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Investigation of Some Physical and Mechanical Properties of Basalt Fiber-Reinforced Polymer (BFRP) Woven Fabrics and Plaster Mesh (PSM) Reinforced Glued Laminated Oak Lumber

Istraživanje nekih fizičkih i mehaničkih svojstava lamelirane hrastove građe ojačane polimernim tkaninama s bazaltnim vlaknima (BFRP) i fasadnom mrežicom (PSM)

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ABSTRACT • *In this study, some physical and mechanical properties of the basalt fiber-reinforced polymer (BFRP) woven fabrics (WF) and plaster mesh (PSM) reinforced glued laminated oak lumber were investigated. The BFRPWF and PSM were used in order to increase the mechanical properties of the laminated elements. One-component polyurethane glue (PUR) was used in the production of lumber. The BFRPWF and PSM were tested in three different locations using non-reinforced laminated oak lumber (LOL), reinforced laminated oak lumber with BFRPWF (LOL-BFRPWF), and reinforced laminated oak lumber with PSM (LOL-PSM). Tests were performed on the LOL, LOL-BFRPWF, and LOL-PSM to investigate their bending strength (MOR), air-dried density (δ_{12}), and modulus of elasticity (MOE). The three-point MOR and MOE in bending tests were applied to the samples. The results showed that the highest value for MOR was found in the laminated wood samples (135.20 N/mm^2) that were prepared using the BFRPWF inter-layer. The lowest value of 112.82 N/mm^2 was found in the LOL samples. The highest value of modulus elasticity was found in the samples prepared with the BFRPWF inter-layer (16167 N/mm^2). The lowest value of 13786 N/mm^2 was found in the LOL samples. It was observed that the samples parallel to the glue line of the laminated material showed higher performance compared to those perpendicular to the glue line. The LOL-BFRPWF samples give better results than LOL-PSM and control samples. Accordingly, the LOL-BFRPWF and LOL-PSM samples have the potential to be used as viable options for both furniture and building materials.*

KEYWORDS: *bending strength; modulus of elasticity; plaster mesh; oak wood; polyurethane adhesive*

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SAŽETAK • *U radu su istražena neka fizička i mehanička svojstva lamelirane građe od hrastovine ojačane polimernim tkaninama s bazaltnim vlaknima (BFRPWF) i fasadnom mrežicom (PSM) kako bi se povećala mehanička svojstva lamelirane građe. U izradi lamelirane građe upotrijebljeno je jednokomponentno poliuretansko ljepilo (PUR). Tijekom ispitivanja određena je čvrstoća na savijanje (MOR), gustoća drva sušenog na zraku (δ_{12}) i modul elastičnosti (MOE) neojačane lamelirane građe (LOL), lamelirane građe ojačane BFRPWF-om (LOL-BFRPWF) i lamelirane građe ojačane PSM-om (LOL-PSM). Za određivanje čvrstoće na savijanje i modula elastičnosti primijenjeno je savijanje u tri točke. Rezultati su pokazali da je čvrstoća na savijanje najveća na uzorcima lamelirane građe ojačane BFRPWF-om (135,20 N/mm²), a najmanja na uzorcima bez ojačanja (112,82 N/mm²). Najveća vrijednost modula elastičnosti izmjerena je na uzorcima ojačanim BFRPWF-om (16167 N/mm²), a najmanja na uzorcima bez ojačanja (13786 N/mm²). Uočeno je da su bolja svojstva uzoraka pri ispitivanju paralelno s lijepljenim spojem nego okomito na slijepljeni spoj. LOL-BFRPWF uzorci dali su bolje rezultate od uzoraka LOL-PSM i kontrolnih uzoraka. Prema dobivenim rezultatima, uzorci LOL-BFRPWF i LOL-PSM mogu poslužiti kao održive opcije u proizvodnji namještaja i proizvoda u graditeljstvu.*

KLJUČNE RIJEČI: *čvrstoća na savijanje; modul elastičnosti; fasadna mrežica; hrastovina; poliuretansko ljepilo*

1 INTRODUCTION
1. UVOD

The main goal in the development of laminated veneer lumber (LVL) is to enhance the dimensional stability of timber products, resulting in improved performance and reliability. In order to achieve the necessary strength levels, it is vital to ensure that the layer arrangement in the LVL is in accordance with the orientation of the timber fibers. An LVL product, characterized by veneers arranged perpendicularly, can be observed as a crossbanded material. Its elevated mechanical properties make it highly desirable for various structural applications (Rahayu *et al*., 2015). Typically, the production process of LVL involves the utilization of secondary-grade materials that exhibit characteristics such as the presence of numerous knots, lower density, and diminished mechanical properties. The composition of LVL can vary significantly as it can be manufactured using a wide range of wood species, including but not limited to Douglas fir, poplar, beech, spruce and others (Burdurlu *et al*., 2007).

To improve the physical and mechanical properties of LVL, FRP composites such as E-glass FRP (GFRP), carbon FRP (CFRP), and aramid FRP (AFRP) are commonly used as reinforcement materials (Johns and Lacroix, 2000; Lopez-Anido *et al*., 2003; Borri *et al*., 2005). While it is true that the manufacturing processes used for these fibers are known to be energy-intensive and come with high initial costs, the emergence of basalt FRP (BFRP), as a mineral-based natural FRP, has brought about notable changes.

BFRP, as supported by studies (Wang *et al*., 2014; Elgabbas *et al*., 2016; Fiore *et al*., 2015), offers the advantage of lower material costs and demonstrates a high level of ecological compatibility throughout its production. Furthermore, basalt fiber has beneficial properties (Patnaik *et al*., 2004) that, when combined with cost-effective production process (Wu *et al*., 2012; Sim *et al*., 2005), result in enhanced high temperature resistance (Sim *et al*., 2005), excellent freeze-thaw performance (Wu *et al*., 2010), and ease of manufacture (Sim *et al*., 2005). In addition, basalt fiber exhibits remarkable tensile properties, characterized by a high tensile strength ranging from 1.85 to 4.8 GPa (Zoghi, 2013).

Currently, there is growing interest in using BFRP as a type of FRP for reinforcing wood composites (Kufel and Kuciel, 2019; Kramár *et al*., 2020). As a newly introduced composite material, BFRP represents another technologically advanced fiber composite material, joining the ranks of carbon fibers (Subagia *et al*., 2014).

BFRP offers significant cost advantages over CFRP, with prices ranging from only one-eighth to one-sixth of CFRP (Wu, 2020). Additionally, BFRP exhibits superior mechanical properties, including higher elastic modulus and tensile strength, when compared to GFRP (Song *et al*., 2021).

Due to its lower density, with basalt weighing approximately one-third of the steel density (2.6 g/cm³ compared to 7.68 g/cm³), BFRP is considered a lighter and more robust construction material compared to steel. It is projected that the mechanical properties of BFRP as a construction material will exert an influence on its environmental performance (Garg and Shrivastava, 2019). The raw materials used in BFRP are characterized by their broad variety, while its production process adheres to environmentally friendly practices, and fulfills the requisites of green sustainable development (Gao *et al*., 2020).

Extensive study has been conducted on the use of BFRP in conjunction with LVL in various technological applications, including wood and LVL elements. These studies have demonstrated notable enhancements in mechanical properties when using different reinforcement configurations (Wang *et al*., 2019; Liu *et al*., 2020; Resvalvo *et al*., 2020; Wdowiak-Postulak and Swit, 2021; Cheng *et al*., 2022; Jian *et al*., 2022; Zhou *et al*., 2022; Núñez-Decap *et al*., 2023; Resvalvo *et al*., 2023).

The behavior of prismatic test specimens made from wild pinewood under compressive loads was examined by de la Rosa *et al*. (2021). The study focused on the effect of fabric confinement, with the use of three types of fabric: two BFRP fabrics with varying grammages and CFRP. Lohmus *et al*. (2021) examined whether the tensile strength of basalt fiber-reinforced plywood can be affected by prestressing and temperature variations. Cheng *et al*. (2022) conducted a study to investigate a straightforward retrofitting technique that involved using small bamboo pieces and a BFRP wrap to enhance the structural strength of locally damaged laminated bamboo lumber (LBL) columns. Rescalvo *et al*. (2023) investigated the LVL mechanical behavior of poplar reinforced with BFRP subjected to shear and compressive stresses. Wdowiak-Postulak *et al*. (2023) conducted an analysis to assess the effectiveness of strengthening glued laminated timber beams through the use of pre-stressed BFRP.

Keskin (2004) investigated the bending properties of structural LVL made of Oak (*Quercus petrea* Lieble). The modulus of rupture, modulus of elasticity, and air-dry density of oak wood was measured to be 106 N/mm^2, 10742 N/mm^2, and 611 kg/m^3, respectively Keskin (2009) made an experiment to determine how timber species, loading direction and chemical impregnation affected the bending properties of LVL samples. The air-dry density for the chosen species was for beech (650 kg/m^3), oak (639 kg/m^3), Scotch pine (537 kg/m^3), spruce (403 kg/m^3) and Uludad fir (385 kg/m^3).

The literature review shows that there are not enough studies on some physical and mechanical properties of the BFRPWF and PSM reinforced glued laminated oak lumber. I believe that this study will contribute to the literature. The current study aimed to comparatively investigate some physical and mechanical properties of the control samples (LOL), the LOL-BFRPWF samples and LOL-PSM samples using polyurethane adhesive cured under room temperature.

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

2.1 Materials
2.1. Materijali

For the study, the oak wood (*Quercus petrea* L.), widely used in the furniture sector, was chosen as the wood material. Its selection was conducted randomly from timber merchants located in Yenice-Karabuk, Turkey. As a test material, pieces of oak lumber (5 mm × 80 mm × 1000 mm) were used. It is a material whose full-dry density (δ_0) is 650 kg/m^3, and δ_{12} is 690 kg/m^3. Also, the *MOE* is 12300 MPa, and the *MOR* is 105 MPa (Bozkurt and Erdin, 2000).

The BFRPWF for 200 gr/m^2 plain materials used in the study was obtained by Dost Chemical Industry Raw Material Industry and Trading Company (Turkey, Istanbul) (Figure 1a). It had the following values: density of 2.8 g/cm^3, thickness of 0.140 mm, modulus of elasticity of 89 GPa, tensile strength of 4.8 GPa, and elongation to fracture of 3.2 % (Fiore *et al*., 2011).

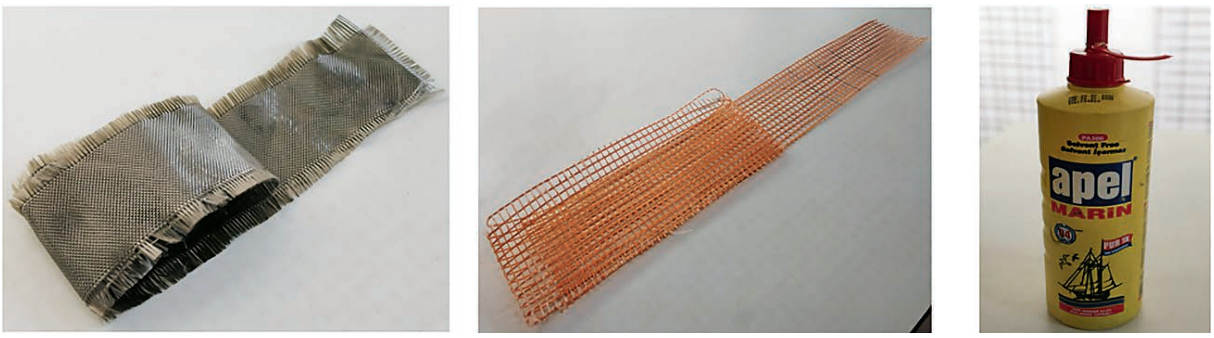
The plaster mesh (PSM) used had a weight of 160 g/m^2. It was alkali resistant and orange in color, with a 4 mm × 4 mm mesh pattern (Figure 1b).

The polyurethane adhesive (PUR) used in this the study was obtained by Apel Kimya Industrial Industry and Trade Company (Turkey, Istanbul) (Figure 1c). At a temperature of 20 °C, the density of the material is measured to be (1.11±0.02) g/cm^3, while at 25 °C, the viscosity is determined to be (14.000±3.000) mPas. When exposed to a temperature of (20 ±2) °C and a relative humidity of (65 ±3) %, the material undergoes hardening within 30 minutes.

2.2 Preparation of experimental samples
2.2. Priprema ispitnih uzoraka

Slats with dimensions of 5 mm thickness, 80 mm width, and 1000 mm length (T × W × L) were obtained from oak timber by a circular saw using the mowing technique. Once stacked, the slats were stored in a temperature-controlled room with a constant temperature of (20±2) °C and relative humidity of (65±5) %. The slats remained in the specified environment until they attained a moisture content of 12 %. The test samples were prepared in accordance with the guidelines outlined in the TS 5497 EN 408 (2006) standard. The PUR was used in the preparation of the samples.

As shown in Figure 2, reinforced laminated elements were produced by placing the BFRPWF or PSM



(a) (b) (c)

Figure 1 Materials used in experiments: (a) BFRPWF, (b) PSM, (c) PUR adhesive
Slika 1. Materijali uključeni u istraživanju: (a) BFRPWF, (b) PSM, (c) PUR ljepilo

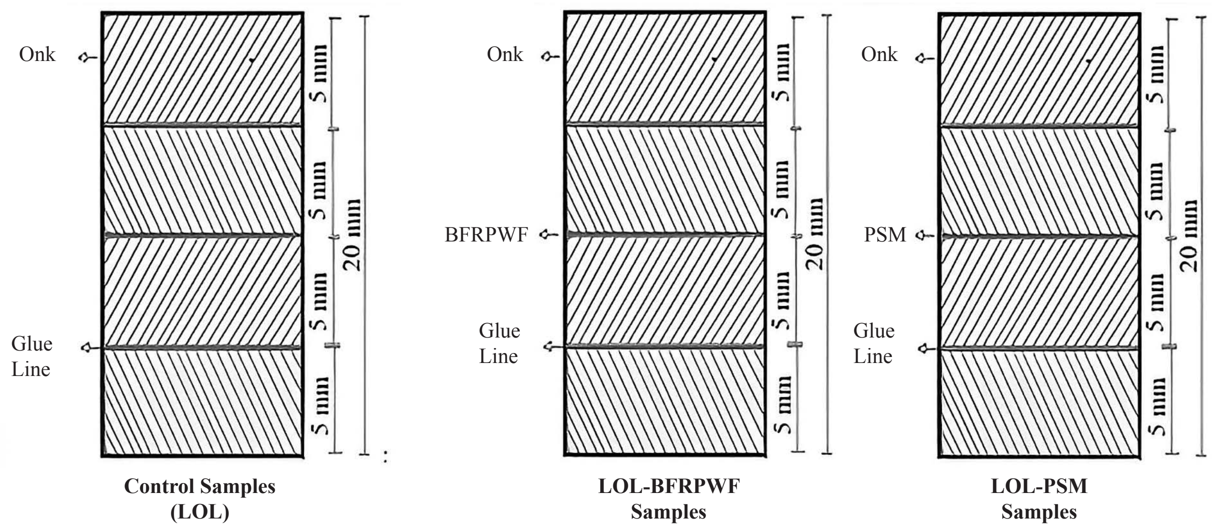


Figure 2 All experimental samples
Slika 2. Svi ispitni uzorci

Figure 3 Pressing of test samples
Slika 3. Prešanje ispitnih uzoraka

between each layer with the aim of inreasing the resistance. For interlayer samples, 3 layers of reinforced materials were used for intermediate support between solid layers. Approximately 200 g/m^2 of adhesive was used for the surface. The samples, which consisted of four layers, were placed into a hydraulic press (Hydraulic Veneer SSP-80; ASMETAL Wood Working Machinery Industry Inc., Ikitelli, Istanbul, Turkey) at room temperature. The press exerted a pressure of approximately 1.5 N/mm^2 on the samples for 3 hours. As a result, the desired laminated veneer lumbers were produced by cold pressure at (20 ±2) °C and (65±5) % relative humidity. Consequently, one wood species (oak), one adhesive type (PUR), two fiber reinforced polymers (BFRPWF, PSM, and control), two load types (perpendicular to the glue line and parallel to the glue line), and 10 samples of each material (1 × 1 × 3 × 2 × 10 = 60) were the variables, and the air-dry density tests were made for a total of 20 variables. A total of 80 specimens were prepared in this research. Prior to testing, all samples were conditioned in a humidity chamber controlled at (20±2) °C and (65±5) % relative humidity (RH) for two weeks. The pressing of test samples is shown in Figure 3.

2.3 Method of testing
2.3. Metode ispitivanja

The air-dry density was measured in accordance with the guidelines outlined in TS 2474 (1976). Test samples were prepared with dimensions of 20 mm × 20 mm × 30 mm for the purpose of determining the density. The samples were subjected to conditioning in an environment with a relative humidity of (65±5) % and a temperature of (20±2) °C. Conditioning was continued until the samples reached an equilibrium moisture content of 12 %. Subsequently, the samples were weighed using a digital precision scale, and their dimensions were determined using a digital precision compass. Next, the equations provided were used to compute the density values of the samples after air drying:

$$\delta_{12} = \frac{M_{12}}{\vartheta_{12}} \qquad (1)$$

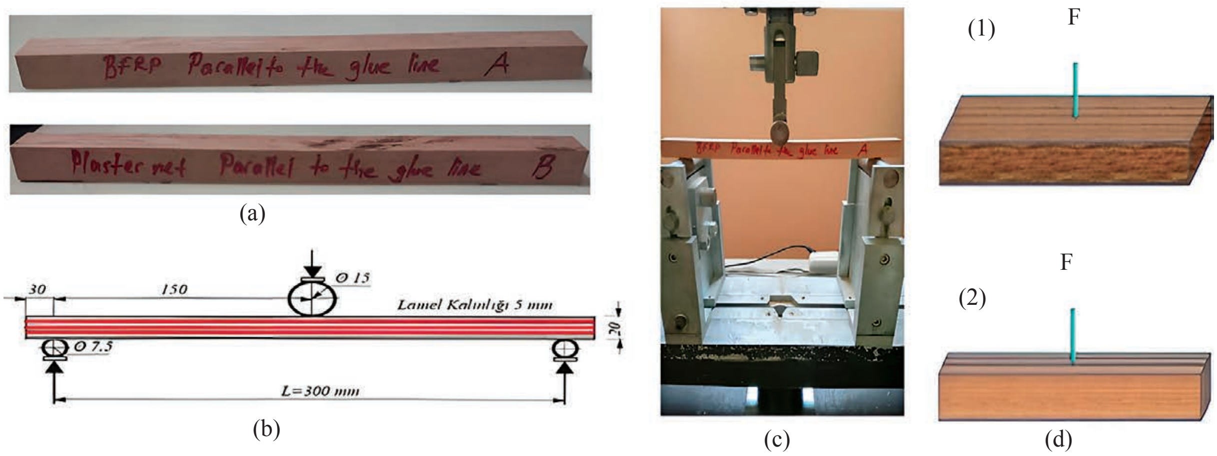


Figure 4 Three-point bending test set-up for laminated samples: (a) vertical crosssection, (b) static system (in mm), (c) testing, (d) loading directions of test specimen according to glue lines: (1) perpendicular, (2) parallel
Slika 4. Postavljanje ispitivanja na savijanje u tri točke za lamelirane uzorke: (a) vertikalni presjek, (b) statički sustav (mm), (c) ispitivanje, (d) smjerovi opterećenja ispitnog uzorka u odnosu prema lijepljenom spoju: (1) okomito, (2) paralelno

Where, δ_{12} is the sample density (g/cm^3), M_{12} is the weight, and ϑ_{12} is the volume (cm^3).

2.3.1 Bending strength and elasticity modulus
2.3.1. Čvrstoća na savijanje i modul elastičnosti

In accordance with the TS EN 326 (1999) standard, the test samples were prepared to facilitate the measurement of *MOR* and *MOE*. The *MOR* experiments were carried out in accordance with the guidelines outlined in the TS 2474 (1976) standard, while the modulus of elasticity tests adhered to the TS 2478 (1976) standard. Each test sample was prepared with dimensions of 20 mm × 20 mm × 360 mm, and two samples were used for each test. Three-point bending test method was carried out (Figure 4c). The bending tests were performed on an electromechanical universal testing machine (UTM) with a capacity of 10 kN. When performing the *MOR* tests, the force was applied to the edge wise position of the test sample in a direction parallel to the glue line and a direction perpendicular to glu line. The test speed was set at 5 mm/min, and the span between the supports was 300 mm. The preload amount was 10 N, and the test ended at 70 % of the maximum force. The *MOR* and *MOE* have been determined using the following equations:

$$MOR = \frac{3 \cdot F_{max} \cdot L}{2 \cdot b \cdot h^2} \quad (2)$$

In the given context, the variables are defined as follows: *MOR* (N/mm^2), F_{max} represents the maximum load applied during testing, measured in N. L denotes the distance between the two supports, measured in mm, b represents the width of the test sample, also measured in mm. Lastly, h is the thickness of the test sample, measured in mm.

$$MOE = \frac{L_1^3 \cdot \Delta F}{4 \cdot b \cdot h^3 \cdot \Delta f} \quad (3)$$

In the given context, the variables are defined as follows:
MOE is the modulus of elasticity (N/mm^2), ΔF represents the load increment, measured in N, L denotes the distance between the two supports, measured in mm, Δf represents the deflection increment, b is the width of the test sample, measured in mm, lastly, h is the thickness of the test sample, also measured in mm.

2.3 Data analyses
2.3. Analiza podataka

The statistical analysis of the experimental data involved calculating the arithmetic mean and standard deviation. Multiple analysis of variance (ANOVA) was used to assess the impact of various factors on the values obtained for all sample groups. Duncan's test was used to determine the significance level of the interaction between the factors, with a significance level set at 5 % ($p < 0{,}05$). This allowed to determine the degree of significance if the mutual strength of the factors exhibited a significant effect.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

Table 1 presents a summary of the test results for some physical and mechanical properties of the samples. Descriptive statistics, including the maximum, minimum, mean, and standard deviation, were used to summarize the data. These statistical values provide an overview of the observed variability and central tendencies concerning the tested properties of the samples.

ANOVA analysis was performed to compare LOL, BFRPWF-LOL and LOL-PSM (Table 2). According to the analysis, the δ_{12}, *MOR* perpendicular to the glue line (⊥*MOR*), *MOR* parallel to the glue line (// *MOR*), *MOE* perpendicular to the glue line (⊥*MOE*), and *MOE* parallel to the glue line (//*MOE*) were statistically significant at the level of 0.05.

In cases where the observed differences between groups were deemed statistically significant, the Duncan's test was used to determine the specific differences between means. This analysis was conducted at a predetermined significance level of α=0.05. The results of the Duncan's test, indicating the significant differences between means, can be seen in Table 3.

This table shows that some physical and mechanical properties of LOL samples showed the lowest values, and some physical and mechanical properties of LOL-BFRPWF the highest. Some physical and mechanical properties of LOL-BFRPWF samples were

Table 1 Descriptive statistical values of some physical and mechanical properties
Tablica 1. Deskriptivne statističke vrijednosti nekih fiz*ičkih* i mehaničkih svojstava lameliranih uzoraka

Process	Values	δ_{12}, kg/m³	⊥ *MOR*, N/mm²	// *MOR*, N/mm²	⊥ *MOE*, N/mm²	// *MOE*, N/mm²
LOL (Control)	*X*	714	108.55	112.82	12501	13786
	SD	21.18	1.93	3.82	72.3	353
	COV (%)	0.45	3.71	14.61	5230	124558
	Min	680	106.15	108.00	12386	13076
	Max	753	112.65	122.30	12650	14199
	N	10	10	10	10	10
PSM-LOL	*X*	738	119.74	127.71	13558	15727
	SD	11.26	4.29	3.01	286	528
	COV (%)	0.13	18.40	9.07	81681	278257
	Min	718	110.05	122.55	13005	14719
	Max	755	125.29	132.30	14030	16612
	N	10	10	10	10	10
LOL-BFRP-WF	*X*	788	125.57	135.20	14526	16167
	SD	22.58	3.97	4.35	498	727
	COV (%)	0.51	15.73	18.95	248282	528799
	Min	758	120.71	129.65	13748	15245
	Max	831	132.73	141.65	15204	17394
	N	10	10	10	10	10

X – Mean values, *SD* – Standart deviation, *COV* (%) – Coefficient of variation, *N* – Number of samples, LOL – Non-reinforced laminated oak lumber (Control), PSM-LOL – Laminated oak lumber with reinforced PSM, LOL-BFRPWF – Laminated oak lumber with reinforced BFRPWF, ⊥ – perpendicular to glue line, // – paralell to glue line.
X – srednje vrijednosti, SD – standardna devijacija, COV (%) – koeficijent varijacije, N – broj uzoraka, LOL – neojačani lamelirani uzorci od hrastovine (kontrolni uzorak), PSM-LOL – lamelirani uzorci od hrastovine ojačani PSM-om, LOL-BFRPWF – lamelirani uzorci od hrastovine ojačani BFRPWF-om, ⊥ – okomito na lijepljeni spoj, // – paralelno s lijepljenim spojem

Table 2 Result of ANOVA
Tablica 2. ANOVA rezultati

δ_{12}, kg/m³	**Source**	***SO***	***DF***	***MS***	***F* Value**	**Sig.**
	Between Groups	0.03205	2	0.016027	44.29	0.000
	Within Groups	0.01086	30	0.000362		
	Total	0.04291	32			
⊥*MOR*, N/mm²	**Source**	***SO***	***DF***	***MS***	***F* Value**	**Sig.**
	Between Groups	2452.2	2	1226.09	42.25	0.000
	Within Groups	870.7	30	29.02		
	Total	2125.2	32			
//*MOR*, N/mm²	**Source**	***SO***	***DF***	***MS***	***F* Value**	**Sig.**
	Between Groups	2750.7	2	1378.87	97.05	0.000
	Within Groups	426.20	30	14.21		
	Total	3184.00	32			
⊥*MOE*, N/mm²	**Source**	***SO***	***DF***	***MS***	***F* Value**	**Sig.**
	Between Groups	22549729	2	11274865	100.91	0.000
	Within Groups	3351935	30	111731		
	Total	25901664	32			
//*MOE*, N/mm²	**Source**	***SO***	***DF***	***MS***	***F* Value**	**Sig.**
	Between Groups	59505749	2	29752874	115.14	0.000
	Within Groups	7752263	30	111731		
	Total	67258012	32			

Table 3 Result of Duncan's Test
Tablica 3. Rezultati Duncanova testa

Technological properties *Tehnološka svojstva*	**Process** / *Proces*					
	LOL		**PSM-LOL**		**LOL-BFRPWF**	
	X	*HG*	*X*	*HG*	*X*	*HG*
δ_{12}, g/cm^3	0.714	C	0.738	B	0.788	A
⊥ *MOR*, N/mm^2	108.55	C	119.74	B	125.57	A
// *MOR*, N/mm^2	112.82	C	127.71	B	135.20	A
⊥ *MOE*, N/mm^2	12501	C	13558	B	14526	A
// *MOE*, N/mm^2	13786	C	15727	B	16167	A

LOL – Non-reinforced laminated oak lumber, PSM-LOL – Laminated oak lumber with reinforced PSM, LOL-BFRPWF – Laminated oak lumber with reinforced BFRPWF , ⊥ – perpendicular to glue line, // – paralell to glue line.
LOL – neojačani lamelirani uzorci od hrastovine (kontrolni uzorak), PSM-LOL – lamelirani uzorci od hrastovine ojačani PSM-om, LOL-BFRPWF – lamelirani uzorci od hrastovine ojačani BFRPWF-om, ⊥ – okomito na lijepljeni spoj, // – paralelno s lijepljenim spojem

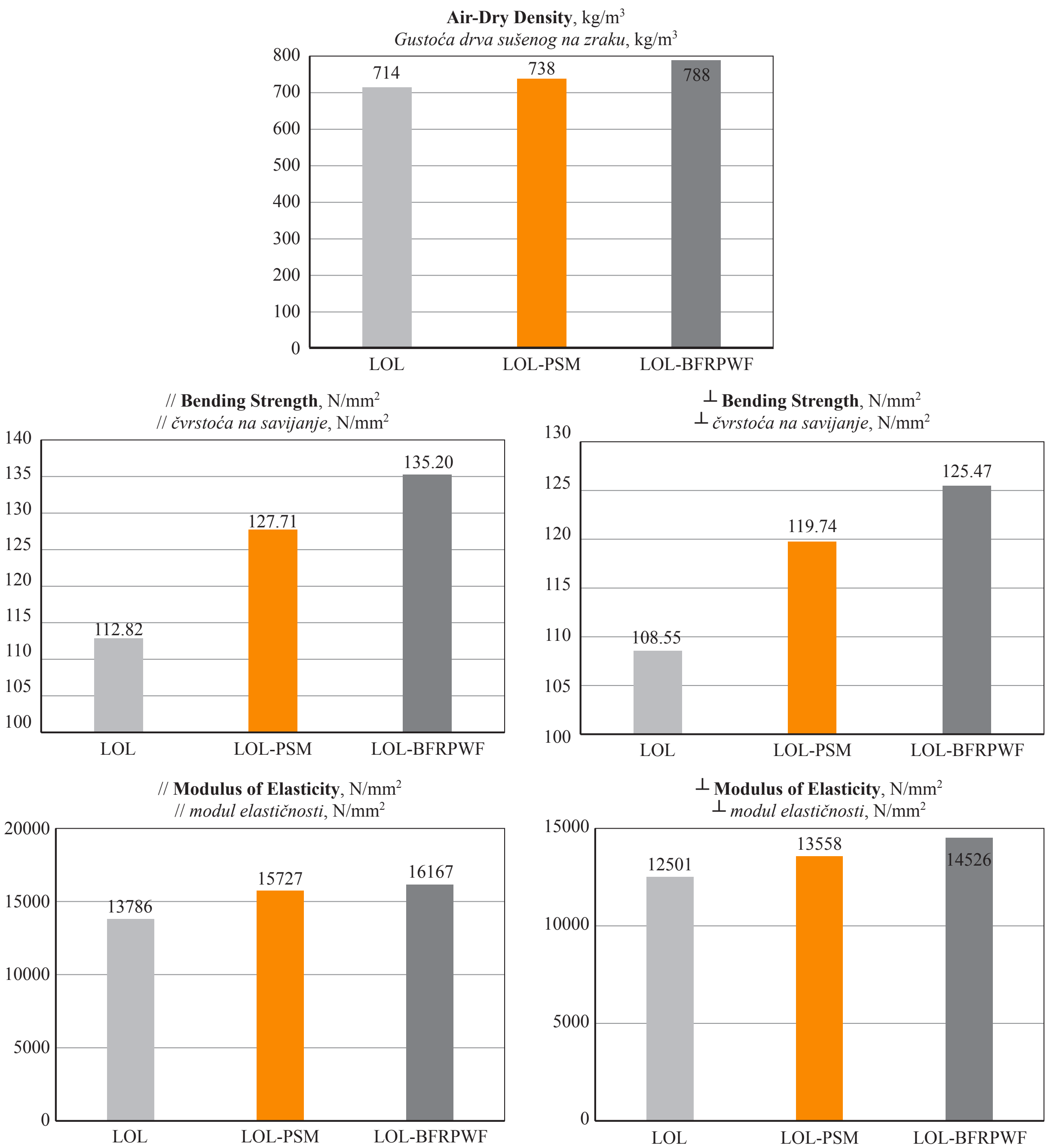


Figure 5 Descriptive statistical values for various physical and mechanical properties such as δ12, // MOR, ⊥MOR, // MOE, and ⊥MOE of laminated oak lumber samples
Slika 5. Deskriptivne statističke vrijednosti za neka fizička i mehanička svojstva kao što su δ12, // MOR, ⊥MOR, // MOE i ⊥MOE uzoraka lamelirane hrastove građe

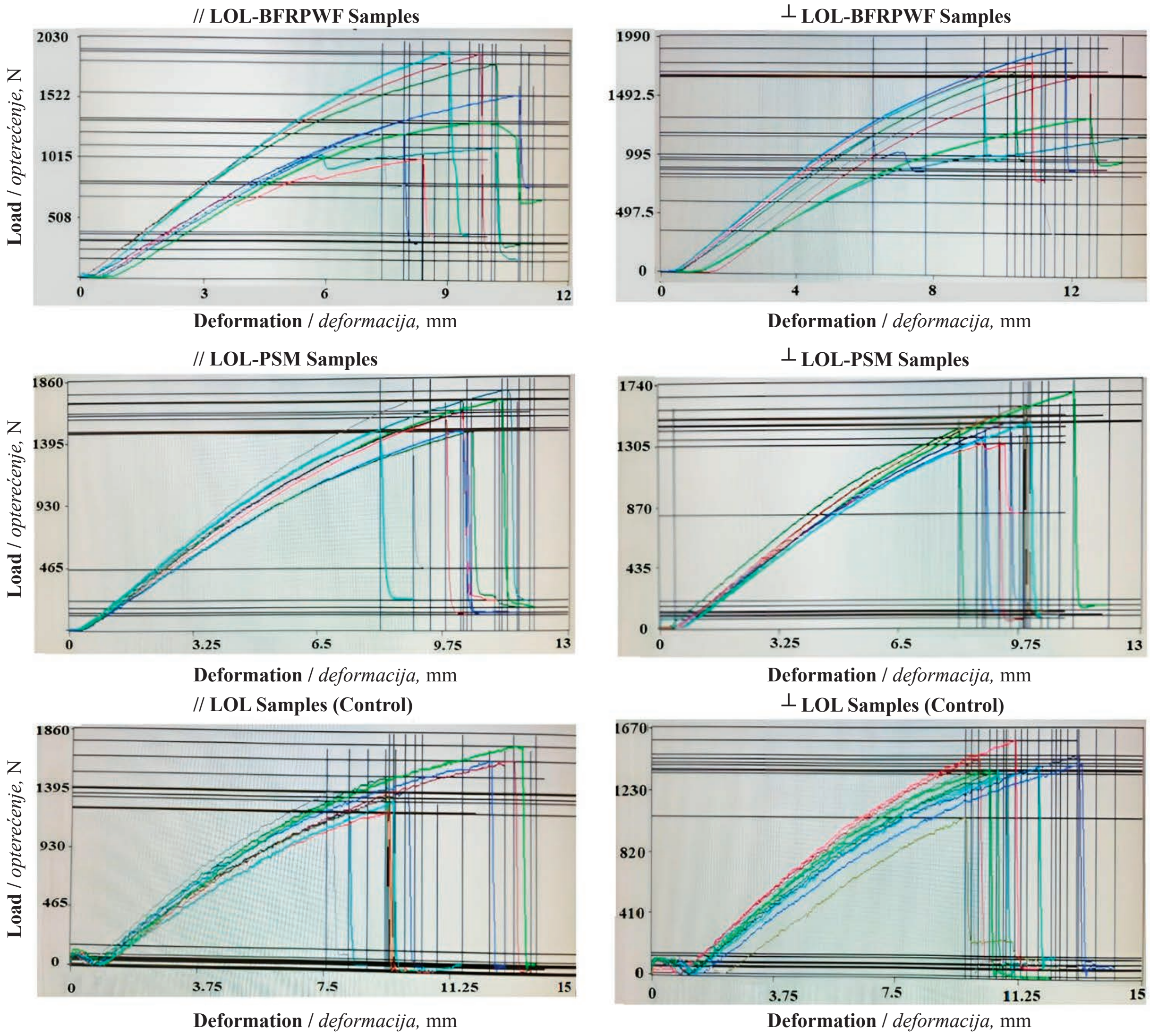


Figure 6 Load – deformation graphs based on bending strength test results
Slika 6. Grafovi *opterećenje – deformacija* na temelju rezultata ispitivanja čvrstoće na savijanje

determined: δ_{12} 788 kg/m^3, *//MOR* 142.20 N/mm^2, ⊥*MOR* 129.66 N/mm^2, ⊥ *MOE* 17349 N/mm^2, *//MOE* 14526 N/mm^2, 90.44 N/mm^2. Thorough analysis of the results showed that the LOL-BFRPWF panels exhibited the most favorable properties. However, it is worth noting that the LOL samples demonstrated the lowest value among all the samples tested. Some physical and mechanical properties of the LOL-BFRPWF samples were higher than those of LOL samples, namely δ12 10.36 %, ⊥*MOR* 15.68 %, //*MOR* 19.83 %, ⊥ *MOE* 16.20 %, //*MOE* 17.27 %.

Similarly, some physical and mechanical properties of the LOL-PSM samples were higher than those of the LOL samples (δ_{12} 3.36 %, ⊥ *MOR* 10.31 %, // *MOR* 13.19 %, ⊥ *MOE* 8.45 %, //*MOE* 14.08 %). Based on the results, it can be concluded that laminated wood materials had higher values (LOL-PSM 14.08 %, LOL-BFRPWF 20.00 %) than the LOL samples that represented their species.

Borri *et al.* (2013) investigated some mechanical properties of low quality wooden beams reinforced with BFRP and flax. They reported that the bending strength of two-layer FFRP and BFRP reinforced low-quality wood beams increased by 38.6 % and 65.8 %, respectively, with the maximum mid-span deflection of 58.2 % and 40.2 %, respectively. Uzel *et al*. (2018) investigated flexural behavior of wooden beams reinforced with different bonding surface materials. The use of retrofitting nets resulted in 34 % increases in terms of load bearing capacity of test specimens.

The values of bending properties of BFRP-glulam beam samples, determined in edgewise samples of this investigation, were also higher than those of unreinforced samples, (Wdowiak-Postulak, 2021). Jinghui Wang and Wang (2020) conducted an investigation on applying BFRP fiber cloth at intervals as a means of reinforcing square long wooden columns. In comparison to the unreinforced wooden columns, the ultimate bearing capacity of the wooden columns with external

BFRP reinforcement exhibited an increase of 8.75 % and 30 %, respectively.

The δ_{12} increase varied between 3.36 % and 10.36 % in the LOL-PSM (738 kg/m^3) and LOL-BFRPWF (788 kg/m^3) samples, respectively. The increase of ⊥*MOR* varied between 10.30 % and 15.68 % in the LOL-PSM (119.74 N/mm^2) and LOL-BFRPWF (125.57 N/mm^2) samples, respectively. The increase of // *MOR* varied between 13.19 % and 19.83 % in the LOL-PSM (127.71 N/mm^2) and LOL-BFRPWF (135.20 N/mm^2) samples, respectively. The increase of ⊥*MOE* varied between 8.45 % and 16.20 % in the LOL-PSM (13558 N/mm^2) and LOL-BFRPWF (14526 N/mm^2) samples, respectively. The increase of // *MOE* varied between 14.08 % and 17.27 % in the LOL-PSM (15727 N/mm^2) and LOL-BFRPWF (16167 N/mm^2) samples, respectively (Figure 5).

In the bending strength test, after the maximum load (Fmax) of the test specimen against the applied force was reached, the end of the test varied with the toughness of the test specimen. The load–deformation graphs obtained during the bending strength tests are shown in Figure 6. With some wood materials, after reaching the maximum load, the test sample suddenly breaks, and the test is then completed. Such materials are referred to as brittle materials. With some materials, after reaching the maximum load, the test sample is broken slowly or gradually, before the test is completed.

4 CONCLUSIONS
4. ZAKLJUČAK

Some physical and mechanical properties of the LOL, LOL-BFRPWF and LOL-PSM samples prepared using PUR adhesive were investigated in this study.

Some physical and mechanical properties of LOL samples were determined: δ_{12} 714 kg/m^3, ⊥*MOR* 108.55 N/mm^2, //*MOR* 127.71 N/mm^2, ⊥*MOE* 12501 N/mm^2, // *MOE* 13786 N/mm^2, 71.72 N/mm^2. The values for LOL-PSM samples were as follows: δ_{12} 714 kg/m^3, ⊥*MOR* 119.74 N/mm^2, //*MOR* 112.82 N/mm^2, ⊥*MOE* 13558 N/mm^2, // *MOE* 5727 N/mm^2, 80, 90 N/mm^2. The values for LOL-BFRPWF samples were as follows: δ_{12} 788 kg/m^3, ⊥*MOR* 125.57 N/mm^2, //*MOR* 135.20 N/mm^2, ⊥*MOE* 14526 N/mm^2, // *MOE* 16167 N/mm^2.

According to the overall results, the LOL-BFRPWF samples demonstrated the best properties among all the tested samples. It should also be emphasized that the LOL samples exhibited the lowest values among all the samples.

Based on the empirical findings regarding the technical characteristics of BFRPWF and PSM as support materials, the strength of the laminated wood material was observed to be enhanced. Given the substantial enhancements in the resistance properties of the intermediate filling material used in laminated wood, it is advisable to prioritize high-strength properties in furniture and construction materials.

5 REFERENCES
5. LITERATURA

1. Borri, A.; Corradi, M.; Grazini, A., 2005: Method for flexural reinforcement of old wood beams with CFRP materials. Composites Part B. Engineering, 36: 143-153. https://doi.org/10.1016/j.compositesb.2004.04.013
2. Borri, A.; Corradi, M.; Speranzini, E., 2013: Reinforcement of wood with natural fibers. Composites Part B. Engineering, 53: 1-8. https://doi.org/10.1016/j.compositesb.2013.04.039
3. Bozkurt, A. Y.; Erdin, N., 2000: Wood Anatomy. Istanbul University publication number: 4263, Faculty of forestry publication number: 466, Istanbul, Turkey.
4. Burdurlu, E.; Kilic, M.; Ilce, A. C.; Uzunkavak, O., 2007: The effects of ply organization and loading direction on bending strength and modulus of elasticity in laminated veneer lumber (LVL) obtained from beech (*Fagus orientalis* L.) and lombardy poplar (*Populus nigra* L.). Construction and Building Materials, 21 (8): 1720-1725. https://doi.org/10.1016/j.conbuildmat.2005.05.002
5. Cheng, G.; Li, H.; Li, H.; Ashraf, M., 2022: Compression resistance of short LBL columns with local damage after retrofitting using basalt fiber reinforced polymer. Journal of Building Engineering, 48: 103941. https://doi.org/10.1016/j.jobe.2021.103941
6. de la Rosa, P.; González, M. D. L. N.; Prieto, M. I.; Gómez, E., 2021: Compressive behavior of pieces of wood reinforced with fabrics composed of carbon fiber and basalt fiber. Applied Sciences, 11 (6): 2460. https://doi.org/10.3390/app11062460
7. Elgabbas, F.; Vincent, P.; Ahmed, E. A.; Benmokrane, B., 2016: Experimental testing of basalt-fiber-reinforced polymer bars in concrete beams. Composites Part B. Engineering, 91: 205-218. https://doi.org/10.1016/j.compositesb.2016.01.045
8. Fiore, V.; Di Bella, G.; Valenza, A., 2011: Glass-basalt/epoxy hybrid composites for marine applications. Materials & Design, 32 (4): 2091-2099. https://doi.org/10.1016/j.matdes.2010.11.043
9. Fiore, V.; Scalici, T.; Di Bella, G.; Valenza, A., 2015: A review on basalt fibre and its composites. Composites Part B. Engineering, 74: 74-94. https://doi.org/10.1016/j.compositesb.2014.12.034
10. Gao, Y.; Zhou, Y.; Zhou, J.; Kong, X.; Zhang, B.; Liu, S., 2020: Blast responses of one-way sea-sand seawater concrete slabs reinforced with BFRP bars. Construction and Building Materials, 232: 117254. https://doi.org/10.1016/j.conbuildmat.2019.117254
11. Garg, N.; Shrivastava, S., 2019: Environmental and economic comparison of FRP reinforcements and steel reinforcements in concrete beams based on design strength parameter. In: Proceedings of the UKIERI Concrete Congress. Jalandhar, India.
12. Gao, P.; Huang, J. T.; Zhou, A.; Zhu, D.Y.; Wei, S.; Li, T.; Dai, D. J., 2019: Experimental research on axial compression of high-strength concrete column strengthened with BFRP and CFRP. Industrial Construction, 49: 139-144 + 160. https://doi.org/10.13204/j.gyjz201909024

13. Jian, B.; Li, H.; Zhou, K.; Ashraf, M.; Xiong, Z.; Zheng, X., 2022: Mechanical evaluation on BFRP laminated bamboo lumber columns under eccentric compression. Advances in Structural Engineering, 26 (5): 809-823. https://doi.org/10.1177/13694332221138312
14. Johns, K. C.; Lacroix, S., 2000: Composite reinforcement of timber in bending. Canadian Journal of Civil Engineering, 27: 899-906.
15. Kramár, S.; Trcala, M.; Chitbanyong, K.; Král, P.; Puangsin, B., 2020: Basalt-fiber-reinforced polyvinyl acetate resin: a coating for ductile plywood samples. Materials, 13 (1): 49. https://doi.org/10.3390/ma13010049
16. Keskin, H., 2004: Technological properties of laminated wood materials made up with the combination of oak (*Quercus petraea* Liebl.) wood and Scots pine (*Pinus sylvestris* Lipsky) wood and possibilities of using them. Gazi University Journal of Science, 17 (4): 121-131.
17. Keskin, H., 2009: Impact of impregnation chemical on the bending strength of solid and laminated wood materials. Materials & Design, 30 (3): 796-803. https://doi.org/10.1016/j.matdes.2008.05.043
18. Kufel, A.; Kuciel, S., 2019: Basalt/wood hybrid composites based on polypropylene: morphology, processing properties, and mechanical and thermal expansion performance. Materials, 12: 2557. https://doi.org/10.3390/ma12162557
19. Liu, Q.; Ma, S.; Han, X., 2020: Study on the flexural behavior of poplar beams externally strengthened by BFRP strips. Journal of Wood Science, 66: 1-13. https://doi.org/10.1186/s10086-020-01887-y
20. Lohmus, R.; Kallakas, H.; Tuhkanen, E.; Gulik, V.; Kiisk, M.; Saal, K.; Kalamees, T., 2021: The effect of prestressing and temperature on tensile strength of basalt fiber-reinforced plywood. Materials, 14 (16): 4701. https://doi.org/10.3390/ma14164701
21. Lopez-Anido, R.; Michael, A. P.; Sandford, T. C., 2003: Experimental characterization of FRP composite-wood pile structural response by bending tests. Marine Structures, 16: 257-274. https://doi.org/10.1016/S0951-8339(03)00021-2
22. Núñez-Decap, M.; Sandoval-Valderrama, B.; Opazo-Carlsson, C.; Moya-Rojas, B.; Vidal-Vega, M.; Opazo-Vega, A., 2023: Use of carbon and basalt fibers with adhesives to ımprove physical and mechanical properties of laminated veneer lumber. Applied Sciences, 13 (18): 10032. https://doi.org/10.3390/app12105114
23. Patnaik, A.; Puli, R.; Mylavarapu, R., 2004: Basalt FRP. A new FRP material for infrastructure market. In: Proceedings of the 4th International Conference Advanced Composite Materials in Bridges and Structures. ACMBS-IV, Montreal, Canada.
24. Rahayu, I.; Denaud, L.; Marchal, R.; Darmawan, W., 2015: Ten new poplar cultivars provide laminated veneer lumber for structural application. Annals of Forest Science, 72: 705-715. https://doi.org/10.1007/s13595-014-0422-0
25. Rescalvo, F. J.; Duriot, R.; Pot, G.; Gallego, A.; Denaud, L., 2020: Enhancement of bending properties of douglas-fir and poplar laminate veneer lumber (LVL) beams with carbon and basalt fibers reinforcement. Construction and Building Materials, 263: 120185. https://doi.org/10.1016/j.conbuildmat.2020.120185
26. Rescalvo, F. J.: Duriot, R.: Pot, G.; Gallego, A.; 2023: Mechanical behaviour of poplar laminated veneer lumber with fiber reinforced polymer under shear and compression stresses. Wood Material Science & Engineering, 18 (3): 893-901. https://doi.org/10.1080/17480272.2022.2086819
27. Sim, J.; Park, C.; Moon, D., 2005: Characteristics of basalt fiber as a strengthening material for concrete structures. Composites Part B. Engineering, 36 (6-7): 504-512. https://doi.org/10.1016/j.compositesb.2005.02.002
28. Song, J.; Gao, W. Y.; Ouyang, L. J.; Zeng, J. J.; Yang, J.; Liu, W. D., 2021: Compressive behavior of heat-damaged square concrete prisms confined with basalt fiber-reinforced polymer jackets. Engineering Structures, 242: 112504. https://doi.org/10.1016/j.engstruct.2021.112504
29. Subagia, I. A.; Kim, Y.; Tijing, L. D.; Kim, C. S.; Shon, H. K., 2014: Effect of stacking sequence on the flexural properties of hybrid composites reinforced with carbon and basalt fibers. Composites Part B. Engineering, 58: 251-258. https://doi.org/10.1016/j.compositesb.2013.10.027
30. Uzel, M.; Togay, A.; Anil, O.; Sogutlu, C., 2018: Experimental investigation of flexural behavior of glulam beams reinforced with different bonding surface materials. Construction and Building Materials, 158: 149-163. https://doi.org/10.1016/j.conbuildmat.2017.10.033
31. Wang, X.; Shi, J.; Liu, J.; Yang, L.; Wu, Z., 2014: Creep behavior of basalt fiber reinforced polymer tendons for prestressing application. Materials & Design, 59: 558-564. https://doi.org/10.1016/j.matdes.2014.03.009
32. Wang, B.; Bachtiar, E. V.; Yan, L.; Kasal, B.; Fiore, V., 2019: Flax, basalt, E-Glass FRP and their hybrid FRP strengthened wood beams: An experimental study. Polymers, 11 (8): 1255. https://doi.org/10.3390/polym11081255
33. Wang, J. H.; Wang, G. B.; 2020: Experimental research on the mechanical properties Xinjiang long rectangular-section popular column strengthened by basalt fiber alternately under axial compression. Industrial Construction, 50: 44-48.
34. Wdowiak-Postulak, A.; Swit, G., 2021: Behavior of glulam beams strengthened in bending with BFRP fabrics. Civil and Environmental Engineering Reports, 31 (2): 1-14 https://doi.org/10. 10.2478/ceer-2021-0016
35. Wdowiak-Postulak, A.; Bahleda, F.; Prokop, J., 2023: An experimental and numerical analysis of glued laminated beams strengthened by pre-stressed basalt fibre-reinforced polymer bars. Materials, 16 (7): 2776. https://doi.org/10.3390/ma16072776
36. Wu, G.; Gu, D. S.; Jiang, J. B.; Wu, Z. H.; Hu, X. Q., 2007: Comparative study on seismic performance of circular concrete columns strengthened with BFRP and CFRP composites. Industrial Construction, 37 (6): 19-23.
37. Wu, Z.; Wang, X.; Iwashita, K.; Sasaki, T.; Hamaguchi, Y., 2010: Tensile fatigue behaviour of FRP and hybrid FRP sheets. Composites Part B. Engineering, 41 (5): 396-402. https://doi.org/10.1016/j.compositesb.2010.02.001
38. Wu, Z.; Wang, X.; Wu, G., 2012: Advancement of structural safety and sustainability with basalt fiber reinforced polymers. In: Proceedings of the 6th International Conference on FRP Composites in Civil Engineering. CICE, Roma, Italy.
39. Wu, X., 2020: Research progress on application of basalt fiber in civil engineering. Bulletin of the Chinese Ceramic Society, 39 (4): 1043-1049.
40. Zhou, W.; Li, H.; Mohrmann, S.; Li, H.; Xiong, Z.; Lorenzo, R., 2022: Evaluation on the axial compression mechanical properties of short BFRP laminated bamboo lumber columns. Journal of Building Engineering, 5: 104483. https://doi.org/10.1016/j.jobe.2022.104483
41. Zoghi, M., 2013: The International Handbook of FRP Composites in Civil Engineering; CRC Press: Florida, FL, USA.

42. ***TS 5497 EN 408, 2006: Timber Structures – Structural and Glued Laminated Timber – Determination of Some Physical and Mechanical Properties. TSE, Ankara, Institute of Turkish Standards, Ankara, Turkey, 2006.
43. ***TS 2472, 1976: Wood – Determination of Density for Physical and Mechanical Tests. Institute of Turkish Standards, Ankara, Turkey, 1976.
44. ***TS 2474, 1976: Wood – Determination of Ultimate Strength in Static Bending. Institute of Turkish Standards, Ankara, Turkey, 1976.
45. ***TS EN 326-1, 1999: Wood – Based Samples – Sampling, Cutting and Inspection. Part 1: Sampling Test Pieces and Expression of Test Results. Institute of Turkish Standards, Ankara, Turkey, 1999.
46. ***TS 2478, 1976: Wood – Determination of Modulus of Elasticity in Static Bending. Institute of Turkish Standards, Ankara, Turkey, 1978.

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