

STRENGTH OF STRUCTURAL FINGER-JOINTS REINFORCED WITH FIBERS

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Abstract

The finger-joints are the kind of top joints most used in wood blades to manufacture glued laminated timber (GLULAM) and present direct influence on their rigidity and final mechanical strength. Thus, the objective of this study was to evaluate the tensile strength parallel to grain with different compositions of reinforcements concentrated on finger-joints. Two geometries were used to execute the finger-joints and two species: *Pinus taeda* and *Eucalyptus* spp. The reinforcements were fabrics from glass or carbon fibers bonded with polyurethane structural adhesive. The treatments used were: "A-Glass", "A-Glass2", "A-Carbon", "A-Without reinforcement", "B-Glass", "B-Glass2", "B-Carbon" and "B-Without reinforcement", being "A" or "B", the geometries and "2", the number of layers of tissue. For statistical analysis, the Dunnett test was used at 95% confidence interval. The results showed that the execution of the unreinforced finger-joints decreased the tensile strength of the woods. For *P. taeda*, all the treatments were significantly inferior to the control (without finger-joints), and for *Eucalyptus* spp., only the treatment "A-Unreinforced" presented inferior performance to the control (without finger-joints), all others presented equivalent mechanical resistance to solid wood. It can be concluded that for the *Eucalyptus* spp. wood, the application of reinforcement on the structural finger-joints improves the tensile strength, equating to the solid wood.

Keywords: finger-joint, geometry; composites; tensile strength, forest planted wood.

Resumo

Resistência de emendas por entalhes múltiplos reforçadas com fibras. As emendas por entalhes múltiplos são a união de topo entre lâminas de madeira mais utilizadas na fabricação da Madeira Laminada Colada (MLC) e exercem influência direta na sua rigidez e resistência mecânica final. Desta forma, o objetivo deste estudo foi avaliar a resistência à tração paralela às fibras da madeira com diferentes composições de reforços sobre as emendas. Foram utilizadas duas geometrias para execução dos entalhes múltiplos e duas espécies: *Pinus taeda* e *Eucalyptus* spp.. Os reforços foram tecidos de fibras de vidro ou de carbono colados com adesivo estrutural poliuretano reativo. Os tratamentos empregados foram: "A-Vidro", "A-Vidro2", "A-Carbono", "A-Sem reforço", "B-Vidro", "B-Vidro2", "B-Carbono" "B-Sem reforço", sendo "A" ou "B", as geometrias e "2", o número de camadas do tecido. Para análise estatística utilizou-se o teste de Dunnett a 95% de confiabilidade. Os resultados mostraram que a execução das emendas sem aplicação de reforço diminuíram a resistência à tração paralela das madeiras. Para o *P. taeda*, todos os tratamentos foram significativamente inferiores à testemunha (sem emendas), e para o *Eucalyptus* spp., apenas o tratamento "A-Sem reforço" apresentou desempenho inferior à testemunha sem emendas, todos os demais apresentaram resistência mecânica equivalente à madeira maciça. Pode-se concluir que para a madeira de *Eucalyptus* spp. a aplicação de reforço sob as emendas melhora a resistência à tração paralela, equiparando-se à madeira maciça.

Palavras-chave: uniões dentadas; geometria; compósitos; resistência à tração; madeira de floresta plantada.

INTRODUCTION

Composites industry technologies have been used frequently by engineering. The use of new synthetic materials, in conjunction with natural polymers, makes industrial products meet the desired properties in project and performance standards. Wood and its derivatives are among the most important building materials and have become more and more usual. However, the availability of large bulk parts is becoming rare and costly, even when coming from certified homogenous plantations. Moreover, the massive parts possess modified physical and mechanical characteristics due to presence of knots, splits and cracks. These defects have detrimental effect in the tensile and compressive strengths (KHELIFA *et al.*, 2015b).

For Segundinho *et al.* (2013), Glued Laminated Timber (GLULAM) presents advantages in relation to solid wood, not only for preferential usage of planted forest species (*Pinus taeda* and *Eucalyptus* spp.), but in function of an industrial process that aims to diminish the influence of defects by means of classification, lamination and gluing. The top connection between wood blades can be performed through glued multiple longitudinal slots (*finger-joints*) or bevels. You can also remove the defects of the sheets and unite them again

through these processes. Therefore, accuracy is essential in the execution to achieve the quality standards requirements (MOLINA *et al.*, 2016).

Finger-joints are the most suitable for GLULAM according to their structural features such as: linearity, dimensional stability, resistance loss prediction and gluing largest area (KHELIFA *et al.*, 2015a). The used geometries are conducted by standards, as European EN 385 (2001), that considers a 20mm (L_d) length, base width (t_d) of 6,2 mm, top width (b_d) of 1 mm and percentage of weakening (v_d) up to 16%. In Brazil, there is the revision project of the Brazilian Standard PNBR 7190 (2011), that considers finger-joint geometries for structural purposes as: $L_d = 21$ mm, $t_d = 7$ mm, $b_d = 1$ mm and $v_d \leq 14\%$, up to $L_d = 28$ mm, $t_d = 7$ mm, $b_d = 1$ mm and $v_d \leq 12\%$.

Generally, wooden beams are more requested by parallel to the grain stresses and, consequently, to the GLULAM blades and its joints. Therefore, develop a new technology that is capable to resist tensile stress has been the objective of many researches in multiple longitudinal joints in recent years (BUSTOS *et al.*, 2003; BAYATKASHKOLI *et al.*, 2012; RAO *et al.*, 2012; IWAKIRI *et al.*, 2013; FINK & KOHLER, 2015; KHELIFA *et al.*, 2015a; HABIFI *et al.*, 2016; KHELIFA *et al.*, 2016). However, there are few works related to composite application exclusively in finger-joints (KHELIFA *et al.*, 2015b).

Composites formed by fibers associated with a polymer matrix have been used to reinforce or to increase the final mechanical resistance and the modulus of elasticity (E_w) of wooden structural elements. The fibers commonly used in this type of reinforcement are glass or carbon, associated to matrices which can be thermoplastic or thermosetting, depending on the application mode and use of the structure. In the reinforcement composites associated to wood, the most used matrices have been polyurethane, phenolic and epoxy (STERLEY *et al.* 2014).

In this sense, the objective of this research was to evaluate the performance of two geometries of finger-joints for structural purposes in wood of *Pinus taeda* and *Eucalyptus* spp., with reinforcements of glass and carbon fibers fabrics glued with reactive polyurethane.

MATERIALS AND METHOD

Samples of the species were selected randomly in lots of commercial sawn wood with approximately 1m³ each. Used wood came from different regions and suppliers, resulting in different processes in primary processing and drying phase. The wood of *P. taeda* used was provenient from planted forests of Santa Catarina State plateaus, with approach age of 28 years. In private sector company, logs were processed in 55 planks, with 300 cm x 20 cm x 2.2 cm of dimension, being conditioned outdoors by the period of 40 days until they obtained average humidity tenor about 18%. Later, these planks were transferred and stored in covered area for 120 days in the Wood Technology Laboratory, reaching an humidity tenor of 15.9%.

The wood *Eucalyptus* spp. was provenient of planted forests in the region of Vale do Caí in the state of Rio Grande do Sul, Brazil, with age among 13 and 15 years old. The logs were selected randomly and sawn in 80 planks with 300cm x 20 cm x 3 cm of dimension. The planks were primarily stored outdoor for approximatedly 30 day in order to lose water. Later, all pieces of *Eucalyptus* spp. Were kiln dried with temperature at 56°C and average humidity of 50% for 6 days, reaching mean moisture content of 12.3%. Then, they were transferred and stored at the Wood Technology Laboratory.

Manufacture of Test Specimens

The planks of *P. taeda* had been resawn in 100 clear pieces, with dimensions of 60 cm x 5 cm x 2,2 cm, and the wood of *Eucalyptus* spp. were sawed in 150 clear pieces, with dimensions of 60 cm x 3 cm, being removed 30 cm each end point. The difference of thickness between the species occurred due to the material being sourced from lumber industries and there was no overthickness compensation for wood retraction after drying. Figure 1 illustrates the steps for preparation of test specimens.

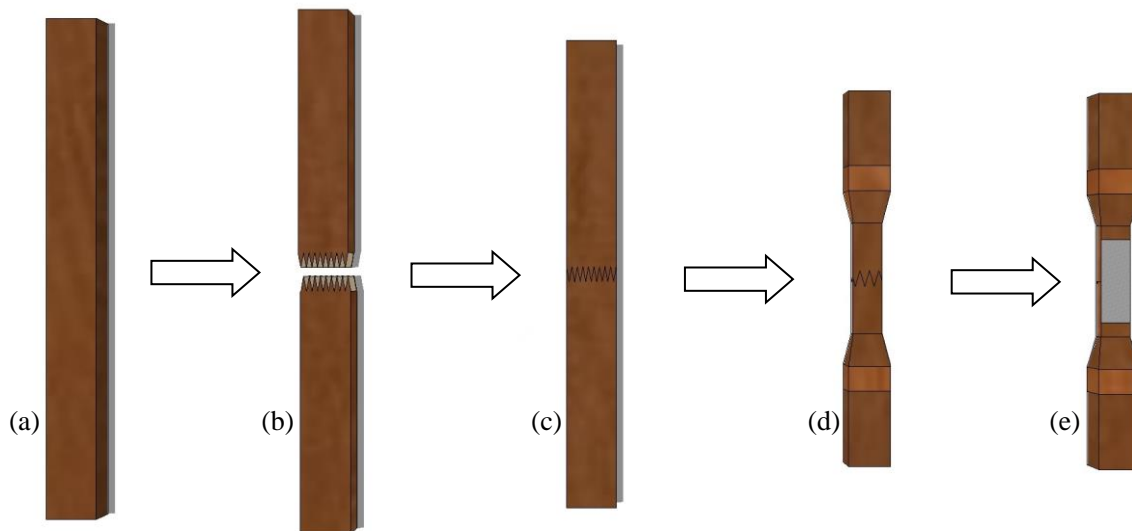
All the above samples were sawn in half, top cutted and milled in high rotation finger-joint machine with the geometries (A) acquired by the Wood Technology Laboratory and (B) used by industry (Figure 1b), as presented in the table 1. All the samples were glued in up to 24 hours after the milling process.

The adhesive used was a monocomponent reactive polyurethane (PUR), characterized by mean grammage 1.15 g.cm⁻³, mean solids content of 99.5% and mean viscosity 10,500 mPa.s at 20°C. The grammage control of PUR adhesive was performed with aid of digital scale, in which the container was weighed before and after each glue application, achieving 200 g/m², as recommended of the manufacturer.

The gluing process of finger-joints (Figure 1C) was performed with two different processes: (A) with automatized hydraulical press in manufacter yard; e (B) with manual press in the Laboratory, monitored with automatic system of data acquisition, model MX440A® of HBM®, softwares Catman Easy® and Quantum X®,

with load cell U10M® with 125 kN capacity. The use of these two systems occurred due to equipment availability in the 24 hours after samples milling.

Figure 1. Phases of the samples production.
 Figura 1. Fases de produção de amostras.



Caption: (a) Pieces with dimensions of 60 cm x 5 cm x 2,2 cm for *P. taeda* and of 60 cm x 5 cm x 3 cm for *Eucalyptus spp.*; (b) Pieces after milling; (c) Pieces after finger-joints gluing; (d) Test specimen drilled according to NBR 7190 (1997) and identification of density test specimen; (e) Finished test specimen, with the fiber fabrics glued on the finger-joints.

Table 1. Geometric variables according to used species and geometries.

Tabela 1. Variáveis geométricas de acordo com espécies e geometrias usada.

Treatments	Length L_d (mm)	Width of base t_d (mm)	Tip width b_d (mm)	Weakening Percentage v_d (%)
<i>P. taeda</i> - A	21,8	6,7	1,5	22%
<i>P. taeda</i> - B	19,1	6,5	1,7	26%
<i>Eucalyptus spp.</i> - A	20,5	6,5	1,5	23%
<i>Eucalyptus spp.</i> - B	18,6	6,6	1,8	27%

Legend: A = geometry of the wood technology laboratory; B = usual geometry in GLULAM industry.

The gluing pressure in the industrial hydraulic system was 4.4 MPa for *P. taeda* and 8.8 MPa for *Eucalyptus spp.* In the manual system of the Laboratory, the gluing pressure was 4.6 MPa for *P. taeda* and 6.5 MPa for *Eucalyptus spp.* These values are lower than those recommended by PNBR 7190 (2011), because in preliminary tests there was a premature rupture of the finger-joints when the pressures suggested by the standard draft were used. The samples were stored for 72 h to completely dry the adhesive. After this period, all the samples were planed and sawed obtaining final dimensions of 45.0 cm x 4.9 cm x 1.8 cm and finally usinated (Figure 1D) according to the NBR 7190 (1997) tensile strength parallel to the grain specimen test.

Reinforcement Application

The synthetic fiber fabrics used as reinforcement were: (i) the bi-directional glass fiber fabric, screen type 1x1, with 5x5 yarns/cm, grammage of 200 gm² and 0.18 mm thickness; and (ii) the bi-directional carbon fiber fabric, twill type 2x2, with 5x5 yarns/cm, grammage of 200 gm² and 0.40 mm thickness.

In the central area of the test specimen of tensile strength parallel to the grains, the adhesive (PUR) was applied with the same control and gluing grammage of the finger-joints, the reinforcement fiber was positioned on this layer of adhesive, the deaeration was performed with the aid of a metal bar and finally a last layer of adhesive was applied. In the case of the treatments with double layer of reinforcement, the steps of fiber application, glue and deaeration were repeated. These processes were performed on both faces of the test specimen. All of them were superficially pressed with 1 MPa of pressure, which is also controlled by the HBM® data acquisition system. The application of the reinforcements occurred up to 24 hours after the machining of the

test specimens, following the same production recommendations of elements in GLULAM. An illustration of the finished test specimen can be seen in Figure 1e.

The length of the applied fiber in the region of the finger-joint was in the ratio of 4:1, being 4 units in length of fiber fabric for each unit of cross-sectional area of the joint. This methodology was adopted after the execution of preliminary tests that used different fiber tissue lengths, in which the occurrence of shear ruptures in the fiber/wood bonding (for a smaller proportion) and ruptures in the base of the test specimen were observed (for a larger proportion).

Table 2 summarizes the experimental design adopted. A total of 221 tensile straight parallel to the grain test specimens having as variables the geometries; the species and three reinforcements composition, being: (i) a layer of carbon fiber tissue, (ii) a layer of glass fiber tissue and (iii) two layers of glass fiber tissue. The control specimens were from bulk wood without joints.

Table 2. Experimental plan.

Tabela 2. Plano experimental.

<i>Species</i>	<i>Geometries</i>	<i>Reinforcements</i>	<i>N. of test specimen</i>
<i>Pinus taeda</i>	A	Glass	10
		Glass 2	10
		Carbon	10
		Unreinforced	10
	B	Glass	15
		Glass 2	15
		Carbon	15
		Unreinforced	15
Control	Without finger-joint	10	
<i>Eucalyptus spp.</i>	A	Glass	10
		Glass 2	10
		Carbon	10
		Unreinforced	10
	B	Glass	15
		Glass 2	15
		Carbon	15
		Unreinforced	15
Control Sample	Without finger-joint	15	
Total			225

Caption: N. = number; Glass = A layer of glass fiber fabric; Glass2 = Double layer of glass fiber fabric; Carbon = a layer of carbon fiber fabric; Unreinforcement = With finger-joints and without reinforcement application; Without finger-joint = test specimen in bulk wood.

Technological evaluation tests

The tensile strength parallel to the grain test was executed in Universal Testing Machine, model EMIC DL 30000, with increasing monotonic loading rate of 10 MPa/min, in test specimens adapted of NBR 7190 (1997), because the norm does not describe an application model of reinforcements in finger-joints.

To test specimens for basic density and moisture content determination were taken from the tops of the tensile strength specimens (Figure 1). The procedures for obtaining bulk density and moisture content of the wood followed the NBR 7190 (1997) standard.

It was also performed the failure mode analysis of the specimens submitted to the tensile strength parallel to the grain test according to the ASTM D 4688 (1999) standard, which suggests six failure modes, based on the number of occurrence, identified as follows:

- Mode I = Rupture throughout the surfaces of glue line with few imperfections (rupture in the wood < 70%);
- Mode II = Rupture throughout the surfaces of glue line with considerable shearing rupture (rupture in the wood > 70%);
- Mode III = Rupture throughout the finger-joint profile, but with some rupture in the base of the joint. Considerable shearing rupture in all profile surface;
- Mode IV = Rupture in the base of the finger-joints. Few imperfections throughout the profile;
- Mode V = Rupture that starts in the end of the finger-joint and continues in the wood;
- Mode VI = Rupture in the wood (not influenced for the finger-joint - all the rupture is in the wood).

Statistic Treatment

Completely randomized design was used (CRD) in two distinct analyses, one for each species. In each one of the analyses the performance of the 8 treatments was evaluated: A Glass, A Glass 2, A Carbon, A Unreinforced, B Glass, B Glass 2, B Carbon, B Unreinforced, in relation to the control specimen (without finger-joints) by Dunnett test at 95% reliability. The analyses were performed in the statistical software SAS ® 9.4.

RESULTS

Tables 3 and 4 present the results of the analysis of variance (ANOVA) for the tensile strength parallel to the grain ($f_{t,0m}$ (12%)) of the species *P. taeda* e *Eucalyptus* spp., respectively. Both species evaluated presented significant differences according to ANOVA.

Table 3. ANOVA results for *P. taeda*.

Tabela 3. Resultados ANOVA para para *P. taeda*.

Source of Variation	Degrees of freedom	Sum of the squares	Average Square	Calculated F	Pr > F
Model	8	15973,83	1996,73	15,18	0,0001
Error	78	10258,86	131,52		
Total corrected	86	26232,70			

Table 4. ANOVA results for *Eucalyptus* spp.

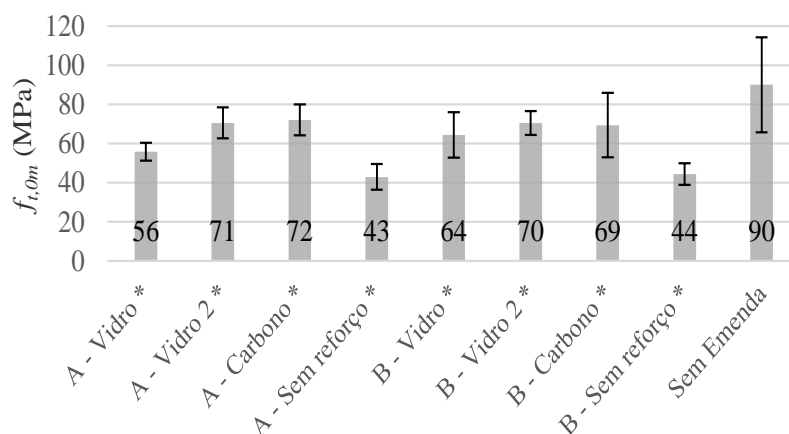
Table 4. Resultados ANOVA para *Eucalyptus* spp.

Source of Variation	Degrees of Freedom	Sum of the Squares	Average Square	Calculated F	Pr > F
Model	8	4.412,17	551,52	2,10	0,0402
Error	124	32.502,44	262,12		
Total corrected	132	36.914,61			

Figure 2 and 3 present, for each species, the results of mean comparison test, corrected at 12% of moisture content, of treatments with the respective control specimens (without finger-joints) in accordance with Dunnett test ($\alpha=0,05$) and its standard deviation. The critical value of Dunnett test was of 2,69 for both analyses.

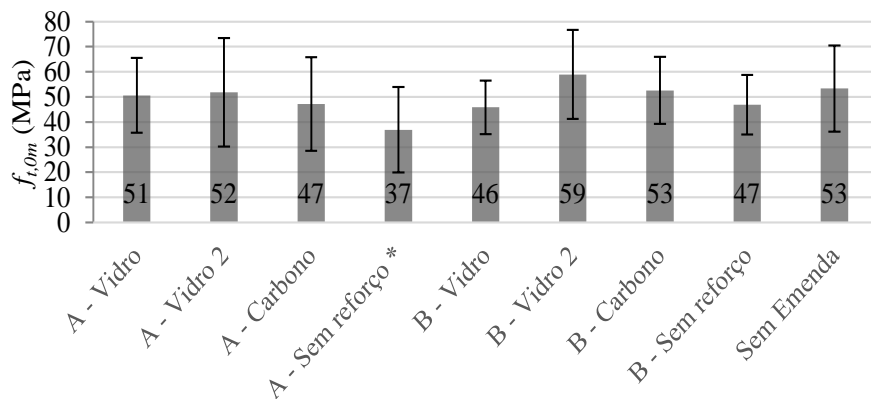
Figure 2. Dunnett test results for *P. taeda*.

Figura 2. Resultados do teste de Dunett para *P. Taeda*.



Caption: $f_{t,0m}$ = Mean tensile strength parallel to the grain; Glass = A layer of glass fiber fabric; Glass 2 = Double glass fiber tissue layer; Carbon = a carbon fibre tissue layer; A and B = Geometries; (*) Treatments followed by asterisk are significantly different from control sample (without emendation) by Dunnett test ($\alpha=0,05$).

Figure 3. Dunnett test results for *Eucalyptus* spp.
 Figura 3. Resultados do test de Dunnett para *Eucalptus* spp.



Legend: $f_{t,0m}$ = Mean tensile strength parallel to the grain; Glass = A layer of glass fiber fabric; Glass 2 = Double glass fiber fabric layer; Carbon = a carbon fibre fabric layer; A and B = Geometries; (*) Treatments followed by asterisk are significantly different from control specimens (without finger-joint) by Dunnett test ($\alpha=0,05$).

Table 5 presents statistical variables of each treatment to both analysis effectuated.







Table 5. Statistical variables - *P. taeda* and *Eucalyptus* spp.
 Tabela 5. Variáveis estatísticas – *P. taeda* and *Eucalyptus* spp.

Species	Treatment	Mean $f_{t,0m}$ 12% (MPa)	Standard Deviation (MPa)	CV (%)	Efficiency (%)
<i>P. taeda</i>	A Glass	55,83	4,54	8,14	62,0
	A Glass 2	70,52	7,91	11,22	78,3
	A Carbon	72,05	7,92	10,99	80,0
	A Unreinforced	42,95	6,60	15,38	47,7
	B Glass	64,33	11,64	18,09	71,5
	B Glass 2	70,47	6,09	8,64	78,3
	B Carbon	68,39	16,44	24,04	76,0
	B Unreinforced	44,38	7,57	17,06	49,3
	Without finger-joint	90,02	24,25	26,93	100,0
<i>Eucalyptus</i>	A Glass	50,59	14,88	29,41	94,9
	A Glass 2	51,81	21,64	41,77	97,2
	A Carbon	47,16	18,63	39,50	88,4
	A Unreinforced	36,89	17,02	46,14	69,2
	B Glass	45,84	10,66	23,25	86,0
	B Glass 2	58,96	17,73	30,07	110,6
	B Carbon	52,60	13,35	25,39	98,6
	B Unreinforced	46,86	11,87	25,32	87,9
	Without finger-joint	53,33	17,13	32,13	100,0

The mean moisture content of *P. taeda* lumberlot was 15.9% and of *Eucalyptus* was 12.3%. The apparent (ρ_{ap}) and basic (ρ_{bas}) densities of the evaluated species were, respectively, 0,49 g.cm⁻³ and 0,40g.cm⁻³ for *P. taeda* and of 0,60 g.cm⁻³ and 0,47g.cm⁻³ for *Eucalyptus* spp.

Failure modes were classified in accordance with the recommendations of ASTM D4688 (1999), based on occurrences number and are presented in table 4.

Table 4. Modes of Rupture
Tabela 4. Modos de ruptura.

Species	Treatments						
<i>P. taeda</i>	A – Glass	-	1	4	3	1	1
	A – Glass2	-	2	1	2	1	4
	A – Carbon	-	-	3	2	-	4
	A – Unreinforced	-	-	4	5	1	-
	B – Glass	-	-	3	5	-	2
	B – Glass2	-	-	1	3	1	5
	B – Carbon	-	-	1	1	1	6
	B – Unreinforced	-	-	3	8	1	-
Total A		0	3	12	12	3	9
Total B		0	0	8	17	3	13
Total <i>P. taeda</i>		0 (0)	3 (4%)	20 (25%)	29 (36%)	6 (7%)	22 (28%)
<i>Eucalyptus</i> spp.	A – Glass	-	1	2	6	2	4
	A – Glass2	-	-	2	1	3	9
	A – Carbon	-	1	-	1	2	10
	A – Unreinforced	2	-	1	4	7	-
	B – Glass	-	-	1	5	1	8
	B – Glass 2	-	1	1	1	3	9
	B – Carbon	-	-	1	2	1	11
	B – Unreinforced	2	2	2	2	4	3
Total A		2	2	5	12	14	23
Total B		2	3	5	10	9	31
Total <i>Eucalyptus</i> spp.		4 (3%)	5 (4%)	10 (8%)	22 (19%)	23 (20%)	54 (46%)
Total General*		4 (2%)	8 (4%)	30 (15%)	51 (26%)	29 (15%)	76 (38%)

Legend: A and B = Geometries; Carbon = A layer of carbon fiber fabric; Glass = A layer of glass fiber fabric; Glass2 = double layer of glass fiber fabric; Unreinforced = With finger-joint and without reinforcement application; % = relative frequency. *Data lost during operation of EMIC machine (1 test specimen in "A Carbon" and 1 test specimen in "A Unreinforced" – *Eucalyptus* spp.).

DISCUSSION

Tensile strength parallel to the grains

The significant differences presented by the ANOVAs in the two performed analyses had been identified in function of the averages of the treatments by Dunnett test. The graphical results of Figure 2, referring to the species *P. taeda*, shows that all the evaluated treatments had been statistical inferior to the control specimens (without finger-joint). However, in relation to Figure 3, allusive to the species *Eucalyptus* spp., only the treatment "A - Unreinforced" presented statistically inferior average resistance to the control sample. Nevertheless, a combined analysis considering the standard deviations and coefficients of variation presented by the treatments (Table 5), bigger variability in the control specimens is observed comparing to the other treatments for the case of *P. taeda*, what does not occur with *Eucalyptus* spp., in which the evaluated treatments had similar behavior. High coefficients of variation within of the treatments, despite data homogeneity, can influence negatively in the performance of the mean comparison tests.

Raftery & Harte (2013), studying the specie *Irish-Grown Sitka Spruce*, obtained maximum tensile strength parallel to the grain of 104 MPa for test specimens without finger-joints and 45 MPa for the specimens with finger-joints. This implies an efficiency loss of 56,7% regarding the clear wood. Analyzing the results of Table 5, it is possible to verify that all the evaluated treatments, in both species, had presented lesser losses of resistance in relation to the presented one by Raftery & Harte (2013).

Pereira *et al.* (2016), in study of unreinforced finger-joints with a hybrid of *E. grandis* Hill ex. Maiden with *E. urophylla* S. T. Blake, found out averages of 50.73 MPa for test specimen without finger-joints and 19,10 MPa for test specimens with the finger-joint. The authors obtained a loss of efficiency of 62,4% in relation to the wood without emendations. Inferior performance compared to the unreinforced treatments evaluated in this study.

The determination of the weakness percentage does not consider directly the species and gluing pressure to be used in the finger-joints production. These factors can be related to the performance and are little

explored by the PNBR (2011) or the Brazilian industries of GLULAM. The wood of *Pinus taeda* had loss of resistance of 52,3% and 50,7% for unreinforced geometries A and B, respectively. For *Eucalyptus* spp. the losses had been of 30,8% and 12,1%, respectively. In this last case, geometry B had loss within the limits established by the degree of weakness estimated in Table 1.

Khelifa *et al.* (2015a) explain that finger-joints can reach approximately 85% to 90% of resistance of the wood without finger-joints, superior values to the results obtained in three of the four treatments (*P. taeda* “A Unreinforced”, *P. taeda* “B Unreinforced” and *Eucalyptus* spp. “A Unreinforced”) with unreinforced finger-joints evaluated in this research, in which the geometries without reinforcement had inferior resistance to the degree of weakness esteemed (Table 1), although the main factors of influence has been controlled during the finger-joints execution. However, a gain in efficiency of the finger-joints for the treatments with reinforcement application is observed when compared with unreinforced finger-joints. Statistically, the results presented in Figure 3 shows that, for the *Eucalyptus* spp. the reinforce application with the same adhesive used by GLULAM industry is significantly more efficient, allowing to achieve performances similar to the clear wood.

Physical properties

According to Habipi & Ajdinaj (2015), the GLULAM can be produced with wood of dicotyledons or conifers, which possess low density (inferior densities to 0,7 g/cm³). Due to the fact that these ones present, generally, easiness in gluing when they present a moisture content between 10% and 18%. The results found in this work are in compliance with the requirements of NBR 7190 (1997) and the literature.

Failure Modes

According to Habipi & Ajdinaj (2015), parts joined by finger-joints and produced from species of lesser basic density tend to fail in the wood, whereas those of high basic density shatter in the joints, where the mechanical resistance of gluing line concentrate the axial tensions. Considering that the average apparent densities (ρ_{AP}) of *P. taeda* and of *Eucalyptus* spp. had been of 0,49 and 0,60 g/cm³ (Figure 3), respectively, this effect could not be observed clearly in Table 4, possibly due to great variation of intraspecific densities.

Bustos *et al.* (2003), evaluating gluing pressures time of cure in finger-joints with wood of *Picea mariana* (P. Mill.) B. S. P., obtained 80% of the ruptures in modes III and IV, superior frequency to the obtained in this research (Table 4). The high frequencies of ruptures in mode IV and VI, for the treatments with reinforcement application, indicate an effective improvement in the performance of longitudinal in relation to unreinforced finger-joints. The factors as the adhesive grammage and gluing pressure had also been important for a rupture in the wood.

The sizing of the structures takes in consideration the parameters of resistance of the wood and not of the longitudinal joints. In this way, it is possible to observe that the performance of reinforced emendations is similar to the one of wood, ensuring more uniform and constant composition of elements in GLULAM.

CONCLUSIONS

Through the analysis performed in this study it can be concluded that:

- the use of fibers increases the strength of the finger-joints equating them to wood without finger-joints for *Eucalyptus* spp. In this way, there is a redistribution of the tensile stress out from joints region, provoking rupture in more fragile areas of the wood;
- The use of one or two layers were enough to increase the resistance of the wood of *Pinus taeda* in relation to the wood without finger-joints, what requires more detailed studies on the number of layers and mainly on the coverage area of gluing the reinforcements;
- PUR adhesive used in the manufacture of structural elements in GLULAM can also be employed in the production of synthetic fiber reinforcements in the area of longitudinal finger-joints;
- the species must be considered in the determination of the degree of weakening that the geometry can cause in the tensile strength parallel to the grain;
- in general, the sizing of the structures takes in consideration the parameters of resistance of the wood and not of the longitudinal joints. In such a way, it was possible to observe that the performance of the strengthened finger-joints for *Eucalyptus* spp. was similar to the one of the clear wood, what can assure more uniform and constant composition of elements in GLULAM, without mechanical resistance losses.

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