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Araştırma Makalesi / Research Article

Effect of Layers Number on The Bending Properties of Chestnut Glulam Beams

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Abstract

In recent years, advances in adhesive and lamination technologies have offered significant opportunities in the production of high-quality and valuable products from low-quality and non-durable cheap wood raw materials. Lamination generally refers to a multilayer material production method. The main goal of this production process is to develop and improve many properties of the created composite product, such as durability and stability. Laminated timber, called glulam, is a layered composite material formed by preparing timber fibers parallel to each other and gluing them together with the help of glue. In this study, the bending properties of solid, 3-layer and 5-layer glulam beams produced from chestnut tree species were investigated experimentally and numerically. The modulus of elasticity (MOE) of 5-layer glulam beams is 13.39% higher than 3-layer beams and 48.31% higher than solid beams. The modulus of rupture (MOR) value of the 5-layer beam is 24.21% higher than the 3-layer beam and 65.28% higher than the solid beam. There is a maximum difference of 2% between the experimental and numerical analysis results. When the results are compared, it is seen that the results are close to each other.

Keywords: Wood structure, Glulam, Chestnut beam, Bending test, Finite element analysis.

Tabaka Sayısının Kestane Glulam Kirişlerin Eğilme Özelliklerine Etkisi

Öz

Son yıllarda, yapıştırıcı ve laminasyon teknolojilerindeki ilerlemeler, düşük kaliteli ve dayanıksız ucuz ahşap hammaddesinden yüksek kaliteli ve değerli ürünlerin üretilmesinde önemli fırsatlar sunmuştur. Laminasyon genellikle çok katmanlı malzeme üretim yöntemini ifade eder. Bu üretim sürecinin temel hedefi, oluşturulan kompozit ürünün dayanıklılığı, stabilitesi gibi birçok özelliğini geliştirip iyileştirmektedir. Glulam olarak adlandırılan tabakalı lamine kereste, kereste liflerinin birbirine paralel olarak hazırlanıp tutkal yardımıyla birbirine yapıştırılmasıyla oluşturulan tabakalı bir kompozit malzemedir. Bu çalışmada, kestane ağacı türlerinden üretilen masif, 3 katlı ve 5 katlı glulam kirişlerin eğilme özellikleri deneysel ve sayısal olarak incelenmiştir. 5 katlı glulam kirişlerin elastisite modülü, 3 katlı kirişlerden %13,39 ve masif kirişlerden %48,31 daha yüksektir. 5 katmanlı kirişin eğilme dayanımı değeri, 3 katmanlı kirişten %24,21 ve solid kirişten %65,28 daha yüksektir. Deneysel ve sayısal analiz sonuçları arasında maksimum %2 fark vardır. Sonuçları karşılaştırıldığında sonuçların birbirine yakın olduğu görülmektedir.

Anahtar Kelimeler: Ahşap yapı, Glulam, Kestane kiriş, Eğilme testi, Sonlu elemanlar analizi.

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1. Introduction

Wood is a desirable material for use in the building industry because of its high strength to weight ratio, simplicity of handling and fabrication, and good aesthetic look, among other qualities (Kilincarslan and Simsek Turker, 2022; Sahin et al., 2020; Toratti and Schnabl, 2007; Yang et al., 2016; Kilincarslan and Simsek Turker, 2020a). Wood is also the naturally occurring building material that is sustainable and environmentally benign (Sütcü and Cambazoğlu, 2023; Abdulghafoor and Al-Baghdad, 2022). Due to these properties, wood material is preferred in various indoor and outdoor building constructions. There are also important disadvantages that limit the usage area of wood material (Di et al., 2022; Güray et al., 2003; Kilincarslan and Simsek Turker, 2020b; Unsal and Ayrılmıs, 2005). It is challenging to forecast how timber elements will behave when subjected to various stresses due to the variability in stiffness and strength properties of wood caused by the presence of inherent flaws and differences in growing circumstances (Ohuchi et al., 2009; Dietsch and Tannert, 2015).

Use of engineered wood products, such as glued laminated timber, could greatly eliminate these natural variances (Kilincarslan and Simsek Turker, 2021; Li et al., 2022; Buchanan and Fairweather, 1993; Shu et al., 2019). Glulam, often known as glued laminated lumber, is a remarkably cutting-edge building material (Fosetti et al., 2015; Kilincarslan and Simsek Turker, 2020c; Sena-Cruz et al., 2013; Wdowiak-Postulak, 2022). A stress-rated engineered wood beam called a "glulam" is made of study, moisture-resistant adhesives that are used to join wood laminations, or "lams," to form a single beam. The member's length is parallel to the grain of the laminations. From straightforward, straight beams to intricate, curving components, glulam is adaptable (Karayılmazlar et al., 2007). Many studies have been conducted on the properties of glulam beams from past to present. The type of wood, the faults it contains, the number and thickness of layers, the type of glue used, and the compression force applied during pressing all have an impact on the qualities of laminated wood products. Evalina et al. (2010) examined the properties of glued laminated beams made of plantation timbers, African wood, and Mangium and discovered that they performed satisfactorily in accordance with JAS 234:2003. Indah et al. (2008) assessed the Acacia Mangium glulam beam's performance using varying lamina thicknesses and discovered that the flexural characteristics of glulam beams with 20 mm thick laminas were poorer than those of beams with 15 mm and 10 mm thick laminas. Wan et al. (2011) examined the bending strength characteristics of glued laminated wood from particular Malaysian hardwood timber and compared the results with JAS 234:2003. They discovered that the results were good. The mechanical characteristics of three-layer glulam beams (83 × 68 × 1100 mm) manufactured of Norway spruce were examined by Kržišnik et al. (2020). Research has indicated that in the case of untreated samples, after two years of exposure to the outdoors, some faint indications of fungal decomposition were seen. Furthermore, a decline in shear strength and an increase in polyurethane bond line delamination impacted glulam's overall performance.

Chestnut *(Castanea sativa*) grows in areas with good drainage, especially in the humid-temperate broadleaf forest zone of the Black Sea region in Turkey. Chestnut fields are under a great human pressure, as chestnut timber has been used extensively by human beings for centuries to make goods and tools. Chestnut timber is valuable and preferred for its durability. Chestnut wood has a very fine texture, medium hardness and weight. It splits easily, is flexible and its unit weight is quite high compared to other wood species (Atasoy and Altıngöz, 2011). The bending characteristics of solid, 3-layer and 5-layer chestnut glulam beams constructed from various kinds of chestnut trees were examined experimentally and numerically in this study. Therefore, it is intended to look at how the chestnut glulam beam's bending characteristics are affected by the number of layers.

2. Materials and Methods

2.1. Preparation of Beams And Experimental Method

Chestnut (*Castenea sativa*) wood type glulam beams measuring 100 mm (b) x 150 mm (h) x 2700 mm (L) were used in solid, 3-layer and 5-layer arrangements. The layer thickness is set to 50 mm for 3-layer beams and 30 mm for 5-layer beams. Melamine formaldehyde glue was used as the glue type between the layers. Melamine resins can harden at temperatures between 90-140 °C without any hardening agent. In the bonding of the lamellas, the instructions for use of the glue manufacturer company were followed. The glue was applied to only one of the opposing lamella surfaces with a brush and at ~180 gr/m^2 calculation. The bonding process involved applying pressure of approximately 1-2 N/mm^2 by compressing the lamellas from three different points using a torture. The compressed drafts were left at room temperature for 24 hours to ensure the glue hardened properly. The study focuses on chestnut wood species, which is extensively utilized in the production of wood composites, particularly for structural purposes. Prior to conducting the bending test, the glulam beams were conditioned in an air-tight cabinet at 65% relative humidity until they reached an equilibrium moisture content of 12% at 25°C. In Figure 1, the cross-sectional view of the beams under bending test is given schematically.

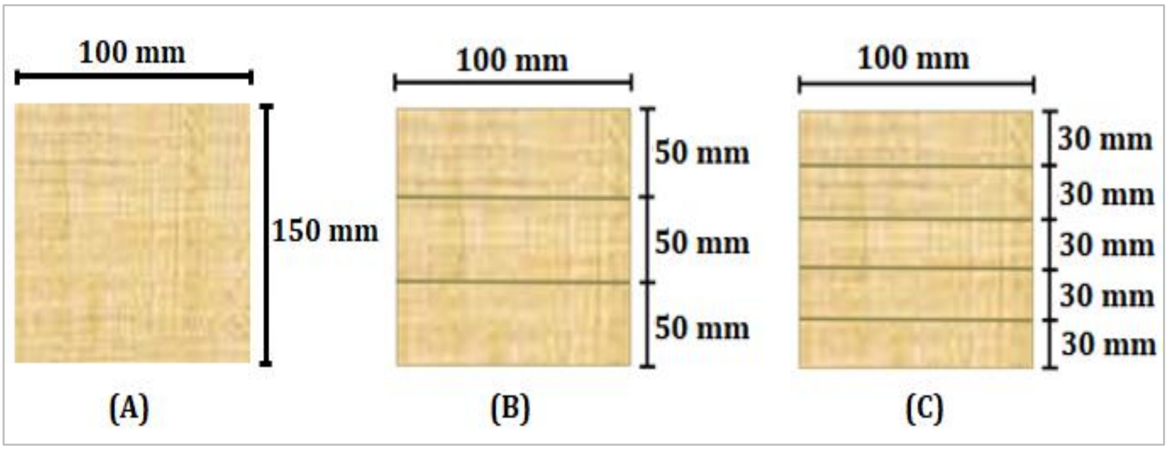

Figure 1. The cross-sectional view of the beams, (A); Solid (B)3-Layer, (C); 5-Layer.

Based on GB/T 26899-2011, a static four-point load bending test (bending test Method A) was conducted with a loading speed of 8 mm/min. Each specimen had an LVDT (Linear Variable Differential Transformer) sensor installed in the middle. The schematic and real view of the experimental setup is given in Figure 2.

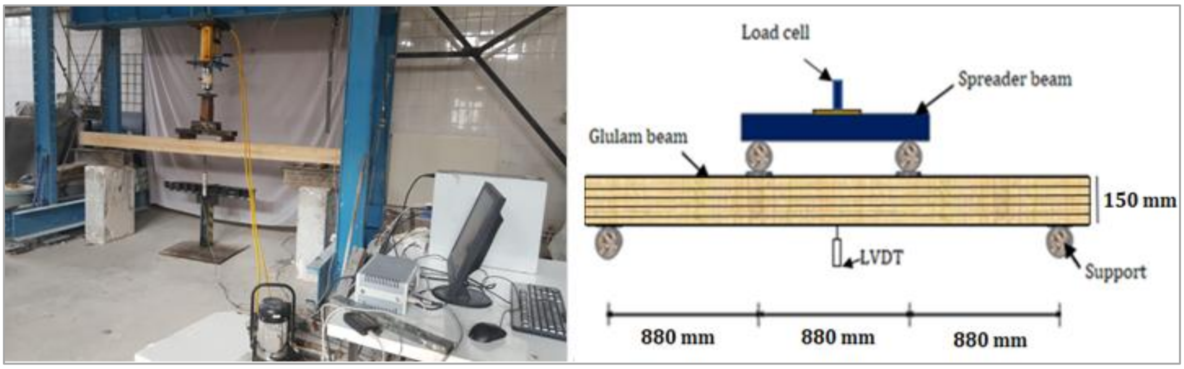

Figure 2. Schematic and real view of the experimental setup.

The following Equation is used to determine the MOE for bending and MOR (Gao et al., 2015):

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

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

Where Δy is the corresponding midspan deflection of ΔP, b is the specimen's width, h is that it is the depth, and P_{max} is the maximum load, l is the specimen's span between supports, s is that it is the span between loading sites, and ΔP is the difference between the upper and lower loads at the proportional limit.

2.2. Finite Element Analysis

The finite element analysis program ANSYS 2022 R2 is used to numerically model and analyze the wooden beams. The timber was modeled using the element SOLID45 which is used for the 3-D modeling of solid elements. The solid element has eight nodes with three degrees of freedom for each node: translations in the nodal x, y, and z directions. SOLID45 has plasticity, stress stiffening, large deflection, and large strain and some other abilities node. Simulating the intricate anisotropic behavior of timber with high precision proves to be impractical. To model timber behavior, the software defines the elastic properties of timber in an orthogonal format. Chestnut glulam beams with solid, 3 and 5 layers were modeled in ANSYS Finite Elements software as shown in Figure 3.

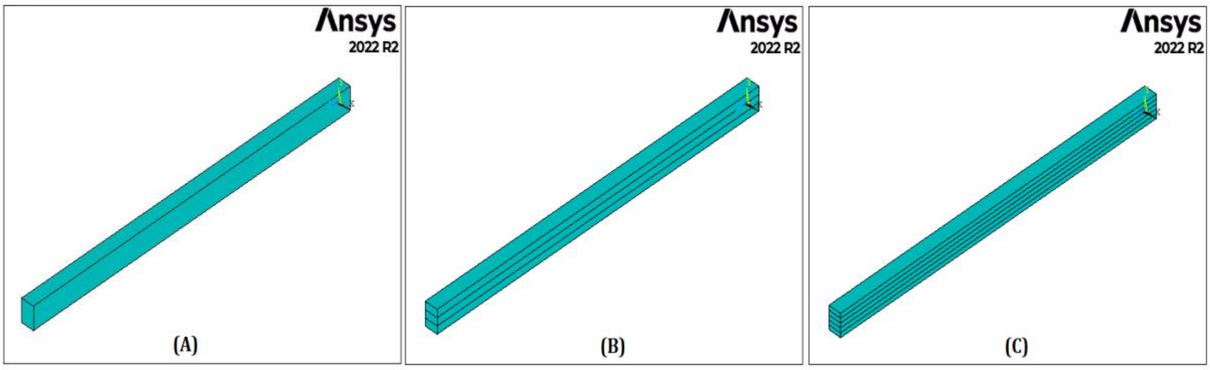

Figure 3. Modeling in ANSYS Finite Element software program (A) Solid wood, (B)3-Layer glulam, (C) 5-Layer glulam.

In numerical analysis, wood is commonly represented as an orthotropic material, owing to its anisotropic nature caused by knots and defects. Engineering parameters such as shear modulus (Gxy, Gxz, Gyz), Poisson's ratio, and MOE in the longitudinal, radial, and tangential directions (Ex, Ey, and Ez) are employed to characterize wood's behaviors. The material properties of wood were derived from the authors' research and documented literature. Following the material definition, the loads and supports are specified, and then the meshing process is carried out. A 25 mm square mesh is employed in the modeling phase.

3. Findings and Discussion

The bending properties of solid, 3-layer and 5-layer beams were investigated experimentally and numerically. Analysis results of beams modeled with finite element software are given in Figure 4.

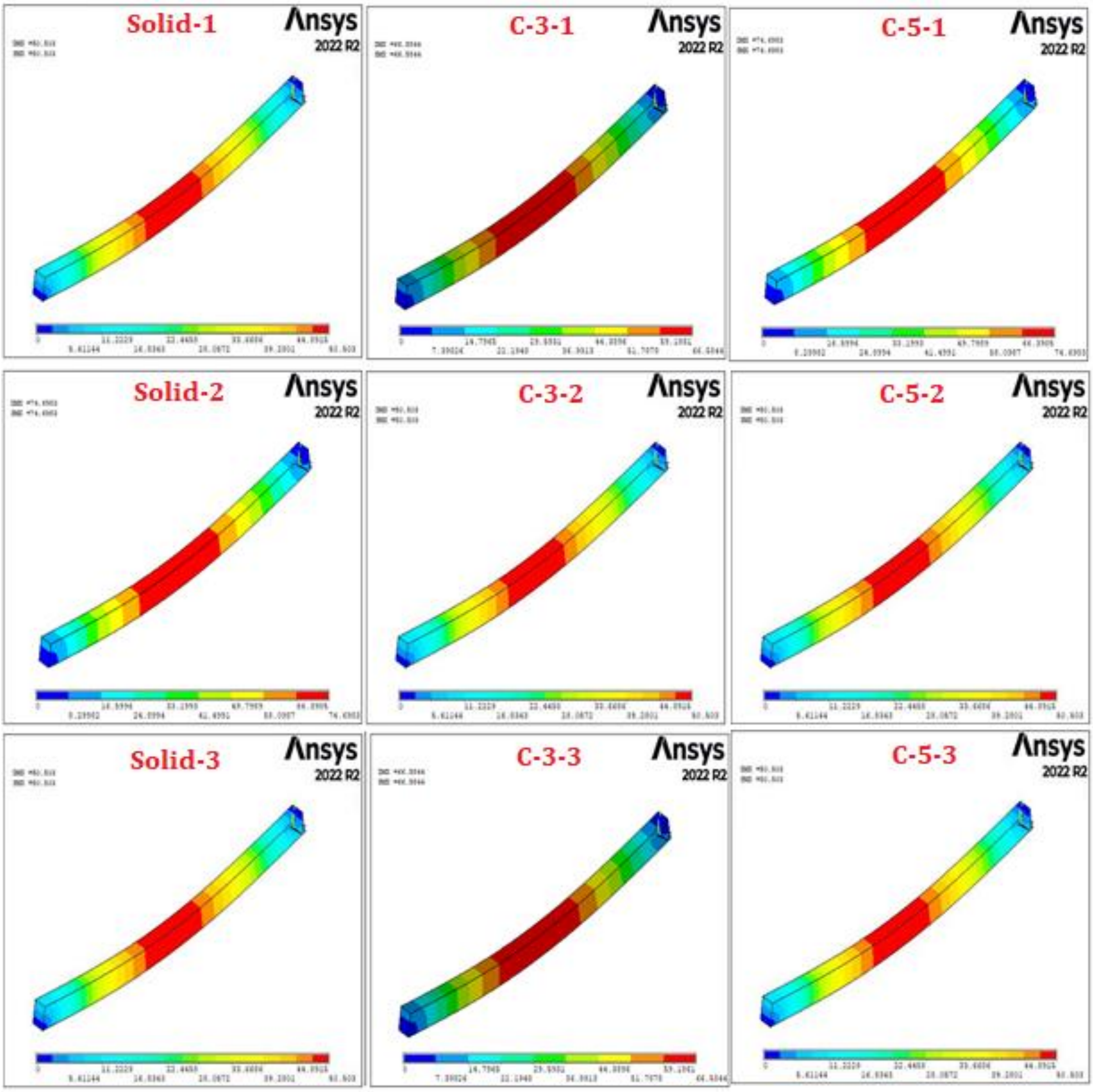

Figure 4. FEM analysis results (A) Solid wood, (B)3-Layer glulam, (C) 5-Layer glulam.

As a result of the experiments, load-displacement curves were obtained. Load-carrying capacity and maximum displacement amounts were examined from the load-displacement curves. 3 replications were made from the beam belonging to 1 series. Maximum load bearing capacity of 5-layer glulam beams is average 24.12 % higher than 3-layer beams and 65.28 % higher than solid beams. The displacement amount of the 5-layer beam is average 12.5 % higher than the 3-layer beam and average 32.80% higher than the solid beam. Figure 5 and Figure 6, MOE and MOR values obtained as a result of experimental and numerical analysis are given.

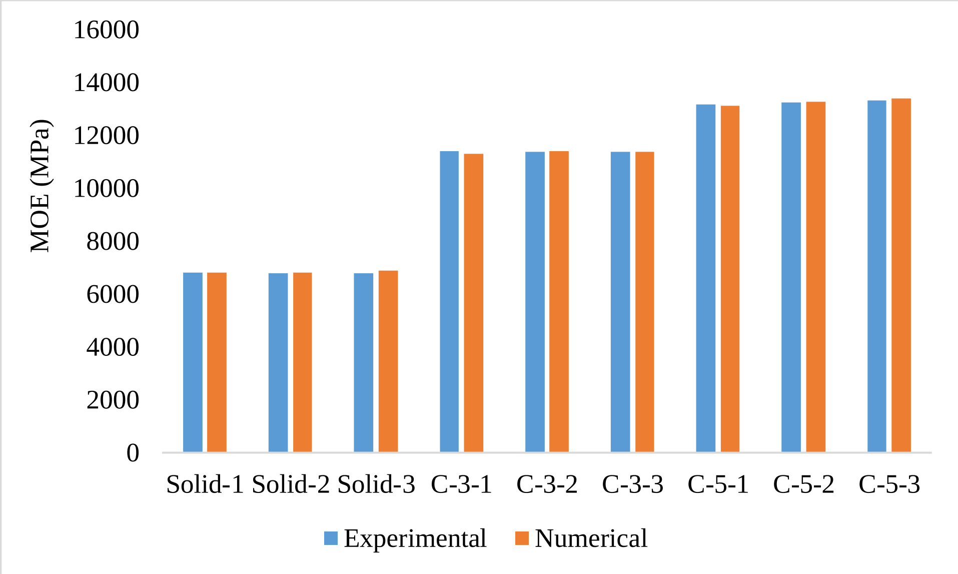

Figure 5. Experimental and numerical results of MOE.

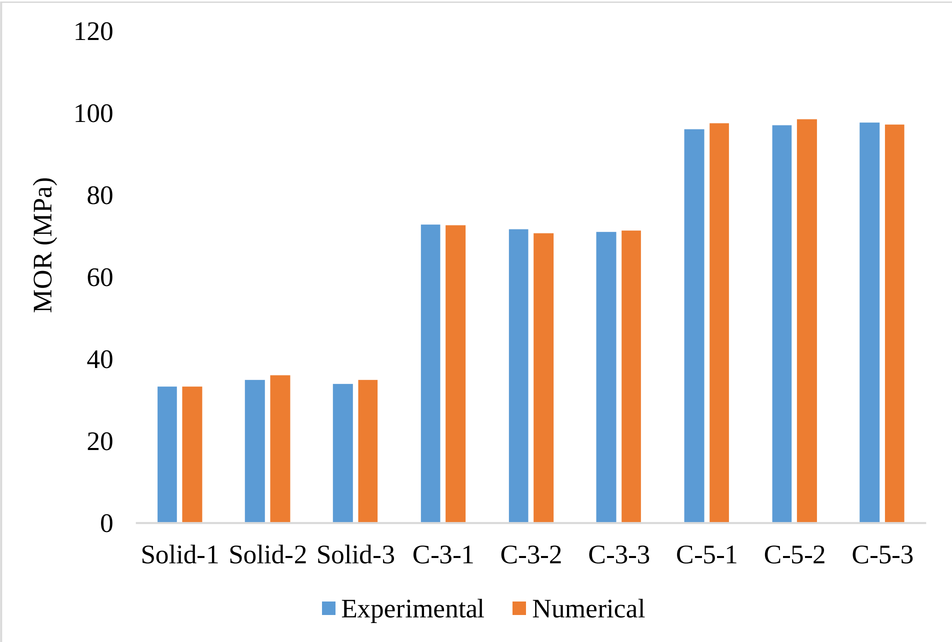

Figure 6. Experimental and numerical results of MOR.

The MOE of 5-layer glulam beams is 13.39% higher than 3-layer beams and 48.31% higher than solid beams. MOR value of 5-layer beam is 24.21% higher than 3-layer beam and 65.28% higher than solid beam. When the ANSYS and experimental analysis results were compared, the modulus of elasticity of the 5-layer beam was determined as 13241 MPa experimentally and 13256 MPa as a result of the numerical analysis. The modulus of elasticity of the 3-layer beam was determined as 11384 MPa experimentally and 11358 MPa as a result of the numerical analysis. The MOE of the solid beam was determined as 6791 MPa experimentally and 6836 MPa as a result of the numerical analysis. The modulus of rupture value of the 5-layer beam was determined 97.01 MPa as experimentally, and 97.75 MPa as a result of numerical analysis. The MOR value of the 3-layer beam was determined experimentally 71.84 MPa, and as a result of the numerical analysis 71.54 MPa. The modulus of rupture value of the solid beam was determined as 34.12 MPa experimentally, and 34.75 MPa as a result of the numerical analysis. The data obtained as a result of the experimental and numerical studies are compatible with each other.

4. Conclusions and Recommendations

The bending characteristics of solid, 3-layer and 5-layer glulam beams constructed from various kinds of chestnut trees were examined experimentally and numerically in this study. Therefore, it is intended to look at how the chestnut glulam beam's bending characteristics are affected by the number of layers. These following results have been concluded:

1. When solid and glulam beams are compared, the bending strength and modulus of elasticity values of glulam beams increased significantly compared to solid beams.
2. The increase in the number of layers increased the load carrying capacity and displacement of the beams.
3. The data obtained as a result of the experimental and numerical studies are compatible with each other. There is a maximum difference of 2% between the experimental and numerical analysis results.
4. The bending strength and modulus of elasticity values increased with the increase in the number of layers.
5. Although the section size remains the same, it is seen that the bending properties of the beams can be improved by simply increasing the number of layers. Load bearing capacity is high in glued laminated timbers, so it is more advantageous to use in wooden structures.

Authors' Contributions

All authors contributed equally to the study.

Statement of Conflicts of Interest

There is no conflict of interest between the authors.

Statement of Research and Publication Ethics

The authors declare that all the rules required to be followed within the scope of "Higher Education Institutions Scientific Research and Publication Ethics Directive" have been complied with in all processes of the article, that The Black Sea Journal of Science and the 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 The Black Sea Journal of Science.

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