Engenharia Agrícola

ISSN: 1809-4430 (on-line)

www.engenhariaagricola.org.br

Doi: http://dx.doi.org/10.1590/1809-4430-Eng.Agric.v39n2p158-165/2019

CHEMICALLY TREATED GLUED LAMINATED PARICÁ TIMBER (*Schizolobium parahyba* var. *amazonicum*)

Rodrigo F. Terezo[1*], Franciele O. de Córdova[2], Carlos A. de P. Sampaio[2]

[1*]Corresponding author. Universidade do Estado de Santa Catarina/ Lages - SC, Brasil.
E-mail: rodrigo.terezo@udesc.br | ORCID ID: https://orcid.org/0000-0002-7562-1931

KEYWORDS

timber, beams, structure.

ABSTRACT

In the production of glue-laminated timber (GLT), boards derived from planted forest wood with easy workability are glued on top of one another. The main objective of the present work was to evaluate the performance of paricá timber GLT beams (5 × 10 cm) on GLT. Three procedures were performed: (1) GLT beams (5 × 10 cm) were produced using natural lamellae without chemical preservatives; (2) the individual lamellae (2.5 × 5 cm) were chemically treated, and then glued together; and (3) the beams formed from the glued natural lamellae (5 × 10 cm) were treated chemically. The positions of lamellae on the beams were determined by their modulus of elasticity values (MOE), which were estimated by a non-destructive bending test with a three-point load. The analytical bends, determined by the homogenized section method, and the experimental bends, measured by the four-point bending test, were compared. The differences between the bends were statistically evaluated, and it was found that the experimental bend (21.65 mm) was less than the analytical bend (34.02 mm). There was no significant loss of shear strength or MOE. The axial strength of the chemically untreated beams (49.18 MPa) was significantly higher than that of the untreated beams fabricated from natural lamellae (40.48 MPa). The results indicate that the gluing of treated lamellae does not affect beam performance.

INTRODUCTION

Cultivation of planted forests with exotic tree species is very common in Brazil. Among them, we shall mention those of the *Eucalyptus* and *Pinus* genera. In the Amazon, there is still no tradition of native or exotic species plantation; however, plantation forests have become a viable solution for the economic recovery of degraded areas with rapid-growth species.

According to Almeida et al. (2013), the paricá (*Schizolobium parahyba* var. *amazonicum*), an Amazonian species with high economic potential, has increasingly become more important among the planted species in Brazil because its fast increases in height and diameter allow it to be used within a few years after planting.

Paricá wood allows easy bark removal, lamination, drying, pressing, and excellent finishing; however, it has low natural durability and is susceptible to the attack by xylophagous organisms. For these reasons, Terezo & Szücs (2010) reported that preservation treatment is necessary for using this wood as a non-temporary element.

According to Calil Neto et al. (2014), water-soluble preservatives are the most efficient methods for protecting wood against deterioration agents. Combinations of copper, chromium, and arsenic (CCA) and copper, chromium, and boron (CCB) are the most commonly applied preservatives in Brazil. However, studies are needed for the production based on glued laminated timber (GLT) to determine the species-adhesive-treatment requirements and to determine the wood that is most suitable for this technique.

GLT is composed of wood reconstituted from wooden lamellae (boards), which are smaller than the finished part. Such lamellae, joined by glue, are arranged in such a way that their fibers are parallel to each other.

Furtado & Terezo (2014) conducted a laboratory analysis of the production process to optimize the quality of paricá GLT. They highlighted critical issues requiring specific actions to obtain products that meet minimum quality standards; this is necessary to reach, gain, and maintain a extricate market face to other products as massive timber. Among these actions, mechanical classification through non-destructive tests stands out.

Teles et al. (2010) defined nondestructive testing (NDT) as the identification of the elastic properties of a given material without changing its end-use capabilities. In

[2] Universidade do Estado de Santa Catarina/ Lages - SC, Brasil.
Received in: 8-17-2018
Accepted in: 1-28-2019

this sense, the NDT of wood is important because it produces more precise results and establishes practical criteria for material classification and characterization.

Terezo et al. (2015) reported that paricá wood, aged from 6 to 28 years, can be used in structural elements as GLT because its resistance class is equivalent to C-20. However, its low durability compromises its use as a durable product and as a main structural element.

GLT's potential to meet the requirements for various geometric applications, such as arches and structural components with curvatures and large spans, increased its popularity in European countries and in the United States because such applications are not possible with sawn wood.

There are few plants in Brazil in this sector; however, a significant number of companies had moved from sawn native wood into the production of planted forest GLT, searching for new species and market innovation. This approach adds value to the planted forest wood and diversifies its possible technological applications in the agribusiness sector, thus sustaining the local population (Nogueira, 2017). Additionally, it is intended to maintain the use of wood with low cost in rural construction because of its high mechanical resistance in relation to its low weight.

In this context, this study investigated the mechanical performance of paricá GLT beams in two cases: the first one with chemically preserved lamellae, and the second with beams. In the second case, we investigated the performance of chemically preserved GLT beams in comparison with natural chemically untreated lamella GLT beams.

MATERIAL AND METHODS

Logs were taken from trees aged 6–10 years from planted forests belonging to the Tramontina Belém S/A Company in the municipality of Aurora do Pará and from privately owned trees between 19 and 28 years old privately owned in the municipality of Tomé-Açu.

After the trees were cut, the logs were sawn into boards (sawn wood), dried in an oven, classified, transported to the technology laboratory in Santa Catarina, and stored in a covered shed until they reached equilibrium humidity (18%). It should be noted that the variability of the wood age was not taken into account because, in a factory, timber from planted forests of different ages is used. Hence, the modulus of elasticity (MOE) is the most important parameter for the production of GLT beams (Cunha & Monteiro, 2010).

In a fiber-parallel strength test (ABNT/NBR - 7190, 1997), paricá wood was classified as C-20. Another characteristic of this wood is that it usually shows few defects during its biological growth (Terezo et al., 2015). Boards without defects (without cracks, excessive tortuosity, or compromise by xylophagous agents) were selected by visual classification, resulting in 84 lamellae. The lamellae used for the manufacture of the GLT beams were obtained from the boards of sawn timber, which had their dimensions reduced by a circular saw to 6.0 × 2.5 × 250.0 cm.

Determination of Lamellae MOE

The MOE was determined from the bend measured in the direction of lower inertia of lamella. For this, two trestles were used as supports with a free 230.0-cm span and a 7.5-kg load in the center of the part, compatible with the wood elastic property. This load was pre-established in a pilot bending test, in which the load at the proportionality limit was 12.0 kg. With a centimeter graduated ruler, the specific displacement was measured on both sides of the lamella. The MOE of the lamellae was determined by:

$$\mathrm{MOE} = \frac{\mathrm{PL}^3}{48\delta I} \quad (1)$$

Where,

MOE is the modulus of elasticity (MPa),

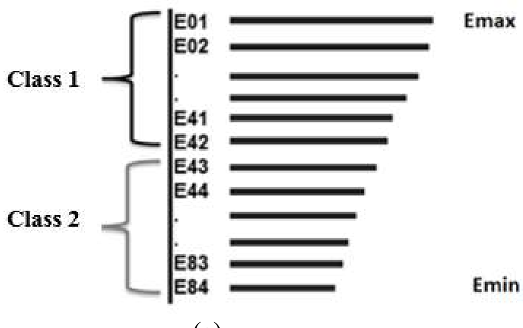
P is the concentrated load (N),

L is the free span (mm),

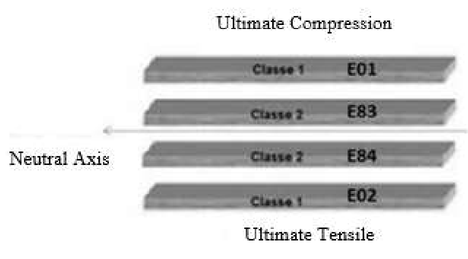
δ is the bend (mm), and

I is the inertia momentum (mm^4).

The lamellae were separated into two classes using the MOEs average values ($MOE_{average}$) as reference. The Class 1 lamellae were more resistant with MOEs above $MOE_{average}$ (a total of 42 lamellae); the Class 2 lamellae were less resistant, with MOEs below $MOE_{average}$ (a total of 42 lamellae). In the assembly of the beams, from the 84 MOE values, the two highest MOEs were grouped in the most extreme (most requested) region with the two lowest MOEs in the regions near the neutral axis to provide stiffness equilibrium between all the beams, as shown in Figure 1.



(a)



(b)

FIGURE 1. Delimitation: (a) classification of lamellae by MOE, and (b) composition of GLT beams.

Chemical Treatment

The chemical preservation was performed in two stages. The initial stage consisted of the treatment of the lamellae only for further assembly of GLT beams (beams with treated lamellae - TL); in the second stage, the GLT beams were glued with natural lamellae (sample treated beams - TB). Chemical impregnation was conducted by using an autoclave with variable pressure cycles, and a combination of chromium, copper, and arsenic (CCA) was used as a water-soluble preservative. After the chemical preservation process, the parts were stored in a shed until they reached moisture equilibrium again, which occurred within 30 days.

GLT Beam Fabrication

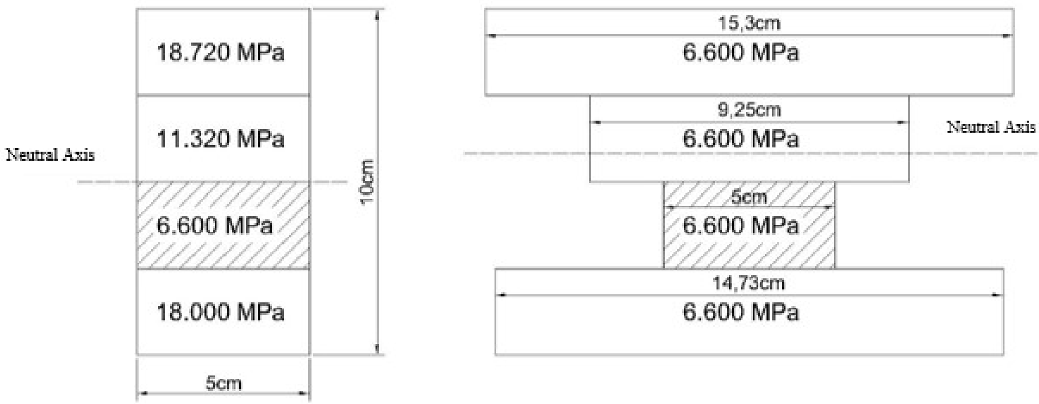
In the bonding process for the preparation of GLT beams, the lamellae were flattened on both sides, and then a resorcinol-formaldehyde (Cascophen RS-216-M) based synthetic resin adhesive, very common in the production of GLT structural beams, was used. The mixture of adhesive and FM-60-M hardener, at 20% relative to the resin, was weighed until it reached the required value for 500 g/m² grammage, the manufacturer's recommended standard for low-density wood.

The glue was spread on the lamellae between the contact faces with the aid of a rubber roller. The maximum time was 30 min (open and closed time processes) until pressing. To ensure perfect horizontality between the lamellae, three metal clips were used as lateral restraints in the most critical regions. Three beams per battery were glued for process optimization.

The beams were produced in a manual press, and the cold pressing time was 24 h, above the minimum recommended by the manufacturer, which is between 10 and 14 h, and 0.8 MPa pressure was applied for bonding. The average ambient temperature for the bonding was 20 °C. After pressing, five beams per treatment were stored for a 48-h glue curing period. Then, the 15 beams were planed until they had the average final dimensions of 5.0 × 10.0 × 240.0 cm.

Sectional Homogenization Method (SHM)

The sectional homogenization method (SHM) consists of replacing the cross section of a part of heterogeneous material in an equivalent dummy MOE section, thus predicting the bend that may occur for a given load. Figure 2 of TL treatment (beam V01) exemplifies this method.



(a) (b)

FIGURE 2. Geometry and MOE of the composed elements of the beam: (a) original section; (b) transformed section.

According to Melzerová et al. (2015), the following steps can be utilized to obtain the homogenized section MOE:

Step 1) Define the lamellae width of the transformed section, choosing as a basis a lamella with a lower modulus of elasticity:

$$b^* = \mathrm{b}\frac{E_i}{E_c} \tag{2}$$

Where,

b^* is the new basis for the lamella (cm);

b is the basis of the chosen lamella (cm);

E_i is the lamella's MOE (MPa), and

E_c is the MOE of the chosen lamella (MPa).

Step 2) Determine the new lamella area and, afterwards, the area of the beam:

$$A^* = {b_i}^* * t \tag{3}$$

Where,

A^* is the new area for the lamella (cm²);

b_i^* is the new basis of the determined lamella (cm), and

t is the lamella height (cm).

Step 3) Owing to the altered beam geometry, it is necessary to redefine the centroid of the transformed section, where the neutral axis passes through:

$$y_{ln} = \frac{\sum_{i=1}^{n} {A_i}^* * di}{\sum_{i=1}^{n} {A_i}^*} \tag{4}$$

Where,

di is the distance from the center of lamella;

i to an arbitrary axis, and

y_{ln} is the distance from the section centroid to this arbitrary axis.

Step 4) Define the inertia momentum (I*) of a composed area:

$$I^* = I + A^* d^2 \tag{5}$$

Where,

I* is the inertia momentum of a composed area (cm^4);

I is the inertia momentum of each lamella (cm^4);

A* is the new lamella area (cm²), and

d is the distance between the part neutral axis and the lamella neutral axis.

Step 5) Define the static moment:

$$Q^*_x = \sum A_i^* * yi \tag{6}$$

Where,

Q* is the static moment, and

yi is the distance between the lamella center and the gravity center of the part.

Step 6) Define shape factor (χ*) for the new part:

$$\chi^* = \frac{A^*}{(I^*)^2} \sum_{i=1}^{n} \frac{1}{b_i^*} \int (Q^*)^2 dy \tag{7}$$

The 1/3 Simpson's rule was used to numerically evaluate the integral in [eq. (7)]:

$$\int_{plate} (Q^*)^2 dy = \frac{t}{6}\ [Q^{*2}(y_s) + 4Q^{*2}(y_c) + Q^{*2}(yi)] \tag{8}$$

Where,

y_s, y_c, and y_i are the upper, middle, and lower y lamellae coordinates, respectively.

Step 7) Define the shear modulus (G_c) in accordance with Bodig & Jayne (1993):

$$G_c = \frac{E_c}{16} \tag{9}$$

Where,

G_c is the shear modulus, and

E_c is the MOE of the chosen lamella (MPa).

Step 8) Calculate the maximum bend:

$$\delta = \frac{\mathrm{Pa}}{48 E_c I^*}(3l^2 - 4a) + \frac{\mathrm{Pa}\chi^*}{2 G_c A^*} \tag{10}$$

Where,

δ is the maximum bend (cm), and

P is the total estimated load (kN).

In a flexural test performed by Terezo & Szücs (2010) with 6 × 12 × 250 cm beams, the obtained load strength of paricá solid wood was compatible with the 3.1 kN proportionality limit.

For the GLT beam, from [eq. (11)]:

$$P_{estimated} = \frac{3{,}1 * W * 2}{\frac{l}{3}} \tag{11}$$

Where,

W corresponds to the strength modulus (cm³), and

L is the lamellae's span (cm).

Using the mean W value (71.90 cm³) and the average L (228 cm) of the lamellae, a 5.86 kN total load P was found for the analytical bend of the GLT beams.

Static Bending Test

For the static bending test of the GLT beams, a system was set up, consisting of a response slab with the beams resting on iron racks with end rollers fixed on them, for the fitting of aluminum bars. These were laterally positioned and used as support for the two displacement transducers, which were parallel to the beam neutral axis. The experimental values were extracted from the "force x displacement" charts, and the bends were calculated by the arithmetic mean of the values provided by the two displacement transducers in a 210 cm constant span.

Characterization of the Bonding Lines

The specimens for characterization of the bonding lines were extracted from the five GLT beams already tested; undamaged regions were selected, resulting in five samples.

The performance of the bonding lines was assessed by the standard tensile and shear tests using a universal testing machine (EMIC - model DL 3,000). The recommendations of Appendix B of ABNT/NBR - 7190 (1997) were followed; however, the shear test specimen was adapted from the French standard (AFN/NF B 5-32, 1942) because of the lower coefficient of variability with this standard.

Statistical Analysis

The bends obtained by the SHM (analytical) method and by the experimental method for the treated and untreated GLT beams were evaluated and compared using the F variance test and Tukey's mean test with a 95% significance level using the completely randomized design (CRD) method.

The experimentally obtained MOEs were for the TL and TB beams and for non-treated (NT) beams. They were all compared by the same statistical analysis explain before.

RESULTS AND DISCUSSIONS

The results as functions of the analytical bend obtained by SHM and of the experimental bend for the three treatments are presented in Table 1.

TABLE 1. Comparison between analytical and experimental values of maximum bends obtained in 21 GLT beams tested by four-points bending.

Treatment	Samples	$\delta_{analytical}$ (mm)	$\delta_{experimental}$ (mm)	Absolute Difference ($\delta_{analytical} - \delta_{experimental}$) (mm)	Relative Difference (%) $\frac{(\delta_{analytical} - \delta_{experimental})}{\delta_{experimental}}*100$
Beams of lamellae individually treated **(TL)**	V1	24.63	20.62	04.01	-16.28
	V4	36.65	23.29	13.36	-36.45
	V7	33.82	22.54	11.28	-33.35
	V13	36.67	21.06	15.61	-42.57
	V16	38.82	23.25	15.57	-40.11
Mean		**34.12 ab**	**22.15 a**	**11.97**	**|33.75|**
Standard deviation		**5.59**	**1.24**	**4.79**	
Variation coefficient		**16.39**	**5.61**		
Treated beams composed of natural lamellae **(TB)**	V3	26.51	16.89	09.62	-36.29
	V5	28.12	17.34	10.78	-38.34
	V12	29.52	21.83	07.69	-26.05
	V18	35.16	23.46	11.70	-33.28
	V 21	32.70	20.75	11.95	-36.54
Mean		**30.40 a**	**20.05 a**	**10.35**	**|34.10|**
Standard deviation		**3.50**	**2.85**	**1.74**	
Variation coefficient		**11.51**	**14.23**		
Beams with no chemical treatment **(NT)**	V8	32.39	27.94	04.45	-13.74
	V9	35.60	21.42	14.18	-39.83
	V14	37.66	19.38	18.28	-48.54
	V17	38.95	23.06	15.89	-40.80
	V22	43.12	21.92	21.20	-49.17
Mean		**37.54 b**	**22.74 a**	**14.80**	**|38.41|**
Standard deviation		**3.98**	**3.19**	**6.35**	
Variation coefficient		**10.60**	**14.05**		

Mean values followed by the same letter in the columns do not differ at 5% probability by Tukey's test.

A comparison between the experimental bends means showed that there were no differences between treatments. However, between the analytical bends (34.02 mm as an average) and experimental bends (21.65 mm as an average), there was a significant difference.

The modulus of elasticity values calculated by the four-point bending test are presented in Table 2.

TABLE 2. Mechanical properties of beams tested by four-point bending.

Treatment	Samples	MOE (MPa)	Axial Stress (MPa)	Shear (MPa)
TL	V 1	21.357	47.53	1.49
	V 4	18.912	40.25	1.27
	V 7	19.533	48.88	1.55
	V 13	20.926	46.08	1.45
	V 16	18.947	38.75	1.21
Mean		**19.935 a**	**44.30 ab**	**1.39a**
Variation coefficient		**5.71%**	**10.20%**	**10.53%**
TB	V 3	26.086	44.68	1.51
	V 5	25.415	38.49	1.30
	V 12	20.176	37.81	1.26
	V 18	18.785	39.29	1.32
	V 21	21.228	42.12	1.42
Mean		**22.338 a**	**40.48 a**	**1.36a**
Variation coefficient		**14.51%**	**7.07%**	**7.33%**
NT	V 8	15.765	57.07	1.91
	V 9	20.561	46.41	1.48
	V 14	22.734	46.50	1.54
	V 17	10.231	49.95	1.58
	V 22	20.103	45.96	1.43
Mean		**17.879 a**	**49.18 b**	**1.59a**
Variation coefficient		**27.77%**	**9.53%**	**11.74%**

Mean values followed by the same letter in the columns do not differ at 5% probability by Tukey's test.

A comparison of the statistical treatments of MOEs and shear stress showed that there was no difference between them. However, there was a significant difference in axial tension. The untreated beams showed greater strength than the treated beams. This may be attributed to moisture in the treated wood owing to the use of water as a means of impregnating the wood with CCA.

The bonding line strength test results for the three treatments are presented in Table 3.

TABLE 3. Normal tensile and shear strength of the glued line.

Treatments	Sample	Normal Tensile (MPa)	Shear (MPa)
	V 1	1.78	1.30
	V 4	1.25	0.94
TL	V 7	1.20	1.19
	V 13	1.70	1.11
	V 16	2.40	1.22
Mean		**1.67 a**	**1.15 a**
Mean at 12%		**1.97 a**	**1.36 a**
Variation coefficient		**29.25%**	**12.07%**
	V 3	1.43	0.92
	V 5	1.78	1.51
TB	V 12	1.34	0.83
	V 18	2.20	0.98
	V 21	1.85	1.44
Mean		**1.72 a**	**1.14 a**
Mean at 12%		**2.03 a**	**1.34 a**
Variation coefficient		**20.11%**	**27.59%**
	V 8	2.05	0.88
	V 9	2.53	1.50
NT	V 14	2.00	1.07
	V 17	1.28	0.87
	V 22	1.55	1.21
Mean		**1.88 a**	**1.10 a**
Mean at 12%		**2.22 a**	**1.30 a**
Variation coefficient		**25.67%**	**23.83%**

Mean values followed by the same letter in the columns do not differ at 5% probability by Tukey's test.

A comparison of the means of tensile strengths normal to the fibers and shear strength of the bonding lines showed that there are no differences among the treatments.

Analytical and Experimental Displacements

The analytical displacements were 33% larger than the experimental ones. This difference may be related to the visual method of measuring the displacement with a ruler for the 7.5 kg weight. However, this has no bearing on the inference regarding the stiffness of the beams because the experimental bends were smaller than the analytically expected results. However, design with the analytical prediction only could lead to the use of a larger quantity of wood, which would be uneconomical. The average relative difference between the displacements (analytical and experimental) observed by Fagundes & Szücs (1998) in their evaluation of GLT pine beams was 9.32%, which was lower than that determined in this work.

Mechanical Properties of Beams

The findings of this work differ from those reported in the literature. This may be related mainly to the origin and age of the trees considered. The MOEs for paricá beams without preservative treatment evaluated by Cavalheiro et al. (2016) using the same glue as that used in this work and for beams chemically treated with CCA were 9,150 and 8,764 MPa, respectively. These values are much lower than our findings, as seen in Table 2.

The research conducted by Terezo & Szücs (2010) on paricá GLT without chemical treatment found an average MOE value of 19,343 MPa. At beam rupture, the values of 40.40 and 1.59 MPa, respectively, were obtained for axial and shear stress, respectively, which are close to the chemically treated beam values found in this work (Table 2). However, the axial tensile strength of the NT beams was significantly higher than that of the TB beams. This difference may be attributed to the fact that the preservation method significantly altered the moisture content of the beams, compromising the wood strength, which requires a more efficient post-treatment drying.

As seen in Table 2, the GLT paricá beams showed superior MOE performance in comparison to GLT *Pinus* sp. beams. However, their performance was inferior to that of GLT *Eucalyptus grandis* beams, except for the third treatment (NT). The 23,391 MPa MOE value for the NT may have been higher because of the composition of the lamellae positioned along the cross section and a better classification of these.

In the case of *Pinus* sp. and *Eucalyptus grandis* GLT beams, the results obtained by Fagundes & Szücs (1998) and Grohmann & Szücs (1998) using the same adhesive as that used this work and a lamella classification obtained average MOE values of 9,460 and 22,987 MPa, respectively. These species are widely used in GLT production. It should be noted that the paricá average apparent density is 490 kg/m³, which is lower than the densities of pine (590 kg/m³) and eucalyptus (640 kg/m³).

Bonding Line Strength

The values shown in Table 3 for this study were lower than those reported in the literature. The average values of untreated beams reported by Terezo & Szücs (2010) for normal tensile and shear parallel to the bonding line were 3.81 and 2.97 MPa, respectively. Cavalheiro et al. (2016) reported a 3.40 MPa value for the shear strength parallel to the bonding line. These lower results may be due to the tree planting site and age variability. The use of adapted shear specimens with smaller areas may have contributed to the differences between our results and those reported in the literature.

Regarding the treatments (TL, TB, and NT), the way the chemical preservation was applied did not directly affect the results; the mean values of relative difference were very similar. With a 95% level of significance, there was no difference in the sequence of the lamellae chemical treatment method, thus there was no influence on the final wood strength.

CONCLUSIONS

We concluded that the simplified methodology for non-destructive lamellae classification for GLT beam composition can be applied when more sophisticated equipment is not available. The lamellar classification for compounding the GLT beams can be used, since the values of the deformations obtained in the laboratory were smaller than the deformations calculated in an analytical way without increasing the section.

It is possible to affirm, with 95% confidence, that there was no difference in relation to the type of chemical treatment applied in the modulus of elasticity, static bending, shear stress, and bonding line strength. However, the untreated beams showed significantly higher axial bending stress strength than the chemically treated beams.

The results obtained for the chemically treated beams in the four-point bending test were equivalent to the values reported in the literature for strength, and the MOE results were very close to or even superior to those of the *Eucalyptus* genus. This is another possibility for the structural use of the chemically treated species.

Regarding the bonding line performance of the GLT beams, we obtained average values below those reported in the literature, which may be related to the use of different specimens. With 95% significance, there were no statistical differences between the treatments. That is, the preservative treatment had no influence on bonding.

The way the chemical treatment was performed did not lead to differences in beam elasticity and bonding. The choice of the best way to carry out the treatment was a function of the size of the structural part. If, because of its large size, it is impossible to fit a part into an autoclave, chemical treatment of the lamellae must be carried out before gluing. For parts with smaller dimensions, enabling beam chemical treatment, cost/benefit analysis is recommended to determine the best economic choice.

ACKNOWLEDGMENTS

We are grateful to the TRATTAR Company, for conducting the chemical treatment of the lamellae and the GLT beams; to SENAI, for the unfolding and flattening (carpentry work) of boards, lamellae, and GLT beams before and after the production process; and to CNPq - 2014 Universal Public Notice, for financial support of this research.

REFERENCES

Almeida DH, Scaliante R de M, Macedo LB, Macêdo AN, Dias AA, Christoforo AL, Calil Junior, C (2013) Caracterização completa da madeira da espécie amazônica paricá (*Schizolobium amazonicum* HERB) em peças de dimensões estruturais. Revista Árvore 37(6):1175-1181. DOI: http://dx.doi.org/10.1590/S0100-67622013000600019

ABNT – Associação Brasileira de Normas Técnicas (1997) NBR 7190: Projeto de estruturas de madeira. Rio de Janeiro, ABNT, 107p.

AFN – Association Francaise de Normalisation (1942) NF B 5-32: Essai de cisaillement. Paris, AFN, 12p.

Bodig J, Jayne B (1993) Mechanics of wood and wood composites. Nova York, Krieger Publishing Company, 712p.

Calil Neto C, Christoforo AL, Ribeiro Filho SLM, Lahr FAR, Calil Junior C (2014) Avaliação da resistência ao cisalhamento e à delaminação em madeira laminada colada. Ciência Florestal 24(4):989-996. DOI: http://dx.doi.org/10.1590/1980-509820142404018

Cavalheiro RS, Almeida DH de, Almeida TH de, Araujo VA de, Christoforo AL, Lahr FAR (2016) Mechanical Properties of Paricá Wood Using Structural Members and Clear Specimens. Internacional Journal of Materials engeneering 6(2):56-59. DOI: http://dx.doi.org/10.5923/j.ijme.20160602.06

Cunha AB da, Monteiro JL (2010) Determinação do módulo de elasticidade em madeira laminada colada por meio de ensaio não destrutivo (“stress wave time”). Revista Árvore 34(2):345-354. DOI: http://dx.doi.org/10.1590/S0100-67622010000200018

Fagundes GSR, Szücs CA (1998) Composição racional de vigas de madeira laminada colada. In: VI Encontro Brasileiro em Madeiras e em Estruturas de Madeira. Florianópolis, Instituto Brasileiro em Madeira e em Estruturas em Madeira, Proceedings...

Furtado FRC, Terezo RF (2014) Proposta de certificação de produtos em madeira laminada colada. Revista do Instituto Florestal de São Paulo 26(1):117-125. DOI: http://dx.doi.org/10.4322/rif.2014.009

Grohmann SZ, Szücs CA (1998) Vigas de madeira laminada colada com lâminas pré-classificadas de *Eucalyptus grandis*. In: VI Encontro Brasileiro em Madeiras e em Estruturas de Madeira. Florianópolis, Instituto Brasileiro em Madeira e em Estruturas em Madeira, Proceedings...

Melzerová L, Janda T, Šejnoha M, Šejnoha J (2015) FEM Models of Glued Laminated Timber Beams Enhanced by Bayesian Updating of Elastic Moduli. International Journal of Mechanical, Aerospace, Industrial, Mechatronic and Manufacturing Engineering 9(5):692-698.

Nogueira D (2017) A versatilidade da madeira laminada colada. Belo horizonte, Revista Construindo, v 8, p1-14.

Teles RF, Menezzi CHS, Souza MR, Souza F (2010) Effect of nondestructive testing of laminations on the bending properties of glulam beams made from louro-vermelho (*Sextonia rubra*). Cerne 16(1):77-85.

Terezo RF, Szücs CA (2010) Análise de desempenho de vigas em madeira laminada colada de parica (*Schizolobium amazonicum* Huber ex Ducke). Scientia Forestalis 38(87):471-480.

Terezo RF, Sampaio CA de P, Do Valle Â, Stüpp ÂM (2015) Propriedades da Madeira de paricá em diferentes idades para uso estrutural. Ciência da Madeira 6(3):244-253. DOI: http://dx.doi.org/10.15210/cmad.v6i3