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# ANALYSIS OF FINGER-JOINTS IN GLASS FIBER-REINFORCED POLYMER (GFRP) COMPOSITE GLUED LAMINATED TIMBER BEAMS

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## ABSTRACT

The objective of this paper was to evaluate the effect of finger-joint reinforcement on the bending strength and stiffness of glulam beams made from high-density *Eucalyptus spp.* glued with resorcinol-formaldehyde adhesive. Six glulam beams were tested: three reinforced with glass fiber-reinforced polymer (GFRP) and three unreinforced for comparison. The GFRP was placed between the last two laminates and at the bottom edge of the glulam only in the finger-joint position. The stiffness and strength of glulam beams were evaluated using static bending tests, which showed that the use of GFRP reinforcement resulted in a gain of more than 100% in average ultimate bending moment and about 10% in average bending stiffness. To calculate the theoretical bending stiffness and normal stresses, a theoretical analysis of beam bending was performed using the transformed section method, which showed agreement with the experimental results.

KEYWORDS: Fiber-reinforced polymer, reinforced glulam beams, theoretical model, bending stiffness and strength, high-density *Eucalyptus spp.* wood.

## INTRODUCTION

Glued laminated timber (glulam) consists of glued laminates that form structural elements that can have different shapes and sizes. Fiber-reinforced composites consist of fibers as reinforcement and a polymer matrix with the aim of improving the mechanical properties of the material, which alone would not be suitable for engineering applications (Li et al. 2007, Agopyan and Savastano Júnior 1997, Sathishkumar et al. 2014, Ku et al. 2011, Bui et al. 1996, Fiorelli and Dias 2011, Raftery and Rodd 2015, Raftery and Whelan 2014, Uzel et al. 2018, Issa and Kmeid 2005). Synthetic fiberglass is widely used to reinforce composites because of its high strength, stiffness, and low cost (Mendonça 2019). The advantages of wood are its high performance at relatively low cost, excellent strength-to-density ratio, and the advantages of fibers, such as high strength and stiffness (Dagher 2000). The function of the polymer matrix is to hold the fibers in place and to transfer stresses between those fibers. Epoxy and polyester resins are most commonly used in construction because they are less affected by temperature variations (Mendonça 2019, Hyer 2009, Mallick 2007). In addition, finger-joints are used in industrial wood production because they allow the production of large laminates and eliminate defects that limit the grade of the wood (Jokerst 1981). The finger-joint length of 28.27 mm is the most commonly used in the production of glulam in North America, as determined after analyzing research on different shapes and lengths of finger-joints (Hernández 1998).

Failure of glulam elements often begins at the finger joints of the tension zone and becomes critical as the distance between adjacent laminate joints decreases (Burk and Bender 1989). It was observed that the highest frequency of failure in wood occurred at the base of finger joints in *Pinus* and in the glue joint in *Eucalyptus spp.* (Azambuja 2006). Fiberglass composites and epoxy resin are used to increase the strength of finger joints. However, failure modes can occur, starting at the finger, followed by reinforcement failure or shear failure in the glue layer, which occurs when the strength of the glass fiber reinforcement is limited by the bond between the epoxy resin and the wood (Bui et al. 1996). Thus, the effects of finger-joint position, length, and position of fiber-reinforced polymer (FRP) in glulam beams without finger-joints and with finger-joints at the last laminate were evaluated. Reinforcement was found to increase the values of elastic modulus (MOE) and modulus of rupture (MOR) (Hu and Cheng 2009). Studies conducted in the United States with glass fiber-reinforced glulam beams have reported that FRP applications as reinforcement in tension at 2% to 3% of the cross-section can increase the bending strength of glulam beams by more than 100% and stiffness by about 10% to 15% (Dagher et al. 2002). In addition, reinforced wood beams and glulam with fiberglass and carbon fiber composites and epoxy resin were evaluated in two different thicknesses (Vanerek and Hradil 2007). The results showed an increase in load-bearing capacity. In most cases, brittle failure of solid wood in the composite was observed; in other cases, failure occurred due to nodal points where failure began. The reinforcement at the bottom of the glulam beams prevented the failure of the finger-joints (Hernández 1998).

The model for calculating the stiffness and strength of fiber-reinforced glulam beams was presented (Fiorelli and Dias 2011). The stiffness is based on the analysis of the transformed section method. This model is based on the Navier/Bernoulli hypothesis (plane sections remain plane after elongation) in the calculation of flexural strength and takes into account the brittle fracture of wood under tension and the bilinear ductile behavior in the compression zone. This theoretical model showed good agreement with the experimental results. Fiber reinforcement in the tension side of glulam beams increases ductility of the compressed zone, and greater vertical displacements in the failure. It has been observed that while the bending failure of a timber beam is typically brittle, the corresponding failure of a timber beam suitably reinforced with fibers on the tensile side is ductile (Dagher 2000).

With this background, the objective of this article was to analyze the influence of glass fiber-reinforced polymer (GFRP) in glulam with finger-jointed joints through theoretical and experimental evaluation using high density *Eucalyptus spp.* In this way, the mechanical performance of reinforced glulam beams with finger-jointed joints is compared with that of unreinforced glulam beams with finger-jointed joints in terms of the behavior of load and vertical displacement, loading, failure mode, improvement in bending stiffness and moment, and changes in stress that should be investigated in the application of the material.

## MATERIAL AND METHODS

Six glulam beams, three reinforced and three unreinforced, were made from *Eucalyptus spp.* wood laminates with average density of 0.95 $g.cm^{-3}$ and average moisture content of 12%, both results obtained from experimental tests according to ABNT NBR 7190-2 (2022). Resorcinol-formaldehyde adhesive (manufactured by Hexion Inc.) was used to bond the glulam beams and finger joints in a weight ratio of five parts resin to one part hardener according to the company's recommendations. Reinforced glulam beams used longitudinal glass fiber (UF 0900, manufactured by Fibertex®) in the finger-jointed laminates. They were 0.5 mm thick, had tensile strength of 1,193 MPa and MOE of 55,736 MPa, both results coming from experimental tests according to ASTM D3039 (2017). Epoxy resin was used in the application of the fiberglass reinforcement to the finger joints.

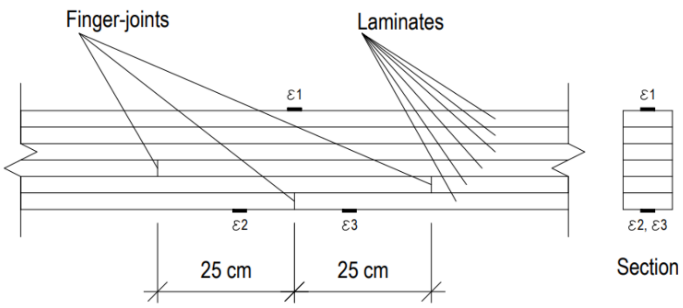
The total of 36 laminates were used to assemble the six glulam beams. Each glulam beam had six laminates with dimensions of 3 cm x 10 cm x 300 cm (laminate thickness x width x length) and length of 300 cm. The laminates were evaluated visually and mechanically by a static bending test (in flat position), in which the modulus of elasticity (MOE) was determined for each timber. Lumber of better quality (fewer defects and higher MOE) was placed in the range of maximum compressive and tensile stress according to the American Plywood Association (2017). The laminates used to fabricate the six glulam beams were distributed so that the laminates with the largest MOE were located at the bottom and top edges, and the laminates without defects were located at the bottom of the glulam beams, which is required for tensile strength in the bending test. The glulam beams were divided into two groups (reinforced and non-reinforced) of three glulam beams after the distribution of the laminates was determined. The six glulam beams were made with finger joints at the three lower laminations. The bottom laminate of each beam had a finger joint at mid-span and the other two laminates had finger joints spaced 25 cm from mid-span according to ABNT NBR 7190-6 (2022). The vertical finger-joint length of 26 mm according to DIN 68140 (1971) and the laminates were glued with resorcinol-formaldehyde (manufactured by Hexion Inc.) under pressure of 1 MPa, and the adhesive was applied with brush of 150 $g.cm^{-2}$ on both sides of the laminates according to the company's recommendation. The glulam beams were glued with resorcinol-formaldehyde under pressure of 1 MPa and adhesive application of 300 g.cm$^{-2}$ on one side of the laminate only, using brush according to the company's recommendations.

The unreinforced glulam beams were fabricated in a single step, while the reinforced beams were fabricated in three steps. The first five laminates of each beam were first glued; then the three-layer glass fiber reinforcement interlayer was applied along the length and width of the glulam beam between the sixth and fifth laminates at the bottom of each glulam beam with the epoxy resin; then the last laminate was laminated. The AR-300 epoxy resin-impregnated fiberglass fabric with AH-30 hardener was used (both manufactured by Barracuda Advanced Composites). The resin and hardener had gel time of 30 min at 25°C and mixing ratio of 3:1 (by volume).

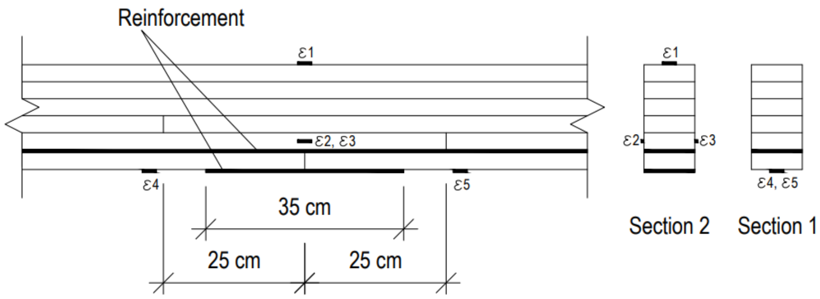
The reinforcement was laid completely along its entire length to avoid problems with bonding between the two laminates because it could come loose. In the third step, the reinforcement was placed at the bottom of the glulam beams with three fiberglass layers of 35 cm length along the beam width (i.e., the reinforcement was placed only at the finger-joint).

The glulam beams were loaded according to the four-point bending test in accordance with ASTM D198 (2022) and the vertical displacement was measured at mean span (S) of 285 cm. The loading rate was equal to 10 MPa per minute considering the maximum stress, according to ABNT NBR 7190-2 (2022), and the glulam beam was supported at two points with a special device to prevent lateral buckling. The beams were equipped with strain gauges. The positions of the strain gauges in the central part of the unreinforced glulam beams are shown in Fig. 1a. Three strain gauges were installed in each of these beams: one on the top in the middle of the beam ($\varepsilon_1$) and two on the bottom ($\varepsilon_2$ and $\varepsilon_3$), about 5 cm from the finger-joint of the bottom laminate.

The positions of the strain gauges in the central part of the reinforced glulam beams are shown in Fig. 1b. Five strain gauges were installed in each reinforced glulam beam: one at the top of the beam ($\varepsilon_1$), two at the side faces of the penultimate laminate ($\varepsilon_2$ and $\varepsilon_3$) centered according to the span and thickness of this laminate, and two at the bottom offset about 5 cm after the end of the externally bonded GFRP ($\varepsilon_4$ and $\varepsilon_5$).




a)




b)

*Fig. 1: Position of the strain gauges: a) Unreinforced glulam beams; b) reinforced glulam beams.*

The tests were performed in three loading cycles; in the first two tests, the load was applied to a vertical displacement value equal to S/300 of the free span (9.5 mm), it was ensured that the load did not exceed the elastic limit of the ultimate load capacity and held constant for 30 s; the test in the last cycle was performed until failure. The displacement was measured in the central area of the beam using a dial indicator. In this way, the theoretical stress values at the time of failure were calculated by the bending of the beam using the transformed cross-section method, according to equations presented in the literature (Fiorelli and Dias 2011).

The experimental results were compared with a theoretical evaluation using the beam bending when applying the transformed cross-section method. This theoretical evaluation was even used to calculate the bending stiffness, since the beams showed an approximately linear behavior until failure. The theoretical value for bending stiffness was calculated by beam bending using the transformed cross-section method, taking into account the MOE and the thickness of each laminate, as well as the width of the glulam beam, as shown in Tab. 1. The experimental bending stiffness (Tabs. 2 and 3) was obtained by linear regression of the experimental values measured in the third loading cycle.

*Tab. 1: Technical information about the glulam beams.*

| Unreinforced beams | | | | Reinforced beams | | | |
|---|---|---|---|---|---|---|---|
| Beam | Width (mm) | Laminate Thickness (mm) | [1]MOE (MPa) | Beam | Width (mm) | Laminate Thickness (mm) | [1]MOE (MPa) |
| [2]B1 | 91.2 | 30.4 | 22119 | [5]B4 | 94.8 | 29.9 | 21752 |
| | | 30.5 | 17902 | | | 30.8 | 16360 |
| | | 30.4 | 14317 | | | 30.8 | 13121 |
| | | 26.9 | 17401 | | | 26.5 | 17459 |
| | | 28.7 | 21159 | | | 26.4 | 19609 |
| | | 26.6 | 21778 | | | 1.5 | 55736 |
| | | - | - | | | 28.5 | 24923 |
| | | - | - | | | 1.5 | 55736 |
| [3]B2 | 92.9 | 30.2 | 21866 | [6]B5 | 94.3 | 30.2 | 23704 |
| | | 30.4 | 18592 | | | 30.1 | 17056 |
| | | 29.9 | 15444 | | | 26.5 | 12231 |
| | | 26.5 | 18300 | | | 28.6 | 18087 |
| | | 28.3 | 20120 | | | 28.7 | 20608 |
| | | 28.6 | 22303 | | | 1.5 | 55736 |
| | | - | - | | | 30.2 | 21310 |
| | | - | - | | | 1.5 | 55736 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| [4]B3 | 92.0 | 30.3 | 20275 | [7]B6 | 94.1 | 30.2 | 20898 |
| | | 30.5 | 17973 | | | 31.3 | 19241 |
| | | 30.1 | 13004 | | | 29.9 | 12985 |
| | | 28.7 | 17346 | | | 28.6 | 17659 |
| | | 28.6 | 20086 | | | 28.4 | 19729 |
| | | 28.7 | 23316 | | | 1.5 | 55736 |
| | | - | - | | | 28.5 | 22547 |
| | | - | - | | | 1.5 | 55736 |

[1]MOE - modulus of elasticity (MPa); [2]B1 - beam 1; [3]B2 - beam 2; [4]B3 - beam 3; [5]B4 - beam 4; [6]B5 - beam 5; [7]B6 - beam 6.

The composition of each glulam beam in terms of distribution of laminates and reinforcement in the correct position are shown in Tab. 1, i.e., the first line of each beam corresponds to the laminate arranged on the top, and so on. It also shows the final width of the glulam beams according to the design, the thickness and MOE of each laminate and reinforcement. For the calculation of compressive stresses ($\sigma_{c,th}$), the cross-section with two reinforcement layers was used for reinforced beams, and for tensile stresses ($\sigma_{t,th}$), the cross-section with only the intermediate reinforcement was used. The experimental values ($\sigma_{t,exp}$) and ($\sigma_{c,exp}$) for the tensile and compressive stresses, respectively, were obtained from the measured strain and MOE of the corresponding laminate, while the average strain was used for the tensile stresses.

## RESULTS AND DISCUSSION

First, it must be clarified that the Brazilian standard ABNT NBR 7190-6 (2022) does specify the size of connections in finger joints. In Brazil, there was a revision project of the Brazilian standard, which corresponds to DIN 68140 (1971).

The experimental results of vertical displacement are shown in Fig. 2 in relation to the total applied load. The vertical displacement values were recorded up to limit, which ensures linear behavior according to ABNT NBR 7190-6 (2022). Therefore, the vertical displacement measuring device was removed before failure to avoid damage.

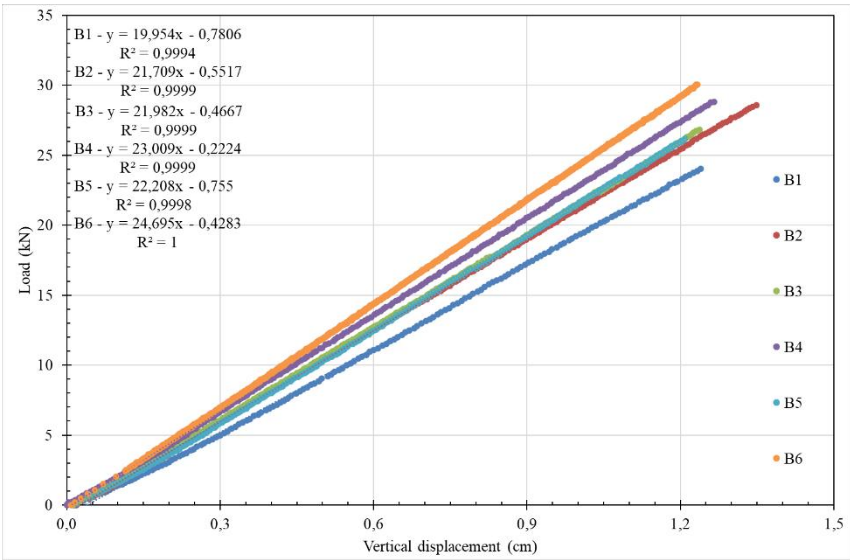



*Fig. 2: Load versus vertical displacement measured at mean span (S) for reinforced and unreinforced glulam beams.*

The theoretical value of flexural stiffness ($EI_{th}$) and the experimental value of flexural stiffness ($EI_{exp}$) of the unreinforced glulam beams were compared in Tab. 2. A minimum difference of about 2% was found between them, ensuring the validity of the original hypothesis according to Fiorelli and Dias (2011).

*Tab. 2: Flexural stiffness of the unreinforced glulam beams.*

| Beam | [1]$EI_{th}$ (kN.m$^2$) | [2]$EI_{exp}$ (kN.m$^2$) |
|---|---|---|
| B1 | 838.4 | 835.2 |
| B2 | 863.5 | 894.8 |
| B3 | 881.1 | 905.0 |
| Mean | 861.0 | 878.3 |

[1]$EI_{th}$ - theoretical flexural stiffness (kN.m$^2$); [2]$EI_{exp}$ - experimental flexural stiffness (kN.m$^2$).

For reinforced glulam beams, the intermediate glass fiber layer between the last and the penultimate laminate and the reinforced layer at the bottom of the beam were considered, the MOE value of the glass fiber was taken into account in the calculation, and the thickness of each reinforcement was 1.5 mm (three glass fiber layers were used), corresponding to about 1.72% of the height of the beam cross section. The use of practical reinforcement ratio of 1.86% of the cross-sectional area resulted in moderate 18% increase in stiffness and a significant 31% improvement in ultimate load, and there are increases in MOE and MOR, as shown in Raftery and Rodd (2015), Hu and Cheng (2009), and Dagher et al. (2002). The use of GFRP reinforcement resulted in an increase of over 100% in mean experimental bending moment and about 10% in mean experimental bending stiffness for the vertical geometry of finger-jointed, glued conditions, and high-density *Eucalyptus spp*. as shown in Tabs. 2, 3, and 4.

The theoretical values of bending stiffness ($EI_{th,1}$) referring to the cross sections with intermediate reinforcement only are given in Tab. 3, as well as the values ($EI_{th,2}$) referring to the cross section with two reinforcement layers; the equivalent theoretical bending stiffness ($EI_{th,eq}$) has been calculated considering a uniform cross section leading to the same value for vertical displacement obtained with the other values. The experimental values of bending stiffness are also given in Tab. 3. They show a minimum variation of about 2% between them, which confirms the validity of the original hypothesis according to Fiorelli and Dias (2011). From the results presented in Tabs. 3 and 4, it can be concluded that the transformed cross-section method can lead to theoretical results close to those observed experimentally. The same increased behavior is also observed in other studies (Fiorelli and Dias 2011, Raftery and Rodd 2015, Raftery and Whelan 2014, Dagher et al. 2002), so the finger joints were able to function in the linear elastic regime with high density wood. The experimental values for applied load and bending moment at failure and their mean values are shown in Tab. 4. Also, the experimental values for applied load and bending moment at failure and stiffness, as well as their mean values, are shown in Tabs. 3 and 4.

*Tab. 3: Bending stiffness for the reinforced glulam beams.*

| Beam | [1]$EI_{th,1}$ (kN.m$^2$) | [2]$EI_{th,2}$ (kN.m$^2$) | [3]$EI_{th,eq}$ (kN.m$^2$) (I) | $EI_{exp}$ (kN.m$^2$) (II) | II/I |
|---|---|---|---|---|---|
| B4 | 918.9 | 972.8 | 933.0 | 949.8 | 1.02 |
| B5 | 927.3 | 985.9 | 942.5 | 917.4 | 0.97 |
| B6 | 946.7 | 1005.3 | 961.9 | 1016.4 | 1.06 |
| Mean | 931.0 | 988.0 | 945.8 | 961.2 | 1.02 |

[1]$EI_{th,1}$ - theoretical bending stiffness related to the cross-sections with only intermediate reinforcement (kN.m$^2$); [2]$EI_{th,2}$ - theoretical bending stiffness related to the cross-section with two reinforcement layers (kN.m$^2$); [3]$EI_{th,eq}$ - equivalent theoretical bending stiffness (kN.m$^2$).

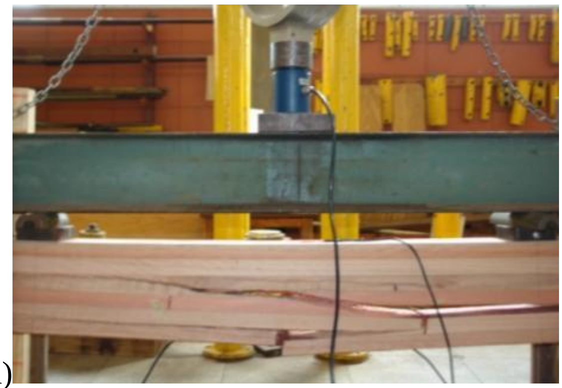
*Tab. 4: Load and bending moment at failure.*

| Beam | [1]$P_u$ (kN) | [2]$P_{u,m}$ (kN) | [3]$M_{exp}$ (kN.cm) | [4]$M_{exp,m}$ (kN.cm) |
|---|---|---|---|---|
| B1 | 54.01 | | 2566 | |
| B2 | 40.46 | 42.39 | 1922 | 2013 |
| B3 | 32.69 | | 1553 | |
| B4 | 79.81 | | 3791 | |
| B5 | 85.19 | 88.47 | 4046 | 4202 |
| B6 | 100.40 | | 4769 | |

[1]$P_u$ - load at failure; [2]$P_{u,m}$ - mean load at failure; [3]$M_{exp}$ - experimental moment of failure (kN.cm); [4]$M_{exp,m}$ - mean experimental moment of failure (kN.cm).

The failure of the unreinforced glulam beams was initiated in the bottom finger-joint by the tensile stress and consequently propagated at the interface between the two bottom laminates (Figs. 3a, c, e and g). Therefore, GFRP reinforcement of the finger-joint is necessary because failure of glulam elements often starts at the finger-joints of the tension zone and becomes critical when the distance between the adjacent laminate joints is reduced (Burk and Bender 1989, Bourscheid et al. 2019).

Failure in the reinforced glulam beams started in the bottom reinforcement due to failure of the glue layer in the timber/reinforcement interface, followed by failure in the bottom finger-joint (Figs. 3b, d, f and h). Therefore, according to Bourscheid et al. (2019), reinforcement in the finger-joints of *Eucalyptus spp.* is essential.

a) 

b) 


*Fig. 3: Failure of glulam: a) unreinforced beam 1; b) reinforced beam 4; c) unreinforced beam 2; d) reinforced beam 5; e) unreinforced beam 3; f) reinforced beam 6; g) unreinforced beams 1, 2 and 3; h) reinforced beams 4, 5 and 6.*

As with higher density wood (Raftery and Whelan 2014, Issa and Kmeid 2005, Burk and Bender 1989, Azambuja 2006), failures of the reinforced and unreinforced glulam beams occurred in the bottom finger-joint due to tensile stresses and consequently propagated into the glue joint, leading to beam collapse.

The strains (ε) in the unreinforced glulam beams corresponding to the last loading cycle and measured until failure are shown in Figs. 4a, c and e, where a linear behavior was observed for all beams. It was also observed that failure in these glulam beams was brittle (Raftery and Whelan 2014, Issa and Kmeid 2005) and occurred mainly in the finger joint.

Strains in reinforced glulam beams corresponding to the last loading cycle and measured to failure of the beam are shown in Figs. 4b, d and f. In general, a linear behavior was observed for most loading times. There is only a disturbance in the values measured in the tensile zone near failure, which probably indicates the onset of failure in the finger joints. The results indicate that the behavior of the strengthened beams is completely different from that of the unstraightened beams, since strengthening changes the failure mode from brittle to ductile and increases the load-bearing capacity of the beams, as Issa and Kmeid (2005) write.

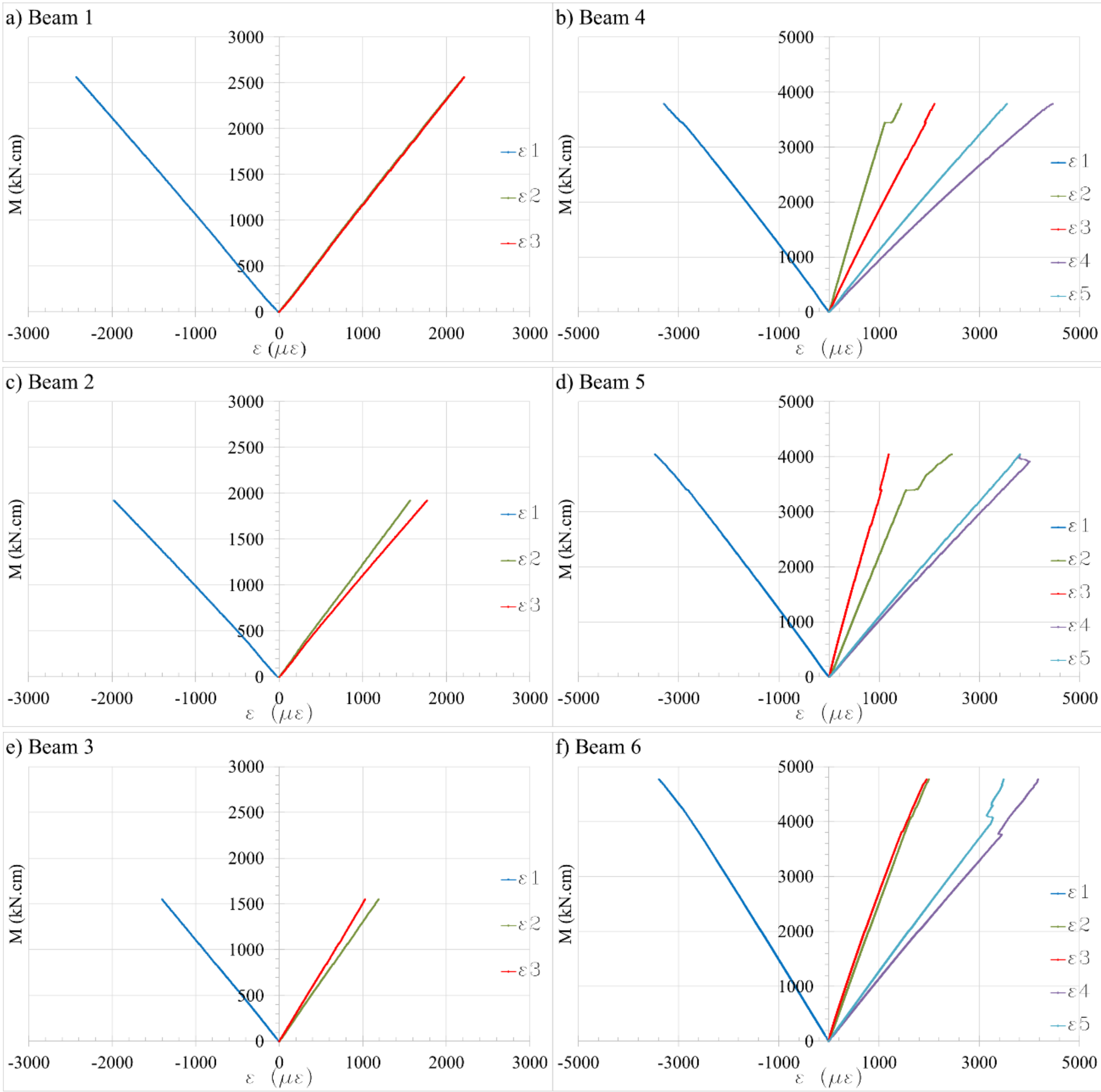



*Fig. 4: Bending moment versus strains in the glulam: a) unreinforced beam 1; b) reinforced beam 4; c) unreinforced beam 2; d) reinforced beam 5; e) unreinforced beam 3; f) reinforced beam 6.*

In the compression zone, there was a linear behavior between the strain and the bending moment to failure in both cases. The slight disturbance of this linearity is observed in the reinforced beams under tension, while no ductility was observed in the compression zone. Such behavior has not been confirmed in other studies (Raftery and Whelan 2014, Issa and Kmeid 2005). The maximum values of experimental and theoretical normal stresses at failure are given in Tab. 5. The table also shows good agreement between the experimental and theoretical normal stress values, except at the top of the B6 beam. Such general behavior between the maximum experimental and theoretical or numerical values has also been observed in other studies (Fiorelli and Dias 2011, Raftery and Rodd 2015, Uzel et al. 2018).

*Tab. 5: Maximum values of normal stresses.*

| Beam | $M_{exp}$ (kN.cm) | Experimental and estimated normal stresses | | | |
|---|---|---|---|---|---|
| | | [1]$\sigma_{t,exp}$ (MPa) | [2]$\sigma_{t,th}$ (MPa) | [3]$\sigma_{c,exp}$ (MPa) | [4]$\sigma_{c,th}$ (MPa) |
| B1 | 2566 | 48.15 | 57.09 | -53.65 | -59.46 |
| B2 | 1922 | 37.20 | 42.65 | -43.20 | -42.82 |
| B3 | 1553 | 25.83 | 35.02 | -28.49 | -32.74 |
| Mean | 2013 | 37.06 | 44.92 | -41.78 | -45.01 |
| B4 | 3791 | 99.66 | 85.04 | -71.73 | -79.46 |
| B5 | 4046 | 81.09 | 80.49 | -82.41 | -88.86 |
| B6 | 4769 | 86.44 | 98.35 | -70.90 | -93.08 |
| Mean | 4202 | 89.06 | 87.96 | -75.01 | -87.13 |

[1]$\sigma_{t,exp}$ - experimental failure tension stresses (MPa); [2]$\sigma_{t,th}$ - theoretical failure tension stresses (MPa); [3]$\sigma_{c,exp}$ - experimental failure compression stresses (MPa); [4]$\sigma_{c,th}$ - theoretical failure compression stresses (MPa).

## CONCLUSIONS

It can be concluded that the bending of the glulam beam using the transformed cross-section method leads to values close to those observed experimentally, since the glulam beam shows a nearly linear behavior until failure. Failure of glulam beams due to tensile stresses began at the bottom finger joint. Increasing the strength of the finger-joint with GFRP reinforcement promoted the strength of the glulam beam and resulted in a twofold increase in average strength compared to unreinforced glulam beams, considering the vertical geometry of the finger-joint, gluing conditions, and high-density *Eucalyptus spp.* wood.

The practical percentage of GFRP reinforcing fibers used was approximately 1.72% of the height of the beam cross-section and resulted in increased stiffness and strength of glulam beams evaluated by the static bending test. It can be concluded that the use of GFRP reinforcement resulted in an increase of more than 100% in the average bearing capacity and about 10% in the average bending stiffness. The linear elastic behavior of glulam beams in the design/stress limit state was observed in the diagrams of loading and vertical displacement. The theoretical and experimental results of the bending stiffness of the glulam beams were close to each other. It is concluded that the transformed cross-section method is suitable for both reinforced and unreinforced glulam beams. The strain diagrams show a linear behavior up to failure, and in the case of the reinforced glulam beams, there was a disturbance in the deformation values of the tension laminates. In the case of the compressed side, there was a practically linear behavior between the strains and the applied bending moment until failure.

It was found that finger joints made from high density *Eucalyptus spp.* need to be strengthened to ensure the safety of structural elements of glulam beams that need to be bent. In addition, the use of high-density wood in this application could be a viable alternative for the manufacture of glulam beams. This research needs to focus on the structural elements of glulam beams, as there are currently no known studies on high-density finger-jointed joints.

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