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Experimental and Numerical Investigation of Flexural Properties of Solid Wood Materials Reinforced with Various FRP

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Abstract

Wood material is destroyed over time by biotic and abiotic factors. Many of the historical buildings are made of wooden materials and these materials can degrade over time with the effect of environmental conditions. In order to ensure the sustainability of these buildings with historical value, they need to be repaired and strengthened over time. In this study, 20x20x360 mm wood specimens of Ash tree species were strengthened with carbon, basalt and glass based FRP materials. The flexural properties of the reference sample without wrapping and the samples reinforced with carbon, basalt and glass based FRP material were examined. For this purpose, at first three-point bending test has been performed, and then obtained results are compared with the numerical ones found from finite element analysis software ANSYS. As result, a good agreement has been found between experimental and numerical results. As a result of the flexural tests, the load-displacement curves, values of flexural strength and values of modulus of elasticity the samples were determined. In this study, it was determined that the highest load carrying capacity value belongs to the sample reinforced with carbon-based FRP polymers.

Keywords: Reinforcement, wood structures, wood materials, numerical, ANSYS

1. INTRODUCTION

Wood is a construction, aesthetic and engineering material with a wide range of uses, its many positive properties [1, 2]. Its biological structure, physical and mechanical properties and chemical composition allow wood to be used in many different products. The fact that wood is a good insulation material and its resistance high values compare to its density are among the reasons for preference [3-7].

In addition to its many positive features, wood also has some undesirable features that limit the areas of use or cause problems during its use. With these inconvenient features, the wooden element requires maintenance, repair and reinforcement over time. There are many studies on those improvements of wooden materials and it is important to strengthen these structures. Wooden structures have traditionally been reinforced with pieces of steel and wood material [8]. It was stated that the investigation of the effect of reinforcement

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with fiber-reinforced polymers (FRP) on different properties of wooden elements dates back to the 60s [9].

Fiber reinforced polymer (FRP) composites consist of fibers embedded in a polymer component matrix. Composite material, which consists of a combination of fiber and this polymer component matrix, has superior properties than its original components. In recent years, various studies have been carried out on the strengthening of wood materials with FRP polymers [10-14]. Spaun (1981) [15] examined the increase in stiffness and tensile strength by performing the bending test of reinforced beams using glass fiber reinforcement. In later studies, carbon fiber started to be used as a reinforcement material for the reinforcement of beams [9]. Garcia et al., (2013) [16] stated in their study that if the lower surface of a beam subjected to bending is reinforced with FRP (carbon and basalt-based fabrics) composite materials, there will be an increase in bearing capacity as well as an increase in ductility.

Kilincarslan and Simsek Türker (2021) [17], are aimed to strengthen the joints of carbon fiber reinforced polymer and glulam column-beam joints. For this purpose, using WV90080 and ALUMIDI 160, WV90110 and ALUMIDI 200 connection elements, they produced 2 column-beam connection samples of each connection type. They prepared one of the samples produced in each connection as a reference and the other as a reinforced sample. They subjected the produced column-beam joint samples to the load-displacement test within the framework of the experiment.

It was determined that the load carrying capacity, energy dissipation capacity and rigidity values of the samples whose column-beam connections were strengthened were high. It has been stated that reinforcement with carbon-based FRP fabric increases the strength and durability of the column-beam connection area.

Karagöz Isleyen and Kesik (2021) [18] 22 used carbon fiber reinforced polymer to improve the mechanical behavior of old wood samples that were damaged over time due to various environmental and biological factors. They investigated the effect of FRP reinforcement on the strength values of old and new wood specimens under bending and compression loads. They found that the values of flexural strength for new wood, reinforced old wood and reinforced new wood increased by 28%, 34% and 59%, respectively, compared to the old unreinforced wood material. They determined that the values of elasticity modulus of new wood, reinforced old wood and reinforced new wood were 15%, 19% and 34% higher than the old wood, respectively.

In this study, it was aimed to investigate the effect of reinforcement with carbon, glass and basalt-based polymer fabric on the flexural properties of Ash beams.

2. MATERIAL AND METHODS

In this study, Ash (*Fraxinus excelsior L.*) wood species, which is widely used in the production of wood composites and especially for structural purposes, is studied. The Ash beam samples used in the study have been supplied from Nasreddin Forest Products (Naswood) Ltd. in the Antalya region. The wooden beams are manufactured from smooth, knot-free, flawless timber with dimensions of 20x20x360 mm. Before the beams are tested, all samples have been kept at temperature 20 ºC (±2) ºC and relative humidity 65% (±5) conditions until they reached the same equilibrium humidity. After the samples were kept in the air-conditioning cabinet, the humidity levels were checked with an electric humidity meter.

Fiber reinforced polymer fabric based on carbon, glass and basalt is used for reinforcement in the study. The technical properties of the FRP fabrics used are given in Table 1.

Table 1 The technical properties of carbon, glass and basalt fabrics (BASF, 2020)

Structure of the Material	Carbon	Glass	Basalt
Weight (g/m^2)	300	300	200
Modulus of Elasticity (GPa)	230	72	82
Tensile strength (N/mm^2)	4900	3900	3200
Design Section Thickness (mm)	0.166	1.162	0.167
Elongation at Break (%)	2.1	4.8	3.5
Width (mm)	500	500	500

In this study, at least two layers of wrapping are used for the strengthened samples with fiber-reinforced polymer fabrics, due to two layers of wrapping is proposed in the practical use of industry. Roll priming is performed to form a thin film layer (0.1 -0.2 mm) with an epoxy-based primer developed for the MasterBrace® FRP (MasterBrace® P 3500) System. After the priming process, Developed Epoxy adhesive for MasterBrace® FRP (MasterBrace® SAT 4500) Fibrous Polymer System is used. Epoxy adhesive is applied to the primed surfaces with a roller to achieve a thickness of 1 mm. As seen in Figure 1, the wrapping process of wooden beams with FRP composites has been performed in a U-shaped reinforcement in three regions of the beam. After the epoxy adhesive is applied, fibrous polymer fabrics cut in appropriate sizes are stretched in the direction of their fibers and adhered to the surface, immediately. Then, it is ensured that the epoxy is absorbed into the fabric and there is not any gap between it and the surface by pressing in the direction of the fibers of the fibrous polymer fabrics with a roller. After the first layer of adhesive is completed, the same operations have been repeated once again, the second layer is wrapped and the wrapping process is completed.

The wrapped beams are kept for 1 week before being subjected to the three-point bending test. Flexural strength tests are carried out on 20x20x360 mm specimens prepared in accordance with TS 2474 (2005). In the bending tests, the loading speed is set as 6 mm/min constant speed and the experiments are carried out. The span of the support points is taken as 300 mm in the experiments.

Figure 1 Image of the wrapping process with FRP polymers, A: Preparing the beams for wrapping after the priming process B: Wrapping the beams with FRP polymer fabric

The flexural strength and modulus of elasticity are determined as follows, respectively.

$$\sigma_E = \frac{aP_{\max} l}{2bh^2} \quad (1)$$

$$E = \frac{\Delta P l^3}{4bh^2 \Delta f} \quad (2)$$

where σ_E is the flexural strength (N/mm^2), $P_{\max}$ is the breaking load (N), l is the space between the support points (mm), b is the width of the specimens (mm) and h is the height of the specimens (mm), $\Delta P = P_2 - P_1$ is the increase of force in the loading/ deflection curve linear section [N], $\Delta f = f_2 - f_1$ is the deflection increase in the middle of the test specimen's length.

The flexural strength and modulus of elasticity values of the beams are determined, and the effect of reinforcement with carbon, glass and basalt-based FRP fabric polymers on the flexural properties of Ash beams are investigated.

The wooden beams are modeled and numerically analyzed in the finite element analysis software ANSYS. Due to wood is an anisotropic material owing to the presence of knots and defects, it is generally modeled as orthotropic material in numerical analysis. The behaviors of wood behaviors are described using the engineering constants such as the modulus of elasticity (MOE) in the longitudinal, radial, and tangential directions (Ex; Ey; Ez), shear modulus (Gxy, Gxz, Gyz), and Poisson's ratio.

After the material definition, the loads and supports are also defined and meshed. The thickness values of the FRP fabrics are taken as 0.166 mm during the modeling. Figure 2, shows A) Reference beam, B) 360 mm long beam reinforced with various FRP fabrics.

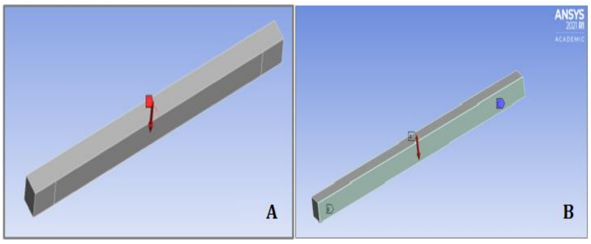

Figure 2 Modeling of beams in ANSYS Software A: Reference sample B: Reinforcement with FRP polymers in 360 mm length

As a result of the analyzes made in the ANSYS Software program, the results are given in Figure 3.

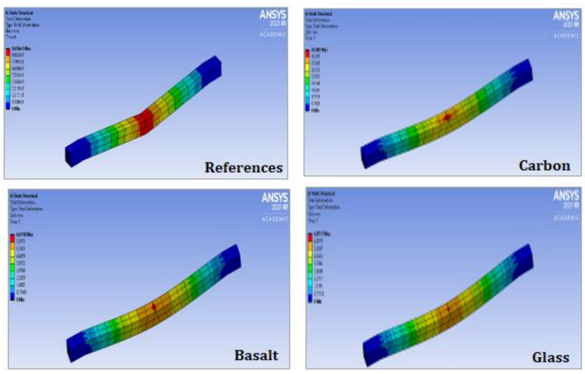

Figure 3 Finite element analysis images of Iroko samples reinforced with Carbon, Basalt, and Glass FRP polymers

After performing the analyzes with ANSYS, the finite element results and the static analysis results are compared.

3. RESULTS AND DISCUSSION

In this study, Ash beams are reinforced with carbon, glass and basalt based FRP fabrics. Reference beams and reinforced beams are subjected to the bending test. Load-displacement graphs and values of flexural strength-modulus of elasticity obtained in the study are given in Figure 4, Figure 5 and Figure 6.

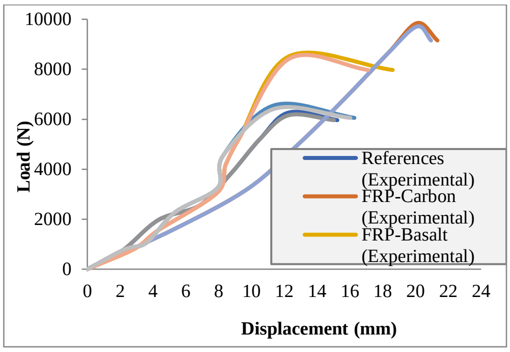

Figure 4 Load-displacement graphs of beams

It was determined that the load bearing capacities of the beams reinforced with carbon, basalt and glass-based FRP polymers increased by 56.95%, 36.00% and 4.57%, respectively, compared to the reference sample. It was determined that the displacement amounts of the reinforced beams increased by 40.02%, 3.37% and 1.04%, respectively, in carbon, basalt and glass-based fabrics compared to the reference beams.

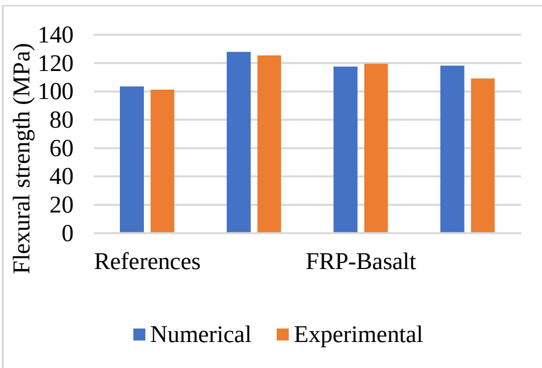

Figure 5 Flexural strength of reference and reinforced beams

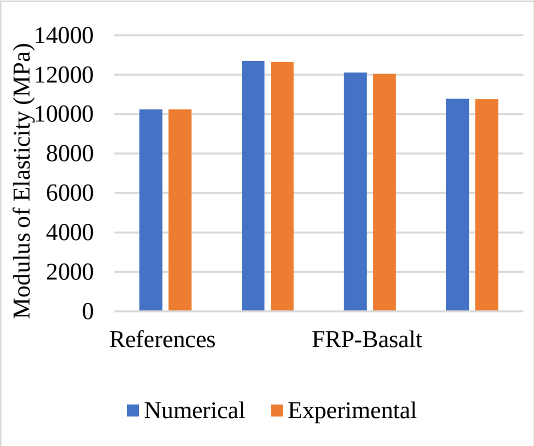

Figure 6 Modulus of elasticity of reference and reinforced beams

When Figure 4 and Figure 5 are examined, the values of flexural strength of the beams reinforced with carbon, basalt and glass-based polymer fabrics increased by 23.68%, 18.10% and 7.71%, respectively, compared to the reference beams. The values of modulus of elasticity increased by 23.36%, 17.48% and 5.02%, respectively. Results of the static bending test were compared with those for numerical ones, it was observed that both results are in good agreement.

4. CONCLUSION

In this study, the effect of reinforcement with carbon, basalt and glass-based fiber reinforced polymer fabric on the bending properties of ash beams was investigated. It has been determined that strengthening with FRP polymers increases the load carrying capacity, displacement amount, flexural strength values and modulus of elasticity of wood materials. When the test results obtained from the experiments and the values obtained by numerical modeling were compared, it was seen that both results gave almost the same values. Compared with the reference samples, it was determined that the highest flexural strength and modulus of elasticity were obtained by carbon-based FRP polymers, and the lowest load-carrying capacity was obtained by glass-based FRP polymers. It has been determined that this change is compatible with the modulus of elasticity values of FRP fabrics. It has been concluded that the FRP polymer fabrics used can be used to strengthen wooden structures.

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The Declaration of Ethics Committee Approval
This study does not require ethics committee permission or any special permission

The Declaration of Research and Publication Ethics
The authors of the paper declare that they comply with the scientific, ethical and quotation rules of SAUJS in all processes of the paper and that they do not make any falsification on the data collected. In addition, they declare that Sakarya University Journal of Science and its editorial board have no responsibility for any ethical violations that may be encountered, and that this study has not been evaluated in any academic publication environment other than Sakarya University Journal of Science.

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