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Investigation of the Bending Properties of Wood Structural Materials Reinforced with Carbon FRP Strips

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ABSTRACT: *The mechanical performance of beams made from brutia (Pinus brutia) wood, reinforced with carbon fiber reinforced polymer (CFRP) strips to increase bending load capacity, is standardized in this research. Two sample groups were created: unreinforced control beams and wooden beams reinforced with CFRP strips. In the reinforcement process, tensile-healthy carbon CFRP strips were applied superficially to the beams using epoxy-based adhesives, thus providing the high elastic modulus and strength properties of CFRP against the limited tensile conditions of the wood. The experimental study included four-point bending tests to evaluate the maximum load-carrying capacity, bending rigidity, and fracture stresses of the beams. The results showed that reinforcement with CFRP strips significantly increased the bending load-carrying capacity of the beams, particularly providing higher rigidity in load-deflection performance and contributing to a delayed onset of crack formation. In addition, more controlled fractures and a reduction in sudden and incipient fractures were observed in the stronger beams. These examples demonstrate that CFRP strip surfacing is an effective performance-enhancing solution for structural elements, applicable in the renovation of historical buildings, the separation of existing timber elements, and in modern timber structure designs.*

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I. INTRODUCTION

Wood continues to be used as an important engineering material today due to its sustainability, lightness, ease of processing, and high strength-to-weight ratio. Being a renewable resource with a low carbon footprint, wood is also environmentally advantageous and finds widespread use in both modern and historical building structures [1,2]. However, the mechanical properties of wood can vary significantly depending on factors such as natural defects, moisture changes, biological degradation, and irregularities in the fiber direction. In particular, the weakness of the tensile zone in elements subjected to bending is one of the main problems limiting the load-bearing capacity of wooden beams. Therefore, strengthening techniques aimed at increasing the bending strength and rigidity of wooden elements are gaining importance from an engineering perspective [3-7].

In recent years, fiber-reinforced polymer (FRP) composite materials have become widely used in strengthening wooden structural elements due to their lightness, high strength, and ease of application [8-10]. Among these materials, carbon fiber reinforced polymer (CFRP) strips stand out as a leading option for improving the bending behavior of wooden beams thanks to their high modulus of elasticity and tensile strength [11]. CFRP strips, applied to wood surfaces with epoxy-based adhesives, contribute to increasing load-bearing capacity, especially in the tensile region [12,13]. Studies in the literature on CFRP-reinforced wood beams show a significant increase in flexural strength and modulus of elasticity. However, the effectiveness of reinforcement varies depending on the type of wood used, the adhesive performance, and the CFRP application details. Therefore, experimentally investigating the reinforcement of different wood types with CFRP is important for the more effective use of the method in engineering applications [14-20].

Pinus brutia, a commonly used softwood species in Turkey, is preferred in structural applications due to its economic accessibility and ease of use. However, its flexural performance is limited due to defects in the fiber direction and its relatively low tensile strength. Therefore, reinforcing pine beams with CFRP strips offers significant improvement potential, especially in terms of flexural strength and modulus of elasticity. In this study, the flexural behavior of pine wood beams reinforced with CFRP strips was experimentally investigated. The flexural strength and modulus of elasticity of unreinforced control specimens and specimens treated with CFRP were determined comparatively. The results reveal the effect of CFRP reinforcement on the structural properties of Scots pine beams and offer a viable method for strengthening timber elements.

II. EXPERIMENTAL SETUP

The solid 20x100x1100 mm Pinus brutia wood samples used in the study were obtained from forestry companies in Isparta. The obtained samples were brought to the Süleyman Demirel University Natural and Industrial Building Materials Application and Research Center. Carbon FRP strips, as shown in Figure 1, were used for reinforcement purposes in the study.

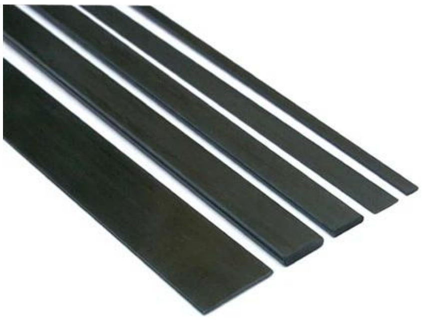

Fig. 1 Carbon FRP strip

In this study, the control samples on which the experiments were performed were coded as CN, and the reinforced timber beams reinforced with carbon FRP strips were coded as CS-R. Experiments were performed on three samples from each series. The reinforcement of the beams with FRP was carried out in four stages. First, the pine wood surface to be treated with FRP was cleaned. Secondly, a primer was applied to the area where the FRP would be placed to ensure compatibility with the wood. Sufficient material must be available and ready for application. The third stage involves bonding the FRP to the surface. A specially developed adhesive is used for this purpose. The adhesive is an epoxy-based material specifically designed for FRP. Before application, the epoxy resin and epoxy hardener are mixed. It is essential to ensure the mixture is thoroughly combined during application. Finally, the FRP strips are cut and prepared to suit the work and then placed on the adhesive-coated surface. To ensure the FRP materials fully absorb the adhesive and that no air gaps remain, they are applied by pressing with a roller.

According to TS 5497 EN 408, the loading device used must be capable of measuring the load applied to the test piece with 1% accuracy. The load was applied at a constant speed, and the movement speed of the loading head was adjusted to reach the maximum load within 300 ± 120 seconds. To determine the flexural strength and modulus of elasticity of the samples obtained in this study, the samples were subjected to flexural testing using a bending testing machine. Then, based on the flexural test results, the flexural strength and modulus of elasticity values of the samples were determined. First, the test was performed on a reference sample, and then on samples reinforced with FRP strips.

III. RESULTS AND DISCUSSION

In this study, three specimens from each series of Scots pine timber beams reinforced with FRP strips were tested to evaluate their bending behavior, and the obtained modulus of elasticity (MOE) and flexural strength (MOR) values were determined. The obtained MOE values are presented in Figure 2, and the MOR values are presented in Figure 3.

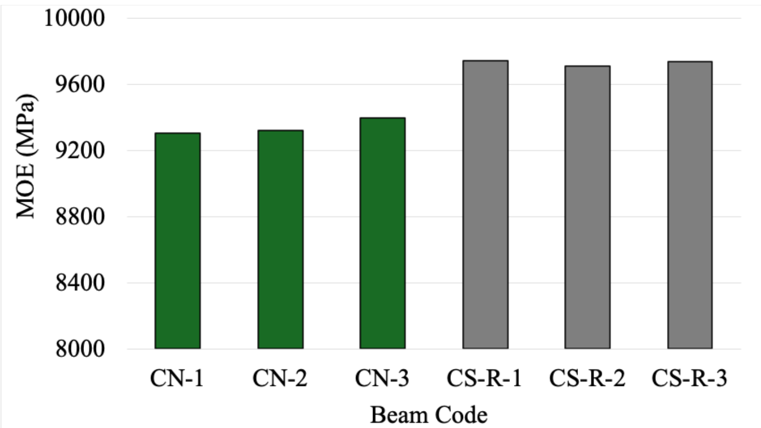

Fig. 2 Modulus of elasticity of wood beams

The modulus of elasticity values of beams made from Scots pine were determined from three samples for each series. As shown in Figure 2, the control samples (CN-1, CN-2, CN-3) yielded very similar results, with MOE values ranging from approximately 9000–9200 MPa. These results indicate that the natural fiber structure and internal defects of unreinforced Scots pine beams are decisive in determining the stiffness properties of the material. In samples reinforced with CFRP strips (CS-R-1, CS-R-2, CS-R-3), a significant increase in MOE values was observed. In the reinforced samples, the modulus of elasticity reached approximately 9600–9800 MPa, indicating that the contribution of the CFRP strip to the tensile region of the beam increased its stiffness. The findings show that the application of CFRP improves the elastic behavior capacity of the beams and that the reinforcement process has a positive effect on the deformation resistance of the material.

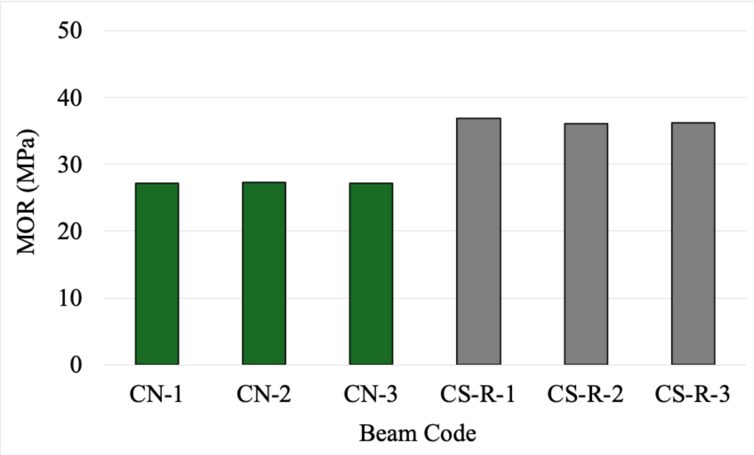

Fig. 3 Modulus of rupture of wood beams

Bending strength results were also obtained from three samples for each series and are presented in Figure 3. The MOR values of the control group samples (CN-1, CN-2, CN-3) were measured in the range of approximately 25–27 MPa. These values indicate that the bending behavior of unreinforced Scots pine beams is limited due to fiber defects and material heterogeneity. The MOR results obtained from the samples reinforced with CFRP strips showed a significant increase compared to the control group. In the reinforced CS-R series, the bending strength increased to the range of approximately 35–38 MPa, thus determining that CFRP reinforcement significantly contributed to the load-carrying capacity of the beams, especially by increasing the capacity in the tension region. This increase reveals that CFRP strips effectively participate in load transfer and that a significant improvement in the fracture strength of the beams occurred after reinforcement.

IV. CONCLUSION

This study experimentally investigated the effectiveness of a reinforcement method using carbon fiber reinforced polymer (CFRP) strips to improve the bending performance of brutia (Pinus brutia) timber beams. Four-point bending tests were performed on three specimens for each series. The modulus of elasticity (MOE) and flexural strength (MOR) values of the unreinforced control specimens and the beams reinforced with CFRP strips were compared. The data clearly show that CFRP reinforcement has a significant and positive effect on the mechanical performance of brutia beams. In the control specimens, MOE values were measured in the range of approximately 9000–9200 MPa. These results indicate that natural wood material offers limited rigidity due to structural heterogeneity and defects in the fiber direction. In contrast, it was determined that the MOE values in the specimens reinforced with CFRP strips increased to the range of 9600–9800 MPa. This increase demonstrates that CFRP strips contribute to the tensile region of the beam, reducing deformations under bending and increasing the beam's elastic behavior capacity. Therefore, it can be said that CFRP reinforcement directly and effectively contributes to the rigidity properties of the beam.

The MOR values obtained in terms of bending strength also revealed a similar improvement. The strength value of approximately 25–27 MPa obtained in the control group reached approximately 35–38 MPa in the reinforced CS-R specimens. This increase in bending strength shows that the CFRP strip actively participates in load transfer in the tensile region, delays crack development, and increases the ultimate load-carrying capacity of the beam. CFRP application provided a significant increase in strength, especially in Scots pine beams exhibiting poor behavior in the tensile region due to defects in the fiber direction.

In general, the results obtained show that CFRP strip reinforcement improves the structural performance of timber beams made from Scots pine by increasing both the modulus of elasticity and bending strength. This situation reveals that CFRP materials offer a lightweight, rapidly applicable, and effective method for strengthening wooden structures. Furthermore, the consistent performance improvement achieved with CFRP reinforcement, despite the variable properties of natural wood, demonstrates that the method is a reliable option in engineering applications. Based on these results, it can be said that CFRP strips are a suitable method that can be widely used, particularly in the restoration of historical buildings, the strengthening of existing wooden structures, and the improvement of low-strength wooden elements.

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