# Mechanical Properties of 9-layer Laminated Pine Wood Veneers Reinforced with Various Materials

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The bending strength and compressive strength properties of wooden laminated elements reinforced with various materials were investigated in this study. Veneers with 9 layers were prepared from Scots pine (*Pinus sylvestris* L.) wood, which is used extensively in Turkey. The veneers were glued with PVAc-D3 adhesive by placing support elements (PVC plastic mesh, fiberglass/PVC mesh, and aluminum wire mesh) between them. The density, bending strength perpendicular to the glueline and bending strength parallel to the glueline were determined in the specimens prepared in conformance with the TS 5497 EN 408 (1998) standards. All of the support materials increased the bending resistances of the specimens. The highest bending strength and compressive strength was obtained in the specimens reinforced with aluminum wire mesh, whereas, the lowest bending strength was obtained in the control specimens and the lowest compressive strength was obtained in the specimens reinforced with fiberglass/PVC mesh.

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## INTRODUCTION

Wood, a sustainable building material, is an engineering material widely used in interior and exterior decoration applications due to its superior properties, such as ease of processing, low energy consumption during processing, availability in various colors and patterns, and low sound and heat conductivity (Laboratory 1974; Kopač and Šali 2003; Aydın and Çolakoğlu 2005; Söğütlü *et al.* 2016). Despite its many advantages, wood also has some disadvantages such as hygroscopicity, heterogeneity, and size limitations (Ali *et al.* 2021).

Effective results have been obtained in the studies for reinforcing laminated wood, which is being used more extensively with the passage of time in the wooden construction and furniture industry, with some non-wood materials. Especially, the use of polymers with fiber additions has provided significant advantages from the aspect of performance and economy (Taheri *et al.* 2009; Şeker 2011).

After reviewing the literature, different studies were observed related to composite laminated wood obtained by reinforcing with various materials. Togay and Ergin (2014) stated that in the Scots pine laminated specimens reinforced using fiberglass/PVC mesh and PVAc-D3 and Desmodur-VTKA adhesives, the fiberglass/PVC mesh decreased the bonding resistance and increased the bending, modulus of elasticity and compressive resistance. Borri *et al.* (2005) stated that as a result of reinforcing wooden beams with fiber reinforced polymers (FRP) that were under four point bending loads, their elasticity and bending resistance increased. Gezer and Aydemir (2010) stated that fir and pine materials reinforced with carbon fiber reinforced polymer (CFRP) materials increased the compressive and bending strength. Bal (2014) studied poplar laminated veneer lumber (LVL) produced using phenol formaldehyde adhesive and reinforced LVL (RLVL) produced by inserting woven glass fibers between the veneer sheets, and the results showed that density, impact bending, and shear strength increased. Li *et al.* (2009) stated that wood beams reinforced with carbon fibers had enhanced flexural performance. Ribeiro *et al.* (2009) studied glued laminated wood beams of maritime pine wood with glass fibers and pultruded lamellas, and the results showed that in the modulus of rupture (MOR) values of beams reinforced with fiberglass increased. Ergin (2011) stated that the use of materials other than wood in wood lamination applications has been continuously increasing and constitutes a critical search for better results using economical products in lamination that increase the technical characteristics of wood. Ulaşan *et al.* (2023) reported that reinforcing laminated wood material with steel wire has a strength-enhancing effect and suggested using 50-mesh steel wire to improve mechanical properties.

When reinforcement by non-woody materials is evaluated within the scope of the literature, it can be noted that the approach has been targeted to have positive developments in the properties of wood by supporting it with different materials. Also, it is of importance to determine more economical and more easily found materials in the manufacture of reinforced laminated wood.

Laminated wood materials have become indispensable in the furniture and timber construction industries, offering a sustainable and high-performance alternative to traditional structural components. The significance of laminated elements is further amplified when reinforced with various materials. In the furniture sector, these advancements allow for slimmer, more aesthetic designs without compromising structural integrity, while in the construction industry, reinforced glulam members enable the realization of complex, large-scale architectural spans that were previously only possible with steel or concrete. Consequently, the integration of reinforced laminated timber is a critical driver for innovation, promoting eco-friendly building practices and superior mechanical efficiency in modern engineering applications

This study aimed to produce wood composite materials reinforced with plastic, fiberglass/PVC mesh, and aluminum wire mesh for the furniture and wood construction industry, to determine some technical properties of these materials, and to make recommendations for the use of these products.

## EXPERIMENTAL

### Materials

*Wood material*

Scots pine (*Pinus sylvestris* L.), which is used extensively in the wooden furniture manufacturing and construction sector, was used as a paper veneer wooden material. The veneers were obtained with the random method from the manufacturing enterprises. The veneers were kept in a climatization chamber with a temperature of 20 ± 2 ºC and relative humidity of 65 ± 5% until they reached a moisture content of 12%.

*Support materials*

Plastic-based mesh, fiberglass/PVC mesh, and aluminum wire mesh were used as support materials between the lamellae (Fig. 1).


**Fig. 1.** Support materials: a) Plastic mesh; b) Fiberglass/PVC mesh; c) Aluminum wire mesh

*Plastic mesh*

It is a material with 4.5 mm between pores, filament thickness of 0.18 mm, weight of 130 g/m², a roll length of 25 m and roll widths of 80–100–120 cm. This material is a PVC (polyvinyl chloride) based plastic material. It is generally used to prevent putty and plaster cracks. The breaking extension of the plaster meshes does not exceed 4%. It is resistant to alkalis, acids and bases (SGT Producer Firm Text 2012).

*Fiberglass/PVC mesh*

The fiberglass/PVC mesh is a material with 1.2 mm between pores, filament thickness of 0.28 mm, weight of 125 g/m², 35% fiberglass – 65% PVC (polyvinyl chloride), can be found in black and gray colors, and roll widths of 60–80–100–120–150 cm. The fiberglass/PVC meshes are used in the manufacture of doors, windows, and tents, in the filter industry and for decoration purposes. It is resistant up to a temperature of 90 ºC. It does not wrinkle and is flexible (SGT Producer Firm Text 2012).

*Aluminum wire mesh*

The aluminum wire mesh is a material with 1.2 mm between pores, wire thickness of 0.20 mm, weight of 135 g/m², a roll length of 30 m and roll widths of 80–100–120–150 cm. Aluminum wires are used extensively as materials under plaster in the construction sector, in the filter industry, and in openings. Furthermore, this wire has a rustproof property. It does not lose this property when in contact with water (Sivas Nalburiye Producer Firm Text 2011).

*Adhesive*

In the study, the single component polyvinyl acetate (PVAc-D3), which is an adhesive called Klebit 303 by the German Kleiberit Company, was used. According to the BS EN 204 (2001) standard, Klebit 303, as a single component, is marketed ready for use in the D3 service class. The technical specifications of the adhesive: density of ~1.12 g/cm$^3$, 13,000 ± 2000 MPa viscosity at 20 °C, 6 to 10 min open time, 0.1 to 1 N/mm$^2$ compression pressure, period of pressure 15 min at 20 °C, and period of complete hardening 7 days (Örs *et al.* 2004; Sögütlü and Döngel 2007).

*Preparation of the test specimens*

Scots pine veneers with a thickness of 2 mm that had been climatized were spread with PVAc-D3 adhesive (180 g/m$^2$) and by placing the support materials (plastic mesh, fiberglass/PVC mesh, aluminum wire mesh) between each layer, draft specimens with 9 layers were prepared. The draft specimens were bonded by being cold pressed under a pressure of 12 kg/cm$^2$ for a period of 8 h (Fig. 2).

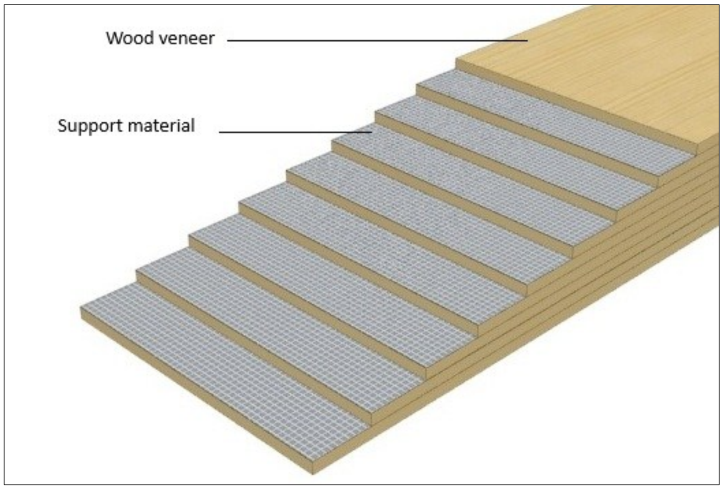


**Fig. 2.** Process of reinforced wooden laminated composites

The numbers and measurements of the specimens, which are given in Table 1, were prepared from the laminated materials manufactured in accordance with the TS 5497 EN 408 (1998) standard.

**Table 1.** The Numbers and Measurements of the Specimens

| Type of Test | Control | Composite | | | Total | Dimensions (mm) |
|---|---|---|---|---|---|---|
| | | Plastic | Fiber | Aluminum | | |
| Density | 10 | 10 | 10 | 10 | 40 | 20 x 20 |
| Bending Strength Perpendicular to Glueline | 10 | 10 | 10 | 10 | 40 | 430 x 20 x 20 |
| Bending Strength Parallel to Glueline | 10 | 10 | 10 | 10 | 40 | 430 x 20 x 20 |
| Compressive Strength | 10 | 10 | 10 | 10 | 40 | 20x20x120 |

The specimens prepared were kept in a climatization chamber with a temperature of 20 ± 2 °C and a relative humidity of 65 ± 3% until they reached an unchanging weight (approximately 3 weeks) and the initial moisture differences were eliminated.

## Methods

*Density*

The dimensions in three each directions of the specimens kept in an environment with a temperature of 20 ± 2 °C and a relative humidity of 65 ± 3% until they reached an unchanging weight were determined with a micrometric digital compass with a sensitivity of ± 0.01 mm and a digital scale with a sensitivity of ± 0.01 g. Accordingly, the air-dried densities were calculated with the equation given below:

$$\delta = \frac{M}{V} g/cm^3 \tag{1}$$

where $\delta$ is density (g/cm$^3$), $M$ is air-dried weight (g), and $V$ is air-dried volume (cm$^3$).

*Bending strength*

The TS 5497 EN 408 (1998) standards were complied with for the bending strength test. In the bending strength experiments perpendicular to the glueline and parallel to the glueline, the distance of 390 mm between supports that was approximately 19-fold the thickness was arranged, whereas, the distance between loading points was arranged at 130 mm. The loading was applied with a fixed speed and was realized in a symmetric manner where the greatest load between the two bending points would be reached between 3 to 7 min (Fig. 3).

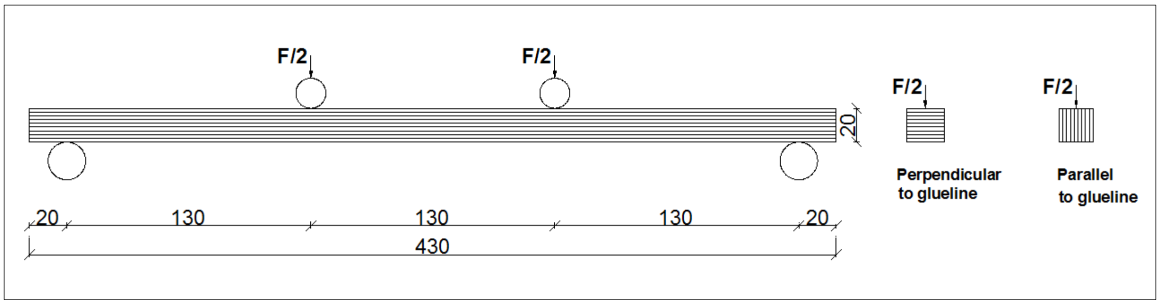


**Fig. 3.** Bending strength of the test specimens (measurements in mm)

Accordingly, the bending strength was calculated with Eq. 2 given below,

$$\sigma_E = \frac{3}{2} \cdot \frac{F(L_s - L)}{b.h^2} \tag{2}$$

where $\sigma_E$ is bending strength (N/mm²), $F$ is the force at break (N), $Ls$ is distance between supports (mm), $L$ is distance between the F/2 forces applied (mm), $b$ is width of piece (mm), and $h$ is the height of piece (mm)

*Compressive strength*

The TS 5497 EN 408 (1998) standards were complied with for the compressive strength test. Accordingly, it was provided that the end surfaces of the test pieces were smooth, parallel to each other, and perpendicular to the axis of the test piece. For this purpose, a total of 40 samples were prepared for the control and three types of reinforcement material (Fig. 4). The application for the bending resistance experiment was made the same, but was realized in the form of loading from a single point.

Accordingly, the compressive strength was calculated with Eq. 3,

$$\sigma_C = \frac{F\max}{A} \tag{3}$$

where $\sigma_C$ is compressive strength (N/mm²), $Fmax$ is maximum load (N), and $A$ is area (mm²).

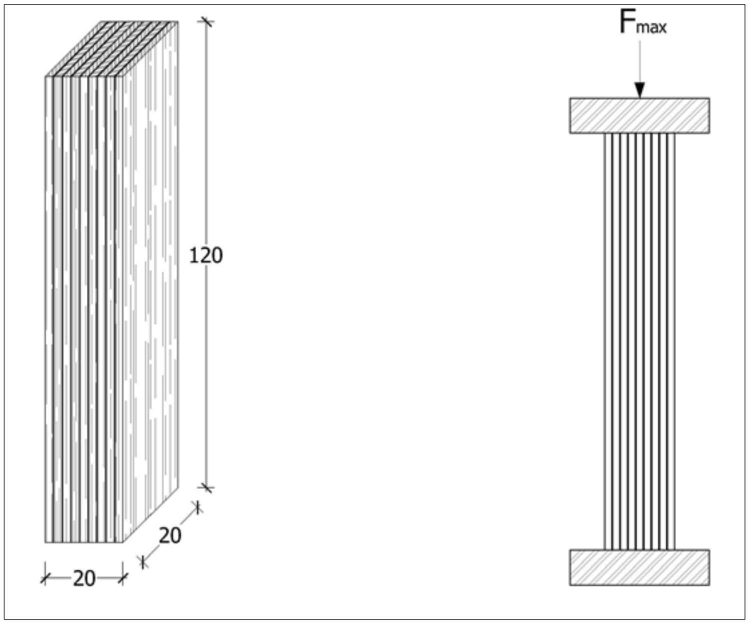


**Fig. 4.** Compressive strength of the test specimens (measurements in mm)

*Numerical analysis of experimental testing*

The finite element analysis (FEM) method was used for the numerical analysis of the experimental results. For this purpose, four-point bending analysis was performed on samples reinforced with three different support materials in the directions perpendicular and parallel to the glueline (Fig. 5). The academically licensed Ansys 2025 software was used in the analyses. Scots pine material was defined as anisotropic plasticity, while other interlayers were defined as isotropic from the Ansys library. The mechanical properties of Scots pine wood material are given in Table 2. These values were synthesized from the findings of different studies in the literature (Güntekin 2023; Pencik 2015; Akter *et al.* 2025). The "Hashin" model was chosen as the fracture criterion.

**Table 2.** Properties of Materials

| Properties of wood | Scots pine |
|---|---|
| Elasticity Modulus X (MPa) | 10600 |
| Elasticity Modulus Y (MPa) | 550 |
| Elasticity Modulus Z (MPa) | 1100 |
| Poisson's Ratio XY | 0,38 |
| Poisson's Ratio YZ | 0,52 |
| Poisson's Ratio XZ | 0,44 |
| Shear Modulus XY (MPa) | 1180 |
| Shear Modulus YZ (MPa) | 1050 |
| Shear Modulus XZ (MPa) | 350 |
| Tensile Strength X (MPa) | 80,5 |
| Tensile Strength Y (MPa) | 3 |
| Tensile Strength Z (MPa) | 3,5 |
| Compressive Strength X (MPa) | 42 |
| Compressive Strength Y (MPa) | 4,5 |
| Compressive Strength Z (MPa) | 5 |
| Shear Strength XY (MPa) | 8 |
| Shear Strength YZ (MPa) | 7 |
| Shear Strength XZ (MPa) | 9 |

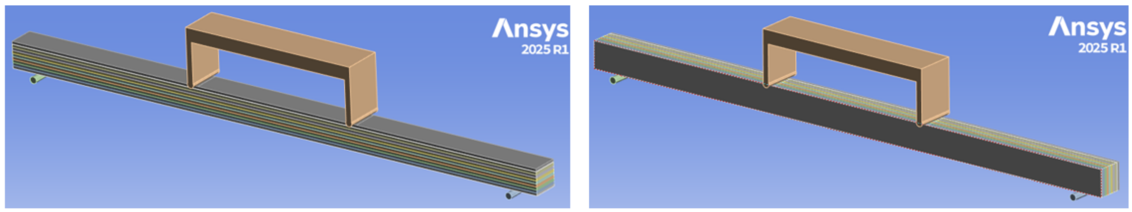


**Fig. 5.** Finite element analysis. a) Perpendicular to the glueline. b) Parallel to the glueline

## Statistical Analysis of Data

The data were analyzed using MSTAT-C 2.1 statistical software (Michigan State University, East Lansing, MI, USA). The statistical results for the data obtained in the experiments were calculated with the arithmetical average, standard deviation, and percentage coefficient of variation. Multivariate analysis of variance (MANOVA) was conducted with the objective of determining the effect of support material on the values obtained for all the groups.

If the differences among groups were statistically significant according to a difference of $p < 0.05$, then the differences among groups were determined with the least significant difference (LSD) test. Thus, the success listings according to the lamination types from the factors in the experiment were determined by separating them into homogeneous groups according to the LSD critical values.

# RESULTS

## Density

The average values for the air-dried densities of the test specimens are given in Table 3.

**Table 3.** The Average Values for the Air-dried Densities (g/cm³)

| Support Material | Xav | S |
|---|---|---|
| Control | 0.58 | 0.01 |
| PVC plastic mesh | 0.61 | 0.03 |
| Fiberglass/PVC mesh | 0.60 | 0.02 |
| Aluminum wire mesh | 0.64 | 0.02 |

*Xav = Arithmetical average; S = Standard deviation*

## Bending Strength

*Bending strength perpendicular to the glueline*

The statistical values for the bending strength perpendicular to the glueline of the test specimens are given in Table 4.

**Table 4.** The Values for the Bending Strength Perpendicular to the Glueline (N/mm²)

| Support Material | $X_{min}$ | $X_{max}$ | $X_{av}$ | S | v (%) |
|---|---|---|---|---|---|
| Control | 54.53 | 83.61 | 64.13 | 11.21 | 17.48 |
| PVC plastic mesh | 68.95 | 85.31 | 74.27 | 6.24 | 8.40 |
| Fiberglass/PVC mesh | 61.53 | 80.41 | 70.95 | 7.53 | 10.61 |
| Aluminum wire mesh | 71.10 | 83.63 | 76.95 | 4.58 | 5.95 |

$X_{min}$ = minimum value; $X_{max}$ = maximum value; $X_{av}$ = arithmetical average;
S = standard deviation; v = coefficient of variation (coefficient of change)

The analysis of variance results for the effect of types of support materials on the bending strength values perpendicular to the glueline are given in Table 5.

**Table 5.** The Analysis of Variance for the Effect of Types of Support Materials on the Bending Strength

| Source of Variance | DF | Sum of Squares | Mean Square | F Value | P Value |
|---|---|---|---|---|---|
| Type of Support Materials | 4 | 5226.466 | 1306.617 | 22.1533 | 0.0000 |
| Error | 36 | 2123.306 | 58.981 | - | - |
| Total | 49 | 7657.530 | - | - | - |

DF = Degrees of freedom

The effect of the type of support material on the bending strength perpendicular to the glueline was found to be statistically significant ($\alpha = 0.05$). The Duncan test comparison results made at the level of type of support material are given in Table 6.

**Table 6.** The Duncan Test Comparison Results Made at the Level of Type of Support Material

| Support Material | Xav | HG |
|---|---|---|
| Control | 65.35 | **C**** |
| PVC plastic mesh | 74.51 | AB |
| Fiberglass/PVC mesh | 70.95 | B |
| Aluminum wire mesh | 76.95 | **A*** |
| LSD ± 6.902 | | |

* = Maximum value; ** = Minimum value; HG = homogeneity group

The highest bending strength perpendicular to the glueline was obtained in the specimens reinforced with aluminum wire mesh, whereas, the lowest was obtained in the control laminated specimens.

*Bending strength parallel to the glueline*

The statistical values for the bending strength parallel to the glueline of the test specimens have been given in Table 7.

**Table 7.** The Values for the Bending Strength Parallel to the Glueline (N/mm²)

| Support material | Xmin | Xmax | Xort | S | v (%) |
|---|---|---|---|---|---|
| Control | 50.40 | 64.39 | 56.30 | 4.73 | 8.40 |
| PVC plastic mesh | 63.49 | 73.52 | 68.51 | 3.46 | 5.05 |
| Fiberglass/PVC mesh | 56.84 | 75.48 | 64.46 | 5.20 | 8.07 |
| Aluminum wire mesh | 59.74 | 86.73 | 76.25 | 8.97 | 11.76 |

The analysis of variance results for the effect of types of support materials on the bending strength values parallel to the glueline are given in Table 8.

**Table 8.** The Analysis of Variance for the Effect of Types of Support Materials on the Bending Strength

| Source of Variance | DF | Sum of Squares | Mean Square | F Value | P Value |
|---|---|---|---|---|---|
| Type of Support Materials | 4 | 11807.635 | 2951.909 | 63.9159 | 0.0000 |
| Error | 36 | 1662.633 | 46.184 | - | - |
| Total | 49 | 13850.003 | - | - | - |

The effect of the type of support material on the bending strength parallel to the glueline was found to be statistically significant ($\alpha = 0.05$). The Duncan test comparison results made at the level of type of support material are given in Table 9 (LSD ± 6.108).

**Table 9.** The Duncan Test Comparison Results Made at the Level of Type of Support Material

| Support Material | Xav | HG |
|---|---|---|
| Control | 56.30 | C** |
| PVC plastic mesh | 68.51 | B |
| Fiberglass/PVC mesh | 64.46 | B |
| Aluminum wire mesh | 76.25 | A* |

The highest bending strength parallel to the glueline was obtained in the specimens supported with aluminum wire mesh, whereas, the lowest was obtained in the control laminated specimens. The differences between the plastic mesh specimens and the fiberglass/PVC mesh specimens were insignificant.

## Compressive Strength

The statistical values for the compressive strength are given in Table 10.

**Table 10.** The Values for the Compressive Strength (N/mm²)

| Support Material | $X_{min}$ | $X_{max}$ | $X_{ort}$ | S | v (%) |
|---|---|---|---|---|---|
| Control | 39.81 | 46.32 | 42.54 | 1.81 | 4.25 |
| PVC plastic mesh | 41.32 | 52.40 | 46.29 | 3.45 | 7.45 |
| Fiberglass/PVC mesh | 37.48 | 44.24 | 40.80 | 2.20 | 5.39 |
| Aluminum wire mesh | 49.07 | 56.93 | 53.94 | 2.69 | 4.99 |

The analysis of variance results for the effect of types of support materials on the compressive strength values are given in Table 11.

**Table 11.** The Analysis of Variance for the Effect of Types of Support Materials on the Compressive Strength

| Source of Variance | DF | Sum of Squares | Mean Square | F Value | P Value |
|---|---|---|---|---|---|
| Type of Support Materials | 4 | 989.071 | 247.268 | 33.5850 | 0.0000 |
| Error | 36 | 265.048 | 7.362 | - | - |
| Total | 49 | 1288.719 | - | - | - |

The effect of the type of support material on the compressive strength was found to be statistically significant ( $\alpha = 0.05$). The Duncan test comparison results made at the level of type of support material are given in Table 12 (LSD ± 2.438).

**Table 12.** The Duncan Test Comparison Results Made at the Level of Type of Support Material

| Support Material | Xav | HG |
|---|---|---|
| Control | 42.54 | C |
| PVC plastic mesh | 46.29 | B |
| Fiberglass/PVC mesh | 41.13 | **C**** |
| Aluminum wire mesh | 53.94 | **A*** |

The highest compressive strength was obtained in the specimens reinforced with aluminum wire mesh, whereas, the lowest was obtained in the specimens reinforced with fiberglass/PVC mesh.

## Finite Element Analysis

Bending stresses were obtained from the regions with the greatest displacement as a result of finite element analysis (Fig. 6). The bending stress was determined as the "Maximum Principal Stress". The bending stresses and percentage variations determined experimentally and from finite element analysis are given in Table 13. The average values of the experimentally obtained bending stresses were compared with the finite element model (FEM) analysis results.

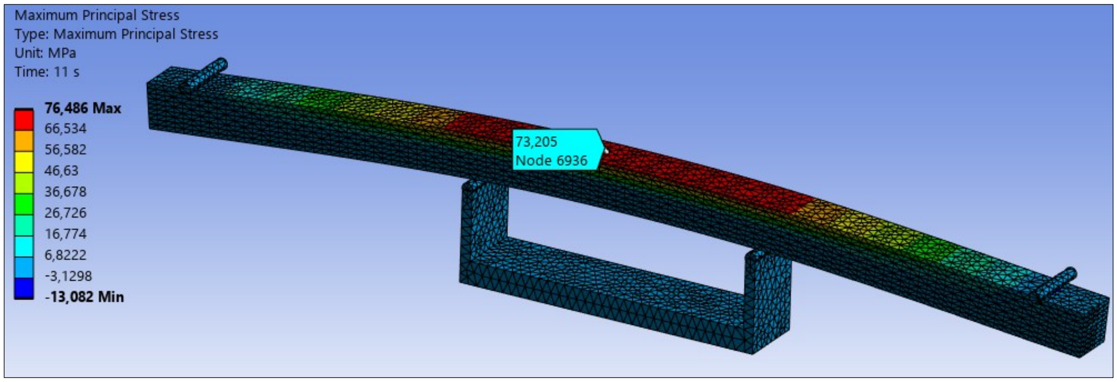


**Fig. 6**. The stress distribution under ultimate load in bending samples

**Table 13.** Comparison of Experimental and Numerical Results

| | Perpendicular to the glueline | | | Parallel to the glueline | | |
|---|---|---|---|---|---|---|
| Support Material | Experimental (N/mm$^2$) | FEM (N/mm$^2$) | Similarity Ratio (%) | Experimental (N/mm$^2$) | FEM (N/mm$^2$) | Similarity Ratio (%) |
| PVC plastic mesh | 74.5 | 76.5 | 2.98 | 68.5 | 72.6 | 5.96 |
| Fiberglass/ PVC mesh | 71.0 | 76.0 | 7.10 | 64.5 | 66.4 | 2.97 |
| Aluminum wire mesh | 77.0 | 75.4 | -2.06 | 76.2 | 76.3 | 0.05 |

As shown in Table 13, the percentage variation between the experimental and FEM analysis results was below 10%, indicating that the FEM model was reliable. The aluminum wire mesh provided the most accurate prediction relative to experimental data, with a deviation of only 0.05% in the parallel to the glueline. In the perpendicular to the glueline, however, the FEM model slightly underestimated the experimental result by 2.06%. These low deviations suggest that aluminum is easier to model numerically due to its homogeneous structure. In contrast, the PVC plastic mesh exhibited an error margin of 2.98% in the parallel direction and 5.96% in the perpendicular direction, reflecting the anisotropic mechanical behavior of the material. Finally, the fiber wire mesh reached the highest error margin of 7.10% in the vertical direction. This discrepancy stems from the complex internal structures of fiber-reinforced materials, which present challenges for full numerical modeling. In summary, while the aluminum wire mesh demonstrated the highest reliability, the model for fiberglass/PVC mesh requires further refinement.

## DISCUSSION

The bending strength properties of wooden laminated elements reinforced with various materials were investigated in this study. With this objective, plastic, fiberglass/PVC mesh, and aluminum wire mesh support elements were placed between the lamellae as 9 layers of paper veneers prepared from Scots pine (*Pinus sylvestris* L.) wood, bonded with PVAc-D3 adhesive, were compared with the unsupported control laminated specimens by determining the bending resistance properties of the specimens and the data obtained were evaluated. The collective results for the effect on bending strength of the reinforcement procedure are given in Table 14.

**Table 14.** The Collective Results for the Effect on Bending Strength and Compressive Strength of the Reinforcement Procedure

| Support Material | Bending (N/mm²) | | | | Compressive (N/mm²) | |
|---|---|---|---|---|---|---|
| | Perpendicular to the Glueline | Increase (%) | Parallel to the Glueline | Increase (%) | Compressive | Increase (%) |
| Control | 65,35 | 0 | 56.30 | 0 | 42.54 | 0 |
| PVC plastic mesh | 74,51 | 14 | 68.51 | 21 | 46.29 | 9 |
| Fiberglass/ PVC mesh | 70,95 | 9 | 64.46 | 14 | 41.13 | -3 |
| Aluminum wire mesh | 76,95 | 18 | 76,25 | 35 | 53.94 | 27 |

The highest bending strength perpendicular to the glueline was obtained in the specimens reinforced with aluminum wire mesh, whereas, the lowest was obtained in the control specimens. All of the support materials increased the bending strength perpendicular to the glueline. This increase, when compared with the control specimens, was approximately 18% in the aluminum wire mesh specimens, approximately 14% in the PVC plastic mesh specimens and approximately 9% in the fiberglass/PVC mesh specimens.

The highest bending strength parallel to the glueline was obtained in the specimens reinforced with aluminum wire mesh, whereas, the lowest was obtained in the control specimens. All of the support materials increased the bending strength parallel to the glueline. This increase, when compared with the control specimens, was approximately 35% in the aluminum wire mesh specimens, approximately 21% in the PVC plastic mesh specimens and approximately 14% in the fiberglass/PVC mesh specimens.

Figure 7 illustrates stiffness of bending specimens of dependences between the load and deflection. It is evident from Fig. 7 that the stiffness of the parallel to glueline was greater than the stiffness of perpendicular to glueline specimens excluding control specimens. As a result of the both loading; the highest stiffness was obtained in the specimens reinforced with aluminum wire mesh.

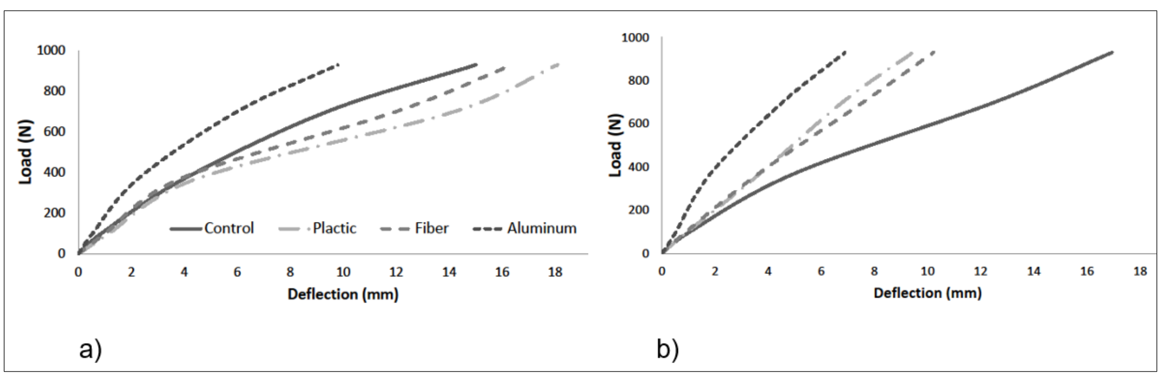


**Fig. 7.** Stiffness of specimens: a) bending perpendicular to the glueline; b) bending parallel to the glueline

While sudden breaks were observed during loading in the unreinforced laminated specimens, there were regional breaks in the reinforced specimens. Furthermore, in the specimens reinforced with aluminum wire mesh, while the first damage after loading was in the form of the lamellae separating from each other, in the other specimens, it was in the form of the papers breaking (Fig. 8). It can be stated that this situation stemmed from the PVAc adhesive not displaying a sufficient bonding strength between the aluminum material and the wooden material.

The highest compressive strength was obtained in the specimens reinforced with aluminum wire mesh, whereas, the lowest was obtained in the specimens reinforced with fiberglass/PVC mesh. Aluminum and plastic support materials increased the compressive strength. This increase, when compared with the control specimens, was approximately 27% in the aluminum wire mesh specimens, approximately 9% in the PVC plastic mesh specimens. However, it decreased approximately 3% in the fiberglass/PVC mesh specimens.

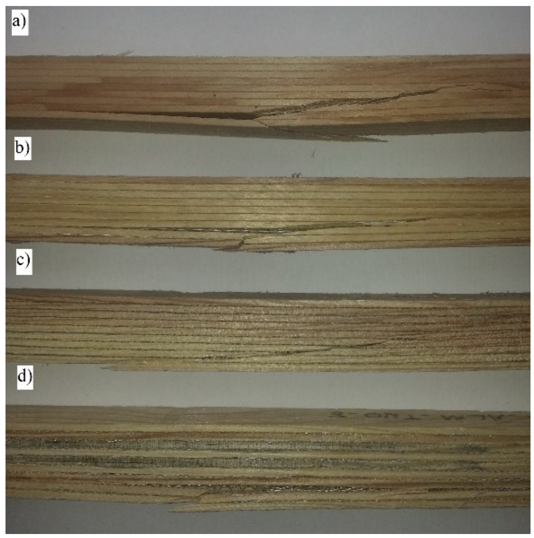


**Fig. 8.** Examples of damages: a) control; b) reinforced with PVC plastic mesh; c) reinforced with fiberglass/PVC mesh; d) reinforced with aluminum wire mesh

Togay and Ergin (2014) stated that in the Scots pine laminated specimens reinforced by using fiberglass/PVC mesh and PVAc-D3 adhesive, the fiber wire decreased the compressive strength (7%), increased the bending strength perpendicular to the glueline (18%), and increased the bending strength parallel to the glueline (7%). Söğütlü *et al.* (2023) reported that reinforcing laminated wood material with steel wire has a strength-enhancing effect. The results of the study are in agreement with the results of similar studies in the literature.

## CONCLUSIONS

In this study, the effects of reinforcement with plastic, fiber, and aluminum wire meshes on the mechanical properties of laminated Scots pine elements were evaluated. The following conclusions were drawn from the results:

1. The highest values for both bending strength (perpendicular and parallel to the glueline) and compressive strength were achieved in specimens reinforced with aluminum wire mesh. Specifically, aluminum reinforcement provided an 18% increase in bending

strength perpendicular to the glueline, a 35% increase parallel to the glueline, and a 27% increase in compressive strength.

2. If aluminum support materials are used, then it is projected that preference for adhesives with a higher bonding strength would increase even more the strength of the materials.
3. In the experiments, delamination was observed in samples with an aluminum support layer. This indicated that the adhesion was insufficient. Using adhesives with stronger adhesion strength could increase the strength. These support materials should be tried with different adhesives.
4. Finite element analysis (FEM) results showed a high correlation with experimental data, with error margins generally below 10%, confirming the reliability of the numerical models used.
5. These findings suggest that reinforcing laminated wood with wire meshes—particularly aluminum—can provide a structural advantage in the production of furniture and construction components where high load-bearing capacity is required.

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