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Short notes

EFFECT OF FREEZE–THAW CYCLE ON THE SCREW-HOLDING STRENGTH OF PLYWOOD

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ABSTRACT

In this study, five-layered plywood boards were produced with poplar, beech, and eucalyptus rotary peeled veneer. One control group and three experimental group test samples were prepared from the produced boards. The experimental group test samples were subjected to 2, 4, and 6 freeze–thaw cycles according to TS EN 321. The density, moisture content, and screw-holding strength of each test sample were determined. Screw-holding tests were performed according to the principles specified in TS EN 13446. In the tests, a screw was applied perpendicular to the surface of the test sample. The poplar plywood had the lowest screw holding strength, with the highest found in the beech plywood. The effects of 4 and 6 freeze–thaw cycles on the screw-holding strength were statistically significant. A strong relationship was found between the screw-holding strength and density of the plywood.

KEYWORDS: Screw-holding strength, freeze–thaw cycle, plywood.

INTRODUCTION

Many factors determine the technological properties of plywood. These include those related to the type of wood used (density, fibre structure, knot count, moisture content, etc.), glue used (glue type, glue quantity, etc.), and pressing process (pressing pressure, temperature, and time). The density of the wood used has the most significant effects on the mechanical properties of the produced plywood (Ranjan et al. 2022, Kawalerczyk et al. 2022, Bekhta et al. 2023).

The mechanical properties of plywood obtained from beech, birch, pine, spruce, alder, okume, eucalyptus, and poplar species have been studied by many researchers. For example, Bal and Bektaş (2014) investigated the effect of factors such as the wood species, glue type, and load direction on the bending and adhesion strength of plywood. Peker and Tan (2014) investigated the effects of the growth conditions, steaming, drying temperatures, number of layers, and adhesive type on the mechanical properties of plywood produced from spruce

veneer. In addition to these tree species, the usability of eucalyptus wood in plywood production has also been studied by some researchers, who have stated that eucalyptus wood can be used in plywood production for general and structural purposes (Çolak et al. 2003; Iwakiri 2006, Bal and Bektaş 2012a, Bal and Bektaş 2014).

One of the most important mechanical properties of plywood is its screw-holding strength. Several important studies have been conducted on the screw-holding resistance of plywood. For example, Wu (1999) investigated the effects of moisture, load direction, and the wood type on the screw-holding strength of pine and sweet gum plywood. Yörür et al. (2017) investigated the effects of the number of guide holes, screw type, screwing direction, moisture content, and adhesive on the screw-holding strength in beech plywood. Bal (2017) investigated the screw-holding strength and screw-head protrusion strength of glass fibre reinforced poplar plywood. Birinci and Kaymakcı (2023) determined the effects of freeze–thaw treatment on the screw-holding strengths of okume, beech, and ozigo plywood. Hoffmeyer and Munch–Andersen (2024) investigated the screw-holding strength of plywood using screw types obtained from different manufacturers.

Despite these studies, the effects of freeze–thaw cycles on the screw-holding strengths of plywood produced from different wood species have not been sufficiently investigated. Therefore, the aim of this study is to investigate the effects of freeze–thaw cycles on the screw-holding strengths of plywood produced using poplar, beech, and eucalyptus veneers and phenol formaldehyde glue.

MATERIAL AND METHODS

Material

Rotary peeled veneers obtained from poplar (*Populus x euramericana* I-214), beech (*Fagus orientalis* L.), and eucalyptus (*Eucalyptus grandis* W. Hill ex Maiden) logs were used to produce the plywood. The eucalyptus, beech, and poplar logs were peeled to obtain veneers with a thickness of 3 ± 0.2 mm at a plywood factory and dried at the same factory. Phenol-formaldehyde (PF) glue was obtained from Gentaş Kimya Sanayi A.Ş. The glue had a dry matter content of 47%, density of 1.12 gr/cm^3, and gel time (at 130°C) of 6–7 min.

Method

The adhesive was applied to only one surface of the veneer sheets at a rate of 200 g/m^2. The PF adhesive was used without any additives or fillers. The plywood sheets were formed in five layers and produced in a laboratory-type electrically heated hydraulic press. The press pressure was 8 kg/cm^2 for the poplar plywood, and 12 kg/cm^2 for the beech and eucalyptus plywood. The pressing time was 18 min, and the press temperature was 180°C.

Moisture tests were conducted according to the principles specified in TS EN 322. Density tests were based on TS EN 323, and screw-holding strength tests were based on TS EN 13446. The prepared test specimens were 15 × 50 × 50 mm (thickness × width × length) in size. The screw-holding strength tests were performed on one surface of each plywood test specimen. Screws were attached at the midpoint of the surface. The tests used 4 × 50 mm (screw diameter × screw length) zinc screws. A drill was used to drive the screws all the way through the test specimens until they protruded from the other side.

A total of four test groups were created. Group 1 was the control group and received no treatment. The test specimens in Groups 2, 3, and 4 were subjected to freeze–thaw cycles twice, four times, and six times, respectively. The freeze–thaw cycles were performed according to TS EN 321. The test specimens were first immersed in water for 70 h, after which they were frozen at -12 ± 2°C for 24 h and dried at 70 ± 2°C for 8 h. These processes constituted a freeze–thaw cycle.

RESULTS AND DISCUSSION

The findings of the density tests of the test specimens are listed in Tab. 1. As can be seen, the poplar plywood test specimens had the lowest density (approximately 420 kg/m³), and the beech plywood test specimens had the highest density (approximately 650 kg/m³). The density of the test specimens varied with the wood type. However, no significant density difference was detected between the test groups (Groups 1–4) formed with test samples obtained from the same wood type (NS). This was important for eliminating the effect of density in the tests performed. Density is the most important factor determining the technological properties of solid wood materials and wood-based composite materials. The mechanical properties of high-density solid wood and wood-based composite materials are higher than those of low-density materials (Bal and Bektaş 2012b, Bal and Bektaş 2014, Ranjan et al. 2022, Bekhta et al. 2023, Birinci and Kaymakçı 2023). Several important factors affect the density of plywood. The wood species is the most important of these factors. The amount and type of glue used, fillers and additives added to the glue, pressing pressure, veneer drying temperature, and veneer thickness are among the factors affecting the density of plywood. If the density of the wood species used is high, the resulting plywood will also have a high density. As the amount of glue used, amounts of fillers and additives added to the glue, and pressing pressure increase, the density of the plywood also increases (Bal and Bektaş 2014, Kallakas et al. 2020; Kūliņš et al. 2021).

Tab. 1: Densities of test groups (kg/m³).

Tree species		**Groups**				**Sig.**
		1	**2**	**3**	**4**	
Poplar	x̄	422.2 A	419.9 A*	428.0 A	429.5 A	NS
	Sd	11.9	16.2	18.2	15.4	
Eucalyptus	x̄	595.0 A	591.9 A	583.5 A	584.5 A	NS
	Sd	32.6	31.2	25.7	23.8	
Beech	x̄	654.5 A	653.7 A	649.9 A	648.6 A	NS
	Sd	12.6	13.7	14.2	15.5	

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

The moisture contents of the test specimens during the tests are listed in Tab. 2. as seen, the moisture contents of the test specimens did not differ between the groups. The differences were statistically insignificant (NS). The moisture content of each test specimen was approximately 10%. The moisture-content equality of the test specimens is important for discussing the results of the screw-retention test. Moisture content is also an important factor affecting the mechanical properties of solid wood and wood-based composite materials.

Previous studies have reported that the moisture contents of solid wood and wood-based composite materials affect their mechanical properties (Kollmann and Cote 1968, Hrázský and Král 2005, Aydın et al. 2006, İlker and Bal 2025).

Tab. 2: Moisture contents of test groups (%).

Tree species		Groups				Sig.
		1	2	3	4	
Poplar	x̄	10.06 A*	10.10 A	9.96 A	10.30 A	NS
	Sd	0.12	0.23	0.25	1.04	
Eucalyptus	x̄	9.96 A	9.93 A	9.62 A	10.02 A	NS
	Sd	0.15	0.22	0.34	0.24	
Beech	x̄	10.10 A	9.98 A	10.10 A	10.20 A	NS
	Sd	0.09	0.23	0.26	0.32	

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

The screw-holding strength data of the test samples are listed in Tab. 3. As seen, the poplar plywood had the lowest screw-holding strength, whereas the beech plywood had the highest. Furthermore, the highest screw-holding strength was measured in Group 1 (control group), with the lowest obtained in Group 4 (the group subjected to six freeze–thaw cycles). In this case, it was determined that the screw-holding strength was statistically significantly affected by the density of the plywood. Test samples with higher density were found to have greater screw-holding strengths than those with lower density. Similar results have been reported in previous studies on this subject. For example, in a study by Birinci and Kaymakçı (2023), the screw-holding strengths of beech, ozigo, and okoume plywood boards were measured, and plywood with a higher density had a higher screw-holding strength. Similar results were also reported by Wu (1999) and Erdil et al. (2002). Furthermore, studies on the screw-holding strengths of wood-based composite panels have also reported that the density affects the screw-holding strength (Wang et al. 2007). Additionally, according to the data in the table, it was determined that the poplar plywood was affected by the freeze–thaw cycles but not by the number of cycles, and there was no statistically significant difference between the experimental groups (Groups 2–4). However, the situation was different for the eucalyptus and beech plywood, where the screw-holding strengths of all the test groups were statistically different from each other. Because all the other conditions were the same, it was found that this difference occurred because the poplar plywood had a significantly lower density than the other types of plywood. During the freeze–thaw cycle, test samples soaked in water for 70 h absorbed a large amount of water, increasing their moisture content and consequently swelling in volume. However, during the drying phase, they shrank by releasing moisture. During this swelling and shrinkage process, the veneers that made up the plywood were perpendicular to each other and therefore subjected to swelling and shrinkage forces, which resulted in the formation of micro- and macro-cracks. As the density of the wood increased, the swelling percentage and pressure also increased. Previous studies on the swelling, shrinkage, and activation energy of wood in water comparing different wood species (sugar maple, Sitka spruce, Douglas fir, quaking aspen) have also reported this phenomenon. It has been reported that the activation energy of Sitka spruce with a density of 0.40 kg/m³ is 32.2 kJ/mol, while that of sugar maple with a density of

0.68 kg/m³ is 47.6 kJ/mol (Stamm 1964, Mantanis et al. 1994). Finally, a study conducted in 2025 determined that the tangential swelling pressures of beech and spruce wood were 2.2 and 1.3 MPa, respectively, at 85% relative humidity (Zauer et al. 2025). Based on these results from previous studies, it is self-evident that, with all other conditions being the same, the deformation of the plywood test specimens with different densities was due to the pressure resulting from swelling in water and rapid drying in a drying oven.

Tab. 3: Screw holding strength test data (N/mm²).

Tree species		Groups				Sig.
		1	2	3	4	
Poplar	x̄	22.0 B	20.5 A	20.2 A	20.1 A*	0.000
	Sd	1.6	0.9	1.1	0.9	
Eucalyptus	x̄	33.6 D	29.9 C	28.3 B	26.0 A	0.000
	Sd	2.6	2.2	1.9	1.8	
Beech	x̄	42.4 D	36.9 C	34.8 B	32.3 A	0.000
	Sd	1.3	1.2	1.4	1.3	

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

Fig. 1 shows the relationship between the screw-holding strength and density using a scatter plot. The data in the graph belong to test samples from Group 1. As can be clearly seen from the graph, as the density of the test sample increased, the screw-holding strength of the same test sample also increased. The direction of the relationship between these two variables was positive, and the strength of the relationship was quite high. The coefficient of determination (R^2) was determined to be 0.72.

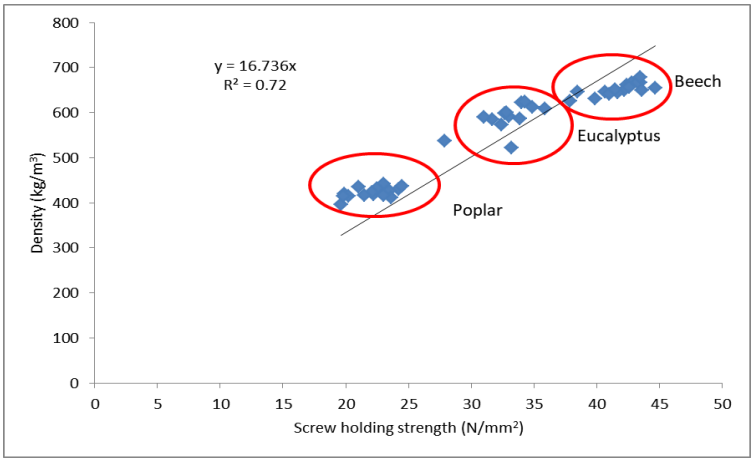


Fig. 1: Graph showing the relationship between density and screw-holding strength.

CONCLUSIONS

This study determined the screw-holding strengths perpendicular to the surfaces of plywood produced using beech, poplar, and eucalyptus veneers. Based on the data obtained, the following conclusions can be drawn: In the experiments, the screw-holding strength obtained perpendicular to the surface was found to be the highest in the beech test specimens, which had the highest density. Freeze–thaw cycles affected the screw-holding strengths of all

the groups. However, increasing the number of cycles was not statistically significant in poplar plywood. For the beech and eucalyptus plywood, the screw-holding strengths of all the groups differed, and this difference was statistically significant. According to the data obtained from the tests, a very strong relationship was found between the density of the plywood sheets and the screw-holding strength.

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