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Effects of Ultrasound-Assisted Varnish and Component Mixing Method on Mechanical and Physical Properties of Varnish Layer

Učinci metode miješanja laka i komponenata potpomognute ultrazvukom na mehanička i fizikalna svojstva sloja laka

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ABSTRACT • *The aim of this study was to determine the effects of mechanical and ultrasound-assisted stirring methods for varnish + components mixing on the varnish layer coating adhesion, surface roughness and glossiness. For this purpose, polyurethane, acrylic and polyester varnish systems were applied on three different wood types, namely Scots pine (Pinus sylvestris L.), Eastern beech (Fagus orientalis L.) and Mahogany (Khaya ivorensis), with mechanical and ultrasound-assisted mixing methods. In the mechanical mixing method, 3 and 5 minutes were applied, while in the ultrasonic mixing method, beside 3- and 5- minute stirring time, 80-watt, and 120-watt ultrasonic power was applied during mixing. When research results are generally evaluated, it cannot be said that ultrasound-assisted mixing method is superior to mechanical mixing method. However, the ultrasound-assisted mixing of varnish components at 80 watts for 3 minutes can be recommended.*

KEYWORDS: *ultrasound stirring; adhesion strength; roughness; glossiness; varnish*

SAŽETAK • *Cilj ovog istraživanja bio je utvrditi učinke mehaničke i ultrazvučno potpomognute metode miješanja laka i komponenata na adheziju sloja laka te na hrapavost i sjaj površine drva. Stoga su na drvo običnog bora (Pinus sylvestris L.), kavkaske bukve (Fagus orientalis L.) i mahagonija (Khaya ivorensis) naneseni sustavi poliuretanskoga, akrilnoga i poliesterskog laka. Sustavi laka pripremljeni su metodama mehaničkog miješanja i miješanja potpomognutoga ultrazvukom. Pri mehaničkoj metodi miješanje je trajalo tri odnosno pet minuta, dok je pri ultrazvučnoj metodi uz vrijeme miješanja od tri i pet minuta tijekom miješanja primijenjena snaga ultrazvuka od 80 i 120 W. U općenitoj ocjeni rezultata istraživanja ne može se reći da metoda miješanja laka i komponenata potpomognuta ultrazvukom ima prednost pred metodom mehaničkog miješanja. Međutim, može se preporučiti miješanje komponenata laka uz pomoć ultrazvuka na 80 W tijekom tri minute.*

KLJUČNE RIJEČI: *ultrazvučno miješanje; adhezivna čvrstoća; hrapavost; sjaj; lak*

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1 INTRODUCTION
1. UVOD

Despite its many advantages, wood has some disadvantages as well. Primarily, wood is a hygroscopic material. Because of these properties, wood material is affected by chemical, physical, biological, and mechanical factors (Berkel, 1972). Therefore, for long service life, wood should be protected.

Varnishing is one of the most popular protection methods that provides protective coatings and enhances the appearance of wooden surfaces, paintings, and various decorative objects. Although polyurethane, lacquer, and shellac are all types of wood finishes that are frequently referred to as varnish, the term actually refers to a particular mixture of resins, oils, and liquids. Most varnishes are a blend of resin, drying oil, drier, and volatile solvent. Varnishes may consist of a single or more than one compounds. Multi-component varnishes are applied by adding and mixing each component in the amounts determined in accordance with the company's recommendations. The performance of dry varnish coating is affected by the proper mixing of varnish liquid that is composed of all components. Although varnish manufacturers give information about how and when these mixtures should be made, this process is sometimes not ideal and causes significant and costly defects in the varnish layer in the short and long term (Baykan *et al*., 2000).

Varnish adhesion strength on wood plays an important role for effective use of the final product for different applications. In many cases, the surface coating fails due to de-bonding from the surface of the wood. There are some factors that limit the service life of varnishes applied on wood material. One of them is the cavitation that occurs in the varnish liquid during the mixing of varnish and its components. The propagation of the acoustic waves in a liquid produces the phenomenon of cavitation (Shutilov and Alferieff, 2020). Cavitation is a process whereby a liquid forms tiny vapour-filled cavities when the static pressure of the liquid falls to less than its vapour pressure. These gaps or cavities, also known as "bubbles," burst under greater pressure and can cause layer flaws. During the varnishing process in furniture and woodworking operations, applicators generally use propeller mixers to mix the varnish and its components. However, propeller mixers can cause cavitation in the liquid mixture. It is believed that cavitation can lead to adverse effects on the applied varnish layer. According to the literature, ultrasonic cavitation may accelerate the breakdown and deterioration of substances that are only partly stable when examined in terms of carbon chains (Effendi and Wulandari 2019). Simple propeller mixers create micro-cavities in the liquid, causing the layer to have a porous structure after drying and adversely affect the quality properties such as surface coating adhesion, surface hardness, scratch resistance, surface roughness and surface gloss. In the long term, other problems are encountered in the medium such as cracks caused by different elastic behaviours in different parts of the varnish surface layer applied with an inhomogeneous mixing, the film layer separated from the surface due to low coating adhesion resistance, and the accumulation of salt and dirt on rough surfaces.

Some of the factors that negatively affect the life of the varnish are also related to the "improper mixing" process that will be the cause of cavitation. Some of the problems caused by improper mixing (AkzoNobel, 2019) are as follows: Insufficient curing, subsidence in the wet layer, formation of non-homogeneous hardness areas on the surface, non-homogeneous gloss distribution on the surface, low coating adhesion resistance, crater formation due to air bubbles in the varnish and subsequent bursting, regional drying time differences, and layer formation in the form of a misty view.

Recently, ultrasonic wave technique has been introduced as one of the methods used for mixing materials and preventing cavitation. The use of the ultrasonic blender eliminates the need to access or shake hermetically sealed plastic or metallic boxes (or bottles) containing any liquids, including those with high viscosity. It is known that composite materials are broken down by the cavitation droplets and shock waves (shockwaves) produced by ultrasonic waves (Mason, 2004). Effendi and Wulandari (2019) used ultrasonic power for clearing petroleum hydrocarbon from low permeability contaminated soils. Halacinski *et al*. (1994) used ultrasound wave technique for effective mixing of various sedimented paints and viscous fluids. Zanghellini *et al*. (2021) used solvent-free ultrasonic dispersion method for nanofillers in epoxy matrix and obtained the best results by ultrasound-assisted mixing. In their study, Stephen *et al.* (2003) described a device that contains a mixing receptacle for ultrasonically spreading an additive with another coating component. Nejad *et al*. (2015) investigated dispersion quality of nanoparticles into a bio-based coating by ultrasound assisted mixing. He *et al*. (2018) used ultrasound stirring method for effective metal composite mixing. Masri *et al*. (2018) presented a comparison analysis of the esterification process using either ultrasonic cavitation or traditional mechanical stirring with a number of recently developed SO_3H-functionalized dicationic ammonium- and diazabicyclo octane (DABCO)-based acidic ionic liquids. In order to enhance the dispersion and dispersal of composite particles in the rubber matrix and the general performance of rubber goods, Cheng and Wang (2022) used ultrasound-assisted mixing. They claimed that the benefits of dispersive mixing and distribute mixing could be enhanced by ultrasonic waves, which would improve the comprehensiveness of rubber goods. All the above researchers reported that the ultrasound-assisted mixing method was beneficial.

Currently, there is limited information about the effect of varnish-component mixing by ultrasound-assisted method on the varnish layer adhesion, roughness, and glossiness of wood materials. In this study, experiment was carried out by comparing the efficiency of mechanical and ultrasound-assisted mixing methods by various time and ultrasonic power in varnish-component mixing.

2 MATERIALS AND METHODS
2. MATERIJALI I METODE

2.1 Wood materials
2.1. Drvni materijali

Three different types of wood were used in this study: Eastern beech (*Fagus Orientalis* L.), Scots pine (*Pinus sylvestris* L.), and Mahogany (*Khaya ivorensis*) as test samples. These wood varieties were chosen due to their widespread use in the wood products business. The wood samples came from Turkish lumber traders in the Turkish city of İzmir, chosen at random.

The timber was selected from sapwood, with smooth fibres, no knots, no cracks, no difference in color and density, annual rings perpendicular to the surfaces and chosen randomly. The sapwood-derived wood samples were conditioned at a temperature of 20 °C and a relative humidity of 65 % until their weights settled. Air-dried specimens from each species were cut in either the radial or tangential direction to the final size of 100 mm × 100 mm × 10 mm and then sanded by paper grit (140, and 180 grit). According to the technique outlined in TS 2470 (1976), test samples (3 wood × 3 varnish × 6 stirring method × 3 test × 10 repeat = 1620) of each wood species with an average moisture content of 12 %.

2.2 Varnishing
2.2. Nanošenje laka

The polyurethane, acrylic, and polyester fillers and topcoat varnishes used in experiments are all solvent-based and applied according to the guidelines in ASTM D 3023 (1998). The varnishes were purchased from companies located in Mugla, Turkey.

Polyurethane filler and topcoat varnishes are solvent-based varnishes that use alkyd resin-based primary components and hardeners based on isocyanate groups enriched with isocyanate prepolymers. Therefore, polyurethanes are polymers available for many technical applications requiring strong bonding force, flexibility, durability, and impact resistance. Polyurethane varnish, a popular type of coating, exhibits several mechanical properties that make it desirable for various applications. (Li *et al*., 2018; Chen *et al*., 2018). Polyurethane varnishes, due to their abrasion resistance, are mainly used for varnishing furniture and floors in rooms with high intensity of movement, such as halls and lounges.

Acrylic filler and topcoat varnishes are solvent-based varnishes that use acrylic resin-based primary components and hardeners based on isocyanate groups enriched with isocyanate prepolymers. They are durable and resistant to UV light, water, and abrasion, and they can be used for both interior and exterior applications.

Polyester filler and topcoat varnishes are solvent-based varnishes that are based on unsaturated polyester resin. They have a very high filling capacity and are suitable for application on various types of wood. The composition of varnishes and the components subjected to the mixture are provided in Table 1.

Before applying the filler varnish, all wooden test pieces were sanded with a vibrating sander using 180-grit sandpaper. The sanded test samples were varnished by spraying with three types of varnish, according to ASTM D 3023 (1998). The manufacturer's instructions for the solvent composition and hardener mixture were considered. Varnishes and components were mixed by two mixing methods, namely ultrasound-assisted stirring, and conventional mechanical stirring. Mechanical stirring was performed by a power mixer with 700 rpm. For ultrasonic stirring, an ultrasonic device was used (Kudos HP 53 kHz) with ultrasound energy (wave powers) of 80 and 120 W. In this study, two mixing times were used: 3 and 5 minutes. The varnish mixtures of polyurethane and acrylic were rested for 10 minutes before application on wood test samples (Megep, 2012). However, as polyester varnish quickly

Table 1 Varnishes and components mixing
Tablica 1. Lakovi i njihove komponente

Varnish type *Vrsta laka*	**Primer coat** / *Temeljni sloj*		**Top coat** / *Završni sloj*	
	Varnish /hardener/ accelerator *Lak / otvrđivač / ubrzivač*	**Solvent** *Otapalo*	**Varnish/hardener/ accelerator** *Lak / otvrđivač / ubrzivač*	**Solvent** *Otapalo*
Polyurethane	2/1	Polyurethane thinner (5 %)	1/1	Polyurethane thinner (5 %)
Acrylic	5/1	Acrylic thinner (40 %)	5/1	Acrylic thinner (40 %)
Polyester	1 kg/20 ml/20 ml	Monostirol (15 %)	1 kg/20 ml/20 ml	Monostirol (15 %)

Table 2 Varnish application conditions
Tablica 2. Uvjeti nanošenja laka

Type of varnish *Vrsta laka*	**Viscosity** / *Viskoznost* DIN Cup/4 mm	**Amount used, g/m²** *Količina nanosa,* g/m²	**Nozzle gap, mm** *Veličina sapnice,* mm	**Air pressure, bar** *Tlak zraka,* bar
Polyurethane	18-20	120-150 (filling) 100-120 (top)	1.8	2
Acrylic	15-18	100-120	1.8	2
Polyester	32-40	100	2.5	2

gels when mixed with its components, no resting time was made. After application every filling varnishing coat, the dried varnish layer was sanded by abrasive papers (220-320-400). Each cross layer of varnish was applied after six hours for polyurethane, three hours for acrylic and 25 minutes for polyester. Application conditions are given in Table 2.

In this study, after applying the varnish to wood samples, some mechanical properties of the applied varnish layer such as hardness and scratch resistance were also determined. The surface hardness of the varnishes was measured using a pendulum hardness device, and the average values were as follows: polyester (143.89), polyurethane (100.49), and acrylic (89.32). Meanwhile, the scratch resistance of the varnishes, in the given order, was as follows: polyurethane (0.31 N), acrylic (0.30 N), and polyester (0.24 N).

2.3 Determination of coating adhesion strength
2.3. Određivanje adhezivne čvrstoće premaza

The adhesion properties of the coated samples were evaluated in accordance with ASTM D4541 standards (2022). For the assessment of the bond strength between the varnish layer and the wood surface, Araldite 2021-1, a robust plastic steel two-component epoxy adhesive, was employed. Steel test spheres, 20 mm in diameter, were securely affixed to the sample surfaces and left for 24 h at room temperature (approximately 20 °C). Subsequently, the adhesive and coating film were meticulously removed using a cutter.

Coating adhesion strength (X) was automatically determined by pull-off tester (PosiTest AT-M Manual) in N/mm² according to Eq. 1.

$$X = 4 \cdot F / \pi \cdot d^2 \quad (1)$$

Where;
F – rupture force (Newton)
d – diameter of experiment cylinder (mm).

2.4 Surface roughness
2.4. Hrapavost površine

Surface roughness of coated test samples, which were coated by three varnish types, was measured by the Mitutoyo Surftest SJ-301 according to DIN 4768 (1990). A diamond scan needle with a width of 5 mm was used by the device to move up and down while measuring the surface roughness on the outline of the cavities and protrusion of the sample surface. The three factors measured were the greatest height of the profile (*Ry*), the average height of the ten tallest spots (*Rz*), and the mean deviation between valleys and peaks (*Ra*). Ra (mean variation) was used as the foundation for reporting the surface roughness. Readings were obtained across the grain (−|).

2.5 Surface glossiness
2.5. Sjaj površine

The gloss of the varnished samples was determined using a gloss meter (BYK Gardner, Micro-TRIGloss) according to ASTM D523-08 (2008). At 60° geometry, the gloss readings were taken both parallel (||) and perpendicular (⊥) to the wood grain. Each uniform measuring angle and orientation were recorded twice for each sample in accordance with the ISO 2813:2014 standard.

2.6 Statistical evaluation
2.6. Statistička procjena

Multiple comparisons were first subjected to an analysis of variance (ANOVA), and significant differences between average values of variables were determined using Duncan's multiple range test at P value of 0.05. This analysis was done to determine the effects of the wood species, varnish type, and stirring method on adhesion resistance, surface roughness, and surface glossiness. A total of 1620 observations (surface binding strength (540), surface roughness (540), and glossiness (540) were statistically analyzed.

3 RESULTS AND DISCUSSION
3. REZULTATI I RASPRAVA

Means of adhesion strength, surface roughness and surface gloss arithmetic and standard deviations are summarized in Table 3.

Table 4 presents data analysis and figures as well as the relationships between wood type (WT), varnish type (VT), and stirring technique (SM) and their impact on adhesion strength. All the factors and interactions had a significant impact ($p < 0.05$) on adhesion strength, surface roughness, and surface glossiness.

The results of the Duncan test for multiple comparisons and homogeneity grouping of adhesion resist-

Table 3 Means of adhesion strength, surface roughness and surface glossiness
Tablica 3. Srednje vrijednosti adhezivne čvrstoće, hrapavosti i sjaja površine

			Adhesion strength, N/mm² *Adhezivna čvrstoća,* N/mm²		**Roughness *Ra* (−|), *µ*m** *Hrapavost Ra* (−|), *µm*		**Glossiness at 60°, GU** *Sjaj pri 60°,* JS	
Wood type *Vrsta drva*	**Varnish type** *Vrsta laka*	**Stirring method** *Metoda miješanja*	Mean	S.D	Mean	S.D	Mean	S.D
Scots pine *obični bor*	Polyurethane	Mechanic / 3	3.86	0.29	0.17	0.04	96.65	2.63
		Mechanic / 5	5.33	1.89	0.12	0.03	97.20	0.54
		Ultrasonic 80 W / 3	5.59	1.04	0.10	0.01	97.62	0.98
		Ultrasonic 80 W / 5	6.27	0.90	0.13	0.04	95.17	4.35
		Ultrasonic 120 W / 3	5.69	0.80	0.11	0.03	95.66	3.44
		Ultrasonic 120 W / 5	3.73	1.42	0.15	0.03	94.86	2.21
	Acrylic	Mechanic / 3	1.96	0.76	0.24	0.05	87.24	5.68
		Mechanic / 5	1.70	0.39	0.16	0.04	83.26	4.04
		Ultrasonic 80 W / 3	2.04	0.49	0.23	0.05	86.66	3.31
		Ultrasonic 80 W / 5	2.50	1.05	0.24	0.08	86.74	4.58
		Ultrasonic 120 W / 3	2.23	0.87	0.23	0.06	83.39	5.52
		Ultrasonic 120 W / 5	1.94	0.48	0.17	0.06	84.33	5.42
	Polyester	Mechanic / 3	4.78	0.61	0.15	0.02	68.90	1.86
		Mechanic / 5	4.29	0.44	0.15	0.03	68.73	1.89
		Ultrasonic 80 W / 3	4.25	0.48	0.10	0.01	74.66	1.71
		Ultrasonic 80 W / 5	4.38	0.38	0.11	0.01	74.45	2.31
		Ultrasonic 120 W / 3	4.26	0.61	0.13	0.01	76.32	1.35
		Ultrasonic 120 W / 5	4.69	1.51	0.13	0.02	71.05	1.84
Eastern beech *kavkaska bukva*	Polyurethane	Mechanic / 3	4.98	1.15	0.28	0.09	89.36	7.46
		Mechanic / 5	7.47	2.01	0.26	0.11	83.19	9.01
		Ultrasonic 80 W / 3	5.53	1.48	0.12	0.06	81.14	8.37
		Ultrasonic 80 W / 5	6.75	1.20	0.15	0.07	85.66	9.00
		Ultrasonic 120 W / 3	5.74	2.15	0.14	0.09	85.53	6.57
		Ultrasonic 120 W / 5	5.86	1.00	0.21	0.09	87.77	8.03
	Acrylic	Mechanic / 3	3.20	1.17	0.23	0.10	77.17	17.10
		Mechanic / 5	2.87	0.89	0.16	0.07	86.47	7.31
		Ultrasonic 80 W / 3	2.90	0.78	0.22	0.06	93.01	1.71
		Ultrasonic 80 W / 5	3.04	0.88	0.11	0.05	79.00	7.37
		Ultrasonic 120 W / 3	2.88	1.18	0.19	0.04	84.63	4.07
		Ultrasonic 120 W / 5	2.83	1.06	0.13	0.05	75.05	6.04
	Polyester	Mechanic / 3	5.00	0.85	0.14	0.02	65.79	5.55
		Mechanic / 5	4.32	0.73	0.12	0.02	64.15	7.01
		Ultrasonic 80 W / 3	5.50	0.84	0.09	0.01	65.30	4.87
		Ultrasonic 80 W / 5	4.76	0.47	0.10	0.02	64.54	6.20
		Ultrasonic 120 W / 3	4.07	0.76	0.11	0.02	65.47	6.20
		Ultrasonic 120 W / 5	4.66	0.74	0.11	0.01	59.29	7.24
Mahogany *mahagonij*	Polyurethane	Mechanic / 3	6.27	0.70	0.24	0.05	77.64	7.37
		Mechanic / 5	7.07	1.32	0.14	0.04	81.78	5.42
		Ultrasonic 80 W / 3	6.78	0.62	0.08	0.03	89.15	2.75
		Ultrasonic 80 W / 5	6.79	0.94	0.14	0.05	89.08	4.74
		Ultrasonic 120 W / 3	6.93	1.02	0.16	0.05	89.05	3.50
		Ultrasonic 120 W / 5	6.09	1.32	0.12	0.04	85.81	7.01
	Acrylic	Mechanic / 3	1.78	1.57	0.22	0.06	76.36	5.30
		Mechanic / 5	1.82	1.02	0.15	0.04	84.20	4.86
		Ultrasonic 80 W / 3	1.38	0.38	0.28	0.05	80.23	3.13
		Ultrasonic 80 W / 5	2.16	0.76	0.25	0.07	79.27	5.72
		Ultrasonic 120 W / 3	1.63	1.02	0.19	0.06	79.39	6.53
		Ultrasonic 120 W / 5	1.83	1.00	0.27	0.11	78.90	8.68
	Polyester	Mechanic / 3	5.97	1.02	0.14	0.02	67.38	2.10
		Mechanic / 5	5.53	0.88	0.14	0.02	69.09	1.39
		Ultrasonic 80 W / 3	5.62	0.67	0.19	0.28	70.76	1.81
		Ultrasonic 80 W / 5	5.45	0.69	0.10	0.01	70.37	1.58
		Ultrasonic 120 W / 3	5.77	0.49	0.13	0.03	70.91	1.27
		Ultrasonic 120 W / 5	5.62	0.80	0.12	0.02	66.81	1.60

Table 4 Interactions between factors influencing adhesion strength, surface roughness and surface glossiness
Tablica 4. Interakcije utjecajnih čimbenika na adhezivnu čvrstoću, hrapavost i sjaj površine

Statistical analysis (*p* value) (Adhesion) / *Statistička analiza (p-vrijednost) (adhezija)*						
WT	VT	SM	WT+ VT	WT+ SM	VT+ SM	WT + VT + SM
0.000*	0.000*	0.005*	0.000*	0.225*	0.000	0.033*
Statistical analysis (*p* value) (Roughness)/ *Statistička analiza (p-vrijednost) (hrapavost)*						
WT	VT	SM	WT+ VT	WT+ SM	VT+ SM	WT + VT + SM
0.102	0.000*	0.000*	0.000*	0.008*	0.000*	0.000*
Statistical analysis (*p* value) (Glossiness) / *Statistička analiza (p-vrijednost) (sjaj)*						
WT	VT	SM	WT+ VT	WT+ SM	VT+ SM	WT + VT + SM
0.000*	0.000*	0.000*	0.000*	0.023*	0.002*	0.000*

* = Significant according to $\alpha \leq 0.05$; WT – Wood Type; VT – Varnish type; SM – Stirring method / * = *značajno pri $\alpha \leq 0,05$; WT – vrsta drva; VT – vrsta laka; SM – metoda miješanja*

Table 5 Results of Duncan test for wood type, varnish type and stirring method as well as mean and standard deviation of adhesion strength, surface roughness and surface glossiness
Tablica 5. Rezultati Duncanova testa za vrstu drva, vrstu laka i metodu miješanja te za srednje vrijednosti i standardne devijacije adhezivne čvrstoće, hrapavosti i sjaja površine

	Adhesion *Adhezija*, N/mm^2		**Roughness (*Ra*)** *Hrapavost* (*Ra*), mm		**Glossiness at 60°, GU** *Sjaj pri 60°,* JS	
		Mean		Mean		Mean
Wood type *Vrsta drva*	Scots pine [b]	3.86 ± 0.12	Scots pine	0.16 ± 0.00	Scots pine [a]	84.61 ± 0.78
	Eastern beech [a]	4.57 ± 0.13	Eastern beech	0.16 ± 0.01	Eastern beech [b]	77.36 ± 0.95
	Mahogany [a]	4.69 ± 0.17	Mahogany	0.17 ± 0.01	Mahogany [b]	78.12 ± 0.64
Varnish type *Vrsta laka*	Polyurethane [a]	5.93 ± 0.12	Polyurethane [b]	0.16 ± 0.01	Polyurethane [a]	89.02 ± 0.61
	Acrylic [c]	2.26 ± 0.08	Acrylic [c]	0.20 ± 0.01	Acrylic [b]	82.52 ± 0.58
	Polyester [b]	4.94 ± 0.07	Polyester [a]	0.13 ± 0.01	Polyester [c]	68.55 ± 0.41
Stirring method *Metoda miješanja*	Mechanic / 3 [bc]	4.20 ± 0.19	Mechanic / 3 [a]	0.20 ± 0.01	Mechanic / 3 [c]	78.50 ± 1.31
	Mechanic / 5 [ab]	4.49 ± 0.24	Mechanic / 5 [b]	0.15 ± 0.01	Mechanic / 5 [bc]	79.79 ± 1.18
	Ult / 80W / 3 [abc]	4.40 ± 0.20	Ult / 80W / 3 [b]	0.16 ± 0.01	Ult / 80W / 3 [a]	82.06 ± 1.13
	Ult / 80W / 5 [a]	4.68 ± 0.20	Ult / 80W / 5 [b]	0.15 ± 0.01	Ult /80W / 5 [ab]	80.48 ± 1.12
	Ult /120W / 3 [abc]	4.36 ± 0.21	Ult / 120W / 3 [b]	0.15 ± 0.01	Ult/ 120W / 3 [ab]	81.15 ± 1.04
	Ult /120W / 5 [c]	4.14 ± 0.08	Ult / 120W / 5 [b]	0.16 ± 0.01	Ult / 120W / 5 [c]	78.21 ± 1.27

Ult: Ultrasonic / *ultrazvučno*

ance, surface roughness, and glossiness, considering different wood types, varnish coatings, and mixing methods, are presented in Table 5.

Table 5 presents the results of the Duncan test, where superscript letters (a, b, c) are commonly used to denote statistical significance. These symbols aid in ranking differences between groups based on the level of significance, typically set at $p<0.05$ or $p<0.01$.

3.1 Adhesion strength
3.1. Adhezivna čvrstoća

In certain samples, cohesive failure between the adhesive and the varnish surface occurred during the adhesion strength test procedure. The analysis did not include these samples. Surface cracks took many different shapes in the cases used in the investigation. Most of these cracks occurred between the varnish and the wood, especially in Eastern beech and mahogany wood samples. On the other hand, with Scots pine wood samples, fractures mostly occurred inside the wood layer. Test samples made of Scots pine were more likely to fracture. This result is consistent with the fact that Scots pine wood is classified as a softwood, whereas Eastern beech and mahogany wood are tougher. The accompanying photos (Figure 1) list the main fracture types that correlate to the various tree species.

The mean values of adhesion strengths are given in Table 4 and illustrated in Figure 2. The mechanical properties of varnishes used in this study vary depending on the specific formulation of the varnish and its application method. It is important to note that the performance of the varnish layer can also be influenced by factors such as the thickness of the coating, surface preparation, and environmental conditions in which it is used. The highest adhesion strength was obtained on Eastern beech / polyurethane varnish / mechanic stirring method / 5 minutes (7.47 N/mm^2). Meanwhile the lowest was observed on mahogany / acrylic varnish / ultrasound stirring method / 3 minutes (1.38 N/mm^2).

When comparing the wood species in terms of surface adhesion strength performance, the ranking was as follows: mahogany (4.69 N/mm^2), beech (4.57 N/mm^2), and pine (3.86 N/mm^2). It is important to note that this result could be influenced by the density differences among the wood species. The adhesion strength of varnish on wood surfaces has been reported to be higher in wood from angiosperm trees compared to gymnosperms (Sonmez *et al.*, 2009).

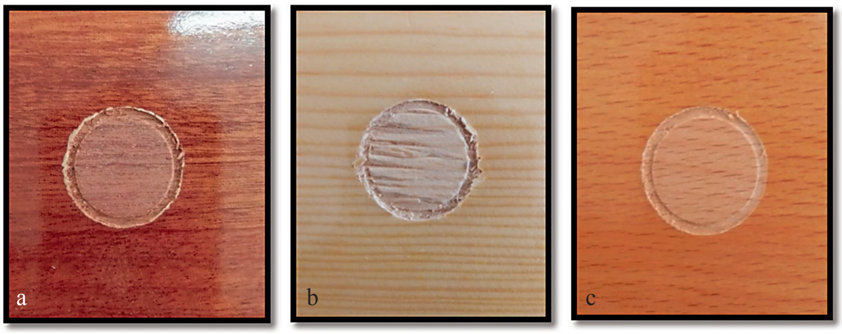

Figure 1 Most common forms of fractures on wood samples (a – Mahogany, b – Scoth Pine, c – Eastern beech)
Slika 1. Najčešći oblici lomova na uzorcima drva (a – mahagonij, b – obični bor, c – kavkaska bukva)

When varnishes were compared in terms of surface adhesion resistance strength, it was seen that they were ranked as follows: polyurethane (5.93 N/mm^2), polyester (4.94 N/mm^2) and acrylic (2.26 N/mm^2). The high adhesion strength of polyurethane varnish was consistent with previous studies (Kilic and Sogutlu, 2023; Gurleyen, 2021; Ghofrani *et al*., 2106; Sogutlu *et al*., 2016; Budakci and Sonmez, 2010). Budakci and Sonmez (2010) studied varnish adhesion properties. According to their research, polyurethane and acrylic varnishes achieved the greatest adhesion strength. The polyurethane outcomes of our study are generally consistent with their observations. The highest and the lowest surface adhesion resistance values of the varnishes obtained in our study were higher than those in the similar study (Gurleyen, 2021). This result may be due to the mixing of varnishes with their components for a standard period of time before the application of varnishes or due to the use of different materials.

The fact that the adhesion resistance of polyester varnish was lower than that of polyurethane varnish was also found in previous studies (Gurleyen, 2021; Ghofrani *et al*., 2106; Sogutlu *et al.* 2016; Budakci and Sonmez 2010. It is possible to discuss that this highest adhesion polyurethane varnish completes its polymerization reaction on the wood surface, making chemical bonding with wood, which creates a stronger adhesion on the surface (Ghofrani *et al*., 2106). In their study, Ghofrani *et al*. (2016) explained that the lower adhesion resistance of polyester varnish (pH 3.8), compared to polyurethane varnish (pH 4.5), can be attributed to the acidity levels present in their respective formulations.

When comparing the effects of the mixing method on adhesion strength, the ultrasound-assisted mixing / 80 W / 5 minutes has the best value. The lowest adhesion performance was obtained in the ultrasound-assisted mixing method / 120 W / 5 minutes. It is seen that, when the ultrasound power increases, it has a negative effect on the adhesion. Temperature has a significant impact on the efficiency of ultrasound-assisted processes (Niemczewski, 2007). Solvent vapours and dissolved gases penetrate the cavitation cavities as the solvent temperature rises. As a result, the cavitation process is less efficient and the fall increases. The other reason for this lowest value may be that the varnish liquid heats up with the extended time and starts to cure early. It is estimated that this early curing or gelling also makes it difficult for the varnish to penetrate the wood material. Viscosity, coating binder type, solid substance, pigmentation, and curing speed all have an impact on penetration, which in turn has an impact on the binding strength (Vitosyte *et al*., 2012).

The adhesion resistance values obtained in tests, where varnishes were pulled off from the wood surface, were influenced by the splitting resistance, a structural property of the wood material. When evaluating the surface adhesion resistance of varnishes on different wood types, Eastern beech and mahogany were found to belong to the top group (a), whereas Scots pine was categorized in a lower group (b). In the literature, it was reported that broadleaf wood generally exhibits higher adhesion strength compared to coniferous wood. This may result from the type of wood materials, anatomical structure, surface properties, resin content, density, cell structure, components of wood, texture, surface roughness, and moisture content. The results are consistent with the literature. It has been reported that hardwood exhibits higher adhesion resistance compared to softwood (Sonmez *et al*., 2009; Budakcı and Sonmez, 2010; Karamanoğlu and Kesik, 2021; Kretschmann, 2010). For example, Scots pine wood exhibited an adhesion resistance of 3.27, whereas ash tree displayed an adhesion resistance of 3.98 (Karamanoğlu and Kesik, 2021). One of the elements affecting the bonding between the samples and the covering would be the species anatomical structure. (Ozdemir *et al*., 2015). Sogutlu *et al*. (2016) estimated that the high adhesion strength of beech compared to pine may be due to the strong adhesion to the surface due to the homogeneous wood structure of broadleaved trees and scattered small trachea. This inference seems reasonable because the adhesion data obtained from mahogany and Eastern beech in our study are higher than that of Scots pine. The study's findings are in line with the above statement. Polyurethane varnish, followed by polyester and acrylic varnish, produced

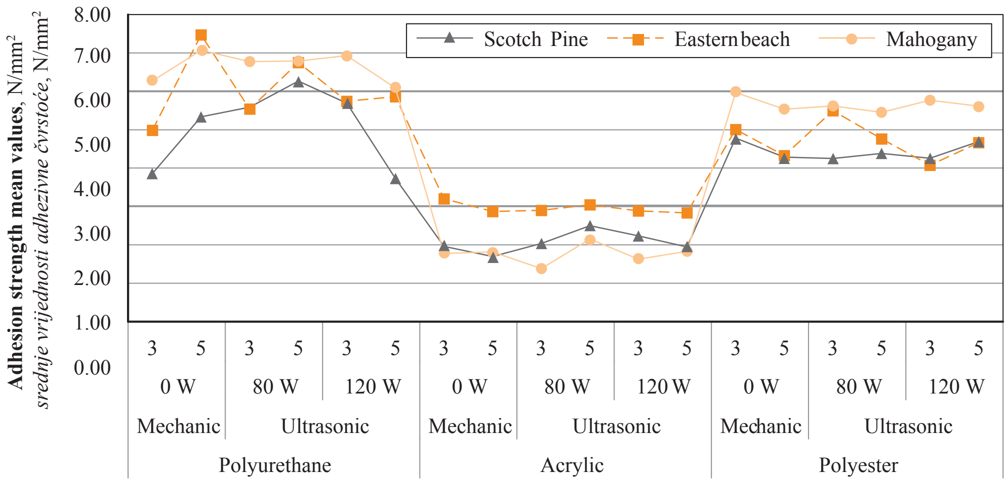

Figure 2 Surface adhesion strength
Slika 2. Adhezivna čvrstoća na površini

the strongest bonding. Similar outcomes were attained in additional trials (Sogutlu *et al*., 2016; Sonmez *et al*., 2009). Sonmez *et al*. (2009) explain this situation as "this highest adhesion two-part polyurethane varnish completes its polymerization reaction on the surface of wood which makes chemical bonding with wood, so it creates a stronger adhesion on surface". Sogutlu (2016) hypothesized that a flexible layer and a weak molecular link with the compounds in wood caused this outcome.

The ultrasound-assisted technique / 80 W / 5 minutes produced the greatest adhesion strength in our research when compared to the stirring method. However, the lowest adhesion was seen in the ultrasound-assisted method / 120 W / 5 minutes. Numerous variables can influence the success of the ultrasonic technique, as highlighted by Kim and Wang (2003). These variables include the type of substance, solid-to-liquid ratio, temperature, wave frequency, and the amount of energy or power used. It is crucial to consider these factors for achieving optimal results when using ultrasonic methods. Effendi and Wulandary (2019) outlined that the increase in ultrasound power also had a great effect on removing pollutants from the contaminated soil. Their results with high ultrasound power have served their purpose. In our study, however, it was observed that the increasing in ultrasound wave power caused an increase in temperature in the varnish and component mixture. It has been estimated that this temperature increase causes earlier curing of the varnishes with their components and negatively affects the adhesion strengths in the dry varnish layer. Kim and Wang (2003) stated that the ultrasound power should be increased as the density increases. Therefore, it is seen that 80-watt ultrasound power is suitable for the densities of the varnish types used in our study. Taking all these factors into account, the surface adhesion resistance values obtained in this study may have been influenced not only by the applied varnish and application method but also by the underlying structural properties of the wood. It should also be noted that there are many variables that determine the results. In most cases, it is not easy to determine which variable has the greatest impact.

3.2 Roughness
3.2. Hrapavost

The mean values of roughness are given in Table 4 and illustrated in Figure 3. As can be seen in Table 4, the highest surface roughness (Ra) value was obtained on Eastern beech / polyurethane varnish / mechanic stirring method / 3 minutes (0.28). The same value was obtained on mahogany / acrylic varnish / ultrasound mixing method 80 W / 3 minutes. Meanwhile the lowest (*Ra*) value was observed on mahogany / polyurethane varnish/ ultrasound 80 W / 3 minutes (0.08).

When the wood species were compared in terms of surface roughness performance, there was no statistical difference between wood types. In general, roughness values (R_a) of Eastern beech and mahogany test samples are expected to be lower than those of Scots pine. However, in our study, the sanding between the varnish layers during the varnishing of the test samples may also have influenced the lack of difference in surface roughness between wood species.

When the surface roughness is compared in terms of varnishes, there is polyester (*Ra* = 0.13), polyurethane (*Ra* = 0.16) and acrylic (*Ra* = 0.20), ranked from lowest to highest.

When the surface roughness is compared in terms of mixing methods, statistically the option with the mechanical stirring method / 3 minutes showed the lowest performance (0.20). All options with ultrasound-assisted stirring methods appear to perform better. The reason for this is our hypothesis, which suggests that ultrasound will mix the liquids more homogeneously. It is

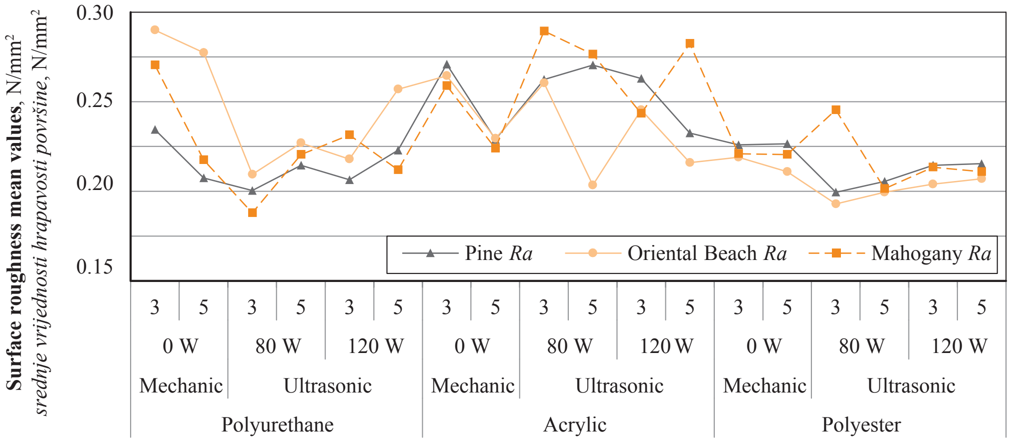

Figure 3 Mean values of roughness
Slika 3. Srednje vrijednosti hrapavosti površine

expected that components with homogeneous mixing will also have smoother surfaces. There was no statistical difference between wood species in terms of surface roughness. This result may be because the wooden test specimens were sanded very well before varnishing and because of sanding between the varnish layers one after the other during varnishing.

When the varnishes were compared in terms of surface roughness, it was seen that the best surface roughness value was obtained with polyester varnish. This may be due to the presence of filler chemicals in polyester varnish that have the ability to make a thicker layer. This may have resulted in the varnish layer being less affected by the raw wood surface roughness. When the mixing methods are compared in terms of surface roughness of the varnish layer, it is seen that ultrasound-assisted mixing performs better in general. The lowest performance was obtained with mechanical mixing for 3 minutes. This result can be interpreted as a positive contribution of ultrasound-assisted mixing, especially with 80 W. He *et al*. (2012) reported that 70 W ultrasonic power provided the best results among the 40, 70 and 100 W options for ultrasound-assisted mixing in composite metal alloys in homogeneous distribution.

3.3 Glossiness
3.3. Sjaj

The mean values of glossiness are given in Table 4 and are illustrated in Figure 4. To ascertain the glossiness for the coated samples, one measurement direction (parallel direction) was observed for the 60° measuring geometry. For coating wooden surfaces, 60° geometry is generally recommended (Salca *et al*., 2021), so the results of glossiness of this study are given based on 60°.

Considering the effects of the factors on the surface gloss, the highest gloss value was obtained on Scots pine / polyurethane varnish / ultrasound 80 W / 3 minutes (97.62). Meanwhile the lowest was observed on Eastern beech / polyester varnish / ultrasound stirring 120 W / 5 minutes (59.29).

When the wood species were compared in terms of surface glossiness performance, the ranking was Scots pine (84.61), mahogany (78.12) and Eastern beech (77.36). However, there was no statistically significant difference between mahogany and Eastern beech.

When varnishes were compared in terms of surface glossiness, it was seen that they were ranked as polyurethane (89.02), acrylic (82.52) and polyester

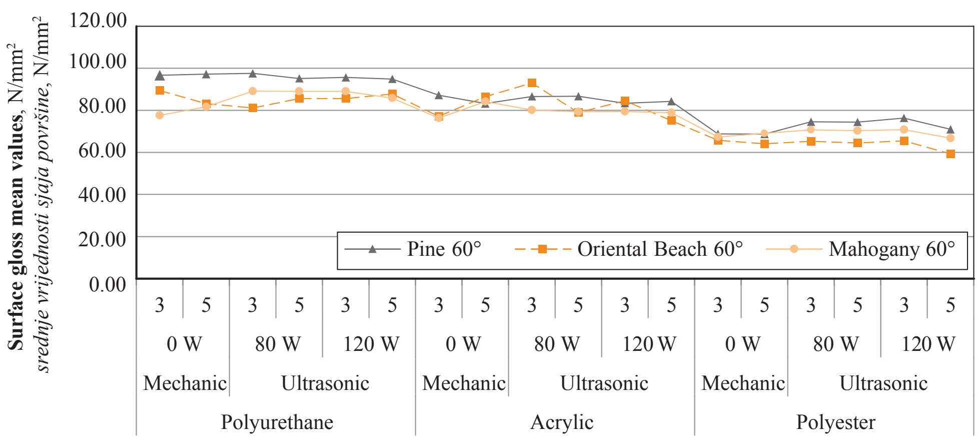

Figure 4 Mean values of surface glossiness
Slika 4. Srednje vrijednosti sjaja površine

(68.55). The high gloss values obtained from samples treated with polyurethane and acrylic varnishes, particularly on Scots pine, are consistent with the literature (Baysal *et al*., 2014; Keskin and Atar, 2008).

When comparing the effects of the mixing method on surface glossiness, the ultrasound-assisted mixing / 80 W / 3 minutes has the highest value (82.06). The lowest glossiness was observed in the ultrasound-assisted mixing / 120 W / 5 minutes (78.21).

During the study, it was observed that increasing the ultrasound wave power raised the temperature in the varnish mixture. It is estimated that this temperature increase accelerates the curing process of the varnishes and negatively affects the gloss of the dry varnish layer.

4 CONCLUSIONS
4. ZAKLJUČAK

The effects of ultrasound-assisted and mechanical mixing method in the varnish component mixture on the surface adhesion resistance, surface roughness and surface glossiness were investigated. The results of this study can be used to choose the finest varnish-component mixing technique when making furnishings. The following is a presentation of the study's particular findings:

In this study, it was determined that Eastern beech and mahogany wood species were more successful in terms of adhesion resistance than Scots pine wood. Scots pine wood, on the other hand, is superior in glossiness compared to other wood species. Meanwhile, it was determined that there was no difference between the three wood species in terms of surface roughness.

In terms of adhesion resistance performance of varnishes, the ranking was as follows: polyurethane, polyester and acrylic. Polyester achieved the best surface roughness performance, followed by polyurethane and acrylic. In terms of surface gloss performance of varnishes, polyurethane achieved the best results, followed by acrylic and polyester.

Between stirring methods, in general, the ultrasound-assisted 80-watt mixing method improved the varnish layer properties. The mixing time of 3 minutes, which is the lower version of ultrasound, was superior to the time of 5 minutes in surface adhesion and surface gloss, while the times of 3 and 5 minutes in surface roughness were in the same group.

Many variables determine the results. In most cases, it is difficult to say which one is the most influential. As a result, ultrasound-assisted / 80 watt / 3 minutes of mixing can be recommended for varnish component mixing. However, to further strengthen this opinion, for future studies, it would be beneficial to test the mechanical and ultrasonic mixing methods with the varnish component mixture applied on glass plates because the surface roughness of timber has a major impact on the binding quality. The area for mechanical bonding between the coating and the timber base grows as the surface roughness rises, and as a result, the adhesion strength also grows (Vitosyte *et al*., 2012). By applying varnish on glass plates, the effect of mixing methods can be seen more clearly by eliminating the effects of wood material properties on the adhesion, roughness, and gloss of varnishes. In addition, ultrasonic and mechanical mixing methods should also be tested with a specific and hybrid method as suggested by prior research, based on mechanical swaying alone and mechanical shaking combined with ultrasonic irradiation (Effendi and Wulandari, 2019).

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