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Experimental and Numerical Investigation of Bending Properties of Crimean Pine Glulam Beams

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Abstract – Wood is one of the oldest building materials used by mankind. The disadvantages of wood material such as durability and very variable properties can be reduced by lamination technology. Layered timber technology is one of the rational methods that produces added value in wood material. Due to its high mechanical properties and less variable physical properties in the construction sector, laminated timber is used in sports halls, bridges, commercial areas as an alternative building material to traditional building materials. In general, the outer layers are produced from wood material with better mechanical properties, and the inner layers using wood material with low mechanical properties. Species such as Douglas fir (*Pseudotsuga menziesii*), Southern pine (*Pinus* spp.), Hybrid (*Larix occidentalis*), Spruce (*Picea* spp.) are used in the production of laminated timber in the USA. In Europe, Norway spruce is mostly seen in laminated timber production. In this study, bending properties of 5-layer glulam beams produced from Crimean Pine wood were investigated. The beams were subjected to a 3-point bending test. As a result of the bending test, the maximum load carrying capacity, bending strength and modulus of elasticity of the beams were investigated. After the experimental study, the beams were modeled and analyzed in the ANSYS end-element software program. Experimental results and finite element modeling analysis results gave close values.

Keywords – Wood Materials, Reinforcement, Glulam, Crimean Pine

I. INTRODUCTION

Wood, an ancient and well-known construction material, stands as the sole naturally renewable resource for building. Throughout centuries, it has been employed in constructing residences, structures like bridges and waterfront facilities, poles, frames, electric and telecommunication lines, and various other applications [1,2]. This material has gained immense popularity in lightweight construction due to its simplicity in crafting, lightweight nature, reusability, and compatibility with the environment. In today's context, wood continues to hold significance for engineers, architects, and builders due to advancements in technology [3]. Technological progress has extended the longevity of wood, ushered in an array of innovative wood-based products like particleboard, plywood, and other panel materials, significantly improved bonding through advanced laminating techniques, and enhanced the load-bearing capacity of fasteners. While the construction market has seen an influx of wood-derived products in recent decades, with many finding widespread usage, wood's primary form is still lumber – pieces cut from tree trunks. Fully grown trees, mainly those with needle-like leaves, provide the structural timber source. When these trees are felled, the trunk becomes a log from which timber is sawn. As with other construction materials, wood products, lumber included, come in various grades and standardized dimensions [4-7].

Glulam is typically produced from lumber containing a moisture content ranging from 10% to 16%. It often exhibits a natural camber or upward deflection. When crafted with a moisture content below 12% and employed in environments maintaining the same moisture level, glulam experiences minimal shrinkage and swelling. Conditions are considered dry when the moisture content during use remains under 16%. Conversely, a wet usage scenario involves a moisture content exceeding 16%. However, glulam is rarely employed in wet conditions [8].

Strength attributes of glulam demonstrate greater potency along the longitudinal axis and relatively reduced strength across the transverse direction. Manufacturers tend to position high-grade lumber on the surface layers (top and bottom) while reserving lower-grade lumber for the central portion (near the neutral plane). Effective joints (interconnecting lumber pieces within a lamination) are either scarf or finger type, with strength-reducing joints and knots strategically staggered. Laminating facilitates precise material placement of varying quality within the member's cross-section. By positioning the most robust material where stresses are most pronounced (typically near the top and bottom for flexural members), overall member performance can be elevated. Laminating also affords uniform distribution of lumber defects along the member's entire length [8-9]. In this study, bending properties of 5-layer glulam beams produced from Crimean Pine wood were investigated experimentally and numerically.

II. Materials and Method

For this investigation, we utilized glulam beams made from Crimean Pine (*Pinus nigra*) wood. These beams were carefully crafted to possess dimensions of 100 mm (width) x 100 mm (height) x 2400 mm (length), and they were arranged in a configuration consisting of five layers. Each layer had a uniform thickness of 20 mm. To bond the lamellas together, we employed melamine formaldehyde glue, adhering strictly to the precise instructions furnished by the adhesive manufacturer. The application of the glue was meticulously carried out, targeting only one of the opposing surfaces of the lamella. This application was achieved using a brush and resulted in an estimated coverage of approximately ~180 gr/m^2.

During the phase of adhesive bonding, controlled compression was exerted on the lamellas at three specific points, expertly managed through the use of a clamp. Subsequent to this compression stage, the assembled beams were diligently kept under room temperature conditions for a duration of 24 hours. This period was essential to ensure the comprehensive and thorough solidification of the adhesive substance.

Crimean pine (*Pinus nigra*), recognized as one of the most valuable and extensively distributed tree species, holds a significant presence across Turkey, encompassing a vast forest area of around 4.4 million ha. Within this context, the Kastamonu Regional Directorate of Forestry (RDF) stands as a notable example, boasting an exceptional region that spans 1.24 million ha of forested land, constituting approximately 65% of the entire expanse. Furthermore, the region is adorned with approximately 228 thousand ha of productive, homogeneous Crimean pine stands that exude vitality [10].

Distinguished by its adaptability, the Crimean pine thrives as a tree species capable of withstanding both warm and cold climates, while also exhibiting a resilient disposition towards soil preferences. This remarkable species demonstrates an extensive range of ecological tolerance that surpasses that of numerous other counterparts, enabling it to naturally flourish across diverse ecological landscapes. The Crimean pine beams used in the study were provided by Nasreddin Forest Products (Naswood) in Antalya Organized Industry. Before subjecting the glulam beams to the bending test, they were conditioned in an air conditioning cabinet at 65% relative humidity and 25°C until the equilibrium humidity reached 12%. In this study, bending properties of 5-layer glulam beams produced from Crimean Pine wood were investigated. In accordance with the standard GB/T 26899-2011, a static four-point load bending test (Method A) was performed at a loading speed of 8 mm/min. To monitor the deformation, an LVDT (Linear Variable Differential Transformer) sensor was placed at the center of each specimen.

In order to calculate the modulus of elasticity (MOE) for bending and modulus of rupture (MOR), Gao et al. (2015) [11] employed the following equation:

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

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

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.

For numerical analysis, the ANSYS 2022 R1 Standard Solver software package is harnessed alongside the finite element method. The chosen model geometry and loading arrangements closely mirror those of the experimentally examined beams. The terminal conditions, acting to constrain vertical displacement of the beam, are emulated as pinned and roller supports within the model. A 25mm rectangular mesh intricately weaves the modeling process. In representing the timber, the SOLID45 element is employed, designed for the three-dimensional depiction of solid components [12].

III. Results and Discussion

Experimentally and numerically determined modulus of rupture and modulus of elasticity values of 5-layer pine glulam and solid beam are given in Fig. 1 and Fig. 2.

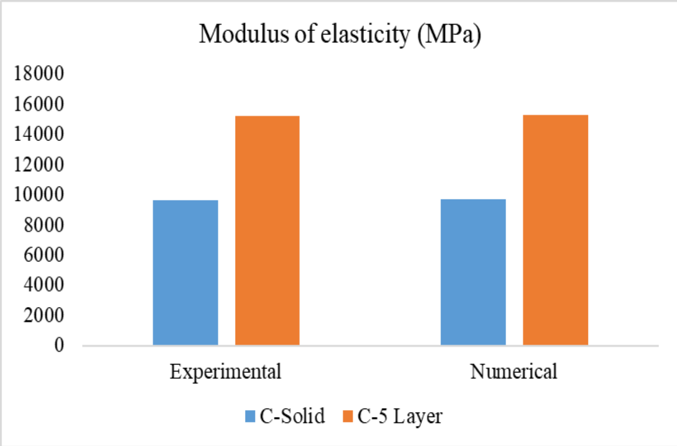

Fig. 1. Results of modulus of elasticity

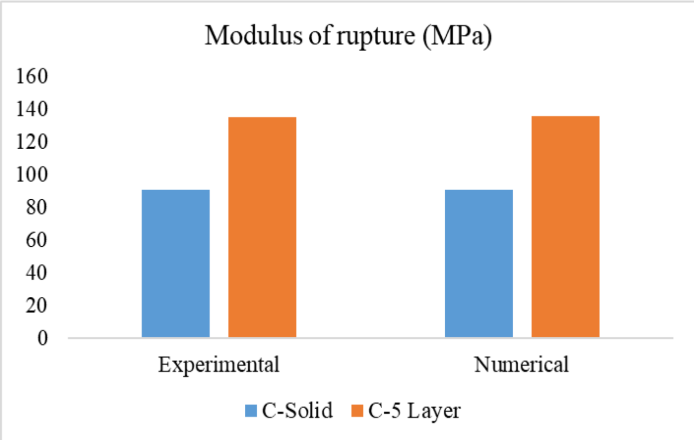

Fig. 2. Results of modulus of rupture

As a result of this study, it was determined that the modulus of rupture value was 33 % higher in the 5-layer beam than in the solid beam. When the modulus of elasticity values was examined, it was determined that the modulus of elasticity of the 5-layer beam was 37 % higher than that of the solid beam. When the experimental and numerical analysis results were compared, it was seen that they gave values close to each other.

IV. Conclusion

In this study, bending properties of 5-layer glulam beams produced from Crimean Pine wood were investigated. Upon conclusion of this investigation, findings unveiled that the 5-layer beam exhibited a remarkable surge of modulus of rupture value in comparison to the solid beam counterpart. Scrutiny of the modulus of elasticity values further accentuated this trend, revealing that the 5-layer beam surpassed the solid beam by an impressive in terms of modulus of elasticity. In this study, it is observed that the bending properties of glulam beams produced with larch wood species have improved significantly compared to solid beams. Therefore, it is thought that the bending properties of the beam can be increased by producing glulam from wood species with low mechanical properties.

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