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Glued laminated Timber Produced with Tropical Brazilian Wood Species

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Authors' contributions

This work was carried out in collaboration between all authors. All authors read and approved the final manuscript.

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ABSTRACT

Despite the wood versatility, its application is, sometimes, difficult because of its properties and performances under different work conditions are not completely known. The present work, developed in Laboratory of wood and wood structures (known as LaMEM), Department of Structures, School of Engineering of São Carlos, University of São Paulo, seeks to contribute for a better utilization of the alternative tropical wood species, especially in the employment to the production of structural elements of glued laminated timber, once that Brazil has a great potential of these species which are under applicated. In this context, the determination of the physical properties, the strength and the stiffness of some alternative tropical species are realized, and the stiffness of structural elements made of the specie, wich presented the best results in specimens tests, were determinated. Beams are tested with two adhesives classes, two pressure intensities

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and two ways of lamination. Experimental methods suggested in Brazilian Technical Codes Association were used. The specie Cedrinho (*Erisma* sp.) presents the best results, and conclusions are made: Cascophen and castor oil adhesives did not influence the beams stiffness properties; the same thing happens for the two pressure intensities, 0,8 MPa and 1,2 MPa. The glulam beams stiffness properties can be influenced by the ways of lamination.

Keywords: Wood properties; timber structures; beams; glued laminated timber; GLT; tropical brazilian wood species; cascophen resin; castor oil resin.

1. INTRODUCTION

The use of wood in the construction of structures in Brazil does not always occur in satisfactory conditions regarding the technology added to the material, despite its versatility and availability. Even considering these favorable aspects, their employment is sometimes hampered by the fact that their physical-mechanical properties and performance in different service conditions are not fully known [1].

For the adequate structural utilization of the wood, it is indispensable the knowledge of its characteristics of resistance and rigidity. This should occur with all species, including alternatives, whose potential is promising, considering the multiple possibilities of use. Among these, it has been gaining more and more space in the international market, with immediate repercussions in the Brazilian civil construction, the use of glued laminated timber (GLT) structural elements, compatible solution for a wide range of structural problems [2].

The use of wood as a structural element has been rethought and is the subject of intensive studies aimed at optimizing its use. Among these studies, we highlight those aimed at the improvement of techniques for repairing already existing structures, as well as to enable the use of species with lower properties [3-5].

The performance of GLT has been proven to be suitable for structural applications. It can also be used as reinforcement of structures, with due study beforehand to avoid that the transmission of loads can concentrate in the joints, thus compromising the element as a whole. Many researches also indicate the best performance of GLT against solid wood, depending on the adhesive and connectors used [6-7].

At the same time, there has been an awareness of the need to make better use of the natural resources coming from tropical forests, in particular with regard to the Amazon Forest, with the dissemination of the concepts of sustainable management and commercialization of certified material. It is less and less compact with selective and predatory exploitation, which led to the exhaustion of several species of consecrated use [8].

Information published by [9] shows a significant decrease in the rate of deforestation in the Amazon Forest. In the period between August 2011 and July 2012, 4.656 km² of forest were deforested, the lowest rate since 1988 representing a 27% reduction in relation to the previous period. In 2014 INPE reported that there was an 18% reduction in the deforestation rate in the Amazon forest between 2013 and 2014 in relation to the previous period.

Thus, the availability of species of lower density increases, evidencing the urgency for the development of research works, whether of a theoretical or theoretical-experimental approach, that allow the adequate knowledge of its applicability to the most diverse practical situations, among them GLT [10].

1.1 Objective

The work proposed here aims to generate subsidies that contribute to the use of tropical species, with a density of up to 0.75 g/cm³, at 12% moisture content, the reference value of [11], in the production of structural parts of GLT.

1.2 Methodology

This research was divided into two phases. In the first one, tests were carried out on glued specimens obtained from four wood species, being determined the tensile strength of toothed seams and shear strength of glue line. For comparison purposes, tests were carried out to determine the tensile strength parallel to the fibers, the normal tensile strength to the fibers and the shear strength in solid wood specimens. In the second phase, the rigidities of structural elements obtained from the specimens whose specimens have the best results were determined by means of static bending tests. Assembled beams were tested with two types of adhesives, two pressure intensities and two lamellae distributions. The experiments were carried out in accordance with the recommendations of [11], and the results obtained from analysis of variance of the means and factorial analysis.

2. ABOUT GLUED LAMINATED TIMBER

Structural elements of GLT are formed by pieces of wood obtained with lamellae of a certain section, joined under pressure, with the aid of adhesives (Fig. 1).

GLT has its most frequent uses in roofing structures, main structural elements for bridges, transmission towers, buildings, boats, stairwells and handrails, decorative ornamental fixtures, frames and furniture. This is because GLT adapts to a significant variety of shapes and presents high resistance to mechanical stresses due to its relatively low self-weight.

GLT products have gained an increasing space in the consumer market. This is due to the use of planted forests in their processing, together with the growing concern with sustainability, as well as the advancement in the technology of adhesives, which facilitates the production of these products [12].

One of the characteristics of GLT is the versatility in obtaining the most varied geometric forms for structural elements. The resulting architectural possibilities are numerous and depend mainly on the indispensable collaboration between architects and engineers [13]. The main advantages are:

- Ease of construction of large structures from pieces of commercial size;
- Reduction of cracks and other defects typically of massive pieces of wood, with large dimensions;
- Possibility of using lower quality parts in less requested areas, and of better quality parts in more requested areas, so that different species can be combined;
- Possibility of applying deflections in opposite way of main loads in manufacturing process;
- Low weight / resistance ratio, not requiring heavy hoisting equipment, as well as leading to foundations with lower intensity actions;
- Good performance under the action of fire, due to cross sections, and high resistance to corrosive agents.

As a restrictive aspect, it can be mentioned that GLT has a higher cost than solid wood, and requires special techniques, equipment and labor specialized in the manufacturing process.

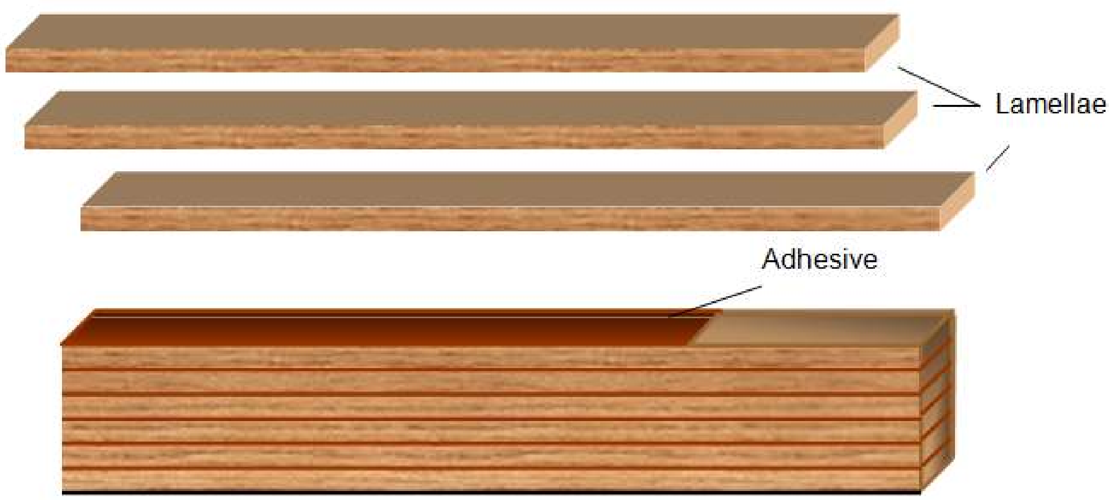

Fig. 1. Glued laminated timber (GLT) beam

3. PRELIMINARY TESTS

Preliminary tests allowed evaluating the performance of some native species by means of tests with specimens, following the guidelines provided in [11]. The species that presented the best results was chosen to carry out the research.

3.1 Materials

For the preliminary tests, native species of wood were used, with densities of up to 0.75 g/cm³, at 12% moisture content, as prescribed by [11]. From the bibliographical research, the species whose densities were inferior or at most equal to the cited value were listed. From this survey, those available in the timber market of the São Carlos region were selected, in four species:

- Envira Branca (*Xylopia* sp.) – density 0.72 g/cm^3;
- Cambará (*Erisma uncinatum*) – density 0.63 g/cm^3;
- Castanheira (*Bertholletia excelsa*) – density 0.70 g/cm^3;
- Cedrinho (*Erisma* sp.) – density 0.62 g/cm^3.

Six lumbers for each species were acquired in the timber market of the region, with nominal dimensions 6 cm x 12 cm x 300 cm, from which were extracted specimens.

Two types of adhesives were used in the bonding of the specimens. The first, resin-based resorcinol, known by the trade name Cascophen (CA), is usually used in the production of GLT structural elements by Brazilian industry. The second, based on resin extracted from castor bean, is a bicomponent polyurethane adhesive (PU) developed and produced by researchers from the Institute of Chemistry of São Carlos, University of São Paulo (IQSC - USP). For the preparation of the specimens, the electrical equipment of the LaMEM workshop was used, such as circular saw, drill and "wing" cutter for toothed patches. A reaction device, with a dynamometric ring, was mounted to provide the desired pressure intensity. For the preparation of the adhesives were used small containers, with capacity of approximately 1 liter, to mix the parts. In the determination of the masses of the parts, a digital scale was used, and brushes were used to distribute the adhesives on the specimens. In the conduction of the tests, two universal test machines were used: AMSLER, with loading capacity of 250 kN, and DARTEC M1000/RC, with a capacity of 100 kN.

3.2 Methods

In this stage, tensile tests were performed parallel to the fibers, normal tensile strength to the fibers and shear strength in solid wood specimens. These were used as control for the comparison with bonded test specimens, in which tests were carried out to determine the strength of the toothed seams, shear strength at normal traction and shear strength at the glue line.

For the preparation of the specimens to be tested, six pieces of wood (beams) of each species, with nominal dimensions of 6 cm x 12 cm x 300 cm, were randomly selected from the commercial establishment that sold the material.

For the species Envira Branca, nine specimens were extracted from each beam: three for tensile tests parallel to the fibers (one for solid wood and two for CA and PU), three for tensile strength normal to the fibers and three for shear strength tests. After the tests with this species, the results indicated the need for more specimens to be made to obtain different intensities of bond strength. Thus, for the other three species eleven specimens were extracted from each beam: five for tensile tests parallel to the fibers (one for solid wood and four for the tests with the adhesives), three for tests of normal traction to the fibers and three for shear strength tests. Being six beams per species, a total of fifty-four specimens were prepared for the Envira Branca species and sixty-six for the others, totaling two hundred and fifty-two tests.

The phenolic base adhesive (CA) was prepared according to the manufacturer's instructions: a bulk part of catalyst for every five parts by mass of adhesive. PU processing was prepared according to the instructions of the IQSC - USP researchers: a bulk part of the catalyst for each bulk part of the adhesive. The adhesive consumption was 350 g/m² and the pressure application time was 10 hours (both adhesives). The healing time of the pieces was 10 hours for CA and ninety-six hours for PU. The bond pressure was 0.8 MPa for all tests.

Due to the first results obtained with the species Envira Branca, it was decided to adopt one more value of sticking pressure for the tests of resistance of the dentate seams to the traction parallel to the fibers for the other species. This new value corresponds to double the value adopted until then, that is, 1.6 MPa.

3.3 Results and Analysis

The following Tables present the tensions obtained for the species Envira Branca, Cambará, Castanheira and Cedrinho. The results presented in MPa refer to solid wood (SW), CA and PU. The column "Pressure" corresponds to the values adopted in the bonding of the specimens, also in MPa.

Table 1. Average tensions obtained for Envira Branca (in MPa)

	Pressure	SW	CA	PU
Parallel tensile	0.8	63.12	54.04	40.09
Shear	0.8	12.53	12.00	11.45
Perpendicular tensile	0.8	2.078	1.76	1.66

Table 2. Average tensions obtained for Cambará (in MPa)

	Pressure	SW	CA	PU
Parallel tensile	0.8	52.17	45.18	25.66
	1.6		47.31	43.61
Shear	0.8	14.02	13.37	10.05
Perpendicular tensile	0.8	2.48	2.47	1.15

Table 3. Average tensions obtained for Castanheira (in MPa)

	Pressure	SW	CA	PU
Parallel tensile	0.8	64.35	38.41	28.05
	1.6		36.50	19.38
Shear	0.8	10.44	7.76	6.37
Perpendicular tensile	0.8	4.84	2.86	2.84

Table 4. Average tensions obtained for Cedrinho (in MPa)

	Pressure	SW	CA	PU
Parallel tensile	0.8	40.60	33.47	37.48
	1.6		34.28	40.44
Shear	0.8	8.37	8.13	8.13
Perpendicular tensile	0.8	2.57	2.21	2.15

The tests on solid wood were performed in order to control the statistical analysis. The results obtained on the specimens bonded with CA and PU was compared with the results obtained on natural wood specimens.

3.3.1 Envira branca

The following Table 5. presents the values obtained in the analysis of variance of the species Envira Branca.

With respect to shear strength, it is observed that the average resistances are close. The analysis of variance of the means bought this situation. For the two adhesives studied, its good performance is demonstrated. As for the parallel traction in toothed seams, the strength of the natural wood was the higher of the three determined. This is probably due to the pressure applied in the preparation of test specimens (0.8 MPa), which may not have been sufficient to promote proper penetration of the adhesive into the wood. This finding led to the adoption of a pressure of more than 0.8 MPa in the preparation of test specimens for the parallel traction test of the other species. Also in the case of normal traction on the glue sheet, the strength of the natural wood was the higher of the three determined. Statistically, the undesirable performance of both adhesives was demonstrated.

3.3.2 Cambará

Table 6 presents results obtained in the analysis of variance of Cambará.

With respect to the results of this species, it can be concluded, at the outset, the convenience of using 1.6 MPa bonding pressure in the preparation of the specimens to determine the tensile strength. For this pressure the best results were obtained. When the pressure of 0.8 MPa was adopted, the results were much lower for PU adhesive and slightly lower for CA. For resin PU, it is evidenced a poor performance of this adhesive for this intensity of pressure. The contrary happens for CA, suggesting a good performance of this one with a sticking pressure of 0.8 MPa. In the case of shear strength, CA provided a result very close to that obtained for solid wood. Lower value was achieved with PU adhesive.

An aspect of relevant meaning in the definition of the native species and the adhesives to be used in the construction of structural elements of laminated wood begins to appear. It is not enough, as reported by Macedo AN in “Madeiras tropicais da Amazônia em madeira laminada colada (MLC)" a work presented to the discipline "Madeiras e suas aplicações" inSchool of Engineering of São Carlos, University of São Paulo, 1997. Macedo corroborated by [14] explain that the density of the species is contained in the range of 0.5 to 0.75 g/cm³ [14a] and [14b] it is necessary to consider the compatibility between the wood and the adhesive, conditioned by the permeability of the species to the adhesives. And, in turn, permeability is associated not only with the anatomical specificities of the species but also with the viscosity characteristics of the adhesive.

It is observed that, for Cambará, good results were obtained with CA, whereas those presented by PU adhesive were not satisfactory. Thus, the compatibility of the species with CA was more favorable. It should be noted that, according to [15], Cambará presents "pores visible only under lens, very small, multiple and solitary, clogged with resin oil and pallets." These peculiarities influence the permeability of the species, making it less compatible with PU compared to CA.

On the other hand, it is concluded that it is convenient to discard the pressure of 0.8 MPa in the production of specimens to evaluate the tensile strength of the seams. With this, it is possible to reduce experimental work without loss of information quality.

3.3.3 Castanheira

The following are presented in Table. 7 the results of the analysis of variance of Castanheira.

For all the resistances and for the two pressures used in the bonding, it was not possible to achieve, with the two adhesives considered, values close to those of the solid wood, thus demonstrating a poor performance, a fact confirmed by the statistical analysis.

Once again, the need to seek the compatibility between species and adhesives (and not only the density range) to define the most suitable species for the production of GLT is evidenced. According to [15], this species shows "medium to large, few, solitary and multiple pores, almost always clogged by bamboos". The small number of pores and the systematic obstruction caused by the bamboos impairs the permeability of the species and limits their use to make structural elements of GLT with the adhesives studied.

Table 5. Analysis of variance for Envira Branca

	Pressure	SW x CA			SW x PU		
		$F_{observed}$	f_C	*P*	$F_{observed}$	f_C	*P*
Parallel tensile	0.8	0.95	5.117	.356	12.50	4.965	.005
Shear	0.8	0.41	5.117	.540	2.67	5.318	.141
Perpendicular tensile	0.8	7.27	4.965	.022	12.72	4.965	.005

Table 6. Analysis of variance for Cambará

	Pressure	SW x CA			SW x PU		
		$F_{observed}$	f_C	*P*	$F_{observed}$	f_C	*P*
Parallel tensile	0.8	1.43	5.117	.262	21.72	5.117	.001
	1.6	0.56	5.117	.473	1.63	5.117	.233
Shear	0.8	0.18	4.965	.678	13.76	4.965	.004
Perpendicular tensile	0.8	0.00	4.965	.979	8.99	4.965	.013

Table 7. Analysis of variance for Castanheira

	Pressure	SW x CA			SW x PU		
		$F_{observed}$	f_C	*P*	$F_{observed}$	f_C	*P*
	0.8	22.90	4.965	.001	29.33	4.965	.000
Parallel tensile	1.6	21.04	4.965	.001	85.82	4.965	.000
Shear	0.8	8.22	4.965	.017	14.54	4.965	.003
Perpendicular tensile	0.8	8.41	4.965	.016	6.89	5.117	.028

Table 8. Analysis of variance for Cedrinho

	Pressure	SW x CA			SW x PU		
		$F_{observed}$	f_C	*P*	$F_{observed}$	f_C	*P*
	0.8	1.17	4.965	.305	0.31	4.965	.592
Parallel tensile	1.6	1.24	4.965	.292	0.00	4.965	.984
Shear	0.8	0.07	4.965	.798	0.06	4.965	.809
Perpendicular tensile	0.8	0.99	4.965	.343	1.62	4.965	.232

3.3.4 Cedrinho

A Table. 8 shows the results obtained in the analysis of variance of the Cedrinho species.

Regarding the results of this species, it can be concluded that it is convenient to use 1.6 MPa bonding pressure in the preparation of the specimens to determine the tensile strength. For this pressure the best results were obtained. In the case of shear strength and normal traction, CA and PU yielded results very close to that obtained for solid wood.

Again, the need to compatibilize species and adhesives (not just the density range) to define the most convenient essences to produce laminated wood is evidenced. According to [15], this species shows "large pores, visible to the naked eye, few, solitary and multiple, thin-walled litters". The small number of pores is compensated by the small obstruction caused by thin-walled litters. This gives the species sufficient permeability to enable its use in the manufacture of structural elements of glued laminated wood with the adhesives studied.

4. MAIN TESTS

4.1 Materials

From the preliminary tests, Cedrinho species was chosen for development this phase of the research. In addition to presenting density 0.62 g/cm³, located in a range indicated for the production of GLT structural elements, presented compatibility for the two adhesives used in tests prescribed by [11],in its Annex B, confirmed by its performance to mechanical stresses.

Adhesives used in bonding of structural elements: CA, based on resorcinol, widely used in the production of structural elements of GLT. The second is a polyurethane (PU) resin, based on castor oil, developed and produced by researchers from Institute of Chemistry of São Carlos, University of São Paulo (IQSC - USP). Derived from castor oil, this adhesive is bi-component and cold cure composed of prepolymer A249 and polyol B16030. Once mixed, usage time is 30 minutes, with viscosity increase after that period.

A pressing device consisting of threaded guides has been mounted to provide the pressure to the beams. The pressure was made by nuts, rotated with a torque wrench, which was calibrated in a load cell. For the four-point static bending test, a hydraulically driven piston-mounted device was used a dynamometric ring with 20 kN capacity.

4.2 Methods

Tables with nominal dimensions of 2 cm x 30 cm, lengths ranging from 400 to 600 cm, were acquired in the region's timber trade, and these were sawed to obtain sheets of nominal dimensions 2 cm x 6 cm x 300 cm, totaling thus 116 lamellae.

4.2.1 Lamellae tests

Static flexion tests were performed on the slides to obtain the elastic moduli. Two supports were adopted that allowed rotation, standardized masses and a dial comparator. The forces were applied in the middle of span and the displacement was measured in the dial comparator on the face opposite of force application surface. The displacement is given by:

$$a = \frac{F\,L^3}{48\,E\,I} \quad (1)$$

Where:

A = displacement measured in *L*/2;
F = applied force;
L =distance between support;
E = modulus of elasticity of the lamellae;
I = Inertia moment of the lamellae.

4.2.2 Criteria for assembling structural elements

The elastic moduli of the slides were classified and separated into two batches: one for the assembly of beams with non-random distribution of slides, and the other with random distribution, each structural element consisting of a set of six superimposed slides. In total, sixteen sets were formed (which gave rise to sixteen beams): eight from the batch of non-random lamellae and eight from the batch of random lamellae.

In the assembly of the beams with non-random distributions (NR), the lamellae with higher moduli of elasticity were arranged in the most requested regions of the part and those of lower modules were placed in the regions of lesser demand. The same did not occur in the assembly of structural elements with random distributions (R). In these, the lamellae of each set were arranged without any criterion, thus guaranteeing the desired randomness.

In order to estimate the values of the beam intensity modules, before calculating those, calculations were made based on the arithmetic mean of the modules' modules, according to the equation:

$$E_{mean} = \frac{\sum_{i=1}^{n} E_i}{n} \quad (2)$$

Where "E_{mean}" is the estimated arithmetic average modulus for the structural part, "Ei" is the lamellae modulus of elasticity (with i varying from 1 to n), and n is the number of lamella that form the beam (six). In order to take into account the contribution of the modulus of elasticity of the slabs as a function of their positions in the section of the beam, a weighted average elasticity modulus, Ep, was also calculated from the following equation:

$$E_P = \frac{\sum_{i=1}^{n} E_i . I_i}{\sum_{i=1}^{n} I_i} \quad (3)$$

Where E_i and $I_i$are, respectively, the modulus of elasticity and moment of inertia of the lamellae in the cross section (i = 1.2. ..., n), with n = 6.

For this last calculation, the section was homogenized as a function of the modulus of elasticity of the first lamellae positioned in the structural element in the upward direction and, from this, the position of the new center of gravity for the section was determined. Then, the moments of inertia of the sections of each slide constituting the beam were calculated and the calculation of the estimated mean modulus of elasticity was then calculated.

4.2.3 Bonding the timber

The preparation of the adhesives followed the manufacturers' recommendations: a bulk part of catalyst for every five parts by weight of adhesive (CA), and a bulk part of catalyst for each bulk part (PU). Once prepared, the adhesives were distributed on the surfaces of the lamellae with brushes. The consumption was 400 grams of CA for each glued beam, and 350 grams for PU adhesive. The parts were then placed in a device mounted with shafts containing threads and nuts to convey pressure to the member. Eight beams were bonded with CA: four with 0.8 MPa pressure intensity and four with a pressure intensity of 1.2 MPa, and eight others with PU, with the same pressure intensities. The time of application of pressure was 10 hours (the two adhesives). The curing time of the bonded pieces was of at least 10 hours for CA and of 96 for the PU adhesive. After curing the beams were fitted and then ready to be tested.

4.2.4 Timber tests

For the static bending test of the beams, two bearings were used which allowed rotation, a comparator watch and, in this case, a device mounted for applying forces in the thirds of the span of the structural element. The load was made by a hydraulic piston, and the force measured by a dynamometric ring with a capacity of 20 kN, with constant K = 0.1828 N/division.

Three loading cycles were applied, with measurements recorded in the last cycle. Six readings, corresponding to 10%, 20%, 30%, 40%, 50% and 100% of a force that would promote a displacement of approximately L/200 were made, and the modulus of elasticity was calculated from the arithmetic mean of the readings. The displacement in the middle of the span (L/2) is given by:

$$a = \frac{F\,L^3}{24\,E\,I}\left(3\frac{L_1}{L} - 4\frac{L_1{}^3}{L^3}\right) \quad (4)$$

Where:

A = displacement at the midpoint of the beam
F = force applied on one third of the beam;
L =distance between beam supports
E = modulus of elasticity of the beam

I = Inertia moment;
L_1 =distance between the support and the application point of the force.

4.3 Results and Analysis

4.3.1 Results obtained for the beams

The values of modulus of elasticity for each lamella were used to orient the assembly of the beams. The symbols were adopted for the identification of the beams:

NR – Elaborated with non-random distribution of lamella
R – Elaborated with random distribution of lamella;
1 – Replica number 1
2 – Replica number 2
CA – Glued with Cascophen
PU – Glued with Castor oil polyurethane resin
0.8 – Glued with pressure intensity 0.8 MPa
1.2 – Glued with pressure intensity 1.2 MPa

The calculated means were obtained according to Eq. 2 (for simple arithmetic mean) and Eq. 3 (for weighted average).

The results obtained show that the beams assembled with non-random distribution of slides (NR) present higher weighted average values than the simple arithmetic mean (difference between 5.7% and 13.4%). This is explained by the lamellae distributions with larger moduli of elasticity in the most requested regions (greater contribution to the moment of final inertia of the part). For the beams with random distribution (R), there is no standard: three had the values of the moduli of elasticity weighted above the values obtained with the simple average and, the others, presented E_p below the values of E_{mean}.

4.3.2 Values obtained from the tests

Four-point tests were performed on structural pieces obeying generic parameters of [11] and [16]. Values of modulus (N/cm²), presented in Table. 9, and were calculated by eq. 4.

4.3.3 Analysis of results

In this work, we tried to determine influence variables (adhesive, bonding pressure and lamellae distribution) on the behavior of the beam. For this purpose, a factorial design 2x3 with two adhesives (CA and PU), two bond strength intensities (0.8 and 1.2 MPa) and two types of lamellae distribution (random and non-random). Influence of the effects (isolated and interacting with each other) on variable response (modulus of elasticity) of the piece was done using MINITAB statistical program, through means analysis of variance. For the verification of the hypotheses, the MINITAB program, ANOVA - Dunnett's subroutine, was used, with a significance level of .05 that is, the possibility of considering the hypothesis H0 as being true and this being false is 5%.

A Table. 10 shows the results obtained in the static bending tests, the distribution, adhesive and pressure columns make up the factorial planning matrix, and the last three columns show the estimated values, residuals and normal scores.

The results of the factorial analysis are shown below. The computational program provides the effect and Pvalue values for the terms distribution, adhesive and pressure, and for combinations of variables.

From Table. 11 it can be stated that only the main effect "distribution" influenced the response, since its *P* value is the only one smaller than .05. The others (adhesive, pressure and their combinations, including distribution) did not fit this condition. This allows us to conclude that both and both collage pressures had a behavior such that they did not influence the final responses of the moduli of elasticity. Regarding the distribution, its negative effect (-9547) indicates that when passing the test from the low level (-1) to the high level (1), the value of the response decreases. It is possible to affirm that the non-random distributions (NR) were advantageous in relation to the random distributions (R), observing the estimated values. This is explained by the fact that the mean of the modulus of elasticity of the beams with NR distribution was greater than the average of the beams with R distribution, which after the tests resulted in a difference close to 9% in favor of non-random ones.

A verification of the final elastic modulus estimation from calculated values was also performed by the analysis of variance of the means. In this case, the control group was that of the values obtained in the static tests, which were then compared with the calculated values. Comparisons were made between the mean static bending versus the arithmetic mean and static bending versus weighted average values. The results are shown in Table 12.

Table 9. E values obtained in the static bending tests

Beams	E (daN/cm²)	Beams	E (daN/cm²)
NR 1 C 0.8	115435	R 1 C 0.8	106119
NR 2 C 0.8	119658	R 2 C 0.8	117518
NR 1 C 1.2	116615	R 1 C 1.2	113120
NR 2 C 1.2	100174	R 2 C 1.2	98689
NR 1 M 0.8	108349	R 1 M 0.8	102557
NR 2 M 0.8	112474	R 2 M 0.8	105055
NR 1 M 1.2	123071	R 1 M 1.2	87134
NR 2 M 1.2	108364	R 2 M 1.2	97574

Mean	108244
SD	9531
CV	0.09

Table 10. Results obtained in the tests of static bending, matrix planning, estimated values, residuals and normal scores

Response	Distribution	Adhesive	Pressure	Estimated	Residuals	E. normal
115435	-1	-1	-1	117547	-2111.36	-0.39573
119658	-1	-1	-1	117547	2111.36	0.39573
106119	1	-1	-1	111819	-5699.39	-0.76184
117518	1	-1	-1	111819	5699.39	0.76184
108349	-1	1	-1	110411	-2062.69	-0.23349
112474	-1	1	-1	110411	2062.69	0.23349
102557	1	1	-1	103806	-1248.86	-0.0772
105055	1	1	-1	103806	1248.86	0.0772
116615	-1	-1	1	108395	8220.12	1.76883
100174	-1	-1	1	108395	-8220.12	-1.76883
113120	1	-1	1	105905	7215.17	0.98815
98689	1	-1	1	105905	-7215.17	-0.98815
123071	-1	1	1	115718	7353.84	1.28155
108364	-1	1	1	115718	-7353.84	-1.28155
87134	1	1	1	92354	-5220.08	-0.56918
97574	1	1	1	92354	5220.08	0.56918

Table 11. Data obtained in factor analysis

Response versus distribution, adhesive, pressure		
Term	**Effect**	***P* value**
Distribution	-9547	.040
Adhesive	-5344	.208
Pressure	-5303	.211
Distribution * adhesive	-5438	.201
Distribution * pressure	-3380	.412
Adhesive * pressure	2230	.583
Distribution *adhesive * pressure	-4999	.236

In analyzes between the arithmetic averages and weighted with the tests of static flexion the results pointed to the equivalence, since their F observed were smaller than the critical one. By studying the *P* value, it is stated that the one closest to the value obtained in the test is the arithmetic average.

There are a small number of related papers referring to the aim of this research. Two citations are the main information in bibliography, as follows.

Komariah et al. [17] studied three tropical essences from Indonesia to confirm the viability of applying them in structural members of GLT (*Acacia mangium*, *Maesopsis eminii* and *Falcataria moluccana*) Author's conclusion is the same of that here obtained: it's possible to use

Table 12. Analysis of variance from means of tests versus calculated

	Mean 1	Mean 2	$F_{observed}$	f_C	*P*	Difference
$Flexion^1 x\ arithmetic^2$	108244	106921	0.15	4.171	.705	-1.2%
$Flexion^1 x\ weighted^2$	108244	112285	0.90	4.171	.351	3.7%

certain low and medium density tropical wood species to produce GLT, once all the species presented good performance when submitted to pertinent tests.

Teles et al. [18] comparing theoretical and experimental deflections of glued laminated timber beams, made with a tropical essence (Sextonia rubra), among their conclusions confirm that the cited wood specie can be employed as raw material for GLT production.

5. CONCLUSIONS

From the discussion of the results presented previously, it is concluded that:

- For the production of structural members of glued laminated timber, it is not enough for the species to have a density between 0.5 and 0.75 g/cm³. So important is the permeability of the species to the adhesives available for the production of GLT.
- There are tropical species with a density between 0.5 and 0.75 g/cm³, with adequate permeability for the production of structural elements of glued laminated timber, using CA and PU adhesives. In this work, the potential of the Cedrinho species is worth mentioning, among those studied.
- It is possible to make an adequate estimate of the stiffness properties of GLT beams using eq. 2 and 3.
- Stiffness properties of GLT beams obtained in static bending tests are not influenced by sticking pressure ranging from 0.8 to 1.2 MPa.
- Adhesives studied do not influence stiffness properties of GLT beams obtained in static bending tests, Cascophen (CA) and castor oil based polyurethane (PU) resin.
- Stiffness properties of GLT beams obtained in static bending tests can be influenced by the arrangement of the lamellae along the cross-sectional height. Beams with non-random distribution of lamellae may have rigidity properties higher than those assembled with random lamellae distribution.
- It is possible to obtain compatible elements for structural employment of GLT, using as raw material, boards of alternative tropical species, used with the adhesives studied in the present work.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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