Bending Characteristics of Laminated Wood Composites Made of Poplar Wood and GFRP

Savojna svojstva lameliranog drva izrađenoga od topolovine i GFRP-a

ABSTRACT • In this study, 4 layers of 5 mm thick slats obtained by sawing method from poplar wood were used. Plain woven GRFP with low density and grammage of 100 g/m² (Type 1) and plain woven GRFP with high density and grammage of 200 g/m² (Type 2) were placed and glued between each layer. Polyvinyl acetate (PVAc-D4), Polyurethane (PU) and dual-component Epoxy (L285-resin and H285-hardener) adhesives were used for gluing the layers. Strength values (bending and modulus of elasticity) between the obtained layers were investigated. As a result of the study, it was determined that epoxy glue has higher strength than polyurethane and polyvinyl acetate glues; Type 2 plain woven fabric has higher strength than Type 1 plain woven fabric; and parallel load to the glue line results in higher performance than perpendicular load to the glue line.

Keywords: poplar; wood laminate; bending strength; modulus of elasticity

SAŽETAK • U radu se prikazuje istraživanje lameliranog drva izrađenoga od piljenjem proizvedenih topolovih platica debljine 5 mm složenih u četiri sloja. Između svakog sloja zalijepljena je plošno tkana GRFP tkanina male gustoće i površinske mase 100 g/m² (tip 1) i plošno tkana GRFP tkanina velike gustoće i površinske mase 200 g/m² (tip 2). Za lijepljenje drva i tkanine upotrijebljena su ova ljepila: polivinilacetatno (PVAc-D4), poliuretansko (PU) i dvokomponentno epoksidno (L285-mola i H285-otvrdnjivač). Istražene su vrijednosti čvrstoće (savijanje i modul elastičnosti) te je utvrđeno da epoksidno ljepilo ima veću čvrstoću nego poliuretansko i polivinilacetatno ljepilo. Nadalje, tkanina tipa 2 ima veću čvrstoću od tkanine tipa 1, a djelovanjem sile paralelno sa sljubnicom dobivena su bolja svojstva nego pri djelovanju sile okomito na sljubnicu.

Ključne riječi: topolovina, drvni laminati, čvrstoća na savijanje, modul elastičnosti

1 INTRODUCTION

1. UVOD

The value of forest products is also increasing due to the continuous decrease in forest resources and the increase of costs in the world. Due to the increase in furniture consumption, it will be possible to meet the demand for forest products by processing the forests in accordance with the scientific principles and to use the cut trees most efficiently. Lamination technique is used for efficient use of wood materials, removal of defects and formation of diagonal fibers in curved formations. With the developing technology, it is used as glued
laminated timber material, which has an important place in today’s design world as a contemporary material that allows to reach the smallest part of the wood by applying small pieces of wood with the help of glue, allowing wider openings and any desired shape.

Regarding solid wood materials, laminated wood materials, which are superior in terms of aesthetic, economic, and technological properties, have been suggested to be preferred in skeletal elements that require strength, particularly in LVL (Laminated Veneer Lumber) furniture production (Eckelman, 1993). Laminated wood materials are used in columns and beams as building elements, and in furniture which is exposed to high static and dynamic forces, in particular by sticking the plaque coating plates hot or cold under prestress under high pressure, flat or inclined (Dongel, 1999).

There are many reports available in the literature on the effects of laminated layer thickness on mechanical properties (Braun and Moody, 1977; Moody, 1981; Youngquist et al., 1984; Keskin, 2001; Altmok et al., 2009; Percin et al., 2009) and glue type (Senay, 1996; Eren, 1998; Dongel, 1999; Guray et al., 2003) and different press pressure (Franklin Glue Comp, 1989; Dilik, 1997; Ulupinar, 1998).

Tests with glass fiber reinforced materials were first carried out by Wanggaard (1964) and Biblis (1965). In these initial experiments, both researchers made experiments using epoxy resin-treated one-way glass fiber on different types of solid wood materials. The first experiment on laminated beams was carried out by Theakson (1965). Experiments were carried out using water-based adhesive and epoxy adhesive with glass fiber woven, glass fiber felt and one-way untreated glass fiber in various shapes. The highest performance was achieved with one-way glass fiber. In recent years, some researches have been carried out on mechanical reinforcement of glass fiber and wood based structural materials (Pidaparti and Johnson, 1996; Hallström and Grenestedt, 1997; Fiorelli and Dias, 2006; Akgül et al., 2009; Ozalp et al., 2009; Riberio et al., 2009; Basterra et al., 2012; Borri et al., 2013; Mstak, 2013; Bal 2014a and 2014b; Osmannzhad et al., 2014; Bal, 2015; Bal and Ozyurt, 2015; Guntekin, 2015).

The elements (beams) under the influence of the bending force are divided into two groups as “horizontal laminar elements” and “vertical laminar elements” according to the applied force direction (Baird and Ozelton, 1990). When the load is applied perpendicular to the glue line, it is called horizontal, and when the load is applied parallel to the glue line it is called vertical element. Examples of horizontal and vertical laminar elements are given in Figure 1.

The aim of this study was to bond and thicken layers between 5 mm thick *Populus nigra* slats using polyvinyl acetate (PVAc-D4), polyurethane (PU-D4) and dual-component epoxy resin (L285 resin + H285-hardener) to determine the bending strength and modulus of elasticity of laminated wood materials produced in 4 layers by placing low-density and high density glass fiber fabric (GFRP) in order to strengthen the layers.

![Figure 1 Examples of load perpendicular to glue line and parallel to glue line](Image)

**Slika 1.** Primjeri djelovanja sile okomito i paralelno na sljubnicu

2 MATERIALS AND METHODS
2.1 Wood material
2.2 Glass fiber fabric (GFRP)

The black poplar wood (*Populus nigra*) used as a solid wood in the preparation of the test specimens was obtained entirely randomly from lumber mills in Usak province. The choice of wood material was to ensure perfect timber, smooth fibers, without knots, with normal growth, no reaction wood, and no fungus and pest damage. The slats were cut from black poplar by a circular sawing machine with the dimension of 5 mm × 70 mm × 1000 mm. The slats were stored until reaching a moisture content of 12 % in an air conditioning room with a temperature of (20 ± 2) °C and a relative humidity of (65 ± 5) %.

2.2 Glass fiber fabric (GFRP)

**2.2.1** Tkanina ojačana slaklenim vlaknima (GFRP)

It is produced from glass fiber materials such as fiberglass, silica, colemante, aluminum oxide, soda. Glass fiber is the most known and used among fiber reinforced composites (Dost Kimya, 2017). Plain woven GFRP with low density and grammage of 100 g/m² (Type 1) and plain woven GFRP with high density and grammage of 200 g/m² (Type 2) were used between slats to improve the mechanical properties of timber structural elements and are shown in Figure 2.

2.3 Glue

2.3.1 Ljepilo

Polyvinyl acetate (PVAc-D4), Polyurethane (PU-D4) and Epoxy (L285 resin + H285-hardener) adhesives were used for bonding slats. Polyvinyl acetate adhesive (PVAc-D4) is an adhesive with advantageous properties such as odorless, easy application, quick curing, cold application and non-flammability (Polisan Ltd. Si., 2017). Polyurethane adhesive (PU-D4) is a one component, polyurethane based, fast and...
moisture curing adhesive for indoor use (Polisan Ltd. Şti. 2017) and Epoxy (L285-resin+H285-hardener) is a polyurethane based (PU) dual component adhesive, which provides excellent adhesion to wood materials and achieves the desired mechanical strength (Dost Kimya, 2017).

2.4 Preparation of experimental samples

2.4. Priprema eksperimentalnih uzoraka

The test specimens were prepared according to the standard “TS EN 408:2010 + A1:2014-04 Timber and Glued Laminates - Determination of Some Physical and Mechanical Properties”. During the production of the test specimens from air-dried 5 mm thick solid materials, 4 solid layers of PVAc-D4, PU-D and Epoxy glues and plain woven GFPR with low and high density interlayer materials and samples without interlayer (as a control) were produced. For interlayer samples, 3 layers of glass fiber material were used for intermediate support between solid layers. In the lamination process, the dimensions of slats are 5×100×1000 mm and 4 layers are bonded. In the case of samples of interlayer materials, the glue solution was applied to the solid bonding surfaces with a brush and glue spread of 180-200 gr/m². In the bonding process, the surfaces are glued and kept for 5-6 minutes (open time). The cold laminating process was carried out by setting the pressure to 1.2 N/mm², cold in the hydraulic press with a pressure gauge suitable for hot and cold preseason for 8 hours (closed time). The laminated material obtained after pressing is prepared with woodworking machines according to the standard. The prepared samples are shown in Figure 3.

By using 2 plain woven types (control, Type 1 and Type 2), 3 glue types (PVAc-D4, PU-D4, and epoxy), 1 wood type (poplar) and 2 load types (bending strength and modulus of elasticity), a total of 90 samples (3×3×1×2×5) were prepared with 5 replicates for each parameter. Prior to testing, all specimens were stored in a conditioning room maintained at (20±2 °C) and 65 % RH until moisture equilibrium was achieved.

2.5 Methods

2.5. Metode

2.5.1 Bending strength

2.5.1. Čvrstoća na savijanje

The prepared test samples were tested, according to the 4-point bending principle, in parallel and perpendicular direction to the glue line using the SHIMADZU universal testing machine placed in the laboratory of Karabuk University Safranbolu Vocational School.

The loading speed of the test machine is 5mm/min. The bending strength, modulus of elasticity and load carrying capacity of the specimens placed with the

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Figure 3 Test Samples of GFRP + Glue + Wood

Slika 3. Ispitni uzorci: GFRP + ljepilo + drvo

Figure 4 Test Samples of Glue + Wood

Slika 4. Ispitni uzorci: ljepilo + drvo
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base points of 360 (mm) are calculated. The 4-point bending strength was determined as (Eq. 1.):

\[
\sigma_{st} = \frac{F \cdot L}{b \cdot h^2} \tag{1}
\]

Where \( \sigma_{st} \) is bending strength (N/mm\(^2\)), \( F \) is the maximum load (N), \( L \) is span (mm), \( b \) is width (mm) and \( h \) is thickness (mm).

2.5.2 Modulus of elasticity

The modulus of elasticity was determined as (Eq. 2.):

\[
E_{\text{mp}} = \frac{\lambda^2 \cdot (F_2 - F_1)}{b_1 \cdot h_1^3 \cdot (W_2 - W_1)} \cdot \left[ \frac{3a}{4\lambda} \right]^{-\frac{3}{2}} \tag{2}
\]

Where \( E_{\text{mp}} \) is modulus of elasticity (N/mm\(^2\)), \( \lambda \) is length measured for identification of the modulus of elasticity, \( b_1 \) is width – dimension in tangential direction (cm), \( h_1 \) is height – dimension in radial direction (cm), \( a \) is distance between loading point and nearest spam (mm), \( F_2 - F_1 \) is increase of the load ratio on the correct line of the load-deflection curve (N), and \( W_2 - W_1 \) is increase in deformation corresponding to \( F_2 - F_1 \) (mm).

2.6 Evaluation of data

The statistical results (arithmetic mean \( X \), standard deviation \( SS \) and coefficient of variation \( %V \)) of the data obtained in the experiments were calculated. In order to determine the test results, multiple variance analysis (ANOVA) was used to determine the effect of factors on the values obtained for all groups. The Duncan test was used to indicate the significance level of the interaction of the factors (\( p < 0.05 \)) with 5 % error. Under the name of homogeneity group (HG), groups that differ were designated as A, B, C, etc.

3 RESULTS AND DISCUSSION

3.1 Bending strength of parallel to glue line

According to the normality analysis test result, the regions show normal distribution. The statistical evaluation results of bending strength of laminated composite material and solid wood materials are given in Table 1 and results of multiple variance analysis are given in Table 2.

The effect of glue type and glass fiber fabric type on the bending strength parallel to the glue line was significant (\( p < 0.05 \)). The double interaction of the glue type and glass fiber fabric type (\( p < 0.05 \)) was negligible with respect to the error. Duncan test results applied to determine which groups are different are given in Table 3 by glue type and Table 4 by glass fiber fabric type.

According to Table 4, the highest bending strength was obtained from Type 2, while the lowest bending strength sample was obtained from control samples.

### Table 1: Bending strength values parallel to glue line (N/mm\(^2\))

| Glue type | Vrsta ljepila | GFRP | Xmin | Xmax | X | SS | %V |
|-----------|---------------|------|------|------|---|----|----|
| PVAc-D4   | Control       | 40.52| 46.13| 43.32| 2.32| 5355|
|           | Type 1        | 47.02| 52.64| 49.83| 2.67| 5358|
|           | Type 2        | 62.96| 68.58| 65.77| 3.52| 5351|
| PU-D4     | Control       | 36.58| 42.20| 39.39| 2.11| 5356|
|           | Type 1        | 42.49| 48.11| 45.30| 2.43| 5364|
|           | Type 2        | 56.98| 62.60| 59.79| 3.20| 5352|
| Epoxy     | Control       | 52.64| 58.26| 55.45| 2.97| 5356|
|           | Type 1        | 60.97| 66.59| 63.78| 3.42| 5362|
|           | Type 2        | 81.38| 87.00| 84.19| 4.50| 5345|

\( SS \) – standard deviation / standardna devijacija, \( V \) – coefficient of variation / koeficijent varijacije
Table 2 Variance analysis results of the effects of glue type and glass fiber fabric type on bending strength values parallel to glue line

Table 3 Duncan test results (N/mm²) of the effect of bending strength parallel to glue line by glue type

Table 4 Duncan test results of the effect of bending strength (N/mm²) parallel to glue line by glass fiber fabric type

Table 5 Bending strength values perpendicular to glue line (N/mm²)

Table 6 Variance analysis results of the effects of glue type and glass fiber fabric type on bending strength values perpendicular to glue line
According to Table 8, the highest bending strength was obtained from Type 2 glass fiber fabric samples, followed by Type 1 glass fiber fabric and control samples.

### 3.3 Modulus of Elasticity Parallel to Glue Line

3.3. Moduli elasticitnosti paralelno sa sljубnicom

The statistical evaluation of the results of laminated wood and modulus of elasticity parallel to glue line is given in Table 9, and the results of multiple variance analysis are given in Table 10.

The effect of the type of glue and glass fiber fabric type was significant with the margin of error ($p < 0.05$) in the modulus of elasticity parallel to the glue line. The double interaction of the glue type and glass fiber fabric type ($p < 0.05$) was negligible with respect to the error. Duncan test results applied to determine which groups are different are given in Table 11 by glue type and Table 12 by glass fiber fabric type.

According to Table 11, the highest modulus of elasticity was obtained from epoxy glue and the lowest modulus of elasticity value was obtained from polyurethane (PU-D4) glue.

According to Table 12, it can be seen that the highest modulus of elasticity was obtained from Type 2 glass fiber fabric samples, while the lowest value was obtained from control samples.

### Table 7 Duncan test results (N/mm²) of the effect of bending strength perpendicular to glue line by glue type

| Glue type / Vrsta ljepila | X     | HG |
|---------------------------|-------|----|
| Epoxy                     | 64.42 | A  |
| Polyvinyl Acetate (PVAc-D4)| 50.32 | B  |
| Polyurethane (PU-D4)      | 45.75 | C  |

### Table 8 Duncan test results (N/mm²) on the effect of bending strength perpendicular to glue line by glass fiber fabric type

| GFRP            | X     | HG |
|-----------------|-------|----|
| Type 2 / tip 2  | 66.42 | A  |
| Type 1 / tip 1  | 50.32 | B  |
| Control / kontrola | 43.75 | C  |

### Table 9 Modulus of elasticity parallel to glue line (N/mm²)

| Glue type / Vrsta ljepila | GFRP | Xmin | Xmax | X   | SS   | %V  |
|----------------------------|------|------|------|-----|------|-----|
| PVAc-D4                    | Control | 2785 | 3127 | 2956| 154.34| 5.200|
| Type 1                     | 3052  | 3393 | 3223 | 79.22| 2.400|
| Type 2                     | 4148  | 4489 | 4318 | 106.22| 2.400|
| PU-D4                      | Control | 3878 | 4220 | 4049| 175.98| 4.300|
| Type 1                     | 3270  | 3612 | 3441 | 61.01| 1.700|
| Type 2                     | 4440  | 4782 | 4611 | 80.84| 1.700|
| Epoxy                      | Control | 4150 | 4492 | 4321| 159.39| 3.600|
| Type 1                     | 4520  | 4862 | 4691 | 275.14| 5.800|
| Type 2                     | 6115  | 6457 | 6286 | 368.42| 5.800|

$\text{SS} = \text{standard deviation} / \text{standardna devijacija}; \%V = \text{coefficient of variation} / \text{koeficijent varijacije}$

### Table 10 Variance analysis results of the effects of glue type and glass fiber fabric type on modulus of elasticity values parallel to glue line

| Source of variance | Sum of square | df | Mean square | F ratio | Level of significance |
|--------------------|--------------|----|-------------|---------|----------------------|
| Glue type (A) / vrsta ljepila (A) | 10053593.200 | 2  | 5026796.600 | 1752.657 | 0.000 |
| Plain woven type (B) vrsta plošno pletene tkanine (B) | 713831.733 | 2  | 3569158.867 | 1244.433 | 0.000 |
| A × B | 216240.267 | 4  | 54060.667 | 18.849 | 0.053 |
| Residual / ostatak | 103251.600 | 36 | 2868.100 |         |         |
| Total / ukupno | 348988507.000 | 45 |         |         |         |
3.4 Modulus of elasticity perpendicular to glue line

The statistical evaluation results of modulus of elasticity of laminated wood material and solid wood are given in Table 13, and the results of multiple variance analysis are given in Table 14.

The effect of the type of glue and glass fiber fabric type on modulus of elasticity values perpendicular to glue line is shown in Table 14. The statistical evaluation results of modulus of elasticity values perpendicular to glue line by glass type are given in Table 15. Duncan test results of the effect of modulus of elasticity (N/mm²) perpendicular to glue line by glass type are given in Table 16.
be 17% higher than the control sample. Muratoglu (2011) achieved high strength with carbon fiber reinforced strip rod (CFRP) and double component epoxy adhesive in reinforcement processes in the restoration of historical buildings.

4 CONCLUSIONS

In this study, the modulus of elasticity of the laminated wood material supported by various glass fiber materials was investigated from 4 aspects. To this purpose (Populus nigra.) wood, which is widely used in the manufacture of furniture and building elements in our country, was made of 4 layers of glass fiber elements placed in porous structure between slats and bonded with epoxy, polyvinyl acetate (PVAc-D4) and polyurethane (PU-D4). As a result of the test, control samples and samples supported by glass fiber fabric were statistically evaluated according to the glue type, glass fiber type and load type. Based on the results, epoxy adhesive showed the highest bending strength parallel and perpendicular to the glue line, while polyurethane (PU-D4) glue showed the lowest bending strength. According to the glass reinforcing fiber type, Type 2 showed the highest bending strength, while the control samples showed the lowest bending strength. Epoxy + Type 2 showed the highest bending strength combined with glue type and glass reinforcing fiber type. Epoxy adhesive showed the highest modulus of elasticity strength parallel and perpendicular to the glue line, while polyurethane (PU-D4) glue showed the lowest bending strength. Regarding the type of glue, epoxy adhesive showed the highest modulus of elasticity perpendicular to the glue line, while polyurethane (PU-D4) glue showed the lowest modulus of elasticity value. Epoxy + Type 2 showed the highest modulus of elasticity combined with glue type and glass reinforcing fiber type.

Based on the experimental results obtained, it was determined that the bending strength and the modulus of elasticity increased the strength of the support materials as compared to the control example. Since there is a significant increase in the strength properties of the material when using the intermediate filler material in the laminated materials, its use may be preferred in furniture and building properties. In the literature, it is stated that the performance will increase as a result of the increase of layer thickness in pine samples. As a continuation of this study, researchers are recommended to focus on different layer symmetry and testing of laminated samples with different filling materials.

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