EUCALYPTUS SPP. GLUED LAMINATED TIMBER WITH REINFORCED FIBER FINGER-JOINTS

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Resumo

Madeira laminada colada de Eucalytus spp. com finger-joints reforçados com fibras. Reforços à flexão usando fibras em elementos estruturais com finger-joints tem emergido como uma técnica particularmente apropriada para a madeira. Neste sentido, o objetivo deste estudo foi avaliar o desempenho da Madeira Laminada Colada (MLC) produzida com madeira de *Eucalyptus* spp. e três composições de reforços, “Vidro”, “Vidro2” e “Carbono” quanto à resistência a tração paralela às fibras, resistência a tração normal, resistência ao cisalhamento e flexão estática. Todos os testes foram executados de acordo com as diretrizes da NBR 7190/1997, sendo emprego o teste de Tukey para as análises estatísticas com intervalo de 95% de confiabilidade. O desempenho da MLC de *Eucalyptus* spp não apresentou diferença significativa na avaliação da linha de cola. Entretanto, na resistência à flexão, os tratamentos “Vidro 2” e “Carbono” foram significativamente superiores aos corpos de prova de MLC sem reforço, chegando a incrementos de 37,8% e 40,5%, respectivamente. Os módulos de elasticidade não diferiram significativamente entre os tratamentos. Foi constatada ruptura por tração na região do finger-joint em todos os corpos de prova avaliados, entretanto, as tensões de flexão foram superiores às resistências à tração paralela às fibras, indicando a influência da espessura das lâminas de madeira e da espessura do reforço no desempenho das emendas reforçadas. Desta forma, é possível concluir que a aplicação de reforço concentrado na região do finger-joint melhora significativamente o desempenho de exemplares em MLC de *Eucalyptus* spp. em flexão.

Palavras-chave: Madeira engenheirada; uso estrutural; uniões em madeira; reforço com fibras

Abstract

Reinforcement for flexion in structural elements with finger-joints using fibers has emerged as a particularly suitable technique for timber. Thus, the objective of this study was to evaluate the performance of Glued Laminated Timber (GLULAM) produced with *Eucalyptus* spp. wood and three reinforcement compositions, “Glass”, “Glass2” and “Carbon” regarding parallel-to-grain tensile strength, normal tensile strength, shear strength and the three-point bending test. All the tests were performed according to the NBR 7190/1997 using the Tukey test for statistical analyzes and a 95% confidence interval. The performance of the *Eucalyptus* spp. GLULAM did not present significant differences in evaluation of the bonding lines. However, the “Glass 2” and “Carbon” treatments were significantly superior to the GLULAM samples without reinforcement in bending strength, reaching increments of 37.8% and 40.5%, respectively. The modulus of elasticity did not differ significantly between them. A tensile rupture was observed in the region of the finger-joints in all the evaluated samples; however, the flexural tensions were superior to the parallel-to-grain tensile strengths, indicating an influence of the timber thickness and reinforcement thickness on the performance of the reinforced joints. Thus, it is possible to conclude that applying concentrated reinforcement in the region of the finger-joints significantly improves the performance of *Eucalyptus* spp. GLULAM samples.

Keywords: Engineered wood; structural purposes; timber joints; fiber reinforcement.

INTRODUCTION

The increase in the timber market due to timber use in civil construction is a reality worldwide. It has primarily occurred because of the great versatility of this material, which can be processed in various ways such as into lumber, slides, particles and fibers. These elements can be combined with adhesives to improve an extensive variety of engineered composites such as Glued Laminated Timber (GLULAM), "I" beams, Laminated Veneer Lumber (LVL) and Cross-Laminated Timber (CLT) (NADIR *et al.*, 2016). Considering the importance that GLULAM has obtained in these practices because of its use in large and durable structures, its capacity to overcome large spans and high loads (GLIŠOVIĆ *et al.*, 2015), as well as the focus on decreasing the use of native wood sources (BAYATKASHKOLI *et al.*, 2012; HABIPI *et al.*, 2016), studies should be carried out to assist the development of using wood provided by planted forests in this technology.

Although it is one of the oldest products resulting from glued timber, GLULAM is not yet a fully justifiable material for use in Brazilian construction projects due to the small tradition of its use, the high cost of adhesives and the small number of companies involved in manufacturing. On the other hand, its advantages in relation to solid wood are relevant, especially due to the possibility of producing structural elements with practically no dimensional limitations, increases in mechanical resistance and rigidity (MIOTTO & DIAS, 2010), the adaptability of the system, and the constant evolution of technologies in the production of engineered composites in wood. However, its bending strength often remains limited by the presence of finger-joints in the stress concentration zones (GLIŠOVIĆ *et al.*, 2015).

According to Danawade *et al.* (2014), finger-joints allow the full use of the wood, removing defects and increasing the material homogeneity, although generally reducing its mechanical resistance. For Khelifa *et al.* (2015b), wood presents high resistance in tensile and compressive strength parallel to the fibers, but usually accompanied by low stiffness. Therefore, reinforcement in wood beams can achieve greater rigidity, without having to increase the dimensions of the structural element.

Wood and its derivatives have been reinforced over the past few decades by a variety of techniques, including the use of steel and aluminum slabs or bars, high strength steel cables, pre-stressed timber and polymers reinforced with fibers (NADIR *et al.*, 2016). Thus, the use of fiber fabrics associated with polymeric matrices as reinforcement in structural wood elements has become more and more usual due to its advantages such as high mechanical resistance considering its weight, excellent resistance to corrosion and good durability (LU *et al.*, 2015).

Epoxy resins are presently considered the first adhesive choice for fiber/wood interfaces. In a project which reviewed several studies evaluating the performance of reinforced engineered timber, Raftery and Rodd (2015) concluded that such products had not yet been introduced in commercial production because of the additional steps to be included in the production process using epoxy resins. In addition, other materials such as the carbon fiber fabrics used in the process are costly. In experimental analyzes, Khelifa *et al.* (2016) showed that the use of a shorter reinforcement length with carbon fiber fabrics but closer to the stress concentration regions may result in a decrease in the wood volume (eliminating hyper-sizing) and increase the mechanical strength of GLULAM.

It should also be noted that for high value construction projects or for those in which stiffness and mechanical resistance are decisive factors, wood from reforestation often have an inferior performance compared to that originating from native tropical forests. From the research perspective, this situation can be overcome by using engineered timber techniques. The development of new products in this category assists in effective utilization and increases the commercial valorization of lower quality wood or from smaller logs (NADIR *et al.*, 2016).

Considering the advantages of using wood composites for structural purposes, this study has the objective to compare the improvement in the mechanical properties of *Eucalyptus* spp. GLULAM with reinforced finger-joints.

MATERIALS AND METHODS

Eucalyptus spp. timber of approximately 13 and 15 years old coming from planted forests of Rio Grande do Sul State was used in this study. The selected material was from a commercial lot of sawed boards with dimensions of 200 cm x 8 cm x 3 cm and approximately 5 m³ in volume. All the timber was conditioned outdoors for approximately 30 days and then kiln-dryed at a temperature of 56 °C and 50% relative humidity for 6 days, reaching an average moisture content of 12%. Next, 250 boards were randomly selected from this lot to produce the samples.

The fiber materials used as reinforcement were bidirectional glass fiber fabric of 1x1 screen type, 5x5 yarn/cm, 200 g/m² and 0.18 mm thickness, and bidirectional carbon fiber fabric, 2x2 twill type, with 5x5 yarn/cm, 200 g/m² and thickness of 0.40 mm. Four units of fiber length were applied for each unit of cross-sectional area in the finger-joint (4:1 proportion). This methodology was adopted based on preliminary tests which analyzed different lengths (proportions) of the fiber fabric materials. These tests showed the occurrence of ruptures by shearing in the fiber/wood bonding for the smaller lengths, and ruptures in the base of the samples for bigger lengths (claw contact area), which is not suitable to evaluate the reinforced finger-joints. The adhesive used was one-component polyurethane (PUR), following the usage parameters indicated by the manufacturer.

The treatments applied were: “Glass”, with one layer of glass fiber fabric, “Glass 2”, with two layers of glass fiber fabric, “Carbon”, with one layer of carbon fiber fabric and an “Unreinforced” control without reinforcement application to finger-joints.

The gluing process of the finger-joints as well as the gluing and pressing process of the GLULAM were performed by a private company.

Sample production

The 250 selected boards were processed in different ways according to the sample to be produced for each technological test. The geometry used in finger-joints is originally based on the PNBR 7190 (2011) standard, which appoints a maximum weakening rate of 14%, but presents a higher value (27%) as a consequence of changes in the length, base width and tip width of the jointings caused by sharpening done on the blades of the finger-jointing machine.

An automated hydraulic press was used to glue the finger-joints at 8.8 MPa of pressure. This value is lower than that recommended by PNBR 7190 (2011), which indicates a pressure of 10 MPa based on the timber density and finger length. However, premature rupture of the joints and occurrence of longitudinal cracks greater than 5 mm in length were observed at the finger base in preliminary tests, therefore requiring adjustment in the implemented pressure to ensure the finger-jointing quality.

The curing process of the adhesive in the finger-joints is completed after 72 h. Then, the finger-jointed boards were planed and sawed, preparing the material for GLULAM gluing. The next step was to apply the adhesive with a gluing machine. The fiber fabrics were positioned over the finger-joints before the boards with adhesive were placed in the press, going through deaeration, and again adhesive application to only then be put in the press.

The grammage measurement was performed using paper sheets (6 cm x 15 cm) of known weight fixed to the boards. Thus, when the board entered the gluing machine, the papers received the adhesive in the same way as the boards. Those paper sheets were then weighed on a precision scale. The average grammage was 197 g/m² per glue line.

The bonding pressures were also monitored along the production of the GLULAM samples. To do so, a HBM MX440A® data acquisition system using Catman Easy® and Quantum X® software programs was used with a U10M® load cell with a capacity of 125 kN. The average pressure used in the fabrication of the GLULAM elements was 0.7 MPa, within the usage recommendations indicated by the adhesive manufacturer, which assumes a variation from 0.6 to 1 MPa

Technological evaluation tests

The technological analyzes were based on the parallel-to-grain tensile strength test, perpendicular-to-grain tensile strength test, shear in the glue line test, static bending test, apparent density, moisture content and evaluation of the rupture modes.

The loading speed adopted in the shear test followed the NBR 7190 (1997) standard, but the adopted sample geometry was similar to the French Standard NF B 5-32 (1942). This sample test model was adopted according to the rupture evidence of the glue line by pure shearing with low variability of the results.

The rupture mode analysis was performed according to ASTM D 4688 (2005), which suggests six rupture modes by counting the number of occurrences per rupture mode and is identified according to Figure 1.

Mode 1: rupture along the glue line surfaces with few faults (wood breakage <70%); Mode 2: rupture along the glue line surfaces with considerable shear rupture (wood breakage> 70%); Mode 3: rupture along the profile of the finger-joint, but with some rupture at the base of the finger-joints; Mode 4: rupture on the base of finger-joints; Mode 5: rupture that begins at the top of the finger-joint and proceeds into the wood; Mode 6 : rupture is in the wood (not influenced by the finger-joint - all the break is in the wood). Adapted from ASTM D 4688 (1999).

Figure 1. Rupture modes according to ASTM D 4688 (2005).
Figura 1. Modos de rupura de acordo com a ASTM D 4688 (2005).

The perpendicular-to-grain tensile strength, parallel-to-grain tensile strength, shear in the glue line and static bending tests were performed in an EMIC DL 3000® universal testing machine, following the criteria established by NBR 7190 (1997). The HBM data acquisition system was used in the static bending test with load measurement and neutral line displacement. The test samples of the static bending test had dimensions of 140 cm x 6 cm x 6 cm, constituting higher dimensions than those proposed by the standard; however, they followed the proportionality standards between cross-section and free span.

The samples for moisture content and apparent density were extracted from the base and top of the parallel-to-grain tensile strength samples. This methodology was adapted in order to allow paired analysis between the apparent density and parallel-to-grain tensile strength. Density could be also related to the gain in resistance. The apparent density and moisture content tests followed the specifications of NBR 7190 (1997).

Statistical parameters

The experimental design (Table 1) chosen was the completely randomized and the statistical tests used were: Grubbs test (or spurious values), normality by Kolmogorov-Smirnov, Bartlett's homogeneity of variances, transformation by Johnson when necessary, analysis of variance (ANOVA), Tukey test with 95% significance, as well as regression analysis to determine the correlation degree between the wood density and the parallel-to-grain tensile strength. Action Stat® software was used for statistical analysis in an Excel® spreadsheet.

Table 1. Experimental plan.
Tabela 1. Plano experimental.

Technological test	Treatment	No. of Samples
Perpendicular-to-grain tensile strength	Glass	7
	Glass 2	7
	Carbon	7
	Unreinforced	7
Parallel-to-grain tensile strength	Glass	15
	Glass 2	15
	Carbon	15
	Unreinforced	15
	Massive	15
Shear	Glass	8
	Glass 2	8
	Carbon	8
	Unreinforced	8
Static bending	Glass	8
	Glass 2	8
	Carbon	8
	Unreinforced	8
Apparent density and moisture content	Glass	30
	Glass 2	30
	Carbon	30
	Unreinforced	30

RESULTS

Physical properties

The average moisture content of the *Eucalyptus* spp. samples was 12%, indicating that the pieces were of adequate moisture content for GLULAM manufacturing. The mean density of the samples was 0.61 g/cm^3.

Glue line strength

Results obtained for glue line shear strength tests are shown in Table 2. No differences between the treatments were observed.

Table 2. Tukey test (p>0.05) for glue line shear strength.
Tabela 2. Teste de Tukey (p>0,05) para resistência da linha de cola ao cisalhamento.

Treatment	Mean ($f_{v,m}$) (MPa)*	Characteristic value ($f_{v,k}$) (MPa)	Coefficient of Variation (%)
Glass	4.70 a	3.29	38
Glass 2	3.77 a	2.64	60
Carbon	4.90 a	3.43	55
Unreinforced	4.84 a	4.38	18

$f_{v,m}$: mean shear strength; $f_{v,k}$: shear strength characteristic value.
*Means followed by the same letter are not significantly different at 5 percent probability leve (Tukey test).

The results obtained in the four evaluated treatments for perpendicular-to-grain tensile strength are shown in Table 3. No differences between the treatments were observed.

Table 3. Tukey test (p>0.05) for perpendicular-to-grain tensile strength on the glue line.
Tabela 3. Teste de Tukey (p>0,05) para resistência à tração perpendicular às fibras na linha de cola.

Treatment	**Mean ($f_{t,90m}$) (MPa)***	**Characteristic value ($f_{t,90k}$) (MPa)**	**Coefficient of Variation (%)**
Glass	1.69 a	1.18	24
Glass 2	1.62 a	1.14	67
Carbon	2.37 a	1.66	35
Unreinforced	2.30 a	2.15	20

$f_{t,90m}$: mean perpendicular-to-grain tensile strength; $f_{t,90k}$: perpendicular-to-grain tensile strength characteristic value.
*Means followed by the same letter are not significantly different at 5 percent probability leve (Tukey test).

The results for mean parallel-to-grain tensile strength tests are shown in Table 4. No differences between the treatments were observed.

Table 4. Tukey test (p>0.05) for parallel-to-grain tensile strength.
Tabela 4. Teste de Tukey (p>0,05) para resistência a tração paralela às fibras.

Treatment	**Mean ($f_{t,0m}$) (MPa)***	**Characteristic value ($f_{t,0k}$) (MPa)**	**Coefficient of Variation (%)**
Solid wood	59.90 a	42.00	29
Glass	45.39 a	31.82	23
Glass 2	58.38 a	40.93	30
Carbon	52.08 a	36.52	25
Unreinforced	46.41 a	34.91	25

$f_{t,0m}$: mean parallel-to-grain tensile strength; $f_{t,0k}$: parallel-to-grain tensile strength characteristic value.
*Means followed by the same letter are not significantly different at 5 percent probability leve (Tukey test).

The rupture modes for parallel-to-grain tensile strength evaluated by treatment are shown in Figure 2.

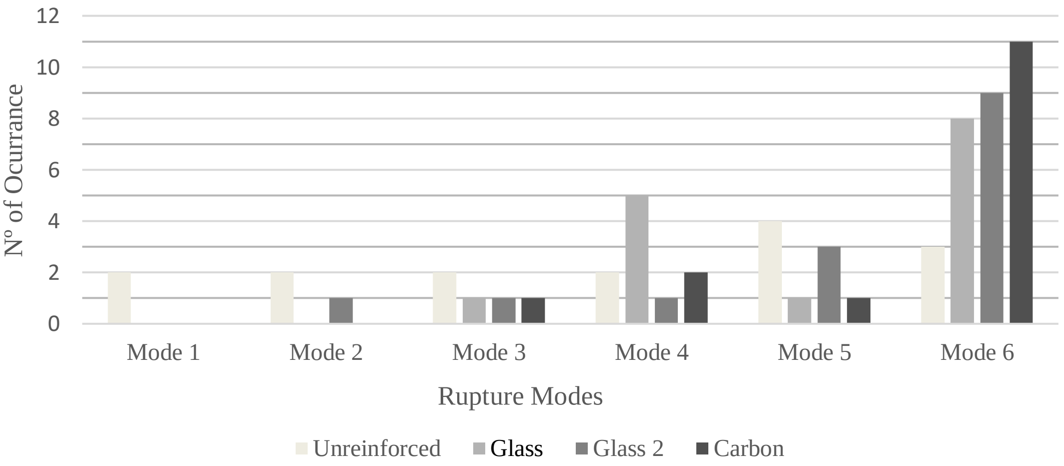

Figure 2. Rupture modes in the parallel-to-grain tensile strength test according to ASTM D 4688 (2005).
Figura 2. Modos de ruptura do teste de resistência à tração paralela às fibras de acordo com ASTM D 4688 (2005).

Figure 3 shows the equations and correlation between the maximum parallel-to-grain tensile strength and density per treatment.

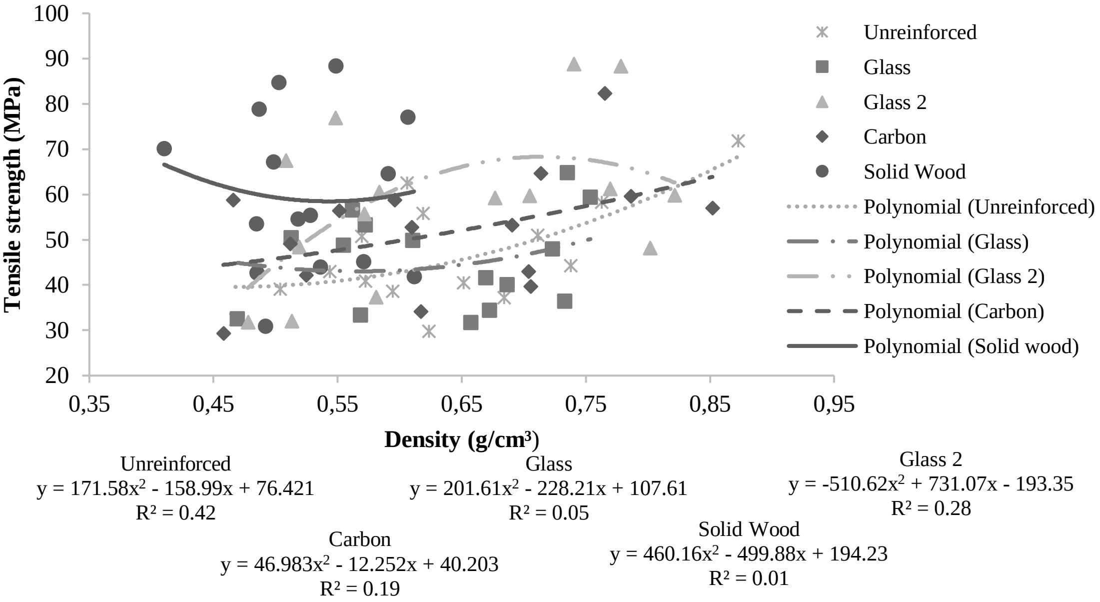

Figure 3. Correlation between the maximum parallel-to-grain tensile strength and density per treatment.
Figura 3. Correlação entre a resistência máxima a tração paralela às fibras e a densidade aparente por tratamento.

Bending test

The ruptures in the bending test occurred in the tensile stress concentration regions in all the evaluated samples, as shown by the bending strength (Table 5) and the parallel-to-grain tensile strength of each treatment (Table 4). The rupture modes of the eight samples of the treatment without reinforcement occurred in the finger-joints, followed by rupture in the glue line. The predominant rupture mode in the "Glass" treatment was in the finger-joints, with total or partial tearing of the glass fiber layer and subsequent rupture in the glue lines. Only the sample test number 1 showed collapse in the wood in this treatment, in addition to finger-joint and fiber layer rupture. Most of the samples for the "Glass 2" treatment presented a rupture in the finger-joint, followed by partial rupture of the fiber layer, except samples number 3 and 4 which also showed rupture in the wood and the glue line, respectively. The samples that received reinforcement application by carbon fibers had the rupture in the finger-joint as the main characteristic and reinforcement added to the wood rupture, except sample 8, which completely collapsed in the wood.

Table 5. Tukey test (p> 0.05) for the static bending test.
Tabela 5. Teste de Tukey (p>0,05) para o teste de flexão estático.

Treatments		**Stress (MPa)**		**MOE (MPa)***
		Bending*	**Shear***	
Glass	Mean	60.30 ab	1.45 ab	17,724.67 a
	CV (%)	24	24	18
	$f_{k,0}$	42.41	1.02	
Glass 2	Mean	66.57 a	1.59 a	17,747.08 a
	CV (%)	14	14	11
	$f_{k,0}$	53.97	1.29	
Carbon	Mean	67.88 a	1.63 a	17,301.17 a
	CV (%)	12	12	6
	$f_{k,0}$	56.50	1.35	
Unreinforced	Mean	48.30 b	1.16 b	15,735.32 a
	CV (%)	14	14	8
	$f_{k,0}$	41.76	1.00	

$f_{k,0}$: characteristic value; CV: coefficient of variation; MOE: modulus of elasticity.
*Means followed by the same letter are not significantly different at 5 percent probability leve (Tukey test).

DISCUSSION

Physical properties

The average moisture content of the *Eucalyptus* spp. samples indicate that the pieces were of adequate moisture content for GLULAM manufacturing. According to Terezo and Szücs (2010), the moisture content of the pieces used to produce GLULAM should be between 7% and 14%. This range ensures that there will be no moisture transfer between the adjacent parts, avoiding possible contractions and/or swelling of the boards.

The density of the samples indicates that the *Eucalyptus* spp. wood used in this study presented a density within the range of 0.40 to 0.75 g/cm³ needed to be used in GLULAM elements (TEREZO & SZÜCS, 2010).

Glue line strength

Miotto and Dias (2010) found average shear strength of 7.7 MPa for unreinforced GLULAM produced with a *Eucalyptus grandis* x *Eucalyptus urophyla* hybrid, which is higher than that found in this study. However, in studying the effect of glass fiber and carbon fiber reinforcements on *Hevea brasiliensis* GLULAM, Nadir *et al.* (2016) obtained a mean shear strength of 5.81, 5.61 and 5.52 MPa for the treatments without reinforcement, reinforced with glass fibers and reinforced with carbon fiber, respectively. These mean values were also higher than those of the present analysis, except for Glass 2 treatment which presented a lower shear strength, probably caused by stress concentration between the reinforcement layers (Table 2).

According to NBR 7190 (1997), the mean perpendicular-to-grain tensile strength of *Eucalyptus grandis* fibers is 2.6 MPa. The results obtained in the four evaluated treatments were inferior to the one described by this standard (Table 3). However, the perpendicular-to-grain tensile strength found by Miotto and Dias (2010) was 1.60 MPa, which indicates a compatible performance with the GLULAM of this study.

The shear strength and perpendicular-to-grain tensile strength tests presented the highest coefficients of variation, above the limiting standards of NBR 7190 (1997), possibly due to the positioning of the fiber fabric materials to decrease the interaction between wood and the adhesive. These characteristics should be better evaluated in order to more accurately determine the influence of fiber grammage on the performance of the glue line.

The mean parallel-to-grain tensile strength of the solid wood was lower (Table 5) than that presented in NBR 7190 (1997) for *Eucalyptus grandis*, 70.2 MPa. In evaluating unreinforced finger-joints with a *Eucalyptus grandis* x *Eucalyptus urophyla* hybrid with a similar jointing geometry adopted in the present study, Pereira *et al.* (2016) found characteristic values of 50.73 MPa for solid wood samples and 24.21 MPa for samples with finger-joints, achieving an efficiency of 47.7% in relation to solid wood. The characteristic value of the solid wood in this study was lower than that obtained by Pereira *et al.* (2016), however the treatment without reinforcement showed a higher value, reaching an efficiency of 83.1%.

For Sviták *et al.* (2014), better performance of the finger-joint is characterized by rupture mode 6, with a fracture of 100% in the wood and outside the finger-joint. This mode had the highest number of occurrences in the treatments in which the reinforcement was applied, reaching 11 occurrences for treatment with carbon fiber, 9 for treatment with double layer of glass fibers and 8 for treatment with one layer of glass fibers, with only 3 ruptures in mode 6 in the samples without reinforcement application from a total of 15 samples evaluated by treatment, as shown in Figure 2.

The polynomial equation which presented the best results can be observed in Figure 3; however, the r^2 indices in all treatments showed poor correlation. Thus, the correlation of the parallel-to-grain tensile strength does not proportionally depend on the quadratic variation of the apparent density.

According to the literature, an increasing trend of the parallel-to-grain tensile strength is identified as wood density increases for some species in samples with finger-joints. For example, Vrazel and Sellers (2004) found a mean tensile strength of 63.76 MPa for *Dipterocarpus* spp. ($\rho_{bas} = 0.78$) and 55.99 and 54.64 MPa for *Pinus* spp. ($\rho_{bas} = 0.58$) and *Pseudosuga menziesii* ($\rho_{bas} = 0.55$) in finger-joints bonded with PUR. However, for Pereira *et al.* (2016), this performance may be influenced by other natural and anatomical characteristics of the wood or by the presence of reinforcement with synthetic fiber in the case of finger-joints, so it is not possible to conclude that this relationship is a rule.

Bending test

In analyzing Glulam of “Irish-grown Sitka” spruce with and without reinforcement with glass fiber bars in different diameters and using epoxy adhesive for reinforcement application, Raftery and Whelan (2014) reached a 68% increase in the treatment with better performance in relation to non-reinforced specimens. However, the authors performed the study in GLULAM without the presence of finger-joint and with reinforcement application throughout the beam.

In a study with spruce (mean density 0.46 g/cm³), Khelifa *et al.* (2015a) produced samples with a finger-joint of 22 mm length with and without carbon fiber layer reinforcement applied along the entire length of the beam. The results found by the authors showed that the reinforcement with carbon fiber layer applied with epoxy resulted in a 33.84% increase in bending stress when compared to the treatment without reinforcement. Therefore, it is possible to affirm that the 40% increase in bending stress obtained by the treatment with carbon fiber layer of this study was similar to that found by other authors (Table 5). However, the mean increment observed in the modulus of elasticity (MOE) of these samples was only 9.9%, while in the study by Khelifa *et al.* (2015a) it increased by 16.7%. The reinforcement length, which in this work was only applied on the finger-joint region, possibly explains this difference in the MOE behavior.

In another study with spruce, Khelifa *et al.* (2016) evaluated the performance of different reinforcement lengths with carbon fiber layers over finger-joints. The authors evaluated three fiber lengths: (i) along all the higher stressed line; (ii) at approximately 50%; and (iii) at approximately 25% of the most stressed line. The obtained results presented increases in bending strength of 30.3%, 16.6% and 16.3%, respectively, in relation to non-reinforced samples. However, this increase in bending strength did not influence the MOE of the samples, with similar results to that achieved by the present study (Table 5). The increases in bending stresses were higher, with 24.8% for “Glass”, 37.8% for “Glass 2” and 40.5% for “Carbon” in relation to the non-reinforced test samples.

CONCLUSIONS

The analyzes performed lead to the following conclusions:

- Although statistical differences were not identified in the shear tests, perpendicular-to-grain tensile strength, parallel-to-grain tensile strength and MOE, it was possible to verify that there was an increase in the bending strength with the application of the reinforcements on the finger-joints;
- The significantly higher differences obtained with the “Carbon” and “Glass 2” treatments in the bending strength show that applying reinforcement only in the finger-joint region is efficient, presenting superior performance;
- An analysis of the rupture modes in the parallel-to-grain tensile strength test reveals an increase in the number of ruptures entirely outside the finger-joint and the reinforcement application areas. However, the same results did not occur in the static bending test. In this way, it is verified that there is a relation between the thickness of the boards in the finger-joint and the thickness or the number of reinforcement layers;
- The use of reactive polyurethane adhesive to apply the reinforcements showed a positive performance over the unreinforced glue lines, dispensing the use of a second type of adhesive to apply the reinforcements.

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