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ARTÍCULO

Some physical and mechanical properties of Laminated Veneer Lumber reinforced with glass fiber mesh

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Abstract:

Structural composite lumbers are used extensively in wooden structures. There are many reasons for choosing these materials, including their light weight, easy assemble, and low cost. Various studies have been conducted to increase the load carrying capacities of these materials. Reinforcement with various natural or synthetic fibers is one method that has been studied. In this study, laminated veneer lumber was produced using poplar veneers and glass fiber mesh. One-component polyurethane glue was used in the production of the boards. The modulus of rupture, modulus of elasticity in bending, impact bending strength, and splitting strength values of the control laminated veneer lumber and laminated veneer lumber reinforced with the glass fiber mesh were investigated. In addition, some physical properties such as the densities and moisture contents of the test samples were investigated. Although the reinforcement of laminated veneer lumber using glass fiber mesh had statistically significant effects on impact bending strength, and splitting strength. The effect on the modulus of rupture and the modulus of elasticity in a static bending test was not significant. In addition, the effects of the reinforcement on the densities and moisture contents of the test samples compared the control samples were statistically significant.

Keywords: Glass fiber mesh, Laminated Veneer Lumber, composite lumber, mechanical properties, modulus of elasticity, modulus of rupture, reinforcement.

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Introduction

Laminated veneer lumber (LVL) has many advantages compared to solid wood. It is largely free from the natural imperfections found in solid wood materials. Its density and mechanical properties are higher than those of the wood from which it is produced. Dimensions that cannot be obtained with solid wood material can be produced in LVL (Neuvonen *et al*. 1998, Bao *et al*. 2001, Saviana *et al*. 2009, Shukla and Kamdem 2009, Bal 2016, Yildirim *et al*. 2020).

Scientific studies have been carried out on the strengthening of laminated wood materials in order to gain higher mechanical properties. For example, Basterra *et al*. (2012) investigated some of the mechanical properties of poplar beams produced with the I-214 poplar clone. Glass fiber fabric, carbon fiber fabric, and linen fiber fabric were used for reinforcement. Tests showed that the differences in the reinforcement made with carbon fiber alone were statistically significant.

Ribeiro *et al*. (2009) conducted a study on the glass fiber and pultrusion board reinforcement of glued laminated wooden beams obtained from maritime pine. Their data showed that the reinforcement with glass fiber did not have a statistically significant effect on the modulus of elasticity of the test samples.

Rowlands *et al*. (1986) conducted experiments using different types of glue and many different forms of glass fiber, graphite fiber, and Kevlar with laminated wood material obtained from maple wood. According to the data obtained, they stated that the most successful type of glue was epoxy, and the most suitable fiber for reinforcement was glass fiber.

Studies on the reinforcement of poplar LVL material were carried out on materials produced in different combinations by Bal and Özyurt (2015), Bal (2014a), Bal (2014b) and Bal (2017). According to the data obtained at the end of these studies, the LVL material reinforced with glass fiber showed significant increases in the bending strength and modulus of elasticity values of the test samples when the glass fiber support was adhered to the tensile region.

However, it has been reported that reinforcing test specimens with glass fiber fabric produces a large weight increase. Thus, the mechanical properties of the test specimens are divided by the density, and specific mechanical properties are obtained. According to these specific mechanical properties, it was concluded that the reinforcement process with glass fiber fabric did not cause a significant increase in the mechanical performance of the LVL material produced from poplar veneer.

In the previously mentioned studies, the glass fiber support was placed either in the tensile zone or in the glue layers, and hot curing glues were used.

The aim of the current study was to comparatively investigate some physical and mechanical properties of control LVL and LVL reinforced with glass fiber mesh (GFM) using polyurethane glue cured under room temperature conditions.

Materials and methods

Materials

Rotary-peeled 600 mm × 600 mm (width × length) veneers with a thickness of 2,8 mm ± 0,2 mm were obtained from poplar (*Populus subspecies*) wood and used in this study. Seven veneer sheets were selected, and each was cut into four pieces, as seen in Figure 1a Each of the 30 cm × 30 cm drafts obtained was included in a different group. In this way, four repetitions and a total of 16 board drafts were created.

A commercial one-component polyurethane glue (Methylene diphenyl diisocyanate (MDI)) was used for bonding the veneers. The viscosity of this glue was 5 000 mPa·s (20 °C) –10 000 mPa·s (20 °C), and it had a density of 1,10 g/cm^3.

The GFM used had a weight of 160 g/m^2. It was alkali resistant and orange in color, with a 4 mm × 4 mm mesh pattern (Figure 1b).

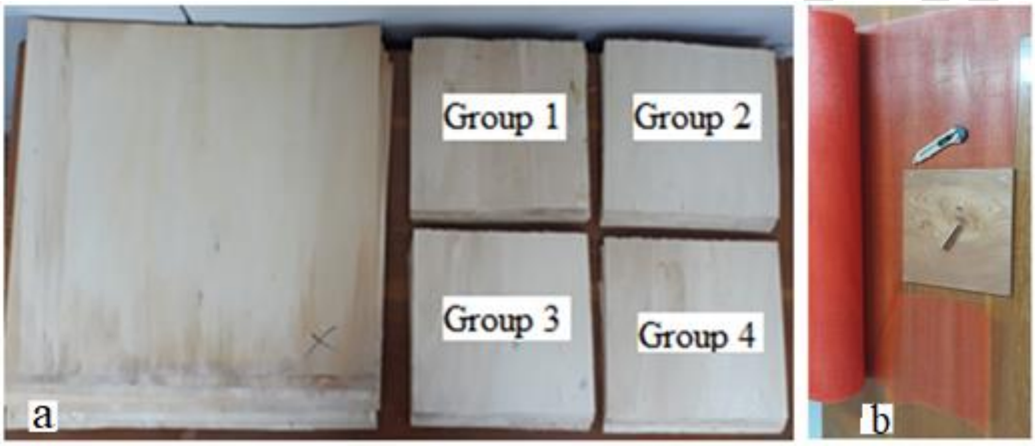


Figure 1: (a) Creation of boards from rotary peeled veneers and (b) Cutting the GFM.

LVL production

Approximately 230 g ± 20 g of glue was applied to the veneer surface with a brush. Glued veneer sheets were placed on top of each other. The GFM wasn't placed in the control group (group 1). GFM were placed on the glue lines of the boards produced for groups 2, 3, and 4. A schematic representation of these boards is given in Figure 2. The board drafts were pressed under room temperature conditions (cold pressing). In the pressing process, the press pressure was 6 kg/cm^2, and the press time was set to 4 h. Boards removed from the press were kept at room temperature conditions for 1 week, and then test samples were prepared. Sixteen test samples were prepared for each group.

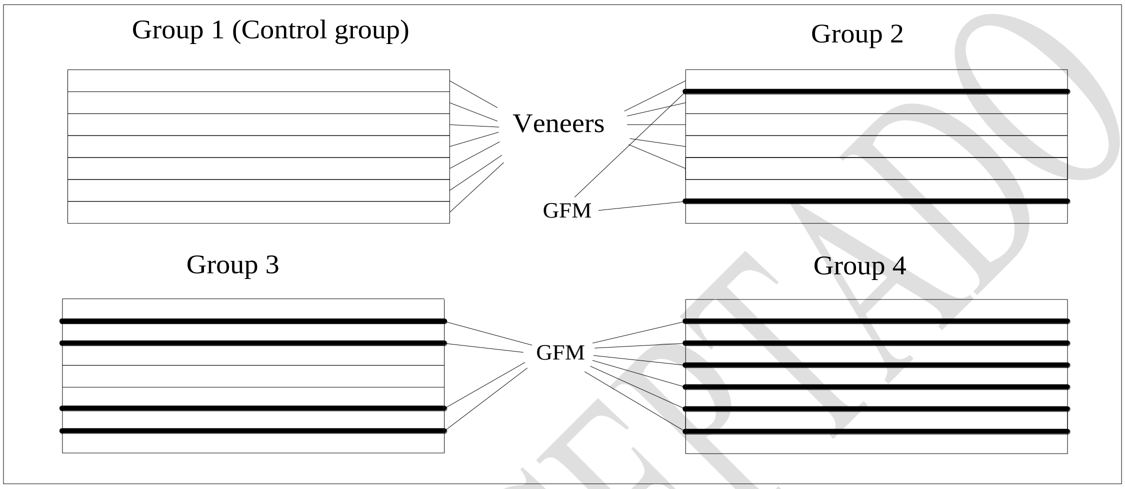


Figure 2: Layer organization of control group and experimental groups.

Methods

Bending strength test specimens were prepared with a 20 mm × 20 mm × 300 mm (thickness × width × length) square section. The modulus of rupture and modulus of elasticity tests were carried out according to standard TS 2474 (1976) and TS 2478 (1976), respectively. Four test specimens were prepared from each board, with a total of 16 test specimens prepared for the bending tests. The bending tests were performed on an electromechanical universal testing machine (UTM) with a capacity of 10 kN, as can be seen in Figure 3a. When performing the bending strength tests, the force was applied to the edge wise position of the test sample in a direction parallel to the glue line. The test speed was set at 5 mm/min, and the span between the supports was 240 mm. The preload amount was 10 N, and the test ended at the breaking point or at 70 % of the maximum force.

The splitting strength test was conducted according to TS 7613 (1989). Test specimens were prepared with a 20 mm × 50 mm × 50 mm (thickness × width × length) square section. A 22 mm diameter hole was drilled in the test specimen so that the cap used for the splitting strength test could be attached (Figure 3b). While performing the splitting strength tests, the preload value was set to 10 N, the test speed was set to 10 mm/min, and the test ended at 80 % of the maximum force.

Screw withdrawal tests were conducted according to TS EN 13446 (2005) (Figure 3c). These tests were conducted on 20 mm × 50 mm × 50 mm (thickness × width × length) samples. The flathead screw used had a total length of 50 mm, shank diameter of 4 mm, and head diameter of 7,6 mm.

Impact bending tests were conducted according to TS 2477 (1976) based on the Turkish standards. The impact bending tests of LVL samples were performed in edgewise directions. The dimensions of the impact bending test samples were 20 mm × 20 mm × 300 mm (thickness × width × length), and the span was 240 mm (Figure 3d).

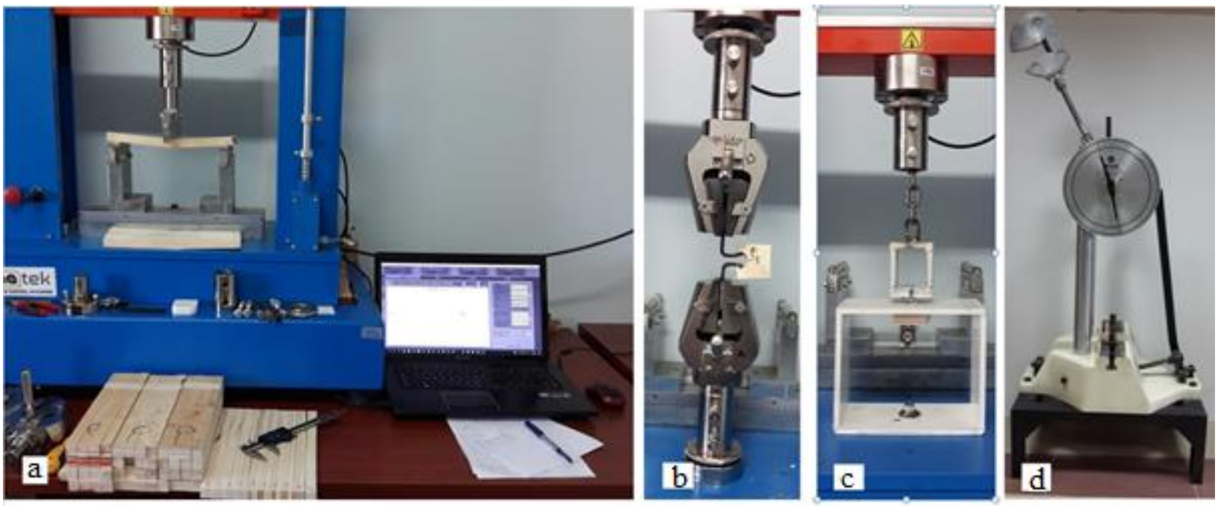


Figure 3: Electromechanical universal testing machine (UTM) and (a) bending strength test, (b) splitting strength test, (c) screw withdrawal test, and (d) impact bending test.

The SPSS statistical package program was used. The data were analyzed using a one-way analysis of variance (ANOVA), and significant differences among groups were determined by the Duncan multiple range test.

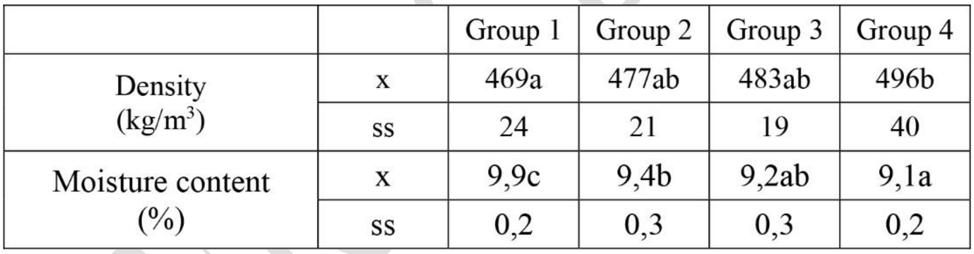
Results and discussion

The density and moisture content values obtained at the end of the tests are given in Table 1. This table shows that the density of group 1, which was the control group, was the lowest, and the density of group 4 was the highest. The density increased not only because the number of GFMs was higher in group 4, but also because more glue was used in group 4. When the boards were being produced, glue was applied to one surface of the veneers in the control group (group 1). In the experimental groups (groups 2, 3, and 4), glue was applied to both surfaces of the veneers (except for the veneers on the outermost surfaces).

Therefore, the densities of the boards differed. At the same time, the moisture contents were also different from each other because, as a result of the glue applied, the surfaces of the veneers were modified and moisture absorption was prevented. In this study, the amount of voids was high as a result of the natural structure of the poplar veneers used. They had a porous structure. After the glue was applied to the veneer surfaces, it could progress toward the interior of the veneer sheets during the pressing stage. After the glue hardened in the pressing stage, it acted as a barrier to the external environment and prevented the progression of moisture toward the interior.

Some other studies on laminated materials have reported the effects of glue on the density and moisture content (Febrianto *et al*. 2009, Hashim *et al*. 2011, Özçifçi *et al*. 2017).

Table 1: Some physical properties of test samples and Duncan test results.



		Group 1	Group 2	Group 3	Group 4
Density (kg/m^3)	x	469a	477ab	483ab	496b
	ss	24	21	19	40
Moisture content (%)	x	9,9c	9,4b	9,2ab	9,1a
	ss	0,2	0,3	0,3	0,2

x: mean value, ss: standard deviation
Different letters (a, b, c, d) indicating significant differences in Duncan test results.

Data on the bending strength, modulus of elasticity in bending, splitting strength, screw holding strength, and impact bending strength are given in Table 2. This table shows that there were slight increases in the modulus of rupture and modulus of elasticity values of the experimental groups (groups 2, 3, and 4) compared to the control group. However, these increases were statistically insignificant ($P > 0,05$). No statistically significant difference was determined between the maximum displacement amounts obtained at the end of the bending strength tests.

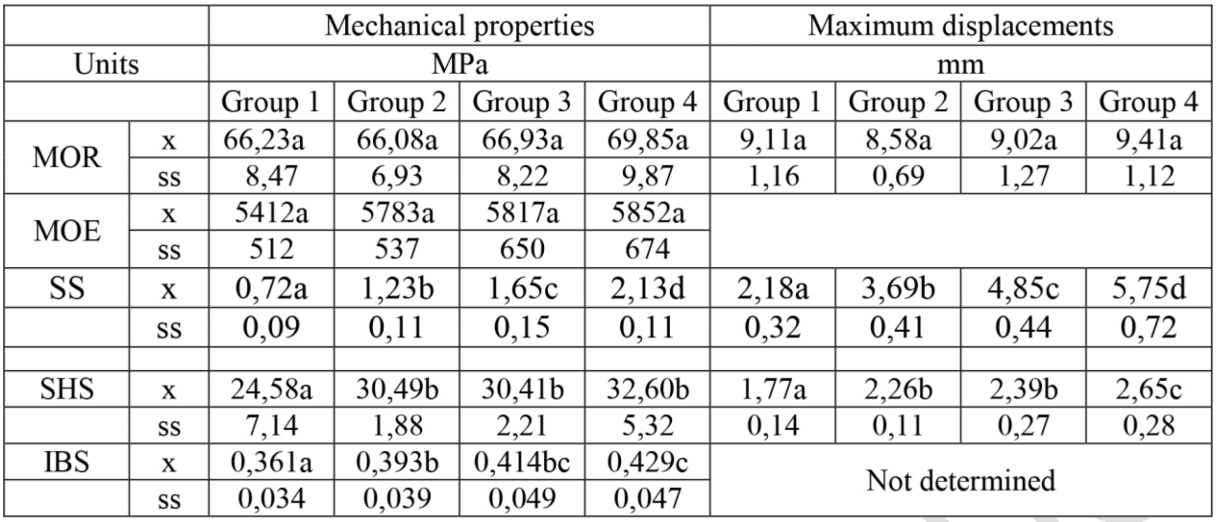
According to the data obtained from the study, the reinforcement made with 2 or 4 GFMs in 7-layer LVL boards produced with poplar veneers slightly increased the bending strength of the produced LVL boards, but it did not make a statistically significant contribution. Bending strength tests were performed on the side surfaces of the test specimens. The force was applied parallel to the glue line. In bending strength tests performed in this way, the force is applied simultaneously to all the veneers forming the LVL test sample, as well as to all the reinforcement materials placed on the glue line.

If the tests were performed by applying the force in the flatwise direction, then the veneer sheets first affected would be the veneer sheets located in the bottom layer (tensile surface). Therefore, in bending strength tests in the edgewise direction, both the veneer sheets that make up the LVL test sample and the reinforcement material collectively resist the applied force. Therefore, bending strength tests performed in the edgewise direction and flatwise direction have different results. This has been reported in previous studies on this subject (Bao *et al*. 2001, Bal 2014a, Karaman and Yildirim 2018, Karaman *et al*. 2021, Yildirim *et al*. 2021).

In many previous studies, it has been determined that the reinforcement materials attached to the lower surface of the test sample or placed on the glue layer increase the modulus of elasticity in bending (Biblis and Carino 2000, Borri *et al*. 2013, Bal and Özyurt 2015). However, contrary to the results obtained in these studies, Ribeiro *et al.* (2009) determined that the reinforcement of glued laminated wooden beams obtained from maritime pine with glass fiber did not have a statistical effect on the modulus of elasticity of the test samples.

Basterra *et al*. (2012) investigated some mechanical properties of poplar beams produced with the I-214 poplar clone. Glass fiber fabric, carbon fiber fabric, and linen fiber fabric were used for reinforcement. Tests showed that the differences in the reinforcement made with carbon fiber alone were statistically significant. However, the effects of strengthening with glass fiber on the flexural strength and modulus of elasticity in bending were not determined.

Table 2: Some mechanical properties of test samples and Duncan test results.



		Mechanical properties				Maximum displacements			
Units		MPa				mm			
		Group 1	Group 2	Group 3	Group 4	Group 1	Group 2	Group 3	Group 4
MOR	x	66,23a	66,08a	66,93a	69,85a	9,11a	8,58a	9,02a	9,41a
	ss	8,47	6,93	8,22	9,87	1,16	0,69	1,27	1,12
MOE	x	5412a	5783a	5817a	5852a				
	ss	512	537	650	674				
SS	x	0,72a	1,23b	1,65c	2,13d	2,18a	3,69b	4,85c	5,75d
	ss	0,09	0,11	0,15	0,11	0,32	0,41	0,44	0,72
SHS	x	24,58a	30,49b	30,41b	32,60b	1,77a	2,26b	2,39b	2,65c
	ss	7,14	1,88	2,21	5,32	0,14	0,11	0,27	0,28
IBS	x	0,361a	0,393b	0,414bc	0,429c	Not determined			
	ss	0,034	0,039	0,049	0,047				

x: mean value, ss: standard deviation
Different letters (a, b, c, d) indicating significant differences in Duncan test results
MOR: the modulus of rupture, MOE: the modulus of elasticity, SS: splitting strength, SHS: screw holding strength, IBS: impact bending strength.

In the bending strength test, after the maximum load (Fmax) of the test specimen against the applied force was reached, the end of the test varied with the toughness property of the test specimen. The load-deformation curves obtained during the bending strength tests are shown in Figure 4. With some wood materials, after reaching the maximum load, the test sample suddenly breaks, and the test is completed. Such materials are referred to as brittle materials. In some materials, after reaching the maximum load, the test sample is broken slowly or gradually, and the test is completed. Such materials are called elastic materials. During a bending strength test, a larger area under the created load–deformation graph indicates greater flexibility for the material, whereas a smaller area indicates greater brittleness. In buildings, load-bearing structural elements such as LVL must be able to carry large loads and have a flexible structure. Therefore, the data obtained in this study are important. Although the bending strength data obtained in groups 2 and 3 were not high enough compared to the control group, the increase observed in the maximum deformation values obtained during this test was considered to be an important result obtained at the end of this study.

Similar results were found by Borri *et al*. (2013) as a result of a bending strength test of reinforced materials with glass fiber fabric. Some of the important differences between this study and previous studies included the weaving feature of the reinforcement material, weight of the reinforcement material, place where the reinforcement material was used in the laminated wood material, type of glue used, press pressure, and press temperature. These differences have been considered to be the cause of the differences in the results obtained.

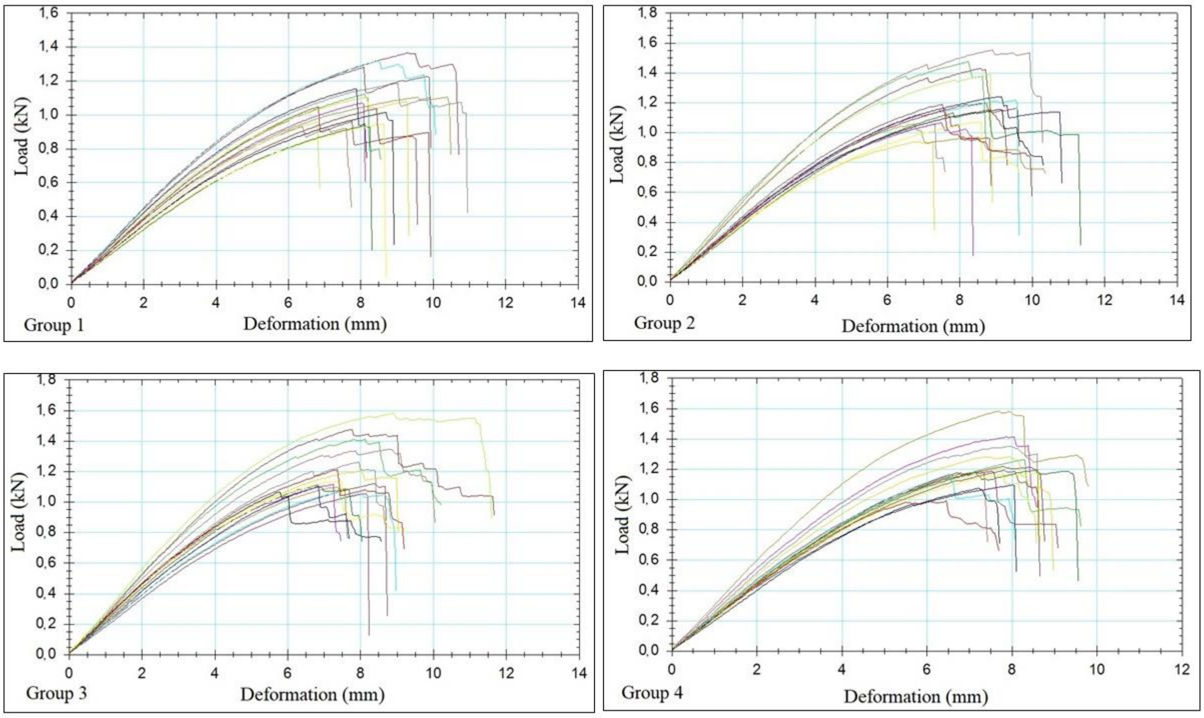


Figure 4: Load–deformation graphs based on bending strength test results.

The impact bending test results are given in Table 2. Based on these findings, it was determined that the impact bending of the test samples in the experimental groups increased compared to the control group. The difference was statistically significant ($p < 0,001$). The greatest impact bending was obtained in group 4. The effect of the reinforcement material used on the impact bending was greater than the effects on the bending strength and modulus of elasticity. The most important reason for this was that the load applied in the impact bending test had a very sudden effect. Whereas this sudden load was easily dispersed in the test samples of the control group, the reinforced test samples resisted this sudden load more stably.

All of the control group test samples were divided into two parts at the end of the test. However, the majority of the experimental group test specimens were broken but not divided into two pieces.

When the splitting strength test data given in Table 2 were examined, it was determined that the increase in the test samples of the experimental group compared to the control group was statistically significant (P < 0,001). Among the mechanical properties presented in this study, the most important effect of reinforcement with GFM was obtained for the splitting strength. The most important reason for this was that, during the splitting strength test, the veneer sheets that made up the LVL boards were exposed to the splitting strength, while the GFM layers within the glue layer were exposed to the tensile strength.

The splitting strength of the wood material was much smaller than the tensile strength of the GFM. For this reason, the splitting strength of the test samples of the experimental group reinforced with the GFM tested in this study was much higher than that of the control group. During the splitting strength test, when the maximum deformation amounts obtained from the test samples in the experimental group were compared with those of the control group, it was determined that the differences were statistically significant (P < 0,001). This could be considered to be a solution to the problem of splitting of the LVL material, especially at the connection points, at the ends of the LVL material, and in the connections made with nails or screws, as a result of strains.

The load–deformation graphs obtained during the splitting strength tests are given in Figure 5. These graphs show that the fracture patterns of group 1, which was the control group, and groups 2, 3, and 4 differ from each other.

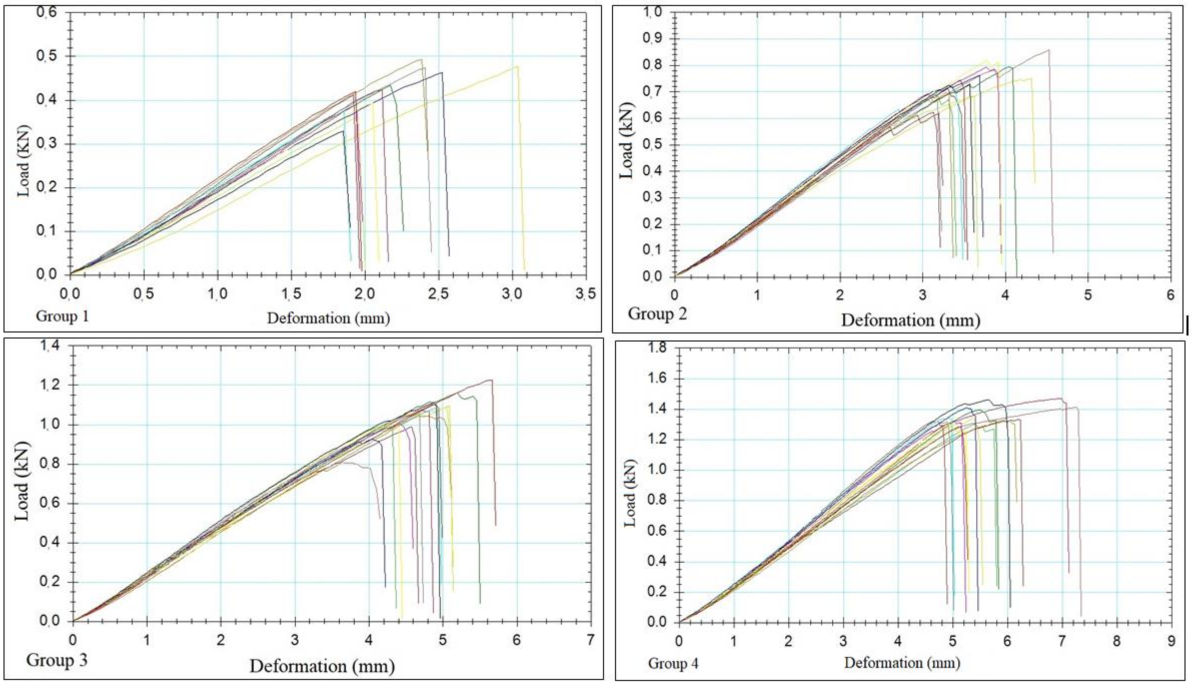


Figure 5: Load-deformation graphs based on splitting strength test results for groups bonded with PU glue.

The data of the screw holding strength tests obtained at the end of the study are given in Table 2. These data show that there were small differences between the screw holding strength values, and the test samples of the experimental group supported with GFM had slightly higher values. The control group and experimental groups had different results from each other, but the differences between the experimental groups were found to be statistically insignificant.

In a previous study on this subject, the screw holding strength, screw-head pull-through, and lateral screw holding resistance of plywood reinforced with glass fiber fabric were investigated by Bal (2017), and it was reported that there was an increase in these resistances. The main reason for obtaining such different results between the previous study and this study is that the reinforcement material used was different. The GFM used in this study is a porous material, and its weight is 160 g/m^2. The glass fiber fabric used in the previous study had a weight of 500 g/m^2.

Another result obtained in the screw holding strength test was the maximum deformation amount. Compared to the control group, the maximum amount of deformation obtained from the test samples of the experimental group increased as the number of GFMs increased. It can be said that this is an important result obtained from the screw holding strength test.

Conclusions

In this study, LVL was produced using PU glue, together with poplar veneers and GFM. Some physical and mechanical properties of the produced boards were determined, and the differences between the test samples of the control group and the experimental groups were investigated.

According to the data obtained for the flexural strength and modulus of elasticity, no statistically significant difference was determined between the control group and the experimental groups. In the splitting strength data, very significant differences were determined between the control group and the experimental group data.

In addition, very great differences were detected between the maximum deflection data obtained at the end of the splitting strength tests. This could offer a solution to the splitting problem with LVL materials, especially at the connection points, at the ends of the LVL material, and in the connections made with nails or screws, as a result of strains.

According to the impact bending test results, the shock resistance values of some experimental groups that received GFM support were higher than those of the control group. The most important difference in the impact bending tests was that, especially in the group 4 test samples, the test sample was broken at the end of the test, but was not divided into two different parts. This was an important result, especially for load-bearing structural members.

Authoship contributions

B. C. B: Conceptualization, data curation, formal Analysis, funding acquisition, investigation, methodology, project administration, resources, supervision, validation, writing – original draft, writing – review & editing.

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