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The Effect of Hot-Cold Shock Test on Changes in Gloss and Roughness in Epoxy Resin Coated Wood Material

Utjecaj testa vruće-hladne provjere na sjaj i hrapavost drvnog materijala premazanog epoksidnom smolom

ORIGINAL SCIENTIFIC PAPER
Izvorni znanstveni rad
Received – prispjelo: 20. 6. 2024.
Accepted – prihvaćeno: 18. 3. 2025.
UDK: 630*84; 674.07
https://doi.org/10.5552/drvind.2025.0222

ABSTRACT • *In this study, epoxy resin was applied as a surface treatment material to wood species of different specific gravity: Scots pine (Pinus sylvestris L.), Turkish beech (Fagus orientalis Lipsky) and sweet chestnut wood (Castanea sativa Mill.). It aimed to determine the changes in roughness values (in accordance with TS 2495 EN ISO 3274 standard and TS 6212 EN ISO 4288 standard) and gloss values (in accordance with TS 4318 EN ISO 2813 standard) in the test specimens pre-post hot and cold shock effect. Surface-treated test specimens were first kept in a fan drying oven at (50 ± 5) °C for an hour and then kept at (-20 ± 2) °C for an hour, in accordance with ASTM D1211-97. All processes were regarded as a cycle, and the experiments continued until 15 cycles were carried out. Then, the gloss and roughness values were determined and analysed with the control specimens in the MSTAT-C statistical program. According to the results, all gloss values of epoxy resin-coated wooden material surfaces decreased after the hot-cold shock experiment, whereas a decrease in roughness was detected. It is thought that this research will contribute to advising the firms that import furniture to nations with various climatic conditions about the physical properties of surface-treated products.*

KEYWORDS: *wood; epoxy resin; gloss; hot-cold shock test; surface roughness*

SAŽETAK • *U ovom je istraživanju za površinsku obradu drva različite gustoće – bora (Pinus sylvestris L.), kavkaske bukve (Fagus orientalis Lipsky) i pitomog kestena (Castanea sativa Mill.), odabrana epoksidna smola. Cilj je bio na ispitnim uzorcima prije i nakon testa vruće-hladne provjere utvrditi promjene hrapavosti (prema standardima TS 2495 EN ISO 3274 i TS 6212 EN ISO 4288) i sjaja (prema standardu TS 4318 EN ISO 2813). Površinski obrađeni ispitni uzorci prethodno su jedan sat sušeni u sušioniku s ventilatorom na 50 ± 5 °C, a zatim su jedan sat hlađeni na –20 ± 2 °C, prema standardu ASTM D1211-97, i taj je postupak ponavljan u 15 ciklusa. Nakon toga u statističkom su programu MSTAT-C određene i analizirane vrijednosti sjaja i hrapavosti svih uzoraka, uključujući i kontrolne. Rezultati su pokazali da su se sjaj i hrapavost drvenih površina premazanih epoksidnom smolom nakon vruće-hladne provjere smanjili. Ovo će istraživanje pridonijeti spoznajama o fizičkim svojstvima površinski obrađenih proizvoda od drva koji se uvoze u brojne zemlje u kojima su klimatski uvjeti različiti.*

KLJUČNE RIJEČI: *drvo; epoksidna smola; sjaj; vruće-hladna provjera; hrapavost površine*

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1 INTRODUCTION
1. UVOD

To protect wood and wood-based products, surface treatments are essential for long-term and efficient use. Especially in wood products, the treatments comprise processes like impregnation, varnishes, and paints (Vardanyan *et al.,* 2015). The varnish, which can form a film layer for the protection of wood, contains basically synthetic, cellulosic and polyurethane varieties; nitrocellulose varnish, alkyd-urethane varnish, acrylic varnish, oil varnish, and water-based varnish are also available as an advanced version of the varnish. The selection of surface treatment and protective layer are essential when wood material is intended to last more extended and be used more appropriately (Ulay and Budakci, 2015). Scientific studies are carried out to examine some physical properties of varnish types after their application to different wood and wood-based material surfaces.

Altiparmak (2017) treated *Terminalia* superba, sweet chestnut (*Castanea sativa* Mill.), and sapele (*Entandrophragma cylindricum*) woods with polyurethane, acrylic, and synthetic varnishes and determined that the gloss increased with the increase in the layer degree (Altiparmak, 2017). After passing natural ageing tests, the Monterey pine (Pinus radiata) wood species test specimens were evaluated using water-based and solvent-based varnished materials. It was determined that the specimens subjected to 500 hours of accelerated aging showed very little gloss and colour variations (Garay *et al.,* 2017). The gloss values of the water-based varnishes were determined to have lower values when compared with the solvent-based varnishes (Yakin, 2001). It was discovered that the wood type was insignificant in terms of the gloss values for varied varnish layers, but the impact of the varnish type was found to be substantial (Budakci, 2003).

The effects of dry heat and artificial heat exposure on the gloss values of specimens of black alder (*Alnus glutinosa* L.) treated with two different types of varnish were examined. In a study comparing the gloss values of specimens coated with UV and water-based varnish, specimens coated with UV varnish had better gloss values than specimens coated with water-based varnish (Salca *et al*., 2021). The study investigated the decorative properties of European beech (*Fagus sylvatica* L.) and Persian walnut (*Juglans regia* L.) specimens. While specimens coated with hydro oils had a visibly higher gloss value in both wood specimens after the oil treatment, control specimens were determined to have lower gloss values (Palija *et al*., 2021). The surface durability of different varnish layers applied in the wood industry was investigated with regard to dry temperature, cigarette fire, wet temperature and gloss. In the study, it was determined that the surfaces with polyurethane (silk mat, matte, filler) and cellulosic filler varnish were resistant to the temperature of 100 °C (dry temperature), while the durability of the synthetic, polyester, cellulosic mat and glossy varnishes was not as good as assumed (Sonmez, 1989). It has been determined that dry heat causes gloss and colour changes on laminate flooring and solid wood. However, it has been determined that the degree of impact on laminate surfaces is lower (Dongel *et al.,* 2008). In their study, Atilgan and Sofuoglu (2023) used varnished wood species of different specific gravity with varnishes frequently used in the industry and exposed them to hot-cold shock tests. They determined a decrease in gloss values and an increase in Rz roughness values of wooden material surfaces after hot-cold shock.

Hot and cold experiments are important indicators for the flexibleness of translucent layers of varnish on the surfaces of wood and their immunity to sudden temperature variations (Sonmez and Kesik, 1999). In their study, Sonmez and Kesik (1999) prepared the test specimens using Turkish beech wood (*Fagus orientalis* Lipsky), Scots pine wood (*Pinus sylvestris* L.) and sessile oak wood (*Quercus petraea* L.) and cellulosic, polyurethane, and acrylic varnish types were put on the specimen surfaces. The test specimens were initially incubated at a temperature of -18 °C for an hour and afterwards at a temperature of 50 °C for another hour. These procedures were regarded as a cycle, and the experiments were carried out up to twenty cycles. The test results determined that, while the gloss values of the oak wood specimens covered with cellulosic varnish have risen, the gloss values of the others have declined (Sonmez *et al.,* 1999). In addition, the cellulosic varnished surface has been stated to show breakage, cracking and colour change when Gubas wood (*Endospermum peltatum* Merr.) is exposed to the hot-cold control experiment through the application of acidic hardening varnish and cellulosic varnish to the wood material surface (Yolanda, 1998). In their study, Budakci *et al*. (2010) applied polyurethane, cellulosic, and acrylic varnishes on the test specimens obtained from the oriental beech, Scots pine and sessile oak, and colour variations were detected following the impacts of accelerated aging and after hot-cold shock methods (Budakci *et al.,* 2010).

Altiparmak (2017) studied the distortion on the surfaces of specimens following the hot-cold shock test with respect to yacht varnish, polyurethane varnish and epoxy varnish types, which were applied on *Terminalia superba*, sweet chestnut (*Castanea sativa* Mill.) and sapele (*Entandrophragma cylindricum*) wood specimens. After 20 cycles of cold check test, no surface cracks or deformations were found on the panel surfaces (Altiparmak, 2017).

Based on the analysis of the hot-cold aging tests conducted on the varnish layers, it is suggested that the wood specimens should be held at the temperatures of -20 and 50 °C for an hour each, and this procedure can be considered as a single period; when the layers do not show any deterioration for ten periods, this should be regarded as satisfactory, and the performance of layers without deterioration in 25 periods should be regarded as an above average performance (Payne, 1965).

In the world, furniture, yachts, etc., made of wood materials are produced in countries and continents using different varnishes. The products are imported or exported. Turkey exports furniture worldwide, from the EU, the USA, and Middle and Far Eastern countries to the Russian Federation.

The sector representatives report a problem: some of the physical properties of the wood material used in furniture, various wood products, and yacht and boat decorations change during the transportation of these products to countries with different climatic conditions. Based on the data obtained from the change in surface roughness and gloss on varnished surfaces, which may be exposed to the effects of sudden climatic changes (hot and cold), it will be possible to select the appropriate type of wood and varnish for the place of use.

The wood species used in the present study were Scots pine (*Pinus sylvestris* L.), sweet chestnut (*Castanea sativa* Mill.) and Turkish beech (*Fagus orientalis* L.), as well as epoxy resin, which is used in the woodworking and furniture industries and the manufacture of various marine vehicles. These tree species and epoxy resin can be deformed in environments where they are exposed to sudden temperature changes (especially furniture, marine vehicles, yachts, etc.). This study aimed to determine the effect of the hot-cold check test on the changes in surface roughness and gloss and to determine the most suitable wood species.

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

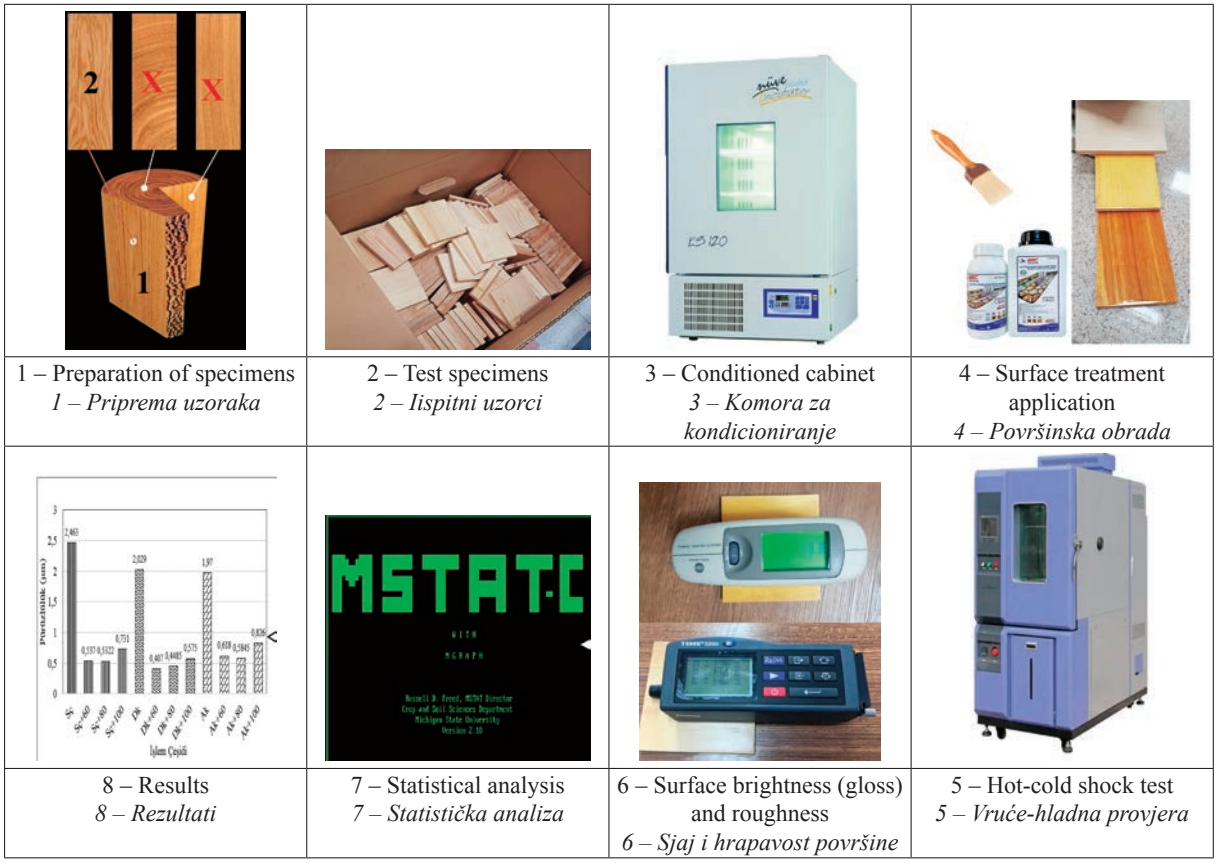
In this study, Scots pine wood (*Pinus sylvestris* L.), Turkish beech wood (*Fagus orientalis* Lipsky) and sweet chestnut wood (*Castanea sativa* Mill.) were used as the wood materials; transparent pour type epoxy resin (Arc brand 150 ultra-transparent casting type glossy epoxy resin) was used as the surface treatment material. The timbers used in the research were randomly selected from Afyonkarahisar Timber Management. The knot-free parts of the lumber were used as specimens. The lumber was carefully selected to ensure that it was dry, smooth-grained, and free of fungi and insects.

Wood specimens were prepared for gloss and surface roughness tests in dimensions of 100 mm × 100 mm × 10 mm (tangential, longitudinal, radial). Three wood types, one varnish type and five repetitions were prepared for each parameter, i.e. a total of 15 test specimens with regard to ISO 3129 (2019). 75 records were acquired in all tests by measuring 5 different objectives on each test specimen. They were kept at (20±2) °C / (65±2) % conditions to reach air dry (12±2) % humidity until they reached a constant weight in accordance with TS ISO 13061-1, 2021 standards (TS ISO 13061-1, 2021).

Before the test specimens were coated with epoxy resin, their surfaces were sanded with sandpaper No. 80 and 100, respectively. The varnish procedure for the test specimens was conducted by the ASTM-D 3023 principles (ASTM-D 3023, 2017). Epoxy resin was applied with a fine-wire brush in a single layer to be 125 g/m^2, and specimens were left to dry for 24 hours.

This test was carried out on the wood material on which paint and varnish were applied by exposing it to sudden cold and heat. The aim was to identify the performance of varnish layers in sudden temperature variations in natural weather conditions. Within this framework, the test specimens, whose surfaces were treated, were arranged in 100 mm × 100 mm × 10 mm dimensions, and they were placed in the cabinet in an upright position, making sure that they were not touching each other and facing the heating/cooling wall after gloss and roughness measurements were made. First, they were kept in the oven at (50±5) °C for an hour. At the end of this period, the test specimens were transferred to the cooling unit, which was calibrated to (−20 ± 2) °C within 1 minute and kept there for 1 hour. Afterwards, the test specimens were taken from the cabin and left to rest for 15 minutes. All procedures were regarded as a cycle, and the processes continued until there were 15 cycles. The roughness and gloss values of the specimens, which were kept at the normal room temperature for 1 hour, were measured after the test (ASTM D 1211-97, 2001).

The gloss values of the test specimens were measured with a measuring device (Konica Minolta Multi Gloss 268 Plus) with respect to TS 4318 EN ISO 2813 by using the light-reflecting property of the wood material treated with epoxy resin. The selected geometry was measured at an incidence angle of 60° (TSE EN ISO 2813). The device calibration is performed in accordance with ASTM-D-523 (ASTM D523-14). The error rate is reduced by measuring at an angle of 60° on dull and glossy surfaces (Ozen and Sonmez, 1990; Ordu and Sofuoglu, 2016). Five repetitions were conducted for each test group. Five measurements were made on each specimen. Tests were carried out on the specimen surfaces in a parallel direction, and the arithmetic averages of these measurements were recorded using the gloss value. Concerning the gloss measurements conducted at 60°, the surfaces were classified as matte, semi-matt,



1 – Preparation of specimens *1 – Priprema uzoraka*	2 – Test specimens *2 – Iispitni uzorci*	3 – Conditioned cabinet *3 – Komora za kondicioniranje*	4 – Surface treatment application *4 – Površinska obrada*
8 – Results *8 – Rezultati*	7 – Statistical analysis *7 – Statistička analiza*	6 – Surface brightness (gloss) and roughness *6 – Sjaj i hrapavost površine*	5 – Hot-cold shock test *5 – Vruće-hladna provjera*

Figure 1 Schematic representation of methods used during the experiment
Slika 1. Shematski prikaz metoda primijenjenih tijekom eksperimenta

semi-gloss, gloss, and very gloss. The experimental process of the study is given in Figure 1.

Surface roughness tests were carried out using the tactile (needle) scanning method and Time TR220 (Time Group Inc., China). Through the measurements, 0.5 mm/s tracking speed, 2.5 mm pickup length (λc), 5 µm stylus radius and 90° stylus angle operations were performed. The surface roughness values were determined with a precision of ±0.01 µm. The specimen roughness was measured using the mean peak-to-valley height (*Ra*). These measurements were all carried out in accordance with EN ISO 3274, TS 2495, and EN ISO 21920-3 principles. A computerised statistical tool called MSTAT-C was used to examine the test findings. It includes variance analysis and a 95 % confidence level by Duncan's test. Homogeneity groups (HG) were the subject of statistical analyses, with different letters denoting statistical significance.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

The results of multiple variance analysis regarding the effects of wood type and hot-cold shock test on gloss values are given in Table 1.

The hot-cold shock test and wood type have been found to be statistically significant (α=0.05) in terms of gloss value impacts and insignificant in terms of interactions (AB). The Duncan's test results, which were performed to determine between which groups the difference was significant, are submitted in Table 2.

Table 1 Multiple variance analysis regarding the effects of hot/cold shock test and wood type on gloss values
Tablica 1. Analiza višestruke varijance s obzirom na utjecaj vruće-hladne provjere i vrste drva na vrijednosti sjaja

Variance source *Izvor varijance*	**Degree of freedom** *Stupanj slobode*	**Sum of squares** *Zbroj kvadrata*	**Mean square** *Srednji kvadrat*	***F* score**	***P*<0.05**
Wood type (A) / *vrsta drva (A)*	2	1121.136	560.568	92.077	0.0004
Hot/cold shock test (B) *vruće-hladna provjera (B)*	1	1725.921	1725.921	283.494	0.0000
AB	2	61.581	30.791	0.5058	
Error / *pogreška*	54	3287.541	60.880		
Total / *ukupno*	59	6196.180			

Table 2 Results of gloss Duncan's test
Tablica 2. Rezultati Duncanova testa za vrijednosti sjaja

	Process type / *Vrsta procesa*	***X* (Gloss)** *X (sjaj)*	**HG**
*Wood type + **Hot/cold shock test **Vrsta drva + **vruće-hladna provjera*	Scots pine (control) / *borovina (kontrola)*	94.01	A
	Sweet chestnut (control) / *drvo pitomog kestena (kontrola)*	88.80	AB
	Turkish beech (control) / *kavkaska bukovina (kontrola)*	84.26	BC
	Scots pine (control) / *borovina (nakon ispitivanja)*	82.55	BC
	Sweet chestnut (control) / *drvo pitomog kestena (nakon ispitivanja)*	80.84	C
	Turkish beech (control) / *kavkaska bukovina (nakon ispitivanja)*	71.50	D

*LSD**= 4.937 *LSD***=4.031 *LSD****=6.982

The highest gloss value was obtained in the Scots pine control (94.01), and the lowest was obtained after the Turkish beech + hot/cold shock test (71.50). After applying the hot-cold shock test, the gloss values of the wood type treated with epoxy resin decreased significantly compared to the control groups.

Table 3 presents the findings of a multiple variance analysis concerning the impact of wood type and the hot-cold shock test on the roughness values.

Wood type (A) and its interactions (AB) were found to be statistically insignificant (α=0.05) in terms of its impact on roughness value, while they were found to be significant in terms of hot-cold shock test (B). The Duncan's test results, which were performed to determine between which groups the variations were significant, are given in Table 4.

The highest roughness value was obtained in Turkish beech control (0.0745), and the lowest was obtained after the Scots pine + hot/cold shock test (0.012). In epoxy resin-treated wood types, roughness values decreased after the hot-cold shock test compared to the control groups.

The heat-treated studies in the literature found that the heat treatment changed the gloss values (Ayata *et al.,* 2018; Cavus *et al.,* 2018). Korkut *et al*. (2023) found that glossiness values decreased by heat treatment when perpendicular and parallel glossiness values of heat-treated wild cherry (*Prunus avium*) wood at 212 °C for 1.5 hours and 2.5 hours (ThermoWood method) were compared with the control specimens.

The average roughness (*Ra*) has been determined to decrease in all test specimens following the hot-cold shock test. The highest roughness reduction (78.66 %) has been detected in the Turkish beech wood, while less reduction in roughness was observed in other wood types. It can be agreed that there are significant variations in pre- and post-hot-cold shock tests. Exposing epoxy resin to heat again after curing may have contributed to stretching the set structure (becoming solid, hard and tough) and led to the smooth surface by bringing the molecules closer together. The roughness decrease observed in the study may be due to increased mechanical and chemical bonding between the epoxy resin and wood material. This is in line with the studies

Table 3 Multiple variance analysis regarding the effects of hot/cold shock test and wood type on roughness values
Tablica 3. Analiza višestruke varijance s obzirom na utjecaj vruće-hladne provjere i vrste drva na vrijednosti hrapavosti

Variance source *Izvor varijance*	**Degree of freedom** *Stupanj slobode*	**Sum of squares** *Zbroj kvadrata*	**Mean square** *Srednji kvadrat*	***F* score**	***P*<0.05**
Wood type (A) / *vrsta drva (A)*	2	0.003	0.001	1.7759	0.1791
Hot/cold shock test (B) / *vruće-hladna provjera (B)*	1	0.028	0.028	35.3543	0.0000
AB	2	0.002	0.001	1.1062	0.3382
Error / *pogreška*	54	0.043	0.001		
Total / *ukupno*	59	0.076			

Table 4 Results of Duncan's test for surface roughness (Ra)
Tablica 4. Rezultati Duncanova testa za vrijednosti hrapavosti (*Ra*)

	Process type / *Vrsta procesa*	***X*, *μ*m**	**HG**
*Wood type + **Hot/cold shock test **Vrsta drva + **vruće-hladna provjera*	Scots pine (control) / *borovina (kontrola)*	0.0745	A
	Sweet chestnut (control) / *drvo pitomog kestena (kontrola)*	0.0503	A
	Turkish beech (control) / *kavkaska bukovina (kontrola)*	0.0470	A
	Scots pine (control) / *borovina (nakon ispitivanja)*	0.0159	B
	Sweet chestnut (control) / *drvo pitomog kestena (nakon ispitivanja)*	0.0140	B
	Turkish beech (control) / *kavkaska bukovina (nakon ispitivanja)*	0.0120	B

*LSD**= 0.02001 *LSD***=0.01634

in the literature, which state that the surface roughness in the treated wood materials decreases with the impact of heat treatment.

4 CONCLUSIONS
4. ZAKLJUČAK

The wood industry faces a problem when shipping surface-treated products. This problem is related to the physical properties of the product surfaces changing due to sudden temperature changes.

Determining the elasticity in the varnish layers on the wooden surfaces or the physical deformation caused by sudden temperature changes is considered significant for solving the problem. Therefore, epoxy resin was put on Turkish beech, Scots pine, and sweet chestnut surfaces as a surface treatment material. Exposing the test specimens to -20 and +50 hot-cold shock test conditions for 1 hour was accepted as one cycle. In total, this process was continued for up to 15 cycles. Gloss and roughness measurements were carried out on the treated wooden surfaces to determine the distortions occurring on the surface before and after the experiment.

It may be stated that changes occurring in the surface roughness and gloss values of the varnished wood material after the hot-cold shock test have not affected the surface characteristics and usage functions of test specimens but have just affected aesthetics. In this respect, the producers and consumers should be informed that surface variations like this can occur in the epoxy, which is used in all three types of wood, the furniture, which can be traded to countries with varied climatic factors, and the finishing material, which is used in marine vehicles like yachts/boats.

Acknowledgements – Zahvala

This study was presented as an oral presentation at the 2nd International Craterization Symposium (ISC'22), a scientific symposium held between the 22nd and 25th of September 2022 in Afyonkarahisar, Turkey.

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