, failure modes of hardwood glulam beams with finger-joints positioned in greater tension stress areas often occur on finger-joints, due to their lack of strength to endure this stress (Nadir and Nagarajan 2014, Tran *et al.* 2016).

Eucalyptus urograndis has been studied in some research in Brazil (Pereira *et al.* 2016, Calil Neto *et al*. 2017, Brito and Calil Junior 2018), however, several other species are also approached in these studies (Segundinho *et al.* 2013, Segundinho *et al.* 2014, Almeida *et al.* 2014, Calil Neto *et al.* 2014, Calil Neto *et al.* 2016, dos Santos 2014). Segundinho *et al.* (2013) compared the values of the modulus of elasticity obtained by tests of transverse vibration and static bending. In this research article, the authors tested glulam beams produced from *Pinus ooccapa*, *Tectona grandis* and *Eucalyptus urograndis*, treated and without chemical treatment. Segundinho *et al.* (2014) evaluated the tension strength and the displacement of the beams similarly to the research presented in (Segundinho *et al.* 2013). In addition, glulam made of *Eucalyptus urograndis* was one of the engineered wood products analyzed by (Almeida *et al.* 2014, Calil Neto *et al*. 2014, Calil Neto *et al*. 2016). The focus of these studies was to verify the bonding quality of some adhesives in glulam produced with Brazilian reforested wood. Pereira *et al.* (2016) compared the tension strength parallel to grain of structural timber with and without finger-joints produced with *Eucalyptus urograndis*. This hybrid of *Eucalyptus* has been the object of studies on connections with self-tapping screws (Calil Neto *et al.* 2017) and metal plates semi-rigid connections (Brito and Calil Junior 2018). Dos Santos (2014) have studied glulam beams made with *Eucalyptus urograndis* in structural sizes, to obtain results of strength and stiffness in static bending, but only a few beams were mechanically tested. Shear tests were performed on the glue line in accordance with ASTM D905-08 (2013) and tension and compression parallel to grain tests were done according to the ABNT 7190 (1997) (dos Santos 2014).

In this research, groups of *Eucalyptus urograndis* glulam beams were produced, and differed in aspects such as the commercial adhesive used; beams height; wood density; and the presence or absence of finger-joints. Therefore, this research aimed to study the feasibility of employing *Eucalyptus urograndis* in glulam beams production. For this purpose, an experimental program was carried out involving a four-point static bending test to determine stiffness and strength in static bending; and the obtaining of specimens from the beams to evaluate glue line shear strength and strength in compression parallel to grain.

MATERIALS AND METHODS

Beams

The timber lamellae for the glulam beams were obtained from planted forests of *Eucalyptus urograndis*. These forests were situated in the states of Bahia and Espírito Santo, Brazil. Forty beams were manufactured in a Brazilian glulam industry in the state of São Paulo. The mechanical characterization of the lamellae to determine their stiffness, density and strength was not performed. The beam groups were created according to their adhesive type, the presence of finger-joints, width and dimensions of the beam, Table 1. The timber boards arrived in the glulam industry planed, kiln dried (10 % - 12 % moisture content) and clear of defects. Then timber boards were planed again with 0,1 mm dimension tolerance under ambient temperature and ambient relative humidity before gluing. The adhesives used to produce the glulam beams belonged to two different groups: melamine-urea-formaldehyde - MUF (type 1 and type 2) and one-component polyurethane

-1C-PUR. The adhesives were applied with a glue proportion of approximately 200 g/m² for 1C-PUR and 450 g/m² for MUF. The lamellae were submitted to a clamping pressure of 1 MPa by means of a hydraulic press under ambient temperature and ambient relative humidity. This pressure value was applied in the production of glulam beams according to recommendations of adhesives manufactures. Moreover, the amount of adhesive used also was based in parameters provided by the adhesive manufacturers.

Table 1: Features and nominal dimensions of each glulam beams group.

Group	Adhesive	Number of beams	Width (mm)	Height (mm)	Lamella thickness (mm)	Length of the beam (cm)	Finger-joint in the beam	Mean density (kg/m³)
1	MUF Type 1	10	60	180	30	360	no	782
2	MUF Type 2	10	60	180	30	360	no	761
3	1C-PUR	10	80	180	30	360	yes	775
4	1C-PUR	10	60	270	30	590	yes	743

Firstly, finger-joints were made on some lamellae before the previously described process for the manufacture of beams in groups 3 and 4. The finger-joints in the board end were produced by mean of a minifinger-joint cutterhead with 20 (22) mm nominal finger length (the value 22 mm is maximum finger length which can be produced utilizing this cutterhead) 6,2 mm pitch width, and 1 mm tip width. The adhesive used in the production of finger-joints was one-component polyurethane - 1C-PUR. The adhesive was applied manually following the recommendation of adhesive manufacturer. A clamping pressure of 10 MPa was applied by means of a hydraulic press during 5 seconds under ambient temperature and ambient relative humidity. Moreover, finger-joints were randomly distributed along the height and length of the beams, always respecting the minimum normative spacing.

Shear of glue line and compression strength parallel to grain specimens

The shear of glue line and the compression strength parallel to grain specimens were extracted from the glulam beams after the realization of the four-point bending test. The glulam beams were sawn with a circular saw to collect these specimens. A piece of about 20 cm in length was discarded from each beam end due to possible irregularities provoked by lamellae and structural elements planning. The specimens were collected from the ends of structural elements where there was not any damage caused by beams rupture, Figure 1. The samples for the shear of glue line were extracted with 10 cm of length, while the samples for the compression strength test were extracted with 20 cm. Table 2 shows the size of the samples used in the tests.

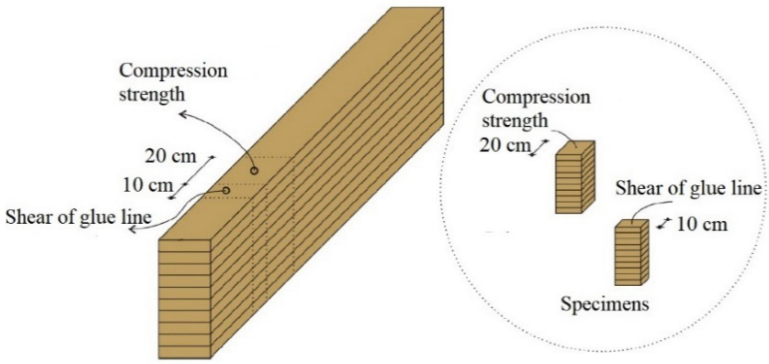


Figure 1: Length and region from extractions of specimens.

Table 2: Samples dimensions for shear of glue line and compression strength parallel to the grain.

Group	Adhesive	Dimensions (mm)	
		Shear of glue line	Compression strength
1	MUF Type 1	60 x 100 x 180	60 x 180 x 200
2	MUF Type 2	60 x 100 x 180	60 x 180 x 200
3	1C-PUR	80 x 100 x 180	80 x 180 x 200
4	1C-PUR	60 x 100 x 270	60 x 270 x 200

Tests procedures

The procedures to evaluate glulam beam bending and stiffness were realized by means of ABNT NBR 7190 - Part 4 (draft) (2021). This normative document is based on the standard ISO 13910 (E) (2014). Moreover, ABNT NBR 7190 - Part 6 (draft) (2021) was used to evaluate the shear strength in glue lines, this standard method is based on EN 14080 (2013). Also, the compression strength parallel to grain test was carried out in accordance with ABNT 7190 (1997). All tests were conducted under ambient temperature and ambient relative humidity.

Four-point bending

The four-point bending tests were carried out to determine the modulus of elasticity in bending (E_m) and the bending strength (f_m) for all structural elements. The test arrangement was made in accordance with ABNT NBR 7190 – Part 4 (draft) (2021), as shown in Figure 2. This test arrangement was adopted because it leads to more conservative results of the modulus of elasticity in bending.

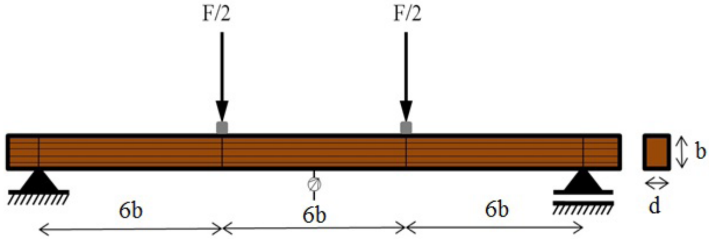


Figure 2: Test arrangement in accordance with ABNT NBR 7190 - Part 4 (draft) (2021).

A dial indicator was placed in the bottom edge of the beam to measure centre-point deflection. Loading was applied in a constant rate of 10 MPa/min. It was controlled by a dynamometric ring, Figure 3.

Figure 3: Test set-up of four-point bending test.

The finger-joint of the bottom edge lamella was positioned between loads when possible due to the maximum bending moment. The modulus of elasticity in bending was calculated from Equation 1 ABNT NBR 7190 - Part 4 (draft) (2021):

$$E_m = \frac{23}{108}\left(\frac{L}{b}\right)^3\left(\frac{\Delta F}{\Delta e}\right)\frac{1}{d} \qquad (1)$$

Where: E_m is the modulus of elasticity in bending (MPa); **Δ***F* is the value of incremental load (N); **Δ***e* is the value of incremental deflection (mm); L is the length along the glulam beam (mm); b is the height of the glulam beam (mm); and d is the width of the glulam beam (mm).

The bending strength was calculated from Equation 2 ABNT NBR 7190 - Part 4 (draft) (2021):

$$f_m = \frac{F_{ult} L}{db^2} \qquad (2)$$

Where: f_m is the bending strength (MPa); F_{ult} is the ultimate applied load (N); L is the length along the glulam beam (mm); b is the height of the glulam beam (mm); and d is the width of the glulam beam (mm).

Compression strength parallel to grain

The compression strength parallel to grain was determined by experiments carried out according to the principles of ABNT 7190 (1997) with adaptations for structural specimens. The Brazilian Code, ABNT 7190 (1997), describes which cross section of the specimen must be 5 cm x 5 cm and yours length 15 cm. But, the specimen in this research had cross section equal to cross section of the glulam beams and had 20 cm length. The slenderness ratio of each group was less than 15 and, therefore, there was not buckling and bending of the specimen in each test realized. This strength is the reference in timber structure design in Brazil. Thus, this test is important to help Brazilian engineers to apply glulam in Brazilian civil construction. Samples were submitted to a compression force using a compression test machine from the company ELE, as shown in Figure 4, with load capacity of 2000 kN.

Figure 4: Test set-up of compression parallel to the grain test.

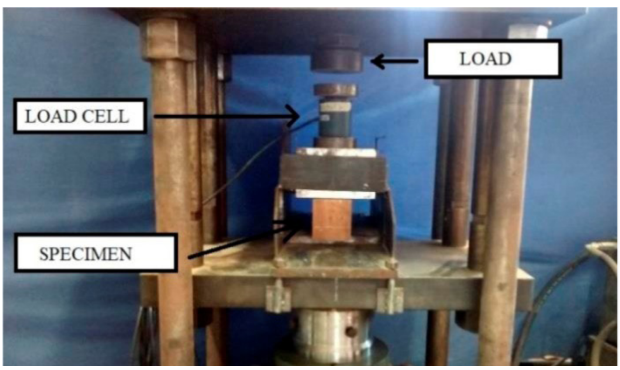
The loading was applied in a constant rate of 10 MPa/min until sample rupture. The compression strength parallel to grain was obtained using Equation 3 ABNT 7190 (1997).

$$f_{c0} = \frac{F_{c0,max}}{A_{c,0}} \qquad (3)$$

Where: f_{c0} is the compression strength parallel to grain (MPa); $F_{c0,max}$ is the ultimate applied load (N); and $A_{c,0}$ is the compressed cross-section (mm²).

Shear of glue lines

The shear test of glue lines was performed to determinate the shear strength of the combination between structural adhesives and *Eucalyptus urograndis* wood. The tests were carried out according to ABNT NBR 7190 – Part 6 (draft) (2021) with adaptations for specimens of EN 14080 (2013). The difference was in the cross section of the sample where its cross section was equal to the width of the glulam beams and 100 mm of thickness, Figure 1. On the other hand, EN 14080 (2013) describes that the cross section must be 40 mm to 50 mm in width and thickness. Samples were submitted to compression force using a compression test machine, Figure 5.



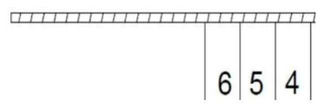


Figure 5: Test set-up of shear test of glue lines.

Loading was applied for more than 20 seconds until material failure. A load cell coupled to a computer was used to measure the load applied to the sample. The shear strength was calculated from Equation 4 ABNT NBR 7190 - Part 6 (draft) (2021). Furthermore, the percentage of adhesive failure was visually analysed.

$$f_{v0} = \frac{F_{v0,max}}{bt} \qquad (4)$$

Where: F_{v0} is the shear strength of the glue line (MPa); $F_{v0',max}$ is the maximum load (N); *b* is the width of the sample (mm); and t is the height of the sample (mm).

RESULTS AND DISCUSSION

Four-point bending test

The bending strength and the modulus of elasticity of each group of glulam beam are shown in Table 3. The characteristic value $f_{m,k}$ was obtained by means of EN 14358 (2016) assumed a logarithmically normally homogeneous. The mean experimental value of stiffness was higher than 17800 MPa for all groups considered. Group 1 presented the highest mean, 20072 MPa, while Group 2 exhibited the lowest mean, 17812 MPa. The results obtained show that coefficient of variation was low for all groups studied. This signifies there was a low variability among the bending stiffness of the tested specimens in each group.

Table 3: The statistical values of the mechanical properties of each glulam beams group.

Group		1	2	3	4
Modulus of elasticity	Mean (MPa)	20072	17812	19612	18168
	Coefficient of variation (%)	9,13	8,70	12,05	3,50
Bending strength	Mean (MPa)	93,9	86,8	61,1	56,5
	Coefficient of variation (%)	19,79	13,63	12,36	13,50
	$f_{m,k}$ (MPa)	54,5	63,9	47,6	41,9
Compression strength parallel to the grain	Mean (MPa)	75,1	68,6	70,4	65,4
	Coefficient of variation (%)	10,57	8,98	6,07	7,26
	$f_{c,0,k}$ (MPa)	67,1	58,4	70,0	63,1
Shear strength of glue line	Mean (MPa)	11,7	10,3	10,6	9,9
	Coefficient of variation (%)	20,12	30,76	27,17	28,63
	Wood Failure (%)	82,92	68,73	92,30	82,99

Groups 1 and 2 have similar features and their mean experimental value of bending strength is slightly different 93,9 MPa and 86,8 MPa, respectively. These results may occur due to the random distribution of lamellae along the beams cross section during assembly. Thus, lamellae with low mechanical proprieties can have been put in the beam position where the highest tension stress occur. Furthermore, in Group 2 there was a predominant failure by tension in the lamella edge. It shows that the collapse in structural elements in this group started in their edge.

Groups 3 and 4, constituted by glulam beams with finger-joints, presented a mean experimental value of bending strength lower than Groups 1 and 2, with no discontinuity in their lamellae, Table 3. Failure mode started in the finger-joints of a large part of glulam beams in Groups 3 and 4, Figure 6. This showed that finger-joints were fragile regions of glulam beams produced with *Eucalyptus urograndis* and 1C-PUR. This structural element type is basically formed of reforested timber, therefore, finger-joints utilization is necessary because boards can present defects and are shorter than glulam beams. Similar failure mode was observed for oak and beech glulam beams with horizontally finger-joints produced with MUF adhesive (Tran *et al.* 2016). This failure occurred initially within the finger-joints due adhesive failure for beech glulam beams and by means finger-joint (rupture in wood) for oak glulam beams (Tran *et al.* 2016). According to Nadir and Nagarajan (2014), the ruptures of the *Hevea brasiliensis* glulam beams with vertically finger-joint also occurred initially from finger-joints. The Group 3 reached only 65,07 % and 70,39 % of the mean bending strength of Group 1 and Group 2 respectively. On the other hand, the Group 4 obtained an mean bending strength equivalent to 60,17 % of the Group 1 and 65,09 % of the Group 2. The failure of the 1C-PUR adhesive in the finger-joints caused the reduction of the bending strength for Group 3 and Group 4 when compared with Group 1 and Group 2 (both without finger-joints). Tran *et al.* (2016) showed that the mean bending strength of the beech glulam beams (3-layer) having finger-joints reached 54,84 % of mean bending strength of the beech solid lamella. In addition, Tran *et al.* (2016) presented the mean bending strength of the oak glulam beams (3-layer) having finger-joints reached 80,01 % of mean bending strength of the oak solid lamella.

Figure 6: Failure mode started in the finger-joint.

In beam failure mode analysis, detachment by shear between two adjacent lamellae due to unsatisfactory adhesion was noticed, Figure 7. This was verified in a beam of Groups 1 and 4, in experimental tests. It probably occurred due to superficial penetration of the adhesive in the lamellae. This problem usually happens in hardwoods, the same timber type used in those groups, because of small pores that hinder adhesive anchorage in the material. Lehmann *et al.* (2016) verified that structural adhesives utilized in the manufacture of their *Fraxinus excelsior* L. glulam did not attain the minimum requirements of delamination.

Figure 7: Detachment by shear due to unsatisfactory adhesion.

Compression strength parallel to grain

The statistical values of the compression strength parallel to grain of each group of glulam beams are shown in Table 3. Group 1 presented the highest mean experimental value of strength in compression parallel to grain, 75,1 MPa, while Group 4 presented the lowest mean, 65,4 MPa. Moreover, all groups with mean density higher than 700 kg/m³ achieved a mean experimental value in compression parallel to grain higher than 60 MPa. The characteristic value of this property was calculated according to ABNT NBR 7190 (1997). Group 3 was the only group which achieved a characteristic value of 70 MPa. All the other groups presented a characteristic value above 50 MPa. Glulam beams made with *Eucalyptus urograndis* can be considered as having a strength class of 50 MPa, due to the fact that the groups studied had similar mean densities.

Shear strength of glue line

The shear strength of glue line is shown in Table 3. This table also shows the percentage of wood failure of the each samples. The mean experimental value of shear strength of glue line was higher than 9,9 MPa for all the groups. Group 1 had the highest mean, 11,7 MPa, while Group 4 presented the lowest, 9,9 MPa. Furthermore, Group 3 had experimental mean rupture in the timber higher than 90 %. The wood failure above 90 % can be seen in the Figure 8 for a glue line of the Group 4. Group 2 showed a mean percentage of 31,27 % of failure in adhesive, the worst among the groups analysed.

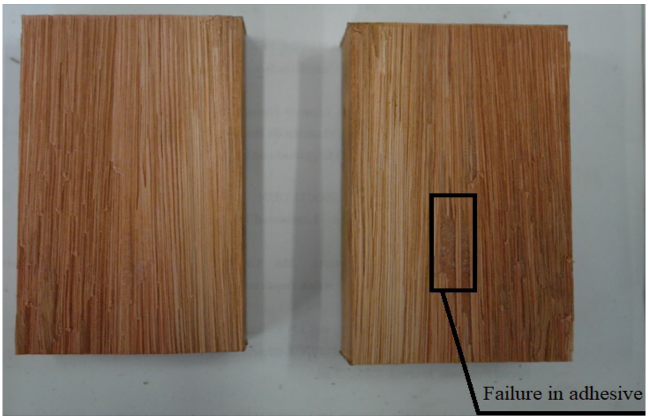


Figure 8: 95 % of wood failure of a specimen of the Group 4.

The percentage of wood failure (Table 3) reveals that the bonding between this wood species and the adhesives is the main problem in using this substrate in the production of glulam. However, the EN 14080 (2013) presents softwood glulam's minimum production requirements. The minimum wood failure percentage depends average shear strength of glue lines according to EN 14080 (2013) Equiation 5, Equation 6 and Equation 7.

$$WF_{mean} \geq 90\ \%\ for\ f_{v,0} = 6\ MPa \qquad (5)$$

$$WF_{mean} \geq 144 - (9 f_{v,0})\ for\ 6\ MPa < f_{v,0} < 11\ MPa \qquad (6)$$

$$WF_{mean} \geq 45\ \%\ for\ f_{v,0} \geq 11\ MPa \qquad (7)$$

The minimum wood failure is 54 % if the average shear strength of the glue line is 10 MPa. Thus, all groups studied reached the minimum production requirements described in EN 14080 (2013) for softwood glulam. However, the EN 14080 (2013) shows that the minimum wood failure percentage must be 20 % for a glue line of softwood glulam with shear strength higher than 10 MPa. All samples from *Eucalyptus urograndis* had at least a glue line with failure exclusive in adhesive. Therefore, the adhesive anchorage in this wood species must be improved or new types of adhesive must be developed, taking chemical adhesion into account. Moreover, Group 2, Group 3 and Group 4 had shear strength less than 4 MPa at least a glue line. This value is the minimum permitted for a glue line according to EN 14080 (2013).

The shear strength of the glue line leads to the conclusion that it is possible to produce glulam with *Eucalyptus urograndis* because Groups 1, 3, and 4 presented rupture exclusively in wood in at least 45 % of the specimens tested in each group. On the other hand, Group 2 presented only 30 % of the tests with rupture in wood. Due to this property, adhesion can be performed satisfactorily in *Eucalyptus urograndis*.

The mean shear strength parallel to grain for solid timber of *Eucalyptus urograndis* was 11,92 MPa according to research developed by Moritani and Calil Junior (2018). Thus, only Group 1 obtained a percentage above 90 % when compared to solid timber (Moritani and Calil Junior 2018), that is 98,15 %. On the other hand, the other groups showed strength above 80 % when compared to solid timber (Moritani and Calil Junior 2018).

Comparative analysis with the mean values of the species of origin of *Eucalyptus urograndis*

Brazilian Code, ABNT 7190 (1997), presents a table with values of mechanical properties of some wood species available in the Brazilian market. These values were obtained from small samples which are clear of defect, ABNT 7190 (1997). Data on the two wood species which were used in the development of *Eucalyptus urograndis* are contained in this table, *Eucalyptus grandis* and *Eucalyptus urophylla*. The mean compression strength parallel to grain of *Eucalyptus grandis* and *Eucalyptus urophylla* is 40,3 MPa and 46,0 MPa, respectively, ABNT 7190 (1997). Thus, glulam beams manufactured with *Eucalyptus urograndis* showed means of such property much higher than the species of origin, Table 3. Group 4 presented the worst mean among the groups studied, however, it showed a mean 62,28 % better than the mean of *Eucalyptus grandis* and 42,17 % better than the mean of *Eucalyptus urophylla*, ABNT 7190 (1997). Moreover, the mean shear strength parallel to grain of *Eucalyptus grandis* and *Eucalyptus urophylla* is 7,0 MPa and 8,3 MPa, respectively, ABNT 7190 (1997). This showed that the values obtained in shear tests of the glue line were better than those obtained in species originated from *Eucalyptus urograndis*, Table 3.

CONCLUSIONS

The *Eucalyptus urograndis* wood has great potential to be applied in glulam industries due to its high mechanical properties and density. This potential was confirmed by the experimental program carried out in this research. However, the main obstacles revealed were the existing structural adhesives, developed for softwoods, used in the manufacturing of the glulam beams, since better results could be achieved if bonding had been more satisfactory. Moreover, the mean percentage of rupture in wood was below 90 % for some groups in the shear of glue lines. Thus, it is possible to conclude that adhesives must be developed taking chemical adhesion to hardwood and hybrid species, like *Eucalyptus urograndis,* into account.

The experimental average value of the bending strength for groups without finger-joints (Groups 1 and 2) remained close to 90 MPa. On the other hand, groups with beams which have finger-joints reached an experimental mean value of bending strength between 56 MPa and 62 MPa. Furthermore, the experimental mean stiffness of all groups studied remained above 17812 MPa. The characteristic value of strength in compression parallel to grain for all groups achieved a value above 50 MPa. Moreover, glulam made with *Eucalyptus urograndis* showed good shear strength of the glue line. This property had a mean above 9,9 MPa for all groups studied.

Finger-joints have proved to be a region of weakness in glulam beams made from *Eucalyptus urograndis* because failure mode has occurred in this area. Furthermore, finger-joints reduced the mean value of bending strength of the beams when compared to the beams without finger-joints, even though this value was above 50 MPa for beam groups with finger-joints. These results prove a great potential for the use of *Eucalyptus urograndis* in glulam.

There was a superiority in the compression parallel to grain and shear properties of the glued line of the groups of *Eucalyptus urograndis* glulam beams when compared to the mean values of the compression parallel to grain and shear strengths of the wood species that gave rise to the studied hybrid species.

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REFERENCES

ABNT. 1997. Projeto de estruturas de madeira. ABNT 7190. ABNT. Rio de Janeiro, Brazil. https://www.abntcatalogo.com.br/norma.aspx?ID=3395

ABNT. 2021. Projeto de estruturas de madeira - Parte 4: Métodos de ensaio para caracterização peças estruturais. ABNT NBR 7190. ABNT. Rio de Janeiro, Brazil.

ABNT. 2021. Projeto de estruturas de madeira - Parte 6: Método de ensaios para caracterização de madeira lamelada colada estrutural. ABNT NBR 7190 (draft). ABNT. Rio de Janeiro, Brazil.

Ahmad, Z.; Lum, W.C.; Lee, S.H.; Razlan, M.A.; Mohamad, W.H.W. 2017. Mechanical properties of finger jointed beams fabricated from eight Malaysian hardwood species. *Construction and Building Materials* 145: 464-473. https://doi.org/10.1016/j.conbuildmat.2017.04.016

Almeida, D.H.; Cavalheiro, R.S.; de Macêdo, L.B.; Calil Neto, C.; Christoforo, A.L.; Calil Junior, C.; Lahr, F.A.R. 2014. Evaluation of Quality in the Adhesion of Glued Laminated Timber (Glulam) of Paricá and Lyptus Wood Species. *International Journal of Materials Engineering* 4(3): 114-118. https://doi.org/10.5923/j.ijme.20140403.07

ASTM. 2013. *Standard test method for strength properties of adhesive bonds in shear by compression loading.* ASTM D905-08. ASTM. West Conshohocken, PA, USA. https://www.astm.org/DATABASE.CART/HISTORICAL/D905-08R13.htm

Booth, T.H.; Jovanovic, T.; Arnold, R.J. 2017. Planting domains under climate change for *Eucalyptus pellita* and *Eucalyptus urograndis* in parts of China and South East Asia. *Australian Forestry* 80(1): 1-9. https://doi.org/10.1080/00049158.2016.1275101

Brito, L.D.; Calil Junior, C. 2018. Optimization semi-rigid connections in frame models: Experimental tests of connections with aluminum alloy profiles in Glulam Lyptus®. In WCTE 2018 - World Conference on Timber Engineering. Seoul, Republic of Korea.

Calil Neto, C.; Christoforo, A.L.; Lahr, F.A.R.; Calil Júnior, C. 2014. Analysis of Specie - Treatment - Adhesive Combinations for Glulam Purpose. *International Journal of Materials Engineering* 4(1): 41-47. https://doi.org/10.5923/j.ijme.20140401.06

Calil Neto, C.; Molina, J.C.; Calil Junior, C.; Lahar, F.A.R. 2017. Modelagem numérica do comportamento de ligações com parafusos auto-atarraxantes em X em corpos de prova de MLC com madeiras do tipo *Eucalipto urograndis*. *Revista Matéria* 22(1). https://doi.org/10.1590/S1517-707620170001.0121

Calil Neto, C.; Molina, J.C.; Calil Junior, C.; Lahr, F.R. 2016. Specie - treatment - adhesive combinations for glulam purpose. *Revista de Engenharia Civil IMED* 3(2): 16-23. https://seer.atitus.edu.br/index.php/revistaec/article/view/1359

Clerc, G.; Lehmann, M.; Gabriel, J.; Salzgeber, D.; Pichelin, F.; Strahm, T.; Niemz, P. 2018. Improvement of ash (*Fraxinus excelsior* L.) bonding quality with one-component polyurethane adhesive and hydrophilic primer for load-bearing application. *International Journal of Adhesion and Adhesives* 85: 303-307. https://doi.org/10.1016/j.ijadhadh.2018.06.017

dos Santos, L.L. 2014. Avaliação estrutural de vigas de madeira laminada colada. Dissertation, Universidade Federal do Espírito Santo, UFES. Vitoria, Brazil. https://repositorio.ufes.br/bitstream/10/3981/1/tese_8492_Lorenzo%20Lube%20dos%20Santos.pdf

EN. 2013. Timber structures - Glued laminated timber and glued solid timber - Requirements. EN 14080:2013. EN. Brussels, Belgium.

EN. 2016. Timber structures - Calculation and verification of characteristic values. EN 14358:2016. EN. Brussels, Belgium.

IBÁ. **2017.** Relatório 2017. Indústria Brasileira de Árvores. https://iba.org/datafiles/publicacoes/pdf/iba-relatorioanual2017.pdf

ISO. 2014. Timber structures - strength graded timber - test methods for structural properties. ISO 13910:2014(E). ISO. Geneva, Swiss. https://www.iso.org/standard/52977.html

Kamke, F.A.; Lee, J.N. 2007. Adhesive penetration in wood - A review. *Wood and Fiber Science* 39(2): 205–220. https://wfs.swst.org/index.php/wfs/article/view/641/641

Knorz, M.; Schmidt, M.; Torno, S.; van de Kuilen, J.W. 2014. Structural bonding of ash (*Fraxinus excelsior* L.): Resistance to delamination and performance in shearing tests. *European Journal of Wood and Wood Products* 72(3): 297-309. https://doi.org/10.1007/s00107-014-0778-8

Lehmann, M.; Schlegel, S.; Ammann, S.; Beyer, M.; Aehlig, K.; Jung, H.; Niemz, P. 2016. Investigation of the bond quality of semi industrially produced ash glulam. In WCTE 2016 - World Conference on Timber Engineering. Vienna, Austria.

López, L.F.; Correal, J.F. 2009. Exploratory study of the glued laminated bamboo *Guadua angustifolia* as a structural material. *Maderas. Ciencia y Tecnologia* 11(3): 171-182. https://doi.org/10.4067/S0718-221X2009000300001

Moritani, F.Y.; Calil Junior, C. 2018. Comparação da resistência ao cisalhamento paralelo às fibras do Eucalyptus urograndis: corpos de provas isentos de defeitos x peças estruturais. In XVI Encontro Brasileiro em Madeiras e em Estruturas de Madeira e III Congresso Latino-americano de Estruturas de Madeira. São Carlos, Brazil. http://soac.eesc.usp.br/index.php/ebramem/xviebramem/paper/view/1157/704

Moya, L.; Gomar, C.P.; Vega, A.; Sánchez, A.; Torino, I.; Baño, V. 2019. Relationship between manufacturing parameters and structural properties of *Eucalyptus grandis* glued laminated timber. *Maderas. Ciencia y Tecnologia* 21(3): 327–340. https://doi.org/10.4067/S0718-221X2019005000305

Nadir, Y.; Nagarajan, P. 2014. The behavior of horizontally glued laminated beams using rubber wood. *Construction and Building Materials* 55: 398-405. https://doi.org/10.1016/j.conbuildmat.2014.01.032

Negrão, D.R.; da Silva Júnior, T.A.F.; Passos, J.R.S.; Sansígolo, C.A.; Minhoni, M.T.A.; Furtado, E.L. 2014. Biodegradation of *Eucalyptus urograndis* wood by fungi. *International Biodeterioration and Biodegradation* 89: 95-102. https://doi.org/10.1016/j.ibiod.2014.01.004

Özçifçi, A.; Yapici, F. 2008. Structural performance of the finger-jointed strength of some wood species with different joint configurations. *Construction and Building Materials* 22: 1543-1550. https://doi.org/10.1016/j.conbuildmat.2007.03.020

Pereira, M.C.M.; Calil Neto, C.; Icimoto, F.H.; Calil Junior, C. 2016. Evaluation of tensile strength of a *Eucalyptus grandis* and *Eucalyptus urophyla* hybrid in wood beams bonded together by means of finger joints and polyurethane-based glue. *Materials Research* 19(6): 1270-1275. https://doi.org/10.1590/1980-5373-MR-2016-0072

Segundinho, P.G.A.; Calil Neto, C.; Dias, A.A.; Calil Junior, C.; Christoforo, A.L. 2014. Evaluation of Brazilian reforestation species in glulam beams before and after preservative chemical treatments. *International Journal of Materials Engineering* 4(6): 192-195. https://doi.org/10.5923/j.ijme.20140406.02

Segundinho, P.G.A.; Carreira, M.R.; Calil Neto, C.; Regazzi, A.J.; Dias, A.A.; Calil Junior, C. 2013. Avaliação do módulo de elasticidade de peças de madeira laminada colada (MLC) obtido por meio do ensaio de vibração transversal. *Ambiente Construído* 13(2): 7-14. https://doi.org/10.1590/s1678-86212013000200002

Serrano, E. 2003. Mechanical Performance and Modelling of Glulam. Chapter 5. In: *Timber Engineering*. Thelandersson, S.; Larsen, H.J. (1st ed.). John Wiley & Sons Ltd: Chichester, England. https://www.wiley.com/en-us/Timber+Engineering-p-9780470844694

Sharma, S.K.; Shukla, S.R.; Shashikala, S.; Poornima, V.S. 2015. Axial variations in anatomical properties and basic density of *Eucalypt urograndis* hybrid (*Eucalyptus grandis* × *Eucalyptus urophylla*) clones. *Journal of Forestry Research* 26(3): 739-744. https://doi.org/10.1007/s11676-015-0080-6

Stark, N.M.; Cai, Z.; Carll, C. 2010. Wood-Based Composite Materials Panel Products, Glued-Laminated Timber, Structural Composite Lumber, and Wood-Nonwood Composite Materials. Chapter 11. In: *Wood Handbook - Wood as an Engineering Material*. Ross, R.J. (1st ed.). General Technical Report FPL-GTR-190, Madison, USA. https://www.fpl.fs.usda.gov/documnts/fplgtr/fplgtr190/chapter_11.pdf

Tran, V.D.; Oudjene, M.; Méausoone, P.J. 2016. Experimental investigation on full-scale glued oak solid timber beams for structural bearing capacity. *Construction and Building Materials* 123: 365-371. https://doi.org/10.1016/j.conbuildmat.2016.07.002

Wright, J.A. 1997. A review of the worldwide activities in tree improvement for *Eucalyptus grandis*, *Eucalyptus urophylla* and the hybrid urograndis. In 24 th Biennial Southern Forest Tree Improvement Conference. Orlando, United States of America.