Turkish Journal of Engineering
https://dergipark.org.tr/en/pub/tuje
e-ISSN 2587-1366

Strengthening of solid beam with fiber reinforced polymers

Şemsettin Kilinçarslan *[1], **Yasemin Şimşek Türker** [1]

[1]Suleyman Demirel University, Civil Engineering Department, Türkiye

Keywords
FRP
Reinforcement
Wood Structures
Wood Materials

Research Article
DOI: 10.31127/tuje.1026075

Received: 19.11.2021
Accepted: 18.05.2022
Published: 31.08.2022

Abstract

Timber, concrete and steel are among the traditional building materials used in the construction of buildings. Since concrete is a durable material, it is a building material used in buildings, highways, dams, sidewalks and many other areas. Wood is one of the oldest building materials, and the use of wood and wood-based materials for structural purposes continues to increase. The deterioration of existing wooden structures may result from fatigue and biological attack over time. The cost of replacing the damaged wooden elements is very high, so it seems more appropriate to repair and strengthen the damaged elements. In this study, 20x20x360 mm solid wood beam is reinforced with fiber reinforced polymers and the effect of fiber reinforced polymers on the bending properties of the beam was investigated. In order to determine the bending properties, three-point bending test was applied to the wood beams. As a result of this study, it was determined that the bending properties of wood beam reinforced with fiber reinforced polymer composites were better than the reference samples

1. Introduction

Wood material is an anisotropic, hygroscopic, sustainable and organic material [1-3]. Wood material has many positive properties [4-5]. Wood material is very suitable for use in structural and non-structural areas [6]. However, there are properties that limit the use of wood material in the structural field. The properties are; knots, fiber curl, termites, insects, fungi, biological deterioration, moisture. These undesirable and use-limiting features can be eliminated both during manufacture and use.

Nowadays, there is a rapid increase in the use of wood materials, especially for structural applications. There are some features that limit the use of wood material in the structural area. These features are fiber curl, knots, cracks, difficulty in finding materials in desired shapes and sizes, changes in production methods, use of materials that grow fast but have low resistance properties in production, high waste rate in the use of solid wood material, joining short pieces. Wood material can be strengthened by supporting with fiber-reinforced polymers both to increase the resistance properties of the joints of the structures to be obtained by using wood material, and to overcome the repair difficulties of the damage caused by external factors, deterioration of the material and earthquakes in previously constructed structures [7-8].

Fiber reinforced polymers generally consist of glass, carbon, graphite, aramid fibers and polymer matrices. Glass is used as the basic raw material in the production of glass fibers. Soda-lime or borax silicates are used in glass fiber production. Additives are added at different rates according to the properties desired to be imparted to the glass [9]. The density of carbon fibers is low compared to metal reinforcement elements; but the resistance properties are higher. carbon fibers; It is produced by processes such as stabilization, carbonization and graphitization [10]. Aramid fibers have high resistance and chemical properties. The tensile strength of aramid fibers is higher than that of steel [11].

Polymer matrices constitute approximately 30-40% of fiber reinforcement elements. During the application of polymer matrices; It undertakes the task of keeping the fibers together, ensuring the desired orientation of the fibers, evenly distributing the load to the fibers and protecting the fibers from environmental effects [10]. Fiber reinforced polymers are produced by combining fibers and polymer matrices under appropriate production conditions. The production process varies according to the desired properties of the final product.

* **Corresponding Author**

*(semsettinkilincarslan@sdu.edu.tr) ORCID ID 0000-0001-8253-9357
(yaseminsimseksdu@gmail.com) ORCID ID 0000-0002-3080-0215

Cite this article

Kilinçarslan, S., & Şimşek Türker, Y. (2023). Strengthening of solid beam with fiber reinforced polymers. Turkish Journal of Engineering, 7(3), 166-171

In structural design, fiber-reinforced polymers are used in the manufacture of new materials, repair of old materials, and structural improvement applications [12-18]. Fiber-reinforced polymers are used in concrete, steel, wooden beams and columns, -I-beam manufacturing, all kinds of strengthening and restoration applications, bridge coatings, reinforcing joints due to their high strength properties [19-21]. FRP composites provide appropriate strength and stiffness, are non-abrasive, and offer excellent ease of installation, reduced long-term maintenance costs, and quick installation in the field [22-24]. It is more convenient to use FRP materials instead of traditional strengthening methods because it requires maintenance and repair over time and its durability is low.

For the successful application of fiber-reinforced polymers in wood material, two different materials must be bonded in a high-quality durable manner [25]. Fiber-reinforced polymer elements can be in the form of strips, plates, rods, and these parts can be assembled with a binder. These reinforcing elements can be placed on the outside of the wood element or on the inside where aesthetic appearance is desired. The fact that the reinforcement element is outside the wood is the most common method used in strengthening works of existing structures [26].

Care must be taken when applying fiber-reinforced polymer elements on wood. First of all, the surface of the wood material should be moisture-free, flat and clean, and the oil and similar substances on it should be cleaned. Wood material should be dry during surface bonding [26].

Nowadays, there are many scientific studies on the longevity and durability of wooden structures. Numerous studies have been carried out on the strengthening of wooden structures with fiber reinforced polymers. When these studies are examined; Pupsys et al. [27], investigated oak wood beams with dimensions of 145 x 145 x 2450 mm strengthened with glass fiber reinforced polymer sheets, and determined that the reinforcement increased the bending properties of oak wood beams. Muratoğlu [28], investigated beams of Eastern beech (*Fagusorientalis* L.) and Scots pine (*Pinus sylvestris*) wood strengthened with carbon fiber reinforced polymers, and determined that the reinforced samples are 108.66 % better bending strength.

Kılınçarslan and Şimşek Türker [29], examined glulam column-beam joint area strengthen with carbon FRP and reported that the values of load carrying capacity, energy consumption and stiffness of strengthened specimens is increased. In addition, found that reinforcement with carbon based FRP fabric increased the strength and durability of the column-beam joints. Wang et al. [30] investigated those bending properties of solid Fir (*Pseudotsuga menziesii Mirb.*) beams reinforced with various fiber-reinforced polymer fabric composites (flax, basalt, E-glass FRP, hybrid FRP) and determined that fiber-reinforced polymers improved the bending properties of wood materials.

Kılınçarslan and Şimşek Türker [14] investigated that effect of reinforcement with carbon-based FRP fabric on load bearing capacity and modulus of elasticity, and stated that ductility and bearing capacity of wood beams is increased after reinforcement with FRP fabric. Ling et al. [31] examinate that Scots pine (*Pinus sylvestris*) beams reinforced with carbon and glass-based polymer fabrics and stated that effect of reinforcement with Carbon-FRP is higher than Glass-FRP. Kılınçarslan and Şimşek Türker [29] investigated that effect of carbon, aramid, basalt and glass-based fiber FRP fabrics on heat treated ash (*Fraxinus excelsior*) beams, and determined that flexural strength and modulus of elasticity increased after reinforced with FRP fabrics of heat-treated wood.

In this study, Ash beams are practically reinforced in a "U" shape from the outer part of the beam with basalt-based polymer fabric used for reinforcement purposes in the market. The beams are subjected to bending test in a universal test device and load-displacement graphs, flexural strength and modulus of elasticity are obtained.

2. Method

Ash (*Fraxinus Excelsior*) is a broad-leaved species that grows in temperate and rarely subtropical and tropical regions of the Northern Hemisphere. This species, which spreads in Europe, Crimea, Caucasus and especially in Britain, is found in Thrace, Eastern and Western Black Sea Region, Marmara and Aegean Region in our country [32]. It spreads on an area of approximately 14410 ha in the forests of our country and its share in the general forest area is less than 1% [33]. Thanks to its smooth trunk and quality wood, it is among the valuable tree species in the forest products sector. In this study, Ash (*Fraxinus Excelsior*) 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. The image of the cut samples is given in Figure 1.

Figure 1. Image of sized samples

Before the beams are tested, all samples have been kept at temperature 20±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.

In this study, basalt-based fiber reinforced polymer fabric is used for reinforcement. The technical properties of the FRP fabric used are given in Table 1.

Table 1. The technical properties of basalt fabrics [34]

Structure of the Material	Basalt
Weight (g/m^2)	200
Modulus of Elasticity (GPa)	82
Tensile strength (N/mm^2)	3200
Design Section Thickness (mm)	0,167
Elongation at Break (%)	3,5
Width (mm)	500

Figure 2. U-shaped reinforcement in three regions of the beam

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 2, 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, fibres 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 bending test. Flexural strength tests are carried out on 20x20x360 mm specimens prepared in accordance with TS 2474 (2005) (Figure 3).

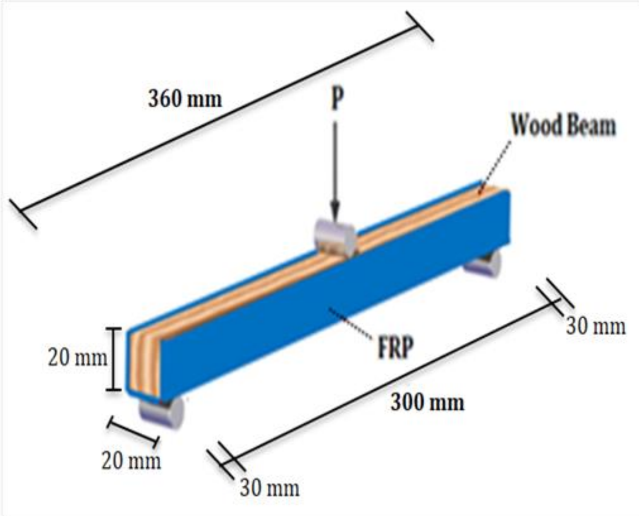

Figure 3. Sample prepared according to the standard for bending test

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. The three-point bending test experimental setup image is given in Figure 4.

Figure 4. Wrapping process of wooden beams with FRP

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 is the σ_E 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), ΔP= P_2-P_1 is the increase of force in the loading/ deflection curve linear section [N], Δ*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 basalt-based FRP fabric polymers on the flexural properties of wood material is determined.

3. Results

In this study, Ash samples are reinforced with basalt-based FRP fabrics. Reference specimens and reinforced specimens are subjected to the bending test. Load-displacement graphs and values of flexural strength and modulus of elasticity obtained in the study are given in Figure 3, Figure 4 and Figure 5.

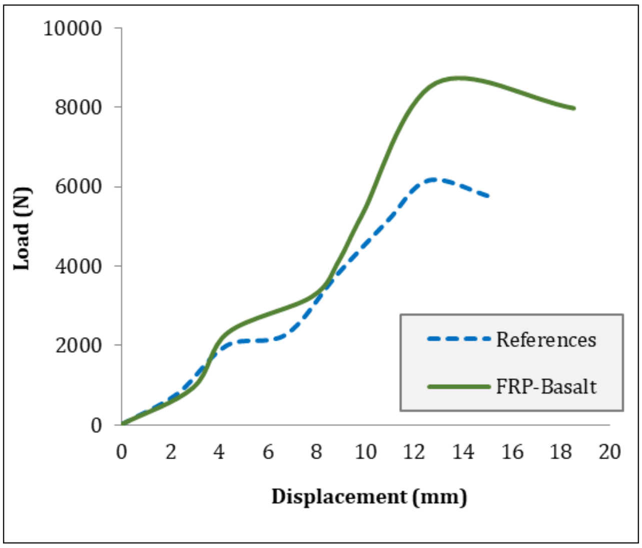

Figure 5. Load-displacement graphs of beams reinforced with reference and basalt-based FRP polymer

It was determined that the load carrying capacity of the basalt-based FRP polymer reinforced sample increased by 40% compared to the reference sample. It was determined that the displacement amount of the reinforced beam increased by 3.32% compared to the reference beams.

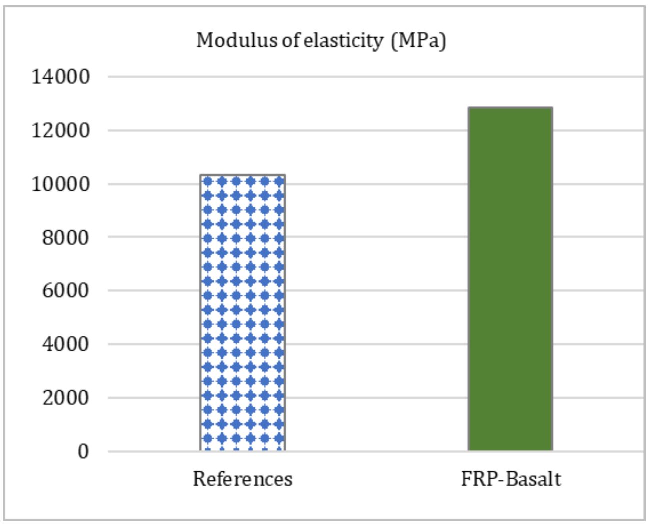

Figure 6. Graphs of modulus of elasticity of beams reinforced with reference and basalt-based FRP polymer

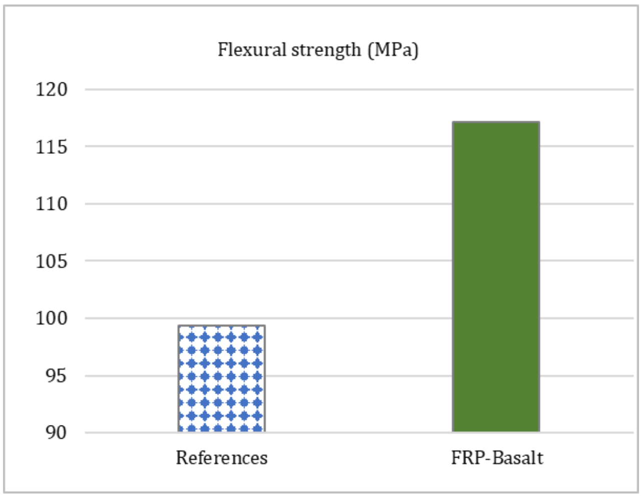

Figure 7. Graphs of flexural strength beams reinforced with reference and basalt-based FRP polymer

When Figure 4 and Figure 5 are examined, it has been determined that the beams reinforced with basalt-based fiber reinforced polymer fabric have flexural strength (117.11 MPa) and modulus of elasticity (12845 MPa). It was determined that the reference beams had flexural strength (99.34 MPa) and modulus of elasticity (10320 MPa). It was determined that the flexural strength value of the reinforced beam increased by 18% and the elasticity modulus value increased by 25% compared to the reference beam.

4. Conclusion

In this study, the effect of basalt-based fiber reinforced polymer fabric on the bending properties of wood material was investigated. Compared to the reference samples, it was determined that strengthening with basalt-based polymers increased the load carrying capacity, displacement amount, flexural strength and modulus of elasticity of wood materials to a certain extent.

Strengthening and joining of wooden materials are generally made with steel elements. However, steel elements detach from wood material over time and are subject to corrosion. Therefore, it reduces the environmental quality over time, harms human health, reduces the usage time of the wooden element and creates environmental problems. Nowadays, most of the historic and existing wooden structures are in need of safe repair and reinforcement. Known repair works, over time, insect failure in different parts of the wooden elements, fungus, rot, etc. Leaving all of the elements that need to be replaced due to reasons from the system can cause important problems in terms of both cost and workmanship and safety of the building. Therefore, it would be more appropriate to replace the damaged elements instead of replacing all the elements used in the building. With the regional change, new combinations (dowel, nail, blotting technique) are formed. Making these combinations does not give the expected result statically. Reinforcing wooden structures with FRP does not take time and provides an aesthetic advantage. For this reason, it is recommended to use basalt-based FRP polymer fabrics used in the study to strengthen the wood material.

Acknowledgement

This study has been prepared within the scope of the thematic area of "Sustainable Building Materials and Technologies" with SDU BAP project with FDK-2019-6950 project code and YÖK 100/2000 doctoral program. The authors thank the SDU BAP unit, YÖK and YÖK100/2000 program staff.

Author contributions

Şemsettin Kilinçarslan: Methodology, Writing-Reviewing, Writing-Original draft preparation. **Yasemin Şimşek Türker:** Methodology, Writing-Reviewing and Editing.

Conflicts of interest

The authors declare no conflicts of interest.

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