Determination of Tensile Strength Perpendicular to the Fibers of Wooden Materials Reinforced with Basalt, Glass Fiber-Reinforced Polymer, and Plaster Mesh

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Wood is a heterogeneous and anisotropic material, and its mechanical properties are different from other building materials. It is necessary to know the mechanical properties of wood materials in buildings, such as carriers, floor beams, roof timber, plywood roof covers, laminated beams, stair or wire poles, yacht poles, and furniture frames. Tensile strength is the resistance of wood material to two forces applied in opposite directions, trying to break and separate the fibers. This study aimed to determine the tension strength perpendicular to fibers of beech timber reinforced with basalt fiber-reinforced polymer (BFRP), glass fiber-reinforced polymer (GFRP), and plaster mesh (PSM). One component polyurethane (PUR-D4) and polyvinyl acetate (PVAc-D4) were used as the adhesive. The BFRP, GFRP, and PSM were added as one layer of reinforced materials. Experimental materials reinforced with BFRP, GFRP, and PSM were tested in the unreinforced locations, of reinforced lumber with BFRP, GFRP, and PSM. Tests were performed to investigate the tensile strength perpendicular to fiber (┴σt). The test results showed that the reinforcement process increased the (┴σ). The ┴σt value of samples reinforced with BFRP was 13%, 32%, and 66% higher than those reinforced with GFRP, unreinforced, and reinforced PSM, respectively. Accordingly, the BFRP shows potential to serve as an option for reinforced wood structural members.

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INTRODUCTION

As an environmentally friendly, sustainable resource, lumber is a renewable material that is commonly used for structural components, building constructions, and a wide range of other applications involving engineered wood. However, the organic nature of lumber means that its mechanical properties may deteriorate throughout its life cycle. Biological degradation (insects, fungi, bacteria), natural defects (knots, deviation, grain, *etc.*), and environmental conditions can also greatly affect mechanical properties and reduce the tensile strength by up to 90% (Thelandersson and Larsen 2003).

The quality of adhesion in glues depends on the fluidity of the glues, which have desired properties such as penetrating both surfaces of the wood material, distributing homogeneously on the applied surface, forming layers, and wetting the surfaces (Vıck

1999). The effectiveness of glue is expected to depend on its viscosity, molecular weight, surface penetration, amount of solid matter, pH ratio, and application method; the adhesion results also will depend on the wood material, type, density, surface roughness and cleanliness (Rowell 2005). The heterogeneous distribution of the glue on the surface where it is applied negatively affects the cohesion and causes the wood material joints to open (Smardzevski 2002). During the processing of wood material, roughness on the surfaces due to the wood structure negatively affects adhesion (Efe and Gürleyen 2007). Sanded surfaces generally show more effective adhesion than planed surfaces in wood materials (Caster *et al.* 1985). A strong adhesion is achieved by properly processing the wood surface with cutters, applying the adhesive evenly over the entire surface, and cold pressing the wooden elements closed together (Selbo 1975). When sufficient pressure is applied to bond smooth-surfaced parts, the transfer of glue from one surface to another becomes uniform and the adhesion resistance gives the best results. When 0.7 N/mm^2 pressure is applied when joining perfect surfaces, adhesion resistance reaches the highest value (Franklin Glue Company 1989).

Fiber-reinforced polymers can exhibit several advantageous properties, including high mechanical strength, non-conductive lightweight composition, reduced recycling requirements, and corrosion resistance. The FRP has been employed for decades to enhance the structural integrity and augment the structural strength of concrete structures (Jiang *et al.* 2019). FRP has been used in bridge coatings, I-beam manufacturing, wooden beams and columns, restoration applications, and all types of strengthening, reinforcing joints due to its strength properties (Schober *et al.* 2015). Structural composite lumber may be reinforced with synthetic fibers to effectively improve its structural properties (Brol and Wdowiak-Postulak 2019). Additionally, FRP strengthening can enhance the bending stiffness and the ultimate bearing capacity of wood beams. Currently, various types of FRPs are available for structural reinforcement, including BFRP (Basalt FRP), GFRP (Glass FRP), AFRP (Aramid FRP), and CFRP (Carbon FRP) (Jian *et al.* 2022).

Many studies have investigated the mechanical properties of wooden structures reinforced with FRP materials. André and Johnsson (2010) investigated the use of GFRP and flax fiber composites to reinforce glue-laminated (glulam) timber samples to achieve tensile strength perpendicular to the fibers and more ductile fracture. Speranzini *et al.* (2010) conducted a four-point bending test on timber beams externally reinforced with hemp, glass, carbon, basalt, and flax FRP. Borri *et al.* (2013) investigated the strengthening of low-grade and high-grade wood beams using flax and BFRP. de la Rosa García *et al.* (2013) studied data obtained experimentally using bending tests of pine timber beams reinforced with composite materials. Osmannezhad *et al.* (2014) investigated the bending strength of the specially reinforced glulams with the GFRP. Schober *et al.* (2015) explained the potential applications of FRP for the reinforcement of timber structures. de la Rosa García *et al.* (2016) studied the increase in stiffness experienced on pine timber beams when reinforced with composite fabrics. The CRFP and BFRP fabrics of different weights were applied, and placed in a "U" shape, wrapping part of the beam section. Basterra *et al.* (2017) studied the flexural behavior of *Populus euroamericana* I-214 low-grade glulam timber beams, internally reinforced with the GFRP. Wang *et al.* (2019) investigated the bending properties of solid fir (*Pseudotsuga menziesii* Mirb.) beams reinforced with flax, GFRP, BFRP, and hybrid FRP. Their findings indicated that fiber-reinforced polymers enhanced the bending properties of wood materials.

Karaman (2021) investigated the bending moment resistance of T-type reinforced with basalt and glass woven fabric. Karaman and Yildirim (2021) investigated the bending moment resistance of L-shaped strengthened basalt and glass woven fabric. Kılınçarsalan and Türker (2023) reported that the ash beams are practically reinforced in a “U” shape from the outer part of the beam with the BFRP. Türker (2024) studied the glulam column-beam connection, which is combined with a wood notching connection, and is wrapped with the CFRP, GFRP, BFRP, and AFRP.

Regarding the tensile strength perpendicular to fibers, joints reinforced with the BFRP, GFRP, and PSM are not applied, and it is considered that there is a deficiency in the literature. The reinforcement with the BFRP, GFRP, and PSM reinforced joints in the structural lumber is a new research topic. This study aims to determine the performance of the tensile strength perpendicular to fibers of wooden unreinforced, reinforced BFRP, GFRP, and plaster mesh (PSM) using the polyvinyl acetate (PVAc-D4), and polyurethane (PUR-D4) adhesive cured under room temperature conditions.

EXPERIMENTAL

Materials

Beech wood (*Fagus orientalis* Lipsky), which is used widely in the wood construction industry, was used as the wooden material. The lumber pieces were selected randomly from Yenice-Karabuk timber merchants in Turkey (Fig. 1a). Careful attention was paid to the fact that the wood material used in experimental studies was not subjected to physical damage, mechanical impacts, or biological harm. It is a material with a full-dry density (D0) of 0.630 g/cm^3 and, air-dry density (Dl2) of 0.660 g/cm^3, and its tensile strength perpendicular to fibers ($\perp\sigma t$) is 7 N/mm^2 (Bozkurt and Erdin 2011).

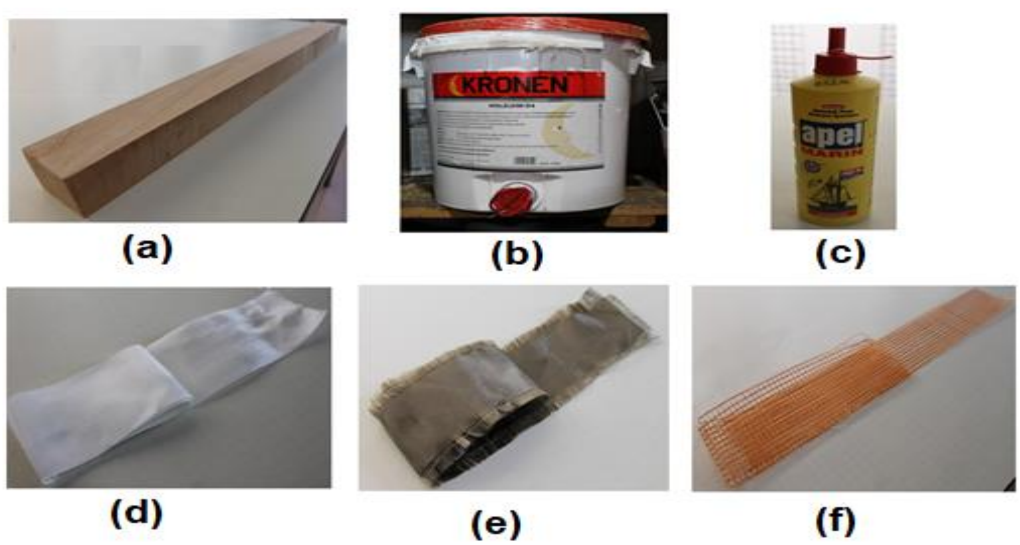


Fig. 1. Materials used in experiments: a) Beech wood, b) PVAc-D4 adhesive, c) PUR-D4 adhesive, (d) GFRP, e) BFRP, and f) PSM

The polyvinyl acetate (PVAc-D4) was obtained from Kronen Furniture Glue Accessory Industrial Products Industry and Trade Limited Company in Turkey (Fig. 1b). The technical properties of the PVAc-D4 were as follows: density of 1.080 g/cm^3, pH of 3.5 (25 °C), viscosity of 14.000 to 15000 mPa·s (25 °C), application amount of (200 gr/m^2).

The polyurethane adhesive (PUR-D4) was obtained from Apel Kimya Industry and Trade Inc., in Turkey (Fig. 1c). The technical properties of the PUR-D4 were as follows: density of 1.110 g/cm^3, pH of 5.0 (25 °C), viscosity of 5000 to 10000 mPas (20 °C), and application amount of (200 gr/m^2).

The BFRP and GFRP for 200 gr/m^2 plain materials were obtained from Dost Chemical Industry Raw Material Industry and Trading Company in Turkey (Fig. 1d,e respectively). The BFRP and GFRP were prepared by cutting to 1000 mm in length and 52 mm in width. The density of BFRP and GFRP are 2.8 gr/cm^3 and 2.56 gr/cm^3, respectively.

The BFRP and GFRP values of elasticity modulus, tensile strength, and elongation to fracture were 8900 and 76000 MPa, 2800 and 2500 MPa, and 3.15% and 3.2%, respectively (Fiore *et al.* 2011) The PSM used weighed 160 g/m^2. It was alkali resistant and orange in color, with a 4 mm × 4 mm mesh pattern (Fig. 1e).

Preparation and Construction of Specimens

In the preparation of the test samples, the wooden materials were sawn using a high-speed circular saw machine to 3 mm thickness, 50 mm width and 1000 mm length, with the annual rings perpendicular to the adhesion surface (Fig. 2a). Once stacked, the slats were stored in a temperature-controlled room with a consistent temperature of 20 ± 2 °C and relative humidity conditions of 65 ± 5%. The slats remained in the specified environment until they attained a moisture content of 12%. The test samples were prepared following the guidelines outlined in the TS 5497 EN 408 (2006) standard. The PVAc-D4 and PUR-D4 adhesives were utilized in the preparation of the samples.

After the edges and surfaces of the wooden materials were smoothed in the planer machine (Fig. 2b), they were brought to the appropriate thickness (2.5 ± 0.1 mm) in the high-speed thicknessing machine, and the pressing process was started (Fig. 2c). For interlayer samples, one layer of reinforced materials (GFRP, BFRP, and PSM) was used for intermediate support between solid layers. Approximately 200 g/m^2 of adhesive was used for surface (Fig. 2d). The samples, which consisted of two 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 h. As a result, the test samples were produced in cold pressure at 20 ± 2 °C and 65 ± 5% relative humidity. The pressing of test samples in the are shown in Fig. 2e.

After the pressing process, one of the edges was smoothed on the planer machine, and test samples were prepared on a high-speed circular saw machine in accordance with the TS ISO 13061-7 (2021) standards (Fig.3a,c). On the Vertical Drill Column Stand Lathe Drill machine, appropriate settings were made, and two holes of Ø25 mm and 50 ± 1 mm depth were opened in the middle of the test samples, symmetrically in the direction of the part thickness. Test samples were obtained by grading on a horizontal circle machine with plotter (Fig. 3b). Specimens under tensile test were fabricated in the form illustrated in Fig. 4. According to this, two adhesive types and three fiber-reinforced polymers (BFRP, GFRP, PSM, and control), and 10 samples of each material (2 x 4 x 10 =80) were the variables. A total of 80 specimens were constructed in this research. Before testing, all samples were conditioned in a humidity chamber controlled at 20 ± 2 °C and 65% relative humidity (RH) for two weeks.

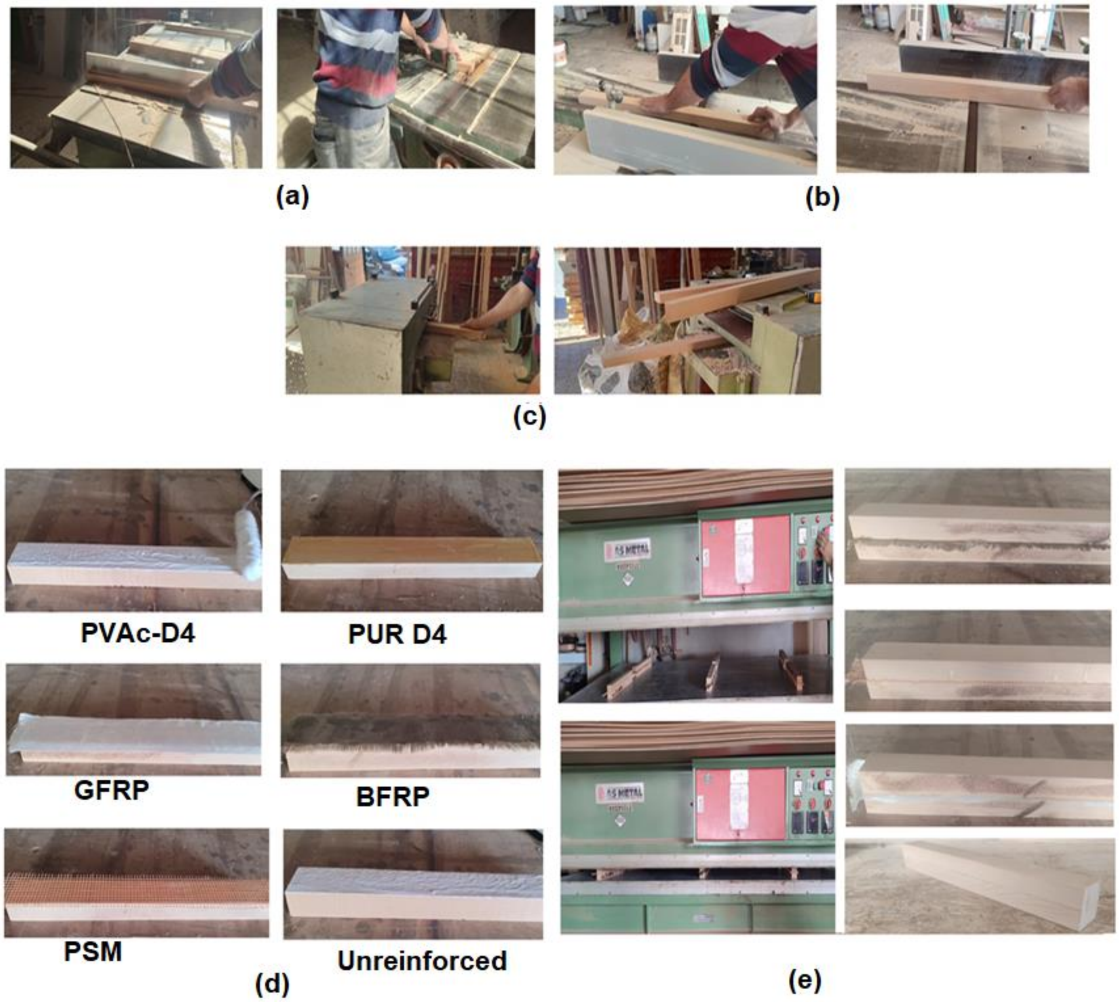


Fig. 2. Production stages of test samples

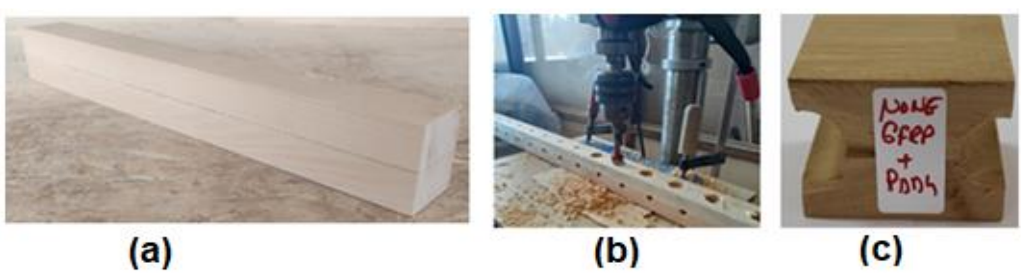


Fig. 3. Manufacturing process for experimental samples: a) Slats, b) Hole drilling process, c) Test samples

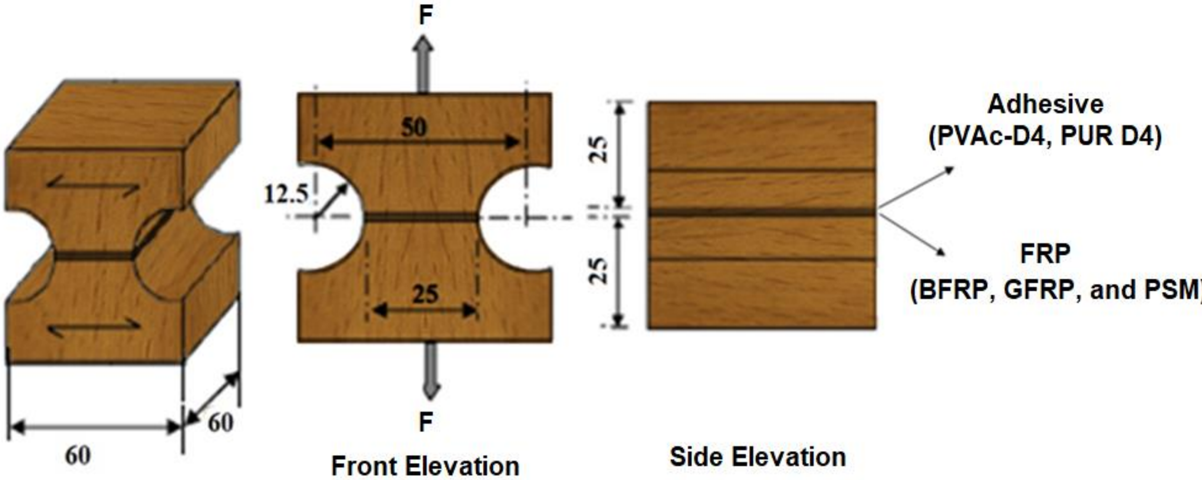


Fig. 4. Geometry of specimens in the test (Unreinforced test samples, reinforced with BFRP, GFRP, and PSM test samples (dimensions in mm)

Mechanical Tensile Tests

For the tensile strength tests, the specimens were tested using an electromechanical universal testing machine (UTM), in the laboratory of Kütahya Dumlupınar University Simav Technical Education Faculty having a capacity of 10 kN, in which they were subjected to a tensile force perpendicular to the substrate wood fibers (Fig. 5). According to the TS ISO 13061-7 (2021) standard, the applied load increased monotonically, due to the crossbar displacement at a rate of 2 mm/min, until the joint rupture. The loading was continued until separation occurred on the surface of the test samples and from the observed load (F_{max}), and the bonding area of the sample (A), the tensile strength perpendicular to fibers ($\perp\sigma t$) was calculated using Eq. 1,

$$\perp\sigma t = \frac{F_{max}}{A} \quad (1)$$

where $\perp\sigma t$ is the tensile strength perpendicular to fibers (N/mm^2), F_{max} is the ultimate applied force (N), and A is the bonding area of the sample (mm^2).

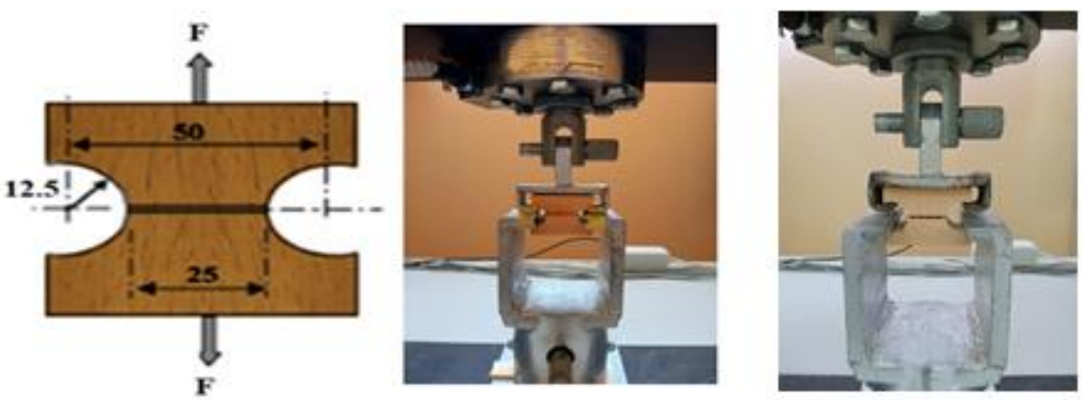


Fig. 5. Apparatus used to hold specimens for the tensile strength perpendicular to fibers tests.

Statistical Analysis

Statistical analysis (Statistical Software, a computer-based statistical package, Minitab, Minitab®18, State College, PA, USA) was performed to examine the data according to the analysis of variance (ANOVA) with the Duncan test ($p < 0.05$).

RESULTS AND DISCUSSION

The mean values $\perp\sigma t$ under tension of the experimental samples with their standard deviation and coefficients of variation are presented in Table 1.

Table 1. Mean Values of the $\perp\sigma t$ of Joints and Their Coefficients of Variation

Adhesive Types	FRP Types	Drilled Types	Mean (N/mm^2)	SD	COV (%)
PVAc-D4	Unreinforced	Undrilled	4.14	0.61	14.77
		Drilled	3.25	0.83	25.54
	BFRP	Undrilled	5.29	0.59	11.15
		Drilled	4.20	0.42	10.00
	GFRP	Undrilled	4.99	0.37	7.41
		Drilled	4.12	0.42	10.19
	PSM	Undrilled	3.35	0.40	11.94
		Drilled	2.45	0.21	8.40
PUR-D4	Unreinforced	Undrilled	4.26	0.57	13.38
		Drilled	3.39	0.71	20.94
	BFRP	Undrilled	5.76	0.20	3.70
		Drilled	4.55	0.32	7.03
	GFRP	Undrilled	5.40	0.32	5.56
		Drilled	3.03	0.33	10.89
	PSM	Undrilled	3.61	0.27	7.48
		Drilled	2.50	0.36	14.40

SD: Standard deviation, COV: Coefficient of variation, No-SMT: Unreinforced samples,
$\perp\sigma t$: tensile strength perpendicular to fibers

According to Table 1, when interactions of the adhesive types, FRP types, and drilled types were compared, the highest $\perp\sigma t$ value was obtained for reinforced BFRP bonded with PUR-D4 adhesive in the undrilled samples (5.76 N/mm^2). The lowest $\perp\sigma t$ value was obtained for reinforced PSM bonded with PVAc-D4 adhesive in the drilled samples (2.45 N/mm^2). It can be said that BFRP, PU-D4 adhesive, and undrilled increase the $\perp\sigma t$ of the wood structural.

The results of the two-way ANOVA analysis of the adhesive types, and fiber-reinforced polymers on the tension strength perpendicular to fibers of the experimental samples under the tension load are given in Table 2.

According to the analysis of variance, as presented in Table 2, the effects of the main factors, including FRP types (B) and hole types (C), were found to be statistically significant. In contrast, adhesive types (A), two-way interactions of adhesive types × FRP types (A×B), and adhesive types × hole types were insignificant at the level of 0.05. Three-factor interactions of adhesive types × FRP types × hole types (A×B×C) were also statistically insignificant ($p \leq 0.05$). Tukey test was carried out to determine these differences. The $\perp\sigma t$ mean according to the independent effects of test variables are given in Table 3.

Table 2. Summary of the ANOVA Results for $^{\perp}\sigma t$

Source	df	Sum of Square	Mean Square	F	Sig.
Corrected Model	15	148.301[a]	9.887	43.865	0.000
Intercept	1	2610.163	2610.163	11580.603	0.000
Adhesive Types (A)	1	0.562	0.562	2.492	0.117
FRP (B)	3	80.503	26.834	119.057	0.000
Hole Types (C)	1	50.176	50.176	222.618	0.000
A×B	3	1.197	0.399	1.770	0.155
A×C	1	1.537	1.537	6.818	0.010
B×C	3	6.577	2.192	9.727	0.000
A×B×C	3	7.750	2.583	11.461	0.000
Error	144	32.456	0.225		
Total	160	2790.921			
Corrected Total	159	88026.309			
R Squared = 0.820 (Adjusted R Squared = 0.802)					

df: Degrees of freedom, [a] Adhesive types (PVAc-D4, PUR-D4), [b] FRP types (BFRP, GFRP, and PSM), and [c] Drilled types (Undrilled, drilled)

Table 3. Independent Effects of Test Variables on Mean Values of $^{\perp}\sigma t$ of Joints

Source		$^{\perp}\sigma t$ (N/mm^2)	SD	HG
Adhesive types	PVAc-D4	3.97	0.496	A
	PUR-D4	4.06	0.385	A
FRP types	BFRP	4.95	0.372	A
	GFRP	4.39	0.401	B
	Unreinforced	3.76	0.681	C
	PSM	2.98	0.311	D
Drilled types	Undrilled	4.60	0.438	A
	Drilled	3.44	0.444	B

$^{\perp}\sigma t$: tensile strength perpendicular to fibers, HG: Homogeneity groups

When the comparison results of adhesive types were examined, it was seen that the highest $^{\perp}\sigma t$ value was obtained for PUR-D4 (4.06 N/mm^2). The $^{\perp}\sigma t$ of PVAc-D4 adhesive was much lower (3.97 N/mm^2). The PUR-D4 was 2.3% stronger than the PVAc-D4 (Table 3). The reason for this, the PUR-D4 was higher than the adhesion and cohesion power, tensile strength, and technological properties of the PVAc-D4 used in the experiments.

For the FRP types, the highest $^{\perp}\sigma t$ value was obtained in BFRP (4.95 N/mm^2), and the lowest was in the PSM (2.98 N/mm^2). The $^{\perp}\sigma t$ value according to reinforced FRP declined in the order to BFRP, GFRP, unreinforced, and PSM. The $^{\perp}\sigma t$ value of samples reinforced with BFRP was 13%, 32%, and 66% higher than those reinforced with GFRP, unreinforced, and reinforced PSM, respectively.

In the literature, some studies reported that BFRP has higher tensile strength and modulus of elasticity than GFRP (Wei *et al.* 2010; Carmisciano *et al.* 2011; Lopresto *et al.* 2011; Dorigato and Pegoretti 2012).

For the drilled types, the highest $^{\perp}\sigma t$ value was obtained in undrilled samples (4.60 N/mm^2), and the lowest was in the drilled samples (3.44 N/mm^2). Holes drilled into the test samples reduced the tensile strength of the wooden fibers.

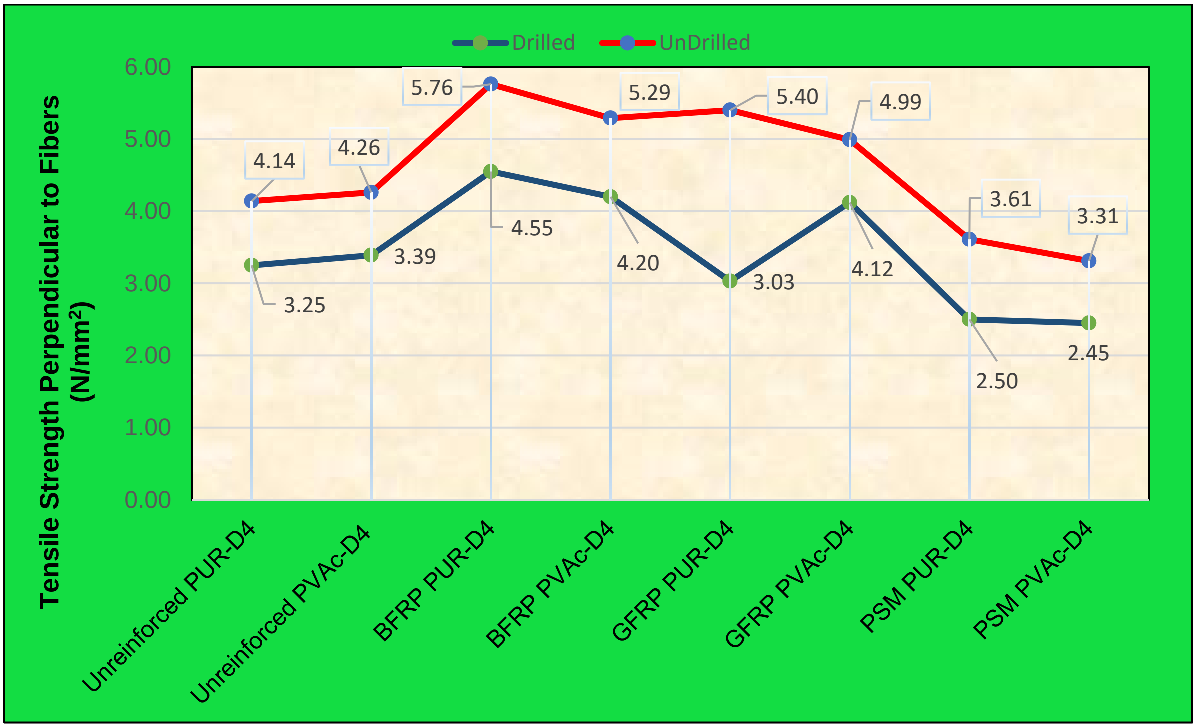
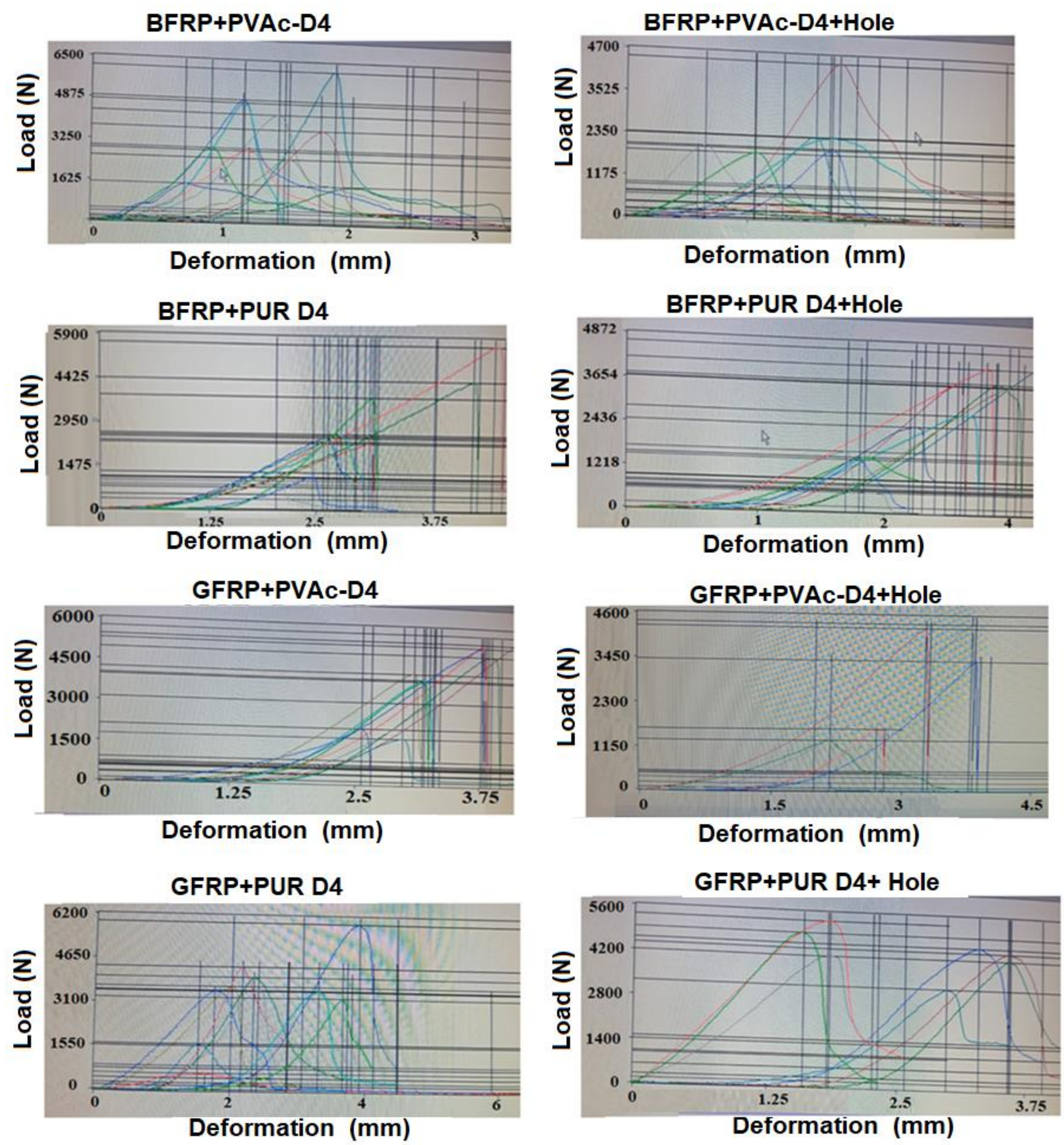


Fig. 6. Product group comparisons according to the adhesive types, FRP types, and drilled types

Figure 6 shows a graphical representation of the effects of the selected monitored factors on the ┴σt of the experimental samples. The combined effect of the type of adhesive, type of the FRP, and the drilled selected type is shown for different cases. In the case of the ┴σt, reinforced BFRP bonded with PUR-D4 adhesive in the undrilled samples achieved an average of 145% higher values than reinforced PSM bonded with PVAc-D4 adhesive in the drilled samples.

Fiorelli and Alves (2003) reported that the increase in stiffness of timber beams strengthened with the GFRP was between 15% and 30%. Yang *et al.* (2008) reported that the ultimate bearing capacity of the FRP-reinforced beam exhibited an increase between 17.7% and 77.3% in comparison to the control beam. André and Johnsson (2010) reported that the maximum bending load of the specimen strengthened with GFRP was 23% higher than that of the specimen strengthened with FFRP. Borri *et al.* (2013) investigated the strengthening of low-grade and high-grade wood beams with flax and BFRP. The findings indicated an increase in bending strength of 38.6% and 65.8%, respectively. Zuo *et al.* (2015) reported that the bending behavior of BFRP-reinforced glulam beams was better compared to the unreinforced control beam, with the ultimate bending capacity, bending stiffness, and ductility coefficient increasing by 20.9% to 111%, 18.7% to 27.6%, and 23.0% to 74.3%, respectively. Basterra *et al.* (2017) conducted comparative experiments and reported that when the reinforcement ratio of GFRP sheet reinforced lumber beams was 1.07% and 1.6%, respectively, the mean stiffness increased 12.1% and 14.7%, respectively, and the bending capacity increased 23%. Monaldoa *et al.* (2019) explained that beams reinforced with BFRP have a bending ultimate load higher by about 20% than GFRP. Kılınçarslan and Türker (2023) determined that the flexural strength value of the reinforced beam increased 18% and the elasticity modulus value increased 25% compared to the reference beam.

In the ⊥σt test, after the maximum load (F_{max}) of the test specimen against the applied force was reached, the end of the test varied with the toughness property of the test specimen. The load–deformation graphs obtained during the ⊥σt tests are shown in Fig. 7. With FRP materials, after reaching the maximum load, the test sample suddenly ruptures, and the test is completed. Such materials are referred to as brittle materials. In some materials, after reaching the maximum load, the test sample breaks away from the adhesion surface slowly or gradually as the test is completed.



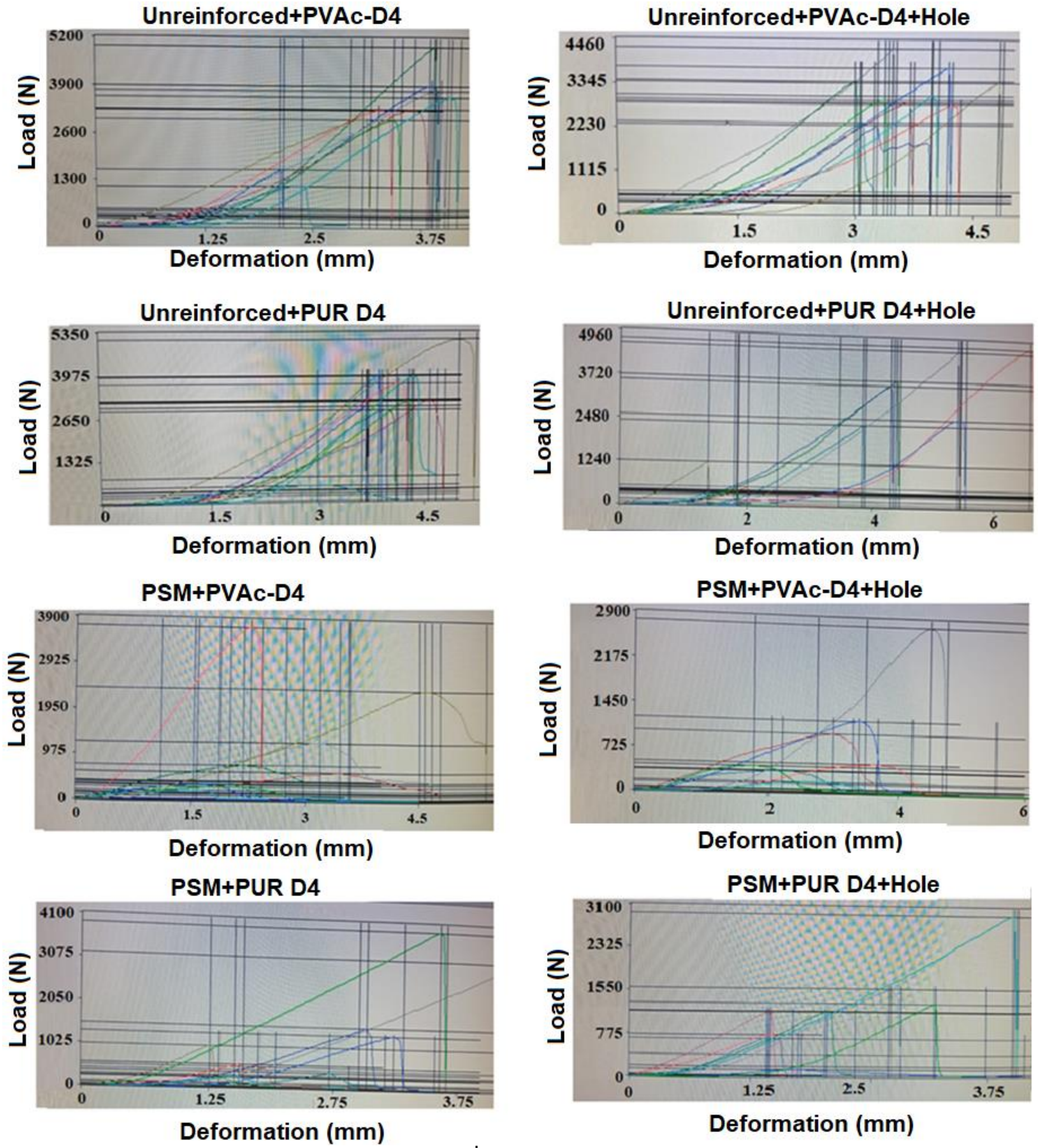


Fig. 7. Load–deformation graphs based on ┴σt test results

Failure Modes

The failure modes given in the study can be judged based on the images taken after the maximum load carrying capacity in the ┴σt test application. The failure modes of unreinforced and reinforced with BFRP, GFRP, and PSM beech samples are given in Fig. 8. It appears that there was no deformation in the beech wood. It has been observed that the tensile failures occurred on the adhesion surface and FRP materials in all experimental groups. In strengthened samples, the rupture was transferred to the glue layer between the layers. The failures were observed in the glue line and FRP materials in all test specimens. It was determined that the PSM+ PVAc-D4+ Hole test specimens had the highest failure.

The PSM+ PUR D4+ Hole, GFRP+PUR D4+Hole, Unreinforced+PVAc-D4+Hole, PSM+PVAc-D4, and Unreinforced+PUR D4+Hole test specimens followed respectively.

Fig. 8. Failure modes of the unreinforced and reinforced with FRP samples

CONCLUSIONS

The tensile strength perpendicular to fibers of the timber reinforced with basalt fiber-reinforced polymer (BFRP), glass fiber-reinforced polymer (GFRP), and plaster mesh (PSM) using PVAc-D4 and PUR-D4 adhesive was investigated in this study.

1. According to the overall results, the experimental samples reinforced with BFRP using PUR-D4 adhesive demonstrated the best properties among all the tested samples. However, it is important to note that the unreinforced samples using PVAc-D4 adhesive exhibited the lowest value among all samples.
2. On the empirical findings regarding the technical characteristics of BFRP as support materials and PUR-D4 as glue, the tensile strength perpendicular to fibers of the wood material was observed to be improved.
3. Given the substantial enhancements in the resistance properties of the intermediate filling material utilized in reinforced wood materials, it is advisable to prioritize high-strength properties in wood furniture and structural timber materials.

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REFERENCES CITED

André, A., and Johnsson, H. (2010). "Flax fiber-reinforced glued-laminated timber in tension perpendicular to the grain: Experimental study and probabilistic analysis," *Journal of Materials in Civil Engineering* 22(9), 827-835. DOI: 10.1061/(ASCE)MT.1943-5533.0000070

Basterra, L. A., Balmori, J. A., Morillas, L., Acuña, L., and Casado, M. (2017). "Internal reinforcement of laminated duo beams of low-grade timber with GFRP sheets," *Construction and Building Materials* 154, 914-920. DOI: 10.1016/j.conbuildmat.2017.08.007

Borri, A., Corradi, M., and Speranzini, E. (2013). "Reinforcement of wood with natural fibers," *Composites Part B: Engineering* 53, 1-8. DOI: 10.1016/j.compositesb.2013.04.039

Bozkurt, Y., and Erdin, N. (2011). *Wood Technology*, Istanbul University Publications, Istanbul, Turkey.

Brol, J., and Wdowiak-Postulak, A. (2019). "Old timber reinforcement with FRPs," *Materials (Basel)* 12(24), article 4197. DOI: 10.3390/ma12244197

Carmisciano, S., De Ros, I. M., Sarasini, F., Tamburrano, A., and Valente, M. (2011). "Basalt woven fiber reinforced vinyl ester composites: Flexural and electrical proprieties," *Materials & Design* 32, 337-342. DOI: 10.1016/j.matdes.2010.06.042

Caster, D., Kutscha, N., and Leick, G. (1985). "Reasons for sanding lumber," *Forest Products Journal* 35 (4), 45-52.

De La Rosa García, P., Escamilla, A. C., and García, M. N. G. (2013). "Bending reinforcement of timber beams with composite carbon fiber and basalt fiber materials," *Composites Part B: Engineering* 55, 528-536. DOI: 10.1016/j.compositesb.2013.07.016

De La Rosa García, P., Escamilla, A. C., and García, M. N. G. (2016). "Analysis of the flexural stiffness of timber beams reinforced with carbon and basalt composite materials," *Composites Part B: Engineering* 86, 152-159. DOI: 10.1016/j.compositesb.2015.10.003

Dorigato, A., and Pegoretti, A. (2012). "Fatigue resistance of basalt fibers-reinforced laminates," *Journal of Composite Materials* 46(15), 1773-1785. DOI: 10.1177/0021998311425620

Efe, H., and Gürleyen, L. (2007). "Bonding strength of some wood materials glued with polyurethane adhesieve and sanded with different sandpapers," *Politeknik Dergisi* 10 (2), 185-189.

Franklın Glue Comp. (1989). *Adhesive Trouble Shooting*, Colombus, USA.

Fiorelli, J., and Dias, A. A. (2003). "Analysis of the strength and stiffness of timber beams reinforced with carbon fiber and glass fiber," *Materials Research* 6, 193-202. DOI: 10.1590/S1516-14392003000200014

Fiore, V., Di Bella, G., and Valenza, A. (2011). "Glass–basalt/epoxy hybrid composites for marine applications," *Materials & Design* 32(4), 2091-2099. DOI: 10.1016/j.matdes.2010.11.043

Jiang, J., Li, P., and Nistico, N. (2019). "Local and global prediction on stress-strain behavior of FRP-confined square concrete sections," *Composite Structures* 226, article ID 111205. DOI: 10.1016/j.compstruct.2019.111205

Jian, B., Cheng, K., Li, H., Ashraf, M., Zheng, X., Dauletbek, A., and Zhou, K. (2022). "A review on the strengthening of timber beams using fiber reinforced polymers," *Journal of Renewable Materials* 10(8), 2073-2098. DOI: 10.32604/jrm.2022.021983

Karaman, A. (2021). "Bending moment resistance of T-type joints reinforced with basalt and glass woven fabric materials," *Maderas. Ciencia y Tecnología* 23, article 444. DOI: 10.4067/s0718-221x2021000100444

Karaman, A., and Yildirim, M. N. (2021). "Effects of wood species of the dowels and fiber woven fabric types on bending moment resistance of L-shaped joints," *Wood Industry and Engineering* 3(2), 12-22.

Kilinçarslan, S., and Türker, Y. S. (2023). "Strengthening of the solid beam with fiber-reinforced polymers," *Turkish Journal of Engineering* 7(3), 166-171. DOI: 10.31127/tuje.1026075

Lopresto, V., Leone, C., and De Iorio, I. (2011). "Mechanical characterization of basalt fiber reinforced plastic," *Composites Part B: Engineering* 42(4), 717-723. DOI: 10.1016/j.compositesb.2011.01.030

Monaldoa, E., Nerillia F., and Vairo, G. (2019). "Basalt-based fiber-reinforced materials and structural applications in civil engineering," *Composite Structures* 214, 246-263. DOI: 10.1016/j.compstruct.2019.02.002

Osmannezhad, S., Faezipour M., and Ebrahimi, G. (2014). "Effects of GFRP on bending strength of glulam made of poplar (*Populus deltoids*) and beech (*Fagus orientalis*)," *Construction and Building Materials* 51, 34-39. DOI: 10.1016/j.conbuildmat.2013.10.035

Rowell, R. (2005). *Handbook of Wood Chemistry and Wood Composites*, CRC Press, ISBN 0-8493-1588-3, New York, USA.

Schober, K. U., Harte, A. M., Kliger, R., Jockwer, R., Xu, Q., and Chen, J. F. (2015). "FRP reinforcement of timber structures," *Construction and Building Materials* 97, 106-118. DOI: 10.1016/j.conbuildmat.2015.06.020

Selbo, M. L. (1975). "Adhesive bonding of wood," Technical Bulletin, No:1512, 1-3, 61, Forest Products Laboratory-Forest Service, Washington, U.S.

Smardzevski, J. (2002). "Technologial heterogeneity of adhesive bonds in wood joints," *Wood Science and Technology* 36(3), 213-227. DOI 10.1007/s00226-002-0127-7.

Speranzini, E., and Tralascia, S. E. (2010). "Engineered lumber: LVL and solid wood reinforced with natural fibers," in: *Proceedings of the WCTE*, Trentino, Italy, pp. 1685-1690.

Thelandersson, S., and Larsen, H. J. (2003). *Timber Engineering*, John Wiley and Sons, West Sussex, UK.

Turker, Y. S. (2024). "Experimental Investigation of rotational behavior of glulam column-beam connection reinforced with carbon, glass, basalt and aramid FRP fabric," *Drvna Industrija* 75(2), 259-270. DOI: 10.5552/drvind.2024.0162

TS 5497 EN 408 (2006). "Timber structures-structural timber and glue laminated timber-determination of some physical and mechanical properties," Turkish Standards Institution, Ankara, Turkey.

TS ISO 13061-7 (2021). "Wood-determination of ultimate tensile stress perpendicular to the grain," Turkish Standards Institution, Ankara, Turkey.

Vıck, C. B. (1999). "Adhesive bonding of wood materials," in: *Wood-Hand Book– Wood as an Engineering Material*, Ch. 9, Forest Prod. Lab. – GTR 113, Madison, WI, US Department of Agriculture, Forest Service, Forest Products Laboratory.

Wang, B., Bachtiar, E. V., Yan, L., Kasal, B., and Fiore, V. (2019). "Flax; Basalt; E-Glass FRP and their hybrid FRP strengthened wood beams: An experimental study," *Polymers* 11(8), article 1255. DOI: 10.3390/polym11081255

Wei, B., Cao, H., and Song, S. (2010). "Tensile behavior contrast of basalt and glass fibers after chemical treatment," *Materials & Design* 31(9), 4244-4250. DOI: 10.1016/j.matdes.2010.04.009

Yang, H. F., Liu, W. Q., Shao, J. S., and Zho, Z. (2008). "Study on flexural behavior of FRP reinforced wood beams," *Journal of Building Materials* 11(5), 591-597. DOI: 10.3969/j.issn.1007-9629.2008.05.016

Zuo, H., Bu, D., Guo, N., and He, D. (2015). "Effect of basalt fiber composite on flexural behavior of glulam beams," *Journal of Northeast Forestry University* 43(4), 91–95. DOI: 10.13759/j.cnki.dlxb.20150116.02

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