Assessment of Torque Performance during Screwing in Beech Plywood Reinforced with Glass Fiber in Phenol-Formaldehyde Resin

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This study aimed to develop plywood, which is generally used as a building material in outdoor areas, by adding low-cost glass fiber and to examine some physical and mechanical properties of the developed plywood. For this, beech veneers (600 × 600 mm dimension, 2 mm thickness in 3% to 5% humidity) were glued with phenol-formaldehyde adhesive at the levels of 10%, 20%, and 30% by adding powdered e-type glass fiber in two different sizes (25 µm and 10 µm) to produce seven-layer beech plywood. Density, equilibrium moisture content, thickness swelling, tensile-shearing, and tensile-perpendicular to the surface were evaluated on test samples cut from the beech plywood in 50 × 50 mm dimension, and screwing torque values were carried out on test samples cut in 500 × 50 mm dimensions. Two-factor analysis of variance (ANOVA) was performed separately for the tests above. Results indicated that in cases where interactions between the glass fiber size and ratio were significant at the 0.05 significance level, the least significant difference value (LSD) analysis of the interaction was performed. According to LSD results, the tensile strength perpendicular to the surface decreased as the glass fiber ratio was increased.

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INTRODUCTION

The use of forest products continues to increase due to the rapid increase in the world population, urbanization, technological developments, social, cultural and economic developments. Existing raw materials can no longer meet the industry's demand. It has become more difficult to obtain raw wood materials due to the industry's growth in wood consumption, highlighting the need for the most cost-effective wood-use approach (Çakıroğlu 2012). In recent years, studies have attempted to obtain more valuable products by combining materials such as glass, steel, stone, plastic, wood, and concrete in different shapes or proportions. On the other hand, the development of carbon, high-strength glass, boron, and aramid fibers continues, and these developed materials were previously used in high-risk applications, but later they were also used in structural applications (Ekinci 2004).

A study reported some mechanical and physical properties of layered veneer timbers glued with phenol formaldehyde adhesive reinforced with glass fiber textile using poplar veneers (Özyurt 2015). As a result of this research, the glass fiber woven support significantly increased the boards' shock resistance, density, and modulus of elasticity. Also, it reduced the tensile and shear resistance, thickness swelling, and water absorption percentages (Özyurt 2015). Bal (2014) investigated the effect of glass fiber textiles on some physical and mechanical properties of laminated wood obtained from poplar veneers; the results showed that the mechanical resistance of reinforced laminated wood is higher than that of ordinary laminated wood.

In another study where the bending strength properties of red pine wood materials reinforced with glass fiber and steel plate were investigated, the bending strength increased by 14% in reinforcement with glass fiber and by 24% in reinforcement with steel plate (Güntekin and Aydın 2015). The bending strength of glass fiber fabric-reinforced wooden laminated materials was examined in another study; where 100 and 200 g/m^2 of glass fiber fabric were added to the samples prepared from chestnut (*Castanea sativa*) wood to examine any increase in their strength.

According to the results, the samples parallel to the glue line showed higher strength than those perpendicular to the glue line (Karaman and Yıldırım 2018). One of the critical mechanical properties is the screwing performance in wood and wood-based materials. There are some studies about the factors affecting the screw-driving torques in wood-based materials. In a study, screw resistances were investigated on glass-fibre-strengthening wood material (Bal and Efe 2015). For this purpose, layered veneer timbers obtained from poplar and layered veneer timbers reinforced with glass fiber textiles were used. Based on the results, the glass fiber reinforcement increased screw pullout resistance, screw head pullout resistance, and screw lateral pullout resistance (Bal and Efe 2015).

The penetration depth and critical torques, including screwdriver air pressure, seating, and maximum torques, were assessed in a study examining the variables influencing the amount of vertical driving force supplied to the screws during the screwing process on particleboard face orientation. The results demonstrated that when the pilot hole was not drilled, the vertical forces used during screwing had a substantial impact on the critical screwing torque magnitude; however, when the pilot holes with a diameter of 3.2 mm were drilled, this effect was not significant. Additionally, it was reported that in boards without drilled pilot holes, the air pressure of the drill during screwing had no discernible impact on the magnitude of the critical screwing torques; however, if pilot holes were drilled, increasing the drill's air pressure from 0.45 to 0.62 MPa resulted in increases in the average maximum torques. (Tor *et al*. 2019).

In a study investigating the effects of countersink hole and screwing direction, pilot hole diameter and pilot hole depth on screwing torque values in medium-density fiberboards were obtained by joining medium-density fiberboards face to face. According to the results, the quadruple interaction between screwing direction, pilot hole diameter and depth, and the condition of the countersink hole is significant (Tor 2019a).

Measurements of seating torque and maximum torque were made in a study examining the effects of the pilot hole diameter drilled on medium-density fiberboard on screwing torques. The statistical analysis indicated that the pilot hole diameter significantly impacted the seating and maximum torque values in medium-density fiberboard. According to the statement, the maximum torque values ranged from 1.18 to 2.68 N.m. In contrast, the average seating torque ranged between 0.37 and 1.23 N.m when screws were tightened on the medium-density fiberboard side surface. The maximum torque values for surface samples ranged from 2.89 to 5.41 N.m, while the average sitting torque values ranged from 0.57 to 1.56 N.m (Tor 2019b).

In this study, the effects of mechanical properties on screwing torques of plywood, which is generally used as a building material in outdoor areas, were improved by adding low-cost glass fiber. Features of glass fiber reinforced composites such as low cost, easy availability, ease of production, and high strength are the main reason these composites have been used in many areas from past to present (Ekiz 2013).

This study aimed to develop a seven-layer plywood material with beech veneers glued with the phenol-formaldehyde adhesive by adding powdered e-type glass fiber. Some physical and mechanical properties (density, equilibrium moisture content, thickness swelling, tensile-shearing, tensile perpendicular to the surface, and screw-driving torques) were carried out on test plywood samples. The effects of the glass fibre size and ratio in phenol-formaldehyde adhesive were evaluated in beech plywood.

EXPERIMENTAL

Materials and Methods

The beech veneers used in the study were supplied by a local company producing plywood in Kastamonu, dried to 3% to 5% moisture and in dimensions of 600 × 600 mm. Toby phenol formaldehyde adhesive, widely used in the plywood manufacturing industries, was obtained from Polisan Kimya Sanayi A.Ş. The phenol-formaldehyde adhesive was mixed with the glass fiber in various different ratios of 10%, 20%, and 30% and added e-type glass fiber in powder form in two different sizes, 25 µm and 10 µm in a room temperature until homogeneously mixed.

a) b)

Fig. 1. Beech veneers (a) and powdered e-type glass fibers of 25 µm and 10 µm (b)

The beech plywood was produced in seven layers based on the TS 1250 (1974). Beech veneers of dimensions 600 × 600 mm were pressed for 10 min in a single-layer hydraulic press set at 120 °C and 12 kg/cm² press pressure. Test samples of the 7-layered plywood were prepared in the Wood Culture Research and Application Center at Kastamonu University. The pilot holes with a diameter of 3.5 mm, equal to the total thickness of the samples, were drilled in the test samples where the screwing torque values were to be determined.

The sheets were produced in the Impregnation Laboratory within the Department of Forest Industry Engineering, Faculty of Forestry, Kastamonu University. The average thickness of the 7-layer plywood produced was measured as 14.28 mm.

Physical Properties

Equilibrium moisture content

The equilibrium moisture content of the samples was determined according to the standard of TS EN 322 (1999) and is shown in Table 1. The moist weights of test samples, each measuring 50 × 50 mm, were weighed on an analytical balance with an accuracy of ±0.01 g. They were kept in an oven at 103±2 °C until they reached a constant weight, and their total dry weight was weighed on an analytical balance with an accuracy of ±0.01 g.

Table 1. Standards and Sample Quantities Used in Physical Property Tests

Test	Standard	Number of Samples
Density	TS EN 323/1 (1999)	20
Equilibrium Moisture Content	TS EN 322 (1999)	10
Swelling to Thickness	TS EN 317 (1999)	10

Swelling to thickness

The thickness swelling of the samples was determined according to the standard of TS EN 317 (1999). Ten of the test samples obtained were used for each test group.

Mechanical Properties

Tensile-shear resistance

Tensile-shear resistance values of the samples were determined according to a standard of TS EN 314-1 (1998) and is shown in Table 2. The experiment was conducted on a Shimadzu brand universal testing machine at Kastamonu University, Forest Industry Engineering, Wood Mechanics and Technology Laboratory.

Table 2. Standards and Sample Quantities Used in Mechanical Property Tests

Test	Standard	Number of samples
Tensile-Shear Resistance	TS EN 314-1 (1998)	10
Tensile Strength Perpendicular to the Surface	TS EN 319 (1999)	10

Tensile strength perpendicular to the surface

Tensile strength perpendicular to the surface of the samples was determined according to the standard of TS EN 319 (1999). The experiment was conducted on a Shimadzu brand universal testing machine at Kastamonu University, Forest Industrial Engineering, Wood Mechanics and Technology Laboratory.

Determination of screwing torque values

As wood material, pilot holes with a diameter of 3.5 mm were drilled at 50 mm intervals with a column drill on the test samples cut in 500 × 50 mm dimensions from the boards produced with veneers obtained from beech logs according to the standard TS 1250

(1974). The pilot hole depths were adjusted to be the total thickness of the test samples. Screwing torque values were tested by placing 10 mm thick metal plates countersunk in the middle of the test samples that was fitted the screw head. Wood screws with Phillips head were 4 × 30 mm in dimension and made out of steel were used in the study.

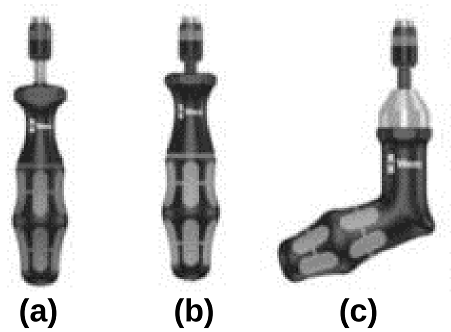

Fig. 2. Torque screwdriver (a) 0.1 < 1.2 N.m, (b) 1.2 < 3.0 N.m, (c) 3.0 < 6.0 N.m

The test samples were screwed with a pilot hole drilled using a torque screw-driver (Fig. 2.). The torque value at the moment when the screw fully contacts or entirely sits on the material surface is obtained as "seating torque", and after the seating torque is obtained, the torque value just before the screw strips in the sample was "maximum torque" value in N.m. Thirty pieces from each test group were used to determine the screwing torque values.

Data Analysis

The data of the tests conducted for physical and mechanical properties were statistically evaluated separately by two-factor analysis of variance (ANOVA) (Table 3). According to the ANOVA results, in cases where interactions were significant at the 0.05 significance level, the least significant difference (LSD) analysis of the interaction was performed. In cases where the binary interaction was insignificant according to the ANOVA results, the LSD analysis was performed on the factors separately, and intra-factor comparisons were made.

RESULTS

Using beech plywood with seven and nine layers, pilot hole diameters of 3.0 and 3.5 mm, pilot hole depths of 60% and 80%, and metal plate thickness of 7.5 and 10 mm, the factors affecting screwing torques were investigated in the study. The average seating torque values ranged between 0.31 and 0.69 N.m, while average maximum torque values were between 0.50 and 4.7 N.m. In this study, in 7-layer poplar plywood samples using 3.5 mm pilot hole diameter and 10 mm metal plates, the average seating torque was determined to be 0.505 N.m, and the maximum torque average was 1.295 N.m in samples with 60% pilot hole depth. In samples with 80% pilot hole depth, the average seating torque was determined to be 0.320 N.m, and the maximum torque average was 1.150 N.m (Tor *et al*. 2020).

In this study, 7-layer beech plywood was created by applying powdered e-type glass fiber in two different sizes, 25 µm and 10 µm, to the adhesive at 10%, 20%, and 30% levels. Tests were carried out for screwing torque values by placing 10 mm thick metal plates countersunk in the middle of the test samples in which pilot holes were drilled with a diameter of 3.5 mm and as much as the plate thickness. For the test samples mixed with 10-micron size glass fibers, the average seating torque was 0.402 N.m, and the maximum torque was 4.72 N.m; in samples with a 10% glass fiber ratio, the average seating torque was 0.415 N.m, and the maximum torque was 4.98 N.m in samples with 20% glass fiber ratio. The maximum torque is 4.98 N.m in samples with a 30% glass fiber ratio with 25 µm glass fiber size. The average seating torque was 0.37 N.m, and the maximum torque was 4.46 N.m. For the test samples mixed with 25-micron size glass fibers, the average seating torque was 0.432 N.m, and the maximum torque was 4.98 N.m; in samples with a 10% glass fiber ratio, the average seating torque was 0.442 N.m, and the maximum torque was 5.32 N.m in samples with 20% glass fiber ratio. The maximum torque was 5.32 N.m in samples with a 30% glass fiber ratio. The examples with 0.44 N.m average seating torque and maximum torque of 5.16 N.m. In addition, in the control samples, the average seating torque was determined as 0.347 N.m, and the maximum torque was 4.35 N.m.

Physical Properties

Table 3 shows statistical results for physical properties.

Table 3. F- and P-Values of Physical Properties

Physical Properties	Source	F-Value	P-Value
Density	Glass Fiber Size (µm)	4.590	0.0337
	Glass Fiber Ratio (%)	6.890	0.0002
	Glass Fiber Size (µm) x Glass Fiber Ratio (%)	1.460	0.2278
Equilibrium Moisture Amount	Glass Fiber Size (µm)	1.600	0.2085
	Glass Fiber Ratio (%)	3.690	0.0133
	Glass Fiber Size (µm) x Glass Fiber Ratio (%)	0.650	0.5831
Swelling to Thickness (2 s)	Glass Fiber Size (µm)	11.840	0.0010
	Glass Fiber Ratio (%)	3.050	0.0340
	Glass Fiber Size (µm) x Glass Fiber Ratio (%)	2.290	0.0856
Swelling to Thickness (24 s)	Glass Fiber Size (µm)	1.140	0.2886
	Glass Fiber Ratio (%)	1.530	0.2150
	Glass Fiber Size (µm) x Glass Fiber Ratio (%)	3.090	0.0323

Density

In the samples with 10-micron glass fiber size, the highest density average was determined as 10% and 30%, and in the samples with 25-micron glass fiber size, the highest density average was detected in the samples with a 10% glass fiber ratio (Table 4). According to the ANOVA results, the interaction between glass fiber size and glass fiber ratio was insignificant, as the P-value was 0.2278 at the 0.05 significance level. Based on the LSD analysis (Tables 5 and 6), the density in samples with a glass fiber size of 10 microns was statistically higher than that of 25 microns. The results showed that 10% and

30% samples were statistically denser than the control samples and samples with a 20% glass fiber ratio.

Table 4. Descriptive Statistical Information for Density Experiment

Glass Fiber Size (µm)	Glass Fiber Ratio (%)	Number of Samples	Average (g/cm³)	Standard Deviation (σ)	Coefficient of Variation (%)
10	0	20	0.726	0.016	2
	10	20	0.730	0.013	2
	20	20	0.716	0.011	2
	30	20	0.730	0.018	2
25	0	20	0.726	0.016	2
	10	20	0.726	0.020	3
	20	20	0.712	0.009	1
	30	20	0.717	0.012	2

Table 5. Comparison of Average Density Values According to Glass Fiber Size

Glass Fiber Size (µm)	
10	**25**
0.726 A*	0.721 B
LSD = 0.0047	
* Means followed by a common letter are not significantly different at the 5% level	

Table 6. Comparison of Average Density Values According to Glass Fiber Ratio

Glass Fiber Ratio (%)			
0	**10**	**20**	**30**
0.726 A*	0.729 A	0.715 B	0.724 A
LSD = 0.0066			
* Means followed by a common letter are not significantly different at the 5% level			

Equilibrium Moisture Amount

In samples with a 10 µm glass fiber size, the highest average moisture content was detected in samples with a 10% glass fiber ratio. In samples with 25 µm glass fiber size, the highest average moisture content was detected in samples with 10% glass fiber ratio. According to the ANOVA results (Table 7), the two-way interaction between glass fiber size and glass fiber ratio was insignificant, as the P-value was 0.5831 at the 0.05 significance level. Therefore, the effect of each factor was examined separately.

Table 7. Descriptive Statistical Information for the Equilibrium Moisture Content

Glass Fiber Size (µm)	Glass Fiber Ratio (%)	Number of Samples	Average (%)	Standard Deviation (σ)	Coefficient of Variation (%)
10	0	20	9.100	0.575	6
	10	20	9.218	0.934	10
	20	20	8.630	1.152	13
	30	20	8.469	0.687	8
25	0	20	9.100	0.575	6
	10	20	9.335	1.930	21
	20	20	9.233	1.182	13
	30	20	8.588	0.620	7

According to LSD analysis, there was no statistical difference between the MC in samples with glass fiber sizes of 10 microns and 25 microns (Table 8 and 9). When compared according to the glass fiber ratio, there was no statistical difference between the control and plywood samples with 10% and 20% glass fiber ratios. In addition, there was a statistical difference between the control samples and the plywood samples with 10% glass fiber content and the plywood samples with 30% glass fiber content.

Table 8. Comparison of Average MC Values According to Glass Fiber Size

Glass Fiber Size (µm)	
10	**25**
8.854 A*	9.064 A
LSD = 0.3284	
* Means followed by a common letter are not significantly different at the 5% level	

Table 9. Comparison of Average MC Values for Glass Fiber Ratio

Glass Fiber Ratio (%)			
0	**10**	**20**	**30**
9.010 A*	9.276 A	8.931 AB	8.529 B
LSD = 0.4644			
* Means followed by a common letter are not significantly different at the 5% level			

Swelling to Thickness

In samples with 10 µm glass fiber size after 2 h of immersion in water, the highest average swelling thickness was detected in samples with a 30% glass fiber ratio.

In samples with 25 µm glass fiber size, the highest average swelling thickness was detected in samples with a 30% glass fiber ratio. According to the ANOVA results (Table 10), the two-way interaction between glass fiber size and glass fiber ratio was insignificant, as the P-value was 0.0856 at the 0.05 significance level. Therefore, the effects of each factor were examined separately. According to the LSD analysis (Table 11 and 12), there was a statistical difference between swelling thickness in samples with glass fiber sizes of 10 µm and 25 µm. When compared according to the glass fiber ratio, there was statistically no difference in thickness swelling between the control and plywood samples with a 10% glass fiber ratio.

Table 10. Descriptive Statistical Information for the Thickness Swelling Test in Water Immersion for 2 h

Glass Fiber Size (µm)	Glass Fiber Ratio (%)	Number of Samples	Average (%)	Standard Deviation (σ)	Coefficient of Variation (%)
10	0	10	2.931	1.089	37
	10	10	2.966	0.956	32
	20	10	4.265	1.567	37
	30	10	4.354	1.693	39
25	0	10	2.931	1.089	37
	10	10	2.498	0.806	32
	20	10	2.637	0.799	30
	30	10	2.992	0.454	15

Table 11. Comparison of Average Values of 2 h Thickness Swelling for Glass Fiber Size

Glass Fiber Size (µm)	
10	**25**
3.629 A*	2.765 B
LSD = 0.5009	
* Means followed by a common letter are not significantly different at the 5% level	

Statistically, there was no difference for swelling in thickness between plywood samples with 20% glass fiber content and plywood samples with 30% glass fiber content. Additionally, there was a statistical difference in swelling thickness between plywood samples with 20% and 30% glass fiber content and plywood samples with 10% glass fiber content.

Table 12. Comparison of 2 h Thickness Swelling Average Values for Glass Fiber Ratio

Glass Fiber Ratio (%)			
0	**10**	**20**	**30**
2.931 BC*	2.732 C	3.451 AB	3.673 A
LSD = 0.7083			
* Means followed by a common letter are not significantly different at the 5% level			

In samples with 10-micron glass fiber size after 24 h of immersion in water, the highest average swelling thickness was detected in samples with a 20% glass fiber ratio. In samples with 25 µm glass fiber size, the highest average swelling thickness was detected in samples with a 30% glass fiber ratio. According to the ANOVA results (Table 13), the two-way interaction between glass fiber size and glass fiber ratio was significant, as the P-value was 0.0323 at the 0.05 significance level.

According to the LSD analysis (Table 14 and Fig 3), there was no statistical difference in thickness swelling between plywood samples with a glass fiber size of 10 µm and 25 µm with a 10% glass fiber ratio. There was a statistical difference in thickness swelling between plywood samples with a glass fiber size of 10 µm and 25 µm with a 20% glass fiber ratio. No difference in thickness swelling was observed between the above plywood samples with with a 30% glass fiber ratio. When compared according to the glass fiber ratio, there was no statistical difference between plywood samples with a glass fiber size of 10 µm and a glass fiber ratio of 20% and 30%. Statistically, there was no difference in swelling thickness between the control with a glass fiber size of 10 µm and the plywood samples with a 10% glass fiber ratio.

Table 13. Descriptive Statistical Information for the Thickness Swelling Test in Water Immersion for 24 h

Glass Fiber Size (µm)	Glass Fiber Ratio (%)	Number of Samples	Average (%)	Standard Deviation (σ)	Coefficient of Variation (%)
10	0	10	5.988	0.902	15
	10	10	5.643	0.259	5
	20	10	6.783	0.699	10
	30	10	6.352	0.927	15
25	0	10	5.988	0.902	15
	10	10	6.063	0.826	14
	20	10	5.758	0.582	10
	30	10	6.218	0.845	14

Table 14. Comparison of 24 h Thickness Swelling Average Values for Glass Fiber Size in each Glass Fiber Ratio

Glass Fiber Ratio (%)	Glass Fiber Size (µm)	
	10	25
Control	5.988 A*	5.988 A
10	5.643 A	6.063 A
20	6.783 A	5.758 B
30	6.352 A	6.219 A
LSD = 0.689		
* Means followed by a common letter are not significantly different at the 5% level		

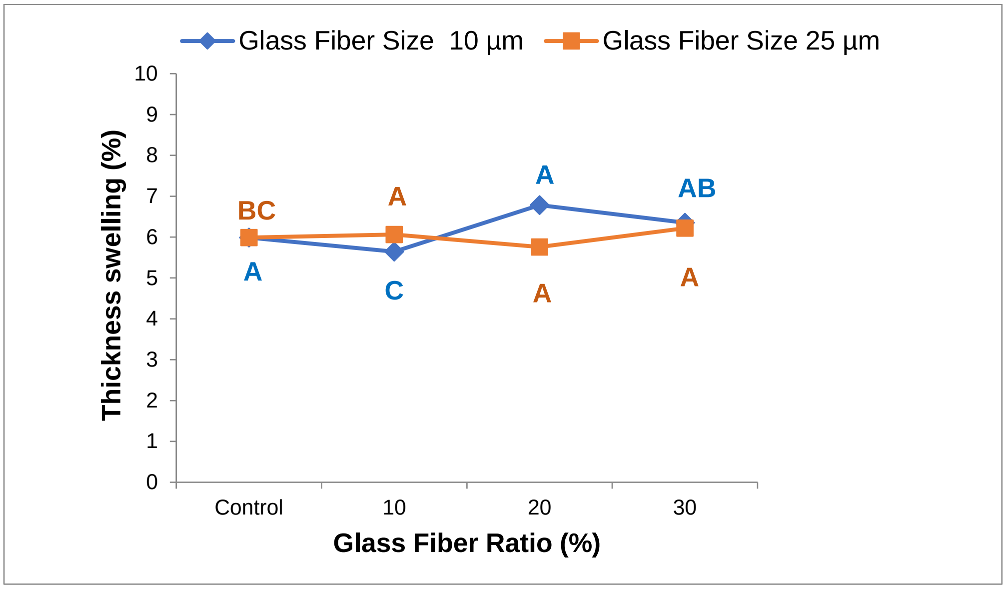

Fig. 3. Comparison of 24-h thickness swelling average values for glass fiber ratio. (* Means followed by a common letter are not significantly different at the 5% level) (LSD:0,689)

There was a statistical difference in thickness swelling between plywood samples with 10 µm glass fiber size and 20% and 30% glass fiber ratio and plywood samples with 10% glass fiber ratio. There was no statistical difference in thickness swelling between plywood samples with a glass fiber size of 25 microns.

Mechanical Properties

F- and P-values for mechanical properties of the sources are given in Table 15.

Table 15. F- and P-Values Based on Mechanical Properties

Mechanical Properties	Source	F-Value	P-Value
Tensile-Shear Resistance	Glass Fiber Size (µm)	1.990	0.1627
	Glass Fiber Ratio (%)	2.270	0.0877
	Glass Fiber Size (µm) × Glass Fiber Ratio (%)	0.690	0.5587
Tensile Strength Perpendicular to the Surface	Glass Fiber Size (µm)	0.000	0.9466
	Glass Fiber Ratio (%)	3.530	0.0191
	Glass Fiber Size (µm) × Glass Fiber Ratio (%)	0.180	0.9096
Seating Torque	Glass Fiber Size (µm)	21.030	<0.0001
	Glass Fiber Ratio (%)	27.730	<0.0001
	Glass Fiber Size (µm) × Glass Fiber Ratio (%)	4.350	0.0053
Maximum Torque	Glass Fiber Size (µm)	17.950	<0.0001
	Glass Fiber Ratio (%)	18.340	<0.0001
	Glass Fiber Size (µm) × Glass Fiber Ratio (%)	3.560	0.0151

Tensile-Shear Resistance

In samples with a 10-micron glass fiber size, the highest average tensile-shear strength was detected in samples with a 10% glass fiber ratio (Table 16). In samples with 25 µm glass fiber size, the highest average tensile-shear strength was detected in samples with a 10% glass fiber ratio. According to the ANOVA table for the tensile-shear strength test, the bilateral interaction between the glass fiber size and glass fiber ratio was insignificant at a significance level of 0.05, so the effects of each factor were examined separately.

Table 16. Descriptive Statistical Information for Tensile-Shear Test

Glass Fiber Size (µm)	Glass Fiber Ratio (%)	Number of Samples	Average (N/mm²)	Standard Deviation (σ)	Coefficient of Variation (%)
10	0	10	2.254	0.248	11
	10	10	2.264	0.380	17
	20	10	2.093	0.397	19
	30	10	1.827	0.308	17
25	0	10	2.254	0.248	11
	10	10	2.275	0.542	24
	20	10	2.271	0.562	25
	30	10	2.135	0.339	16

Table 17. Comparison of Glass Fiber Size Average Tensile-Shear Strength Values

Glass Fiber Size (µm)	
10	**25**
2.234 A*	2.109 A
LSD = 0.1758	
* Means followed by a common letter are not significantly different at the 5% level	

According to the LSD analysis (Table 17 and 18), there was no statistical difference between the tensile-shear strength of the samples with a glass fiber size of 10 and 25 µm.

Table 18. Comparison of Glass Fiber Ratio Average Tensile-Shear Strength Values

Glass Fiber Ratio (%)			
0	**10**	**20**	**30**
2.255 A*	2.270 A	2.182 AB	1.981 B
LSD = 0.2486			
* Means followed by a common letter are not significantly different at the 5% level			

Compared to the glass fiber ratio, there was no statistical difference in tensile-shear strength between the control and plywood samples with 10% glass fiber ratios. Statistically, there was no difference in tensile-shear strength between plywood samples with 20% glass fiber content and plywood samples with 30% glass fiber content. In addition, there was a statistical difference in tensile-shear strength between control samples and plywood samples with 10% glass fiber content and plywood samples with 30% glass fiber content.

Tensile strength perpendicular to the surface

In samples with a 10 µm glass fiber size, the highest average tensile strength perpendicular to the surface was determined in samples with a 10% glass fiber ratio (Table 19). In samples with 25 µm glass fiber size, the highest average tensile strength perpendicular to the surface was determined with a 10% glass fiber ratio.

Based on ANOVA results, the two-way interaction between glass fiber size and glass fiber ratio was insignificant, as the P-value was 0.9096 at the 0.05 significance level. Therefore, the effects of each factor were examined separately. The LSD analysis (Tables 20 and 21) showed that there was no statistical difference between the tensile strength perpendicular to the surface in the samples with a glass fiber size of 10 and 25 µm. Compared to the glass fiber ratio, there was statistically no difference in tensile strength perpendicular to the surface between the control and plywood samples with 10% glass fiber ratios.

Table 19. Descriptive Statistical Information for Tensile Strength Perpendicular to the Surface

Glass Fiber Size (µm)	Glass Fiber Ratio (%)	Number of Samples	Average (kg/cm²)	Standard Deviation (σ)	Coefficient of Variation (%)
10	0	10	1.509	0.369	24
	10	10	1.385	0.401	29
	20	10	1.226	0.406	33
	30	10	1.149	0.191	17
25	0	10	1.509	0.369	24
	10	10	1.285	0.352	27
	20	10	1.274	0.182	14
	30	10	1.180	0.436	37

Table 20. Comparison of Glass Fiber Size Average Tensile Strength Values Perpendicular to the Surface

Glass Fiber Size (µm)	
10	**25**
1.31726 A*	1.31200 A
LSD = 0.1561	
* Means followed by a common letter are not significantly different at the 5% level	

Statistically, there was no difference in tensile strength perpendicular to the surface between plywood samples with 20% glass fiber content and plywood samples with 30% glass fiber content. In addition, there is a statistical difference in tensile strength perpendicular to the surface between the control and plywood samples with 20% and 30% glass fiber content.

Table 21. Comparison of Glass Fiber Ratio Average Tensile Strength Values Perpendicular to the Surface

Glass Fiber Ratio (%)			
0	**10**	**20**	**30**
1.5090 A	1.3350 AB*	1.2498 B	1.1648 B
LSD = 0.2208			
* Means followed by a common letter are not significantly different at the 5% level			

Determination of screwing torque values

In samples with 10 µm glass fiber size, the highest average seating torque was detected in samples with a 20% glass fiber ratio (Table 22). In samples with 25 µm glass fiber size, the highest average seating torque was detected in samples with a 20% glass fiber ratio. According to the ANOVA results, the two-way interaction between glass fiber size and glass fiber ratio was significant, as the P-value was 0.0053 at the 0.05 significance level. As per the LSD analysis (Table 23 and Fig 4), the glass fiber size was 10. There was a statistical difference in seating torque between 10 and 25-micron plywood samples with 10% glass fiber content.

Table 22. Descriptive Statistical Information for Seating Torque

Glass Fiber Size (µm)	Glass Fiber Ratio (%)	Number of Samples	Average (N.m)	Standard Deviation (σ)	Coefficient of Variation (%)
10	0	30	0.347	0.047	14
	10	30	0.402	0.061	15
	20	30	0.415	0.066	16
	30	30	0.370	0.058	16
25	0	30	0.347	0.047	14
	10	30	0.432	0.048	11
	20	30	0.442	0.046	10
	30	30	0.440	0.050	11

There was no statistical difference in seating torque between plywood samples with a glass fiber size of 10 and 25 µm with a 20% glass fiber ratio. There was a statistical difference in seating torque between two plywood samples with a glass fiber size of 10 and 25 µm with a 30% glass fiber ratio. Compared to the glass fiber ratio, there was no difference in seating torque between plywood samples with 10 µm glass fiber size and 10% and 20% glass fiber ratio. Statistically, there was no difference in seating torque between the control with a glass fiber size of 10 µm and the plywood samples with a 30% glass fiber ratio. There was a statistical difference in seating torque between the control samples with a glass fiber size of 10 µm, the plywood samples with a 30% glass fiber ratio, and the plywood samples with a 10% and 20% glass fiber ratio. There was a statistical difference in seating torque between plywood with a glass fiber size of 25 microns and a glass fiber ratio of 10%, 20%, and 30% and the control samples.

Table 23. Comparison of Average Seating Torque Values According to Glass Fiber Size

Glass Fiber Ratio (%)	Glass Fiber Size (µm)	
	10	25
Control	0.343 A*	0.343 A
10	0.402 B	0.432 A
20	0.415 A	0.442 A
30	0.370 B	0.440 A
LSD=0.0271		
* Means followed by a common letter are not significantly different at the 5% level		

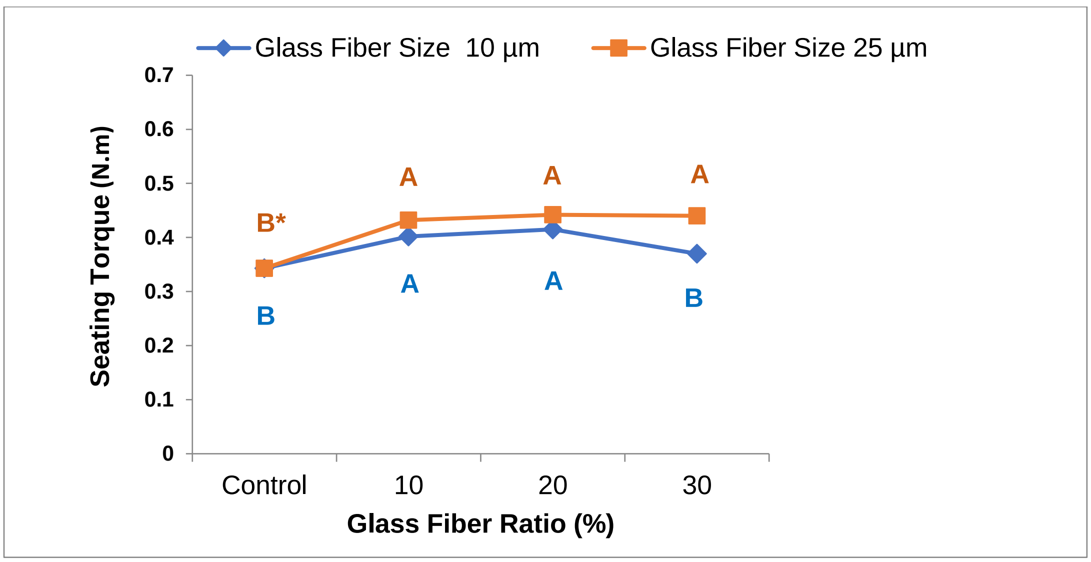

Fig. 4. Comparison of average seating torque values according to glass fiber ratio in each glass fiber size. (* Means followed by a common letter are not significantly different at the 5% level) (LSD:0.0271)

In samples with a 10 µm glass fiber size, the highest maximum torque average was detected in samples with a 20% glass fiber ratio (Table 24). In samples with a 25 µm glass fiber size, the highest maximum torque average was detected in samples with a 20% glass fiber ratio. According to the ANOVA results, the two-way interaction between glass fiber size and glass fiber ratio was significant, as the P-value was 0.0151 at the 0.05 significance level. The LSD result (Table 25 and Fig 5) was examined because the two-way interaction between the glass fiber size and glass fiber ratio was significant at 0.05.

Table 24. Descriptive Statistical Information for Maximum Torque

Glass Fiber Size (µm)	Glass Fiber Ratio (%)	Number of Samples	Average (N.m)	Standard Deviation (σ)	Coefficient of Variation (%)
10	0	30	4.350	0.552	13
	10	30	4.717	0.665	14
	20	30	4.975	0.589	12
	30	30	4.458	0.755	17
25	0	30	4.350	0.552	13
	10	30	4.975	0.638	13
	20	30	5.317	0.517	10
	30	30	5.158	0.428	8

According to the LSD analysis, there was no statistical difference in maximum torque between plywood samples with a glass fiber size of 10 and 25 µm with a 10% glass fiber ratio. There was a statistical maximum torque difference between plywood samples with a glass fiber size of 10 and 25 µm with a 20% and 30% glass fiber ratios. When compared according to the glass fiber ratio, there was no difference in maximum torque between plywood samples with a glass fiber size of 10 µm and a glass fiber ratio of 10% and 20%. There was a difference in maximum torque between plywood samples with a glass fiber size of 10 microns and a 20% and 30% glass fiber ratios. A 10% glass fiber ratio seems to represent an optimal amount of fiber in the composite material where there is sufficient reinforcement from the fibers without overloading the matrix. At this ratio, the fibers are likely well-distributed within the polymer matrix, allowing for strong interfacial bonding between the fibers and the matrix material. This leads to higher tensile-shear strength, as the fibers contribute to load transfer effectively. Statistically, there was a maximum torque difference between the plywood samples with a glass fiber size of 10 µm and a 20% glass fiber ratio and the control samples. There was a statistical maximum torque difference between the plywood samples with 20% and 30% glass fiber content, with a glass fiber size of 25 µm, and the control samples. There was a statistical maximum torque difference between plywood samples with 20% and 30% glass fiber content, with a glass fiber size of 25 µm, and plywood samples with a 10% glass fiber ratio (Fig. 5.).

Table 25. Comparison of Average Maximum Torque Value by Glass Fiber Size in Each Glass Fiber Ratio

Glass Fiber Ratio (%)	Glass Fiber Size (µm)	
	10	**25**
Control	4.350 A*	4.350 A
10	4.717 A	4.975 A
20	4.975 B	5.317 A
30	4.458 B	5.158 A
LSD=0.3022		
* Means followed by a common letter are not significantly different at the 5% level		

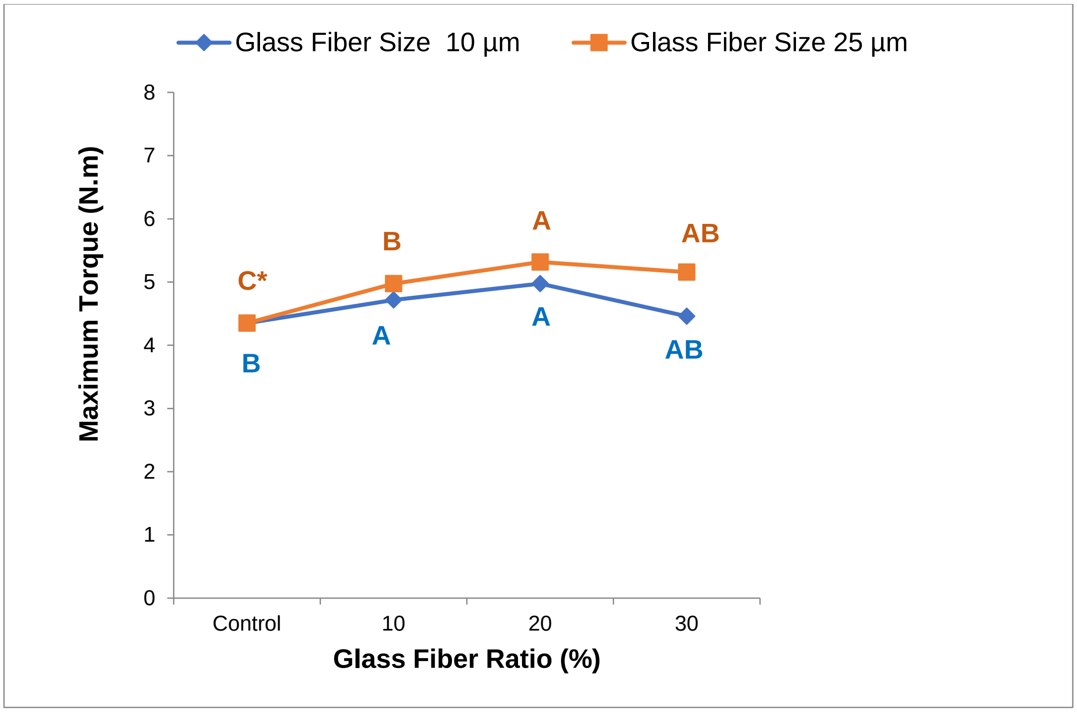

Fig. 5. Comparison of average maximum torque value according to glass fiber ratio in each glass fiber size (* Means followed by a common letter are not significantly different at the 5% level) (LSD = 0.3022)

CONCLUSION AND RECOMMENDATIONS

1. The physical and mechanical characteristics of beech plywood with a 20% glass fiber ratio and a 25 µm glass fiber size were evaluated in this study. Samples with a 10% and 30% glass fiber ratio had a slightly greater density average than the control samples. Samples with a 10% glass fiber ratio also had the greatest moisture average, with an average that was higher than the control samples.
2. Samples with a 30% glass fiber ratio showed the highest average swelling thickness after 2 h of submersion in water. Additionally, samples with a 10% glass fiber ratio had the highest average tensile-shear resistance, which was on average higher than that of the control samples. The average tensile-shear resistance dropped as the glass fiber ratio rose.
3. Of all the glass fiber ratios used in the test, samples with a 20% had the highest maximum torque averages and the highest average seating torque averages. The study showed that by adding inexpensive e-type glass fiber to the glue improved maximum torque and seating torque.
4. The findings of this study can help to understand prevent health issues such as cumulative damage to connective soft tissues and injuries to the hand, wrist, forearm, shoulder, and neck brought on by repetitive motions, powerful movements, and restricted or fixed postures related to torque. Accessing adequate

and high-quality raw materials is made more difficult by the daily growth in the number of industrial production enterprises.

5. Working with the plywood made of different classes of glass fibers and tree species will result in the economic benefit of increasing its class of life span through improved resistance values and screwing torque value. This development also means utilizing and valorizing raw material that comes from forests in an effective and efficient manner.

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