Gazi | AKADEMİK YAYINCILIK

GAZİ
JOURNAL OF ENGINEERING SCIENCES

Effect of the Wrapping Layers Number and Length on the Flexural Properties of Chestnut Beams Reinforced with Basalt-FRP

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Submitted: 19.11.2023 Revised: 18.12.2023 Accepted: 22.12.2023 doi:10.30855/gmbd.0705S03

Keywords: Wrapping layers number, chestnut beams, Basalt-FRP, wrapping length

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ABSTRACT

Traditional wooden structures often face deterioration due to elevated levels of humidity and temperature. When wood beams suffer dam-age, the typical approach has been either replacement or reinforcement with steel. However, there remains a pressing need to fortify and restore these structures, thus averting the necessity for demolition. The strengthening and rehabilitation of such existing wooden edifices have emerged as a focal point for numerous re-searchers. In recent times, Fiber reinforced polymers (FRP) are used in various areas such as buildings and bridges due to their ease of application, light weight, high strength and resistance to environmental effects. A multitude of researchers have successfully employed FRP composite materials in fortifying wooden members and structures. In this study, 70x70x1200 mm chestnut beams were strengthened 1, 2, 3 layers and 300 mm, 600 mm, 900 mm length with Basalt-FRP fabrics. Beams reinforced with fiber reinforced polymers were subjected to bending tests. As a result of the bending test, it was determined that the bending properties of the beam increased as the number of wraps and length increased.

Sargılama Tabaka Sayısı ve Uzunluğunun Bazalt-FRP ile Güçlendirilmiş Kestane Kirişlerin Eğilme Özelliklerine Etkisi

ÖZ

Geleneksel ahşap yapılar genellikle yüksek nem ve sıcaklık nedeniyle bozulmayla karşı karşıya kalmaktadır. Ahşap kirişler hasar gördüğünde genel olarak çelik eleman ile güçlendirme veya yer değiştirme yapılmaktadır. Yapıların güçlendirilmesi ve restore edilmesi, yıkım zorunluluğunun ortadan kaldırılması yönünde bir ihtiyaç bulunmaktadır. Bu tür mevcut ahşap yapıların güçlendirilmesi ve rehabilitasyonu birçok araştırmacının odak noktası olarak ortaya çıkmıştır. Son zamanlarda, Fiber Takviyeli Polimerler (FRP) uygulama kolaylığı, hafif olması, dayanımının yüksek olması, çevresel etkilere karşı dirençli olması sebebiyle binalar ve köprüler gibi çeşitli alanlarda kullanılmaktadır. Çok sayıda araştırmacı, ahşap elemanların ve yapıların güçlendirilmesinde FRP kompozit malzemeleri başarıyla kullanmıştır. Bu çalışmada 70x70x1300 mm kestane kirişler 1, 2, 3 kat ve 300 mm, 600 mm, 900 mm uzunlukta Bazalt-FRP kumaş ile güçlendirilmiştir. Fiber takviyeli polimerlerle güçlendirilmiş kirişler eğilme testlerine tabi tutulmuştur. Eğilme testi sonucunda sargılama sayısı ve uzunluğu arttıkça kirişin eğilme özelliklerinin arttığı tespit edilmiştir.

Anahtar Kelimeler: Sarma katmanları sayısı, kestane kirişler, Bazalt-FRP, sarma uzunluğu

To cite this article: Y. Simsek Turker, S. Kilincarslan, “Effect of the Wrapping Layers Number and Length on the Flexural Properties of Chestnut Beams Reinforced with Basalt-FRP” *Gazi Journal of Engineering Sciences,* vol.9, no.4, pp. 23-30, 2023. doi:10.30855/gmbd.0705S03

1. Introduction

Wood stands out as an exceptionally effective material, showcasing remarkable resilience under both compressive and tension loads, a quality nearly unparalleled in relation to its modest weight density [1-4]. Nevertheless, its historical reputation has not leaned towards durability, owing to its inherent characteristics. Traditionally, wooden components like beams, tasked with bearing bending loads, have often faced either substitution or fortification using conventional methods that incorporate commonplace building materials like concrete or steel [5-9].

In recent decades, various methods have been employed to reinforce wooden elements, although only a few have been successfully put into commercial use [10-12]. Nonetheless, some of these techniques have found application in fortifying existing wooden beams, particularly in cases where a complete replacement of the wooden element was not feasible, often due to a variety of reasons [13-15]. In this context, the utilization of composite materials as reinforcements for wooden elements experiencing bending loads or shear loads has garnered significant attention. This interest is further fueled by the continual advancements in FRP materials, coupled with their broader availability in diverse materials and forms [16-18]. While extensive research and development have been directed towards the utilization of FRP for reinforcing, repairing, and enhancing the performance of reinforced concrete and pre-stressed concrete structures, significantly less attention has been given to wooden and masonry structures [19]. The very nature of the material itself can necessitate reinforcement interventions for wooden elements, stemming from various factors such as an increase in dead loads, a decline in the mechanical properties of the element, or the mitigation of excessive displacements [20].

In recent times, there has been a notable surge in the utilization of FRP composites in highway bridge decks [21-23]. In particular, when employing composite materials to reinforce wood elements subjected to bending loads, it is crucial to give meticulous attention to various facets of the process. Firstly, meticulous planning of the type of intervention to be executed holds paramount importance [24-26]. This is due to the fact that there exists a multitude of techniques for reinforcing a wood element, each employing different arrangements of the FRP elements, and consequently, potentially yielding distinct outcomes [27-29]. Once a method is chosen, the subsequent phase involves the selection of the most fitting FRP elements. Given the extensive array of products and the diverse mechanical properties exhibited by FRP elements in market, designers approaching this reinforcement technique might find it challenging to make an optimal selection. FRP fabric composite materials have been used especially in strengthening wooden materials. Micelli et al. (2005) [30] investigated the possibility of attaching CFRP rods as reinforcement into glulam beams, keeping the latter case in mind. Test findings showed that adding CFRP rods improved glulam beams' ultimate capacity and stiffness by 26–82% and 8–19%, respectively. In order to assess the bond's performance. De et al. (2005) [31] performed pull-out experiments on CFRP rods that had been joined using epoxy resin and glulam components. The length of the bonded joint, the rod's surface pattern, and the direction of the wood fibers with regard to the joint's longitudinal axis were the test variables used. They used the joint test results as the basis for a local bond-slip model. Johnsson et al. (2006) [32] evaluated a total of ten specimens under four-point bending from three different series of glulam beams reinforced with rectangular pultruded CFRP bars. The experimental results were compared with analytical models in several aspects. The authors report an average improvement in the short-term flexural load-carrying capacity of 49–63%. More recently, Gentry (2011) [33] proposed the use of FRP pins positioned transversely across the plies of a glulam to reinforce wood beams in shear. The test findings show that the pinned set of glulams had a much smaller dispersion than the nonpinned specimens. Rehabilitation and repair of steel [34] and reinforced concrete [35, 36] structures. The potential to employ them to reinforce and repair timber structural components was added to these uses. One of the earliest applications for e-glass/epoxy laminates was in the mid-1990s for the restoration of shattered hardwood utility poles. Similar applications of composites have also been used to strengthen timber piles, as shown in Ref. Lopes Anido et al., 2003 [37] Hybrid glued-laminated wood articles were also produced by sandwiching thin laminates of E-glass/epoxy composite materials in between the wood layers [38]. The structural behavior of many Sitka wood beams reinforced with steel and composite materials was investigated by Gilfillan et al., 2003 [39]. Both short- and long-term mechanical stress assessments were performed on these woods. According to experimental results, adding FRP materials to frames significantly boosted their overall strength.

In studies on strengthening wooden beams with FRP, there are no studies on the bending properties of chestnut beams reinforced with basalt fiber reinforced polymers based on the number of FRP layers and FRP length. In this study, the effect of wrapping length and wrapping layer number of basalt-based fiber reinforced polymer on the bending properties of solid chestnut beams was examined. As a result of examining the bending properties, modulus of rupture and modulus of elasticity properties were determined.

2. Material and Method

For this study, chestnut wood was selected, a prevalent choice in our country for producing wood composite materials, particularly for structural applications. Solid beams, crafted from Chestnut wood (*Castenea sativa*), were employed, measuring 70x70x1300 mm in size. The chestnut beams utilized were sourced from Nasreddin Forest Products (Naswood), a company located in the Antalya Organized Industrial Region. Before the solid beams were subjected to the bending test, they were kept in the air conditioning cabin at 65% relative humidity and 25°C until the equilibrium humidity reached 12%. Beams were strengthened 1, 2, 3 layers and 200 mm, 400 mm, 600 mm length with basalt-fiber reinforced polymer fabrics. The process of reinforcing with FRP fabrics involves four main steps. Initially, the material's surface is cleaned, and then a primer is applied. Subsequently, the adhesive is applied to the surface within 1–1.5 hours after the primer application. In the last stage, fiber polymer fabrics are wrapped around the adhesive-treated surface. The basalt-based MasterBrace FIB 600/100 CFS fabrics are sourced from ÜNAL TEKNİK® Practice Construction Industry and Trade. Ltd. Sti. The properties of the tested beams are given in Table 1.

Table 1. Properties of the tested beams (RLA: Reinforcement Laye, RLE: Reinforcement Length, RFT: Reinforcement fabric type, RS: Reinforcement Status)

No	RLA	RLE	RFT	RS	Code
1	-	-	-	-	References
2	1	200	Basalt	+	1-200-R
3	2	200	Basalt	+	2-200-R
4	3	200	Basalt	+	3-200-R
5	1	400	Basalt	+	1-400-R
6	2	400	Basalt	+	2-400-R
7	3	400	Basalt	+	3-400-R
8	1	600	Basalt	+	1-600-R
9	2	600	Basalt	+	2-600-R
10	3	600	Basalt	+	3-600-R

Beams were subjected to four-point bending tests. Figure 1 shows schematic drawing of the 4-point bending test.

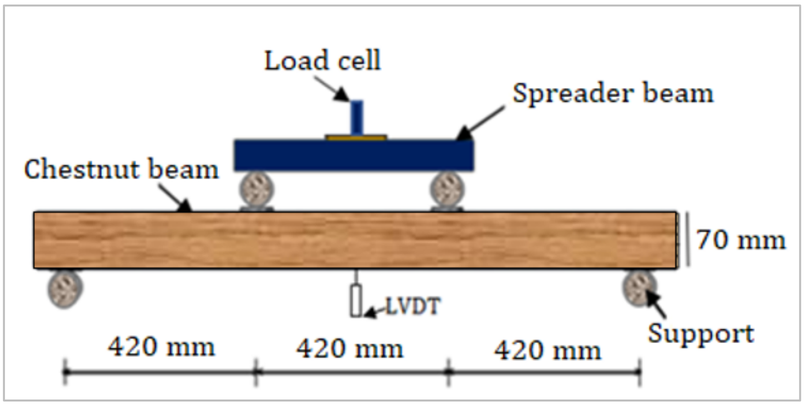

Figure 1. Schematic drawing of the 4-point bending test

The beams were subjected to testing using a 1000 kN oleo-dynamic actuator. A steel spreader beam (Figure 2) was employed to facilitate four-point bending. The distance between the two loading points was approximately one-third of the span. The tests were conducted under displacement control, with the crosshead of the electro-mechanic dynamometer or actuator moving at a rate of 5 mm/min. Bending loading persisted until either a sudden increase in loading, signifying failure, was detected by the loading instrument, or substantial damage was visually observed. In order to prevent the timber from crushing, supports and loading points, constructed from steel cylinders with a diameter of 20 mm, were utilized for beam testing. Both unreinforced and reinforced beams underwent testing following the same experimental procedure as the initial tests. This was done to ensure a fair comparison of the beam capacities. Figure 2 shows the real view of the experimental setup.

Figure 2. Bending test experimental setup

To compute the bending modulus of elasticity (MOE) and modulus of rupture (MOR), Gao et al., (2015) [40] utilized the subsequent formula:

$$\mathrm{MOE}=\frac{\Delta P\,(l-s)(2l^2+2ls-s^2)}{8\Delta y b h^3} \tag{1}$$

$$\mathrm{MOR}=\frac{3P_{max}(l-s)}{2bh^2} \tag{2}$$

In the formula below, the variables represent the following parameters:

Δy: Midspan deflection corresponding to ΔP
b: Width of the specimen
h: Depth of the specimen
P_{max}: Maximum load applied
l: Span between supports of the specimen
s: Span between loading sites of the specimen
ΔP: Difference between the upper and lower loads at the proportional limit.

3. Results and Discussion

The flexural strength and modulus of elasticity values of strengthened 1, 2, 3 layers and 200 mm, 400 mm, 600 mm length with basalt-fiber reinforced polymer fabrics chestnut beams are given in Figure 2 and Figure 3.

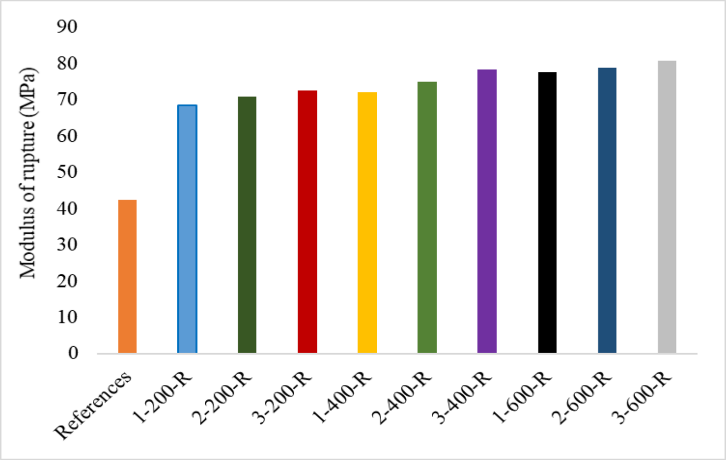

Figure 2. Experimental results of modulus of rupture

Among the beams strengthened with basalt FRP, the highest modulus of rupture value (80,70 MPa) is in the beam coded 3-600-R. The lowest modulus of rupture value (68,54 MPa) is in the beam coded 1-200-R. The modulus of rupture value of the 3-200-R coded beam is 5.60% higher than the 1-200-R coded beam and 2.52% higher than the 2-200-R coded beam. The modulus of rupture value of the beam coded 3-200-R is 41.50% higher than the reference beam. The 3-400-R coded beam is 8.20% higher than the 1-400-R coded beam and 4.40% higher than the 2-400-R coded beam. The modulus of rupture value of the beam coded 3-400-R is 45.80% higher than the reference beam. The modulus of rupture value of the 3-600-R coded beam is 2.24% higher than the 2-600-R coded beam and 3.94% higher than the 1-600-R coded beam. The beam with code 3-600-R is 100% higher than the reference beam.

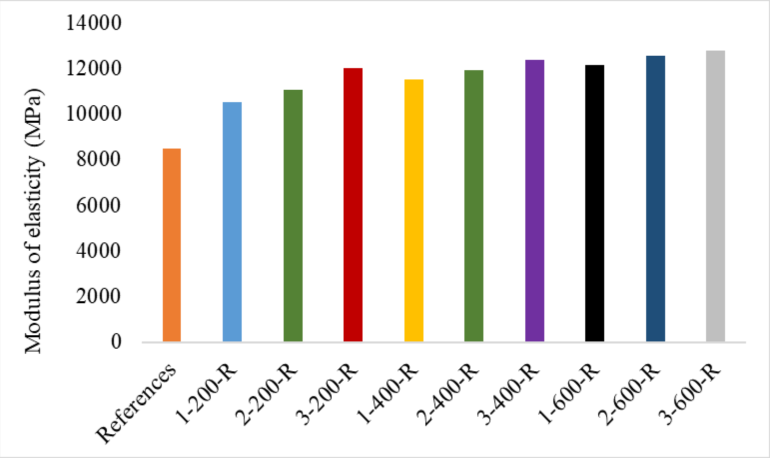

Figure 3. Experimental results of modulus of elasticity

Among the beams strengthened with basalt FRP, the highest modulus of elasticity value (12796 MPa) is in the beam coded 3-600-R. The lowest modulus of elasticity value (10506 MPa) is in the beam coded 1-200-R. The modulus of elasticity value of the 3-200-R coded beam is 7.91% higher than the 2-200-R coded beam and 12.40% higher than the 1-200-R coded beam. The beam coded 3-200-R is 29.23% higher than the reference beam. In the 3-400-R coded beam, it is 3.66% higher than the 2-400-R coded beam, and 6.96% higher than the 1-400-R coded beam. The beam coded 3-400-R is 31.49% higher than the reference beam. Among the longest wrapped beams, the 3-600-R coded beam is 1.95% higher than the 2-600-R coded beam and 5.08% higher than the 1-600-R coded beam. The beam coded 3-600-R is 33.67% higher than the reference beam. It is seen that the bending properties of the strengthened beams are improved compared to the reference beam. Flexural properties increased depending on the number and length of reinforcement layers. Pupsys et al., (2017) [41] studied 145 x 145 x 2450 mm oak wood beams treated with glass fiber reinforced polymer sheets. They found that the reinforcement improved the oak wood beams' bending characteristics. Muratoğlu (2011) [42] examined beams made of Scots pine (*Pinus sylvestris*) and Eastern beech (*Fagusorientalis* L.) wood that had been strengthened using carbon fiber-reinforced polymers. The results showed that the bending strength of the reinforced samples was 108.66 percent more. The bending characteristics of solid Fir (*Pseudotsuga menziesii Mirb.*) beams reinforced with different fiber-reinforced polymer fabric composites (flax, basalt, E-glass FRP, hybrid FRP) were examined by Wang et al., (2019) [43]. It was found that the bending characteristics of wood materials were enhanced by the fiber-reinforced polymers. After conducting an investigation on the impact of carbon-based fiber-reinforced polymer (FRP) fabric on load bearing capacity and modulus of elasticity, Kılıncarslan and Simsek Turker (2019) [44] concluded that the use of FRP fabric increases the ductility and bearing capacity of wood beams. Scots pine (*Pinus sylvestris*) beams reinforced with carbon and glass-based polymer fabrics are examined by Ling et al. (2020) [45] who report that the impact of carbon-FRP reinforcement is greater than that of glass-FRP reinforcement. Uzel et al., (2018) [46] examined the bending properties of glue laminated wooden beams produced from *Pinus Pinussylvestris*. The main variables taken into account in the study are the number of laminations, adhesive material types and reinforcement meshes used on the lamination surfaces. Within the scope of the experimental study, glue laminated beams with 90 x 90 mm beam sections and 5 and 3 lamination layers were produced. Epoxy and polyurethane adhesives were used in the lamination process. In addition, aluminum, fiberglass and steel wire meshes were used on the lamination surfaces in order to increase the adhesion strength on the lamination surface. The load-displacement responses, ultimate capacities, ductility ratios, initial stiffness, energy dissipation capacities and damage mechanisms of glue laminated beams were compared with solid beams. They determined that the highest ultimate load capacities were obtained in tests of glue-laminated beams manufactured using five laminated layers and reinforced with polyurethane glue in the direction perpendicular to the lamination surface using steel wire reinforcement meshes.

4. Conclusions

Four-point bending tests were performed to investigate flexural behavior of beams strengthened by basalt-FRP. Beams were strengthened 1, 2, 3 layers and 200 mm, 400 mm, 600 mm length with basalt-fiber reinforced polymer fabrics. Main findings are as follows:

- The beam coded as 3-200-R exhibits a 5.60% increase in the modulus of rupture compared to the 1-200-R coded beam and a 2.52% increase compared to the 2-200-R coded beam.
- The modulus of rupture for the 3-200-R coded beam surpasses that of the reference beam by 41.50%. Similarly, the 3-400-R coded beam demonstrates an 8.20% and 4.40% increase in modulus of rupture compared to the 1-400-R and 2-400-R coded beams, respectively.
- The modulus of rupture for the 3-400-R coded beam exceeds that of the reference beam by 45.80%.
- The 3-600-R coded beam displays a 2.24% and 3.94% increase in modulus of rupture compared to the 2-600-R and 1-600-R coded beams, respectively.
- The beam with code 3-600-R exhibits a 100% increase compared to the reference beam.
- The beam labeled as 3-200-R demonstrates a 7.91% increase in modulus of elasticity compared to the 2-200-R coded beam and a 12.40% increase compared to the 1-200-R coded beam.
- The 3-200-R coded beam surpasses the reference beam by 29.23%. In the case of the 3-400-R coded beam, it exhibits a 3.66% increase in modulus of elasticity compared to the 2-400-R coded beam and a 6.96% increase compared to the 1-400-R coded beam.
- This results in the 3-400-R coded beam surpassing the reference beam by 31.49%. Among the longest wrapped beams, the 3-600-R coded beam showcases a 1.95% increase in modulus of elasticity compared to the 2-600-R coded beam and a 5.08% increase compared to the 1-600-R coded beam. Consequently, the 3-600-R coded beam surpasses the reference beam by 33.67%.

When wrapped with basalt-based fiber reinforced polymers, the bending properties of solid chestnut beams increased with the increase in the wrapping length and the number of wrapping layers. It is seen that the use of basalt-based FRPs in wooden beams, which deform and lose their load-bearing properties over time, increases the load-carrying capacity of the beams.

Conflict of Interest Statement

The authors declare that there is no conflict of interest.

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** This paper was presented at the 5th International Conference on Artificial Intelligence and Applied Mathematics in Engineering (ICAIAME 2023) and the abstract was published as an e-book.*
