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Short notes

EVALUATION OF SOME MECHANICAL PROPERTIES OF METAL-MESH REINFORCED POPLAR LAMINATED VENEER LUMBER

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ABSTRACT

This study aimed to reinforce laminated veneer lumber boards produced with poplar veneers using metal mesh. The metal mesh and poplar veneers were bonded using polyurethane adhesive. A control group (group 1) and three experimental groups were formed. The metal mesh was placed inside the two outermost adhesive layers in group 2, inside the four outermost adhesive layers in group 3, and on the bottom surface (tensile zone) of the board in group 4. The modulus of rupture, modulus of elasticity in bending, splitting strength, and adhesion strength of the produced boards were investigated. According to the data obtained, the modulus of rupture and modulus of elasticity increased in the reinforced groups. Although the reinforcement in one group reached 20%, the other groups had smaller values. Therefore, the reinforcement effect of the metal mesh on the flexural properties remained limited. The splitting strength increased significantly. Compared to the control group, the splitting strength of group 3 increased by approximately 80%. The adhesion strength decreased slightly in the reinforced groups.

KEYWORDS: LVL, poplar veneer, reinforcement, mechanical properties.

INTRODUCTION

Producing panels with high mechanical performances using low-cost, fast-growing species is the goal of most panel manufacturers. This topic has also been the subject of scientific studies, and some research has been conducted on strengthening solid wood and wood-based composite materials. For example, Biblis and Carino (2000) bonded fiberglass to both surfaces of plywood panels and reported that their bending strength and modulus of elasticity increased. Bal (2014a,b) investigated some mechanical properties of LVL material reinforced with woven glass fibre. Bal (2017) reported that reinforcing plywood with woven

glass fibres increased its nail and screw holding capacity. Pasztory et al. (2019) conducted a study on the reinforcement of a panel produced from poplar bark with glass fibre mesh and determined that the reinforcement material improved the mechanical performance of bark-based panels. Sankar and Sajan (2021) investigated some properties of plywood reinforced with copper fibres. Karri et al. (2022) investigated the bonding quality of poplar plywood reinforced with hemp fibres and lignin-phenolic adhesives. Sokolović et al. (2023) conducted a study on the strengthening of poplar LVL reinforced with carbon fibres and found significant increases in the flexural strength and modulus of elasticity in experiments conducted on the side surface of the LVL. Akkurt et al. (2024) investigated the effects of the thermomechanical densification of surface coatings on the flexural strength and load-bearing capacity of poplar and black alder plywoods. Qiu et al. (2025) investigated the mechanical and acoustic properties of metal-mesh-reinforced eucalyptus boards.

Previous studies have aimed to reinforce LVL panels with natural or synthetic materials, using carbon, glass, basalt, hemp, and cannabis fibres. These studies have experimented with various adhesives, including phenol formaldehyde, PVA, epoxy adhesive, and polyurethane (PU) adhesive. However, the mechanical properties of poplar LVL bonded with PU adhesive and reinforced with metal mesh have not been sufficiently investigated. Therefore, the aim of this study was to investigate some selected properties of poplar LVL produced using PU adhesive and reinforced with metal mesh.

MATERIAL AND METHODS

Material

This study used peel veneers made from poplar (*Populus* subspecies) wood, with a thickness of 3 ± 0.1 mm and dimensions of 30 × 30 cm (width and length). Eight perfect rotary-peeled veneer with these dimensions were selected, and four boards were created for each group. Metal mesh with a wire diameter of 0.3 mm, thickness of 0.8 mm, and mesh size of 12 was used to reinforce the experimental sheets. This metal mesh was cut into 30 × 30 cm pieces and used to reinforce the LVL boards in three different experimental groups. A single-component polyurethane adhesive (4,4'-methylenediphenyl diisocyanate) with the viscosity 5,000–10,000 cP (20°C) and density 1.10 g/cm³ was used to bond the veneers and metal mesh to each other. After gluing, eight veneer sheets were stacked on top of each other and pressed in a cold press. The veneer sheets were arranged with their loose surfaces facing the centre of the sheet. The metal-mesh arrangement is shown in Fig. 1. In group 4, paper was used on the outer surface to prevent the adhesive from sticking to the press plate. The press pressure was set to 6 kg/cm², the pressing time was 45 min, and the press temperature was 25°C.

METHOD

Density tests on the bending-strength test specimens were performed according to the TS EN 323, with the density calculated by dividing the weight of the test specimen by its volume.

The bending-strength test was performed according to the TS EN 310 standard. A total of 32 test specimens were prepared, with eight from each plate. The force was applied to the top surface of 16 of the bending-strength test specimens and to the side surface of the other 16.

To allow bending tests to be performed on both the flat and side surfaces, the test specimens were prepared with a 20 × 20 mm square cross-section.

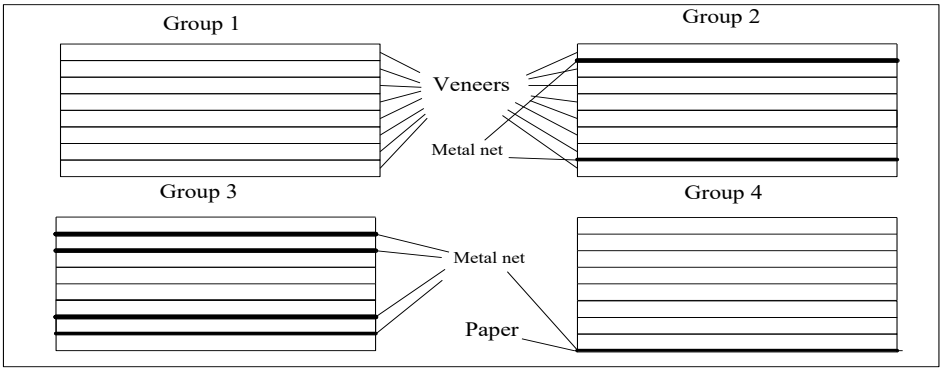

Fig. 1: Layer organization of control- and experimental-groups.

The principles specified in the TS 7613 standard were followed in calculating the splitting strength. Test specimens were prepared as 50 × 70 mm samples with the same thickness as the panels. A 32 mm diameter hole was drilled in one edge of each test specimen. The force was applied through this hole. During the splitting-strength tests, the preload value was set to 10 N, the test speed was 5 mm/min, and the end of the test was set to 50% of the maximum force.

Adhesion-strength tests were performed in accordance with the principles specified in the TS EN 14279 + A1 (2010). Test specimens were cut in the direction of the fibre of the surface layer. Fifteen test specimens were prepared for each group of adhesion tests. Adhesion- strength tests were performed on test specimens from groups 1 and 2. In group 1, the adhesion-resistance tests were conducted to determine the veneer-to-veneer adhesion performance. In group 2, the tests were conducted to determine the veneer-to-metal mesh adhesion performance. Adhesion- strength tests were performed in two groups: untreated and pretreated. As a pretreatment, the test specimens were first soaked in water for 12 h and then boiled in boiling water for 4 h. Afterwards, the test specimens were cooled, dried, and tested.

RESULTS AND DISCUSSION

The density data obtained from the laboratory studies are listed in Tab. 1. The lowest density of 461 kg/m³ was obtained in group 1 (control group), with the highest of 552 kg/m³ obtained in group 3. The densities of the other groups are ranked within this range. The difference between the density values of the groups was statistically significant ($P < 0.001$). The factor affecting the densities of the groups was the metal mesh used for reinforcement. As the number of metal meshes increased, the density increased. However, the increase in density did not lead to proportional increases in the mechanical properties. Generally, in wood-based composite materials, assuming all other variables remain constant, the mechanical properties increase with the density of the material. This is especially true for wood-based composite materials produced by hot pressing, such as plywood, LVL, OSB, fibreboard, and particleboard, as reported in previous studies on this subject (Bal and Bektaş

2012; Akkurt et al. 2024; Castanié et al. 2024). In the present study, the press pressure and all other parameters were kept constant for all groups. Densification of the produced material was not intended. The number of metal meshes was the only difference between groups.

Tab. 1: Density data (kg/m³)

Statistical values	Groups				Sig.
	1	2	3	4	
x̄	461 A*	506 B	552 C	494 B	0.000
sd	25	13	22	33	

x̄: arithmetic mean, sd: standard deviation, *: lowest value; With different letters (*A, B, C) indicating significant differences in Duncan test results.

Modulus of rupture (MOR) test data is listed in Tab. 2. The highest MOR was found in group 4, in the test performed flatwise direction (74.9 N/mm²). The lowest was found in group 1, in the test performed edgewise direction (57.4 N/mm²). The MOR values of the other groups were within this range. In both the flatwise and edgewise direction tests, the differences between the groups were statistically significant ($P < 0.001$). Compared to the control group, the reinforcement material was the most effective for group 4 on the flat surface. In this group, the reinforcement material was on the bottom surface of the test specimen. The reinforcement effect was approximately 20%. On this surface, the reinforcement material was in the tensile zone of the test specimen and resisted the force applied to it. In groups 2 and 3, the veneer sheet on the bottom surface (tensile zone) of the test specimen resisted this force. The test ended when the veneer sheet on the bottom surface broke during the test. Therefore, the metal mesh placed between the layers in groups 2 and 3 did not provide a significant increase in the strengthening of the test specimen. In tests conducted on the edgewise direction, the same effect was not achieved in group 4 because the reinforcing material remained on the lateral surface of the test specimen. In previous studies on the strengthening of wood materials, the MOR increased significantly when the reinforcing material was bonded to the underside of the board (Biblis and Carino 2000, Borri et al. 2013).

During MOR testing, when comparing results in terms of the direction of force application, tests performed in the flatwise direction showed greater MOR values than those performed in the edgewise direction. The most important factor causing this difference was the press pressure. When producing LVL panels, the press pressure acts in the flatwise direction. Therefore, the thickness of the material decreases and its density increases in this direction. As a result, the MOR value obtained at the end of a test is higher than that obtained in an edgewise test. This situation is particularly noticeable in wood-based composite materials produced by hot pressing. This difference has been identified in previous studies (Bal and Bektaş 2012, Bal 2014a,b, Castanié et al. 2024). The thickness of wood-based materials produced in both hot and cold pressing decreases during pressing. This decrease increases with the press pressure, with a greater press pressure resulting in a greater decrease in the thickness of the produced wood-based composite material. Thus, the density of the material, MOR, and difference between the flatwise and edgewise values also increase. In three-point bending strength tests, according to the MOR formula, there is an inverse relationship between the MOR and square of the material thickness (h^2). Assuming all other factors remain constant, as the material thickness decreases as a result of to the pressing

pressure, the MOR increases. This is a general rule. A detailed study on this subject was conducted by Akkurt et al. (2024), and the relationship between the load-carrying capacity and MOR of plywood sheets whose thickness was reduced by pressing was reported.

However, the present study did not use a pressure high enough to cause a decrease in material thickness. No densification was performed on the produced material. During the production of LVL boards, a constant low pressure (6 kg/cm²) was applied to all the boards. In some previous studies using wood veneer and reinforcement material, higher pressures (more than 10 kg/cm²) were applied. As a result, the reinforced material produced was found to have higher MOR values (Sokolović et al. 2023).

Tab. 2: MOR test data (N/mm²).

		Groups				
Modulus of rupture (MOR)	**Statistical values**	1	2	3	4	**Sig.**
Flatwise direction	x̄	61.8 A*	63.5 AB	66.7 B	74.9 C	0.000
	sd	5.1	5.1	4.2	6.6	
Edgewise direction	x̄	57.4 A*	61.4 AB	64.9 B	59.2 C	0.000
	sd	4.0	3.7	4.3	4.4	

x̄: arithmetic mean, sd: standard deviation, *: lowest value; With different letters (*A, B, C) indicating significant differences in Duncan test results.

Modulus of elasticity (MOE) data obtained during the bending tests are presented in Tab. 3, which shows that the highest value was obtained in group 4 in the flatwise direction (5526 N/mm²). The lowest MOE was obtained in group 1 during the tests performed in the edgewise direction (4534 N/mm²). The MOE values of the other groups fell between these two values. The MOE of the groups were statistically different from each other ($P < 0.001$). All of the experimental groups had higher MOE values than the control group. Furthermore, in the tests performed in the flatwise direction, the MOE values of groups 1 and 4 were higher than those found in the tests performed in the edgewise direction. However, this situation was different for groups 2 and 3. When the test specimens from group 1 (control group) were tested in the flatwise direction, the reductions in board thickness due to the press pressure, even if very small, caused an increase in the MOE. This occurred primarily because, according to the MOE formula used in the 3-point bending test, there was an inverse relationship between the MOE and cube of the material thickness (h^3). Assuming all the other variables remained constant, the MOE increased as the thickness of the wood-based composite material produced by pressing decreased. Similar results have been reported in previous studies on this subject (Castanié et al. 2024, Akkurt et al. 2024). Previous studies on the strengthening of wood-based laminated materials have reported an increase in the MOE as a result of strengthening (Bal 2014a,b, Karaman et al. 2021). Furthermore, previous studies on the strengthening of wood materials have reported a significant increase in the MOE when the strengthening material was bonded to the tensile zone (Biblis and Carino 2000, Borri et al. 2013).

Tab. 3: MOE test data (N/mm²).

		Groups				
Modulus of elasticity (MOE)		1	2	3	4	P value
Flatwise direction	x̄	4678 A*	4723 AB	4980 B	5526 C	0.000
	sd	295	397	413	274	
Edgewise direction	x̄	4534 A*	4826 B	5174 C	4962 BC	0.000
	sd	301	321	306	486	

x̄: arithmetic mean, sd: standard deviation, *: lowest value; With different letters (*A, B, C) indicating significant differences in Duncan test results.

Data from the splitting tests are listed in Tab. 4, which shows that the lowest splitting strength (0.65 N/mm²) was obtained in group 1, and the highest value (1.16 N/mm²) was obtained in group 3. The values of all strengthened groups were higher than those of the control group. The difference between the groups was statistically significant ($P < 0.001$). The splitting strengths of the test specimens from groups 2 and 3 were 43% and 80% higher, respectively, than the splitting strength values of the test specimens from the control group. The increase in splitting strength due to strengthening was much greater than the increases in the MOR and MOE. Similar results have been reported in previous studies on this subject (Bal 2014a,b). Data on the deformation at splitting were also obtained at the end of the splitting strength test and are listed in Tab. 4. During the splitting test, the test was terminated after approximately 9 mm of deformation in the test specimens from group 1. However, in group 3, the test ended after approximately 20 mm of deformation. Most of the test specimens from the control group split into two separate pieces at the end of the test. In contrast, although the reinforced test specimens from groups 2 and 3 split, they did not split into two separate pieces. It was determined that the reinforced test specimens were able to withstand the splitting load for a longer period and had a higher load-bearing capacity.

Tab. 4: Splitting strength test data (N/mm²).

		Groups				
		1	2	3	4	**P value**
Splitting strength (N/mm²)	x̄	0.65 A*	0.93 C	1.16 D	0.73 B	0.000
	sd	0.07	0.12	0.11	0.08	
Deformation at splitting (mm)	x̄	8.76 A*	10.24 A	19.77 B	9.13 A	0.000
	sd	3.47	1.61	5.61	0.99	

x̄: arithmetic mean, sd: standard deviation, *: lowest value; With different letters (*A, B, C) indicating significant differences in Duncan test results.

In this study, tensile-shear tests were conducted to determine the adhesion strengths of the produced material. These tests were performed on test samples from group 1 to determine the veneer-to-veneer adhesion performance and on test samples from group 2 to determine the veneer-to-metal net adhesion performance. Additionally, two separate groups were created: one without pretreatment and one with pretreatment. Adhesion test data are listed in Tab. 5. According to these data, the adhesion strengths of the test samples from the control group were 2.29 N/mm² in the unpretreated group and 2.03 N/mm² in the pretreated group (4 h of immersion in boiling water). No separation was detected in the glue line in the test samples from the control group. Wood failure was detected in all the test samples. It was determined that the PU glue used in the bonding process provided extremely strong adhesion.

Furthermore, in the test samples from group 2, which were reinforced with metal mesh, the adhesion strengths were 2.09 N/mm² in the untreated group and 1.85 N/mm² in the pretreated group (4 h of immersion in boiling water). In the test samples from group 2, where reinforcement material was used in the glue line, a slight decrease in tensile-shear strength occurred compared to that of the control group. Similar results were reported in a study by Sviták and Ruman (2017), where decreases in the tensile-shear strength were observed in both test samples using epoxy glue and test samples using PU glue. The adhesion strength values obtained from the tensile-shear tests were well above the 1 N/mm² value specified in the relevant standard (TS EN 314-2). Therefore, no wood or glue failure percentages were calculated. The obtained adhesion strength values were quite high. Therefore, it can be said that the PU glue used was very successful in veneer-to-veneer and veneer-to-metal mesh bonding.

Tab. 5: Bonding test data (N/mm²).

		Groups			
		1	2	1	2
		Without pretreatment		With pretreatment	
Tensile-shear strength (Adhesion strengths)	$\bar{x}$	2.29	2.09	2.03	1.85
	sd	0.52	0.52	0.37	0.43

$\bar{x}$: arithmetic mean, sd: standard deviation.

CONCLUSIONS

In this study, LVL panels were produced by reinforcing poplar veneer sheets with metal mesh, and some mechanical tests were carried out on test samples prepared from these panels. The following conclusions can be drawn from the obtained data. The densities of the produced panels increased with the number of metal-mesh layers used. The greatest MOR and MOE values were obtained in the test samples where the metal mesh was glued to the bottom surface (tension zone) of the panel. The splitting strength increased significantly in all the reinforced groups. Placing the metal mesh between layers provided a significant improvement in the splitting strength, especially in group 3. The PU adhesive used in the production of the panels successfully ensured both veneer-to-veneer and veneer-to-metal mesh adhesion. The obtained adhesion strength values were well above the 1 N/mm² value specified in the relevant standard.

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