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Comparison of Some Mechanical Performances of UV Varnish Systems Used in Furniture and Yacht Manufacturing

Usporedba mehaničkih svojstava UV lakova koji se upotrebljavaju u proizvodnji namještaja i gradnji jahti

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ABSTRACT • This study comparatively evaluated the scratch and abrasion resistance of daylight UV-curable and high-energy UV-curable varnish systems applied to Scots pine (*Pinus sylvestris* L.), oriental beech (*Fagus orientalis* L.), and mahogany (*Khaya ivorensis*) wood species commonly used in furniture and yacht manufacturing. Scratch resistance was determined using a progressive loading method, while abrasion resistance was assessed based on mass loss using a Taber abrasion testing machine. The results indicated that both wood species and varnish type had statistically significant effects on scratch and abrasion resistance. High-energy UV-curable varnish systems exhibited significantly higher scratch resistance than daylight UV-curable systems across all wood species. In abrasion resistance, mahogany showed the lowest mass loss (0.11 g), indicating the highest resistance, whereas Scots pine and oriental beech exhibited higher mass loss values (0.20 g). The findings suggest that varnish type has a stronger influence on scratch resistance, whereas abrasion resistance is more closely related to wood species characteristics. Overall, high-energy UV-curable varnishes provide superior surface performance in applications requiring high durability.

KEYWORDS: daylight UV-curable varnishes; high-energy UV-cured varnishes; scratch resistance, abrasion resistance

SAŽETAK • U ovom je istraživanju provedena usporedna ocjena otpornosti na ogrebotine i habanje dvaju sustava lakova: onih koji otvrdnjavaju pod utjecajem dijela Sunčeve UV svjetlosti te onih koji otvrdnjavaju pod utjecajem visokoenergetskog UV zračenja. Sustavi lakiranja nanášeni su na uzorke borovine (*Pinus sylvestris* L.), kavkaske bukovine (*Fagus orientalis* L.) i drva mahagonija (*Khaya ivorensis*) kao drvnih vrsta koje se najčešće primjenjuju u proizvodnji namještaja i gradnji jahti. Otpornost na ogrebotine određena je metodom postupnog

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povećanja opterećenja, dok je otpornost na habanje ispitana mjerenjem gubitka mase uz pomoć Taber abraser uređaja. Rezultati su pokazali da i vrsta drva i tip laka statistički značajno utječu na otpornost na ogrebotine i na habanje. Visokoenergetski UV lakovi pokazali su znatno veću otpornost na ogrebotine od dnevnih UV lakova na svim ispitivanim vrstama drva. Pri ispitivanju otpornosti na habanje drvo mahagonija zabilježilo je najmanji gubitak mase (0,11 g), što upućuje na najveću otpornost tog drva na habanje, dok su borovina i kavkaska bukovina imale veće gubitke mase (0,20 g). Dobiveni rezultati potvrđuju da tip laka znatnije utječe na otpornost na ogrebotine, dok je otpornost na habanje više povezana sa svojstvima drva. Zaključno, visokoenergetski UV lakovi osiguravaju vrhunska površinska svojstva u primjenama koje zahtijevaju veliku trajnost i otpornost na trošenje.

KLJUČNE RIJEČI: UV lakovi koji otvrdnjavaju pod utjecajem dijela Sunčeve UV svjetlosti; UV lakovi koji otvrdnjavaju zbog djelovanja visokoenergetskog UV zračenja; otpornost na ogrebotine; otpornost na habanje

1 INTRODUCTION

1. UVOD

In mega yachts operating under open-sea conditions, cracking of varnish layers at the joints of fixed furniture and decorative wooden elements represents a frequently encountered durability problem. During navigation, vessels are exposed to dynamic loads and repetitive wave-induced shock impacts, which generate cyclic stresses on interior components. Simultaneously, wooden materials used in interior applications undergo dimensional changes due to high ambient humidity and pronounced day–night temperature fluctuations, leading to repeated swelling and shrinkage. Although the use of advanced lamination adhesives has significantly enhanced the dimensional stability of wooden substrates, the coating systems applied to these surfaces may not always exhibit sufficient elasticity to accommodate substrate movement. As a result, incompatibility between the mechanical behavior of the varnish film and the hygroscopic movement of wood can induce surface deformations and cracking over time. To mitigate this problem, laminated wood materials have increasingly been adopted in yacht interiors, a practice that continues today due to their improved dimensional stability compared to solid wood. Nevertheless, despite these advancements, coating failures such as cracking have not been entirely eliminated. Alternative materials, including carbon fiber and other advanced composites, offer superior mechanical performance and resistance to environmental stresses; however, they fail to replicate the aesthetic qualities, tactile warmth, and natural appearance of wood. In the mega-yacht market, owners and clients generally expect interiors characterized by high-quality craftsmanship and extensive use of natural wood elements, reflecting both luxury and traditional maritime design values (Tunçgenç, 2023).

Turkey holds a significant position in the world of mega yacht manufacturing. Mega yachts up to 70 meters in length are produced, particularly in shipyards located in Antalya and Istanbul. In the Antalya Free Zone in particular, numerous luxury yachts are manufactured and outfitted, benefiting from advanced ship-

yard infrastructure and creating substantial export volumes of high-end vessels. Within these facilities, daylight-curing UV varnishes are widely employed by manufacturers to protect wooden components due to their rapid curing and enhanced resistance to ultraviolet degradation, reflecting prevalent industry practices in Turkish mega yacht finishing. In mega yachts operating under open-sea conditions, one of the most critical durability issues observed in fixed interior furniture is the cracking of varnish layers at joint regions. These failures primarily result from flexural stresses induced by high wave impacts, which generate cyclic deformation at connection points of built-in furniture systems. In addition, temperature fluctuations and elevated humidity levels contribute to dimensional changes in wooden flooring materials, leading to surface deformations and coating distress. Considering these service conditions, research efforts have increasingly focused on wood species selection and varnish system performance to enhance coating durability under marine environments. Selected examples of these studies are presented below.

Altıparmak (2017) comparatively evaluated the scratch resistance of yacht, polyurethane, and epoxy varnishes applied to sapele, chestnut and limba wood. The results demonstrated that yacht varnish consistently provided the highest scratch resistance across all wood species, whereas epoxy coatings exhibited comparatively lower performance. Statistical assessment revealed that varnish type was the dominant factor affecting scratch resistance, followed by wood species. Accordingly, the use of yacht varnish was recommended for applications where enhanced scratch durability is required.

Söğütü *et al.* (2017) evaluated the abrasion and scratch resistance of polyurethane, single- and two-component water-based, and synthetic varnishes applied to sapele wood (*Entandrophragma cylindricum*) in radial and tangential sections. Varnish type significantly affected both properties, whereas cutting direction was not statistically significant. Polyurethane coating exhibited superior abrasion and scratch resistance, whereas yacht varnish performed comparatively

lower; comparative analysis indicated no significant variation between the water-based formulations.

Aykaç and Sofuoğlu (2021) examined the performance of cellulose, synthetic, polyurethane, and water-based varnishes applied to bamboo (*Bambusa*) surfaces commonly used in the furniture industry. Coating hardness, gloss, color change, and film thickness were assessed. The results showed that, except for polyurethane, all varnishes reduced surface hardness compared to the control. Gloss values increased up to three-fold, while synthetic varnish caused the greatest shift toward yellow–red tones and exhibited the highest total color change (ΔE^*); the minimum total color difference was recorded for the water-based system. The greatest film thickness was obtained with cellulose varnish, whereas the water-based coating produced the thinnest layer.

Tekin (2009) evaluated the abrasion resistance of synthetic, polyurethane, water-based, acid-catalyzed, and cellulose varnishes applied in one to three layers on several wood species. Abrasion resistance was significantly influenced by wood species, varnish system, and coating thickness. The highest performance was achieved with walnut coated with three layers of acid-catalyzed varnish, while the lowest was observed in linden with a single layer of water-based varnish. Wood species and varnish type were identified as the dominant factors, followed by layer thickness.

Numerous studies on coating performance have primarily focused on cellulosic, solvent-based, and water-based varnishes applied to different wood substrates (Ugulino *et al.* 2017; Budakçı *et al.* 2017), particularly for indoor furniture applications. In humid environments such as kitchens and bathrooms, vinyl coatings have been used; however, water-based and UV-curable systems are generally recommended due to their improved environmental and performance characteristics (Philipp, 2010). Accordingly, water-based and UV-curing technologies are widely recognized as effective and sustainable solutions for wood finishing processes (Salca, 2016; Gürleyen *et al.*, 2017).

Recent research on UV-curable coating systems has focused on varnishes cured at different wavelength ranges, with particular emphasis on optimizing resin formulations and photoinitiator chemistry. These developments aim to reduce energy consumption while improving coating flexibility and application performance. Despite their high curing efficiency, conventional high-energy UV systems require specialized equipment and substantial capital investment, limiting their adoption in small and medium-sized enterprises. In contrast, daylight-curable UV systems offer lower equipment costs and greater practical applicability for smaller-scale manufacturers. Ongoing studies continue

to promote the broader industrial implementation of UV-based coating technologies.

Göktaş *et al.* (2024) compared the effects of mechanical and ultrasonic-assisted mixing on the surface hardness and scratch resistance of varnish systems applied to Oriental beech, Scots pine, and mahogany. The highest scratch resistance values were obtained in polyester varnish mixed mechanically for 5 minutes and in acrylic varnish subjected to low-power (80 W) ultrasonic treatment. In contrast, high-power ultrasonic applications negatively affected scratch performance. Overall, ultrasonic-assisted mixing did not provide a consistent improvement over conventional mechanical mixing in terms of coating performance.

Akdemir *et al.* (2024) investigated the influence of mechanical and ultrasonic-assisted mixing of varnish components on adhesion strength, surface roughness, and gloss of polyurethane, acrylic, and polyester systems applied to mahogany, Oriental beech, and Scots pine. The findings indicated that ultrasonic mixing did not demonstrate a clear superiority over conventional mechanical stirring; however, ultrasonic treatment at 80 W for 3 minutes was suggested as a potentially favorable condition in terms of overall coating performance.

UV-curable coatings are widely applied to heat-sensitive substrates such as wooden furniture, parquet flooring, and plastic products due to their rapid curing and low thermal load (Schwalm, 2006). However, despite their extensive industrial use, the literature provides limited comprehensive studies comparing the performance characteristics of different UV-curable systems under varying application and service conditions.

When other studies on UV varnish system are examined, it is evident that scratch and abrasion performance mainly depends on coating formulation, crosslink density, and application parameters. Higher crosslink density improves surface hardness and scratch resistance, although excessive rigidity may lead to brittleness (Bertrand-Lambotte *et al.*, 2021). Coating thickness and layer number are also critical factors influencing abrasion resistance, with optimal thickness providing better performance (Papp *et al.* 2018). In addition, curing conditions and chemical structure significantly affect surface durability, while additives and multilayer systems enhance performance (Henke *et al.*, 2023; Bongiovanni *et al.*, 2002). Overall, the mechanical performance of UV varnish systems is governed by multiple interacting parameters that must be optimized for improved results.

This study compares the performance of two different UV-cured varnish systems with very short drying times and high film resistance. The main reason for preferring UV-cured varnish systems, in practice, is

that UV-cured systems represent the latest technology in wood painting technology and their use is rapidly increasing worldwide. Both high-energy UV-cured and daylight-cured UV varnishes were applied to different wood surfaces, and performance tests were conducted to determine which system provides more technical advantages in furniture and mega yachts. There is insufficient research on UV varnishes in the literature. This study will contribute to academic research and the manufacturing sector in this regard. In this respect, the study provides data that directly supports the application of UV varnish systems on the scratch and abrasion resistance of different woods.

2 MATERIALS AND METHODS

2. MATERIJALI I METODE

2.1 Wooden materials used in experiments

2.1. Drveni materijali uključeni u istraživanje

Within the scope of the study, commonly utilized wood species Scots pine (*Pinus sylvestris* L.), oriental beech (*Fagus orientalis* L.), and mahogany (*Khaya ivorensis*) were selected as the primary substrates for experimental evaluation.

2.2 Varnishes used in experiments

2.2. Lakovi upotrijebljeni u istraživanju

Two types of varnish systems were applied to the experimental samples in this research. These are acryl-



Figure 1 Samples used in experiments

Slika 1. Ispitni uzorci



ic-based varnishes cured with UV light energy at daylight wavelength and acrylic-based systems cured with high UV light energy.

2.3 Preparation of experimental samples

2.3. Priprema ispitnih uzoraka

The samples used in the scratch and abrasion tests were prepared from Scots pine (*Pinus sylvestris* L.), oriental beech (*Fagus orientalis* L.), and mahogany (*Khaya ivorensis*) wood according to TS 2470 (TS 2470 1976). The dimensions of the test samples used in the experiment are given below:

Sample dimensions for scratch tests

(100 × 100 × 5 mm)

Sample dimensions for abrasion tests

(100 × 100 × 5 mm)

Experimental specimens measuring 100 × 100 × 5 mm were initially acclimatized under standardized laboratory conditions (20 ± 2 °C and 65 ± 3 % relative humidity) and maintained until equilibrium moisture content was achieved. Then, the experimental samples were prepared by applying daylight-curing UV varnishes with a spray gun and high-power UV-curable coating systems with an automatic machine to the wood surfaces (Figure 1).

2.4 Preparation and application of varnishes

2.4. Priprema i nanošenje lakova

Daylight UV-curable varnishes consisted of varnish (100 parts), hardener (100 parts), and photoinitiator (2 parts). After mixing, the formulation was diluted with polyurethane thinner to 30 s (DIN Cup 4) and applied by spray gun.

High-energy UV-curable varnishes were single-component systems containing pre-incorporated photoinitiator. They were diluted to 12–14 s (DIN Cup 4) and applied using an automatic spray system. Images showing the application of daylight and high-energy UV-curable varnishes are given in Figure 2.

Daylight UV system application: Panels were sanded sequentially with 120-, 150-, and 180-grit abra-



Figure 2 Images of the application process of daylight UV-curable and high-energy UV-curable varnishes

Slika 2. Prikaz postupka nanošenja UV lakova

sives. A filler coat (120 g/m²) was applied, followed by 10 min flash-off and 10 min UV curing using a hand-held mercury lamp (320–400 nm). After sanding (220 grit), a second filler coat (10 g/m²) was applied and cured again. Final sanding (220–400 grit) was followed by application of a 120 g/m² topcoat and curing. Application was performed using an HVLP spray gun (0.9 mm nozzle, 3 bar). The daylight UV system used a manually operated mercury lamp system (AkzoNobel Kemipol). This system operates in the 320–400 nm range and is suitable for on-site applications and fixed furniture surfaces. Its investment cost is approximately 45 times lower than that of high-energy systems.

High-energy UV system application: Filler varnish (120 g/m²) was applied and flashed off for 10 min in a tunnel oven at 25 °C (Superfici). Curing was performed using a mercury UV lamp (120 W/cm, 400–450 mJ/cm², 320–400 nm). The process was repeated for the second filler layer. After sanding (220–400 grit), a topcoat (120 g/m²) was applied and cured under identical UV conditions. Application was carried out using a Superfici Compact automatic spray system equipped with a Kremlin pump and Airmix guns.

2.5 Scratch and abrasion tests

2.5. Ispitivanje otpornosti na ogrebotine i habanje

Scratch and abrasion tests were performed according to TS EN 15186 (2012) and TS 4755 (1986) at the AkzoNobel Kemipol R&D laboratory.

Scratch test: Scratch resistance was measured using a diamond stylus under increasing loads (0.1 N increments) (Figure 3). The scratch value was defined as the minimum load causing visible coating failure after one circular pass. Evaluations distinguished between elastic deformation and true film failure under controlled illumination.

Abrasion test: Abrasion resistance was determined using a Taber abrasion tester under 5,000 cycles with 500 g load. Mass loss was measured using a 0.0001 g precision balance. Mass loss was used as the main evaluation criterion due to differences in coating flexibility between systems. Samples were weighed before and after testing (Figure 4).

2.6 Experimental design and statistical analysis

2.6. Plan pokusa i statistička analiza

A total of 60 specimens were prepared (3 wood species × 2 varnish types × 2 tests × 5 replicates). Scratch and abrasion tests were conducted separately. A general linear model (GLM) was used to evaluate the effects of wood species, varnish type, and their interaction at a 5 % significance level. Significant differences were analyzed using the LSD test. Statistical analyses were performed using Minitab (Version 17, 2023).

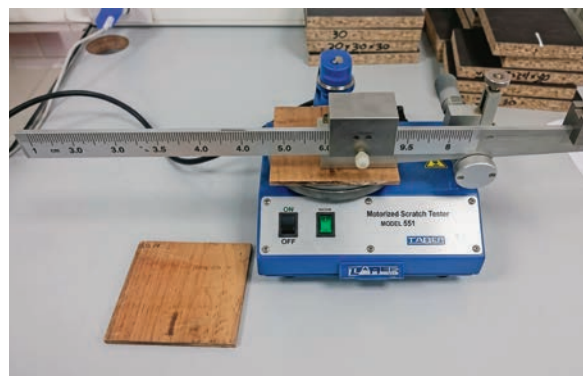


Figure 3 Erichsen Universal 413 scratch tester
Slika 3. Uređaj za ispitivanje otpornosti na ogrebotine Erichsen Universal 413



Figure 4 Taber 5135 abrasion tester
Slika 4. Uređaj za ispitivanje otpornosti na habanje Taber 5135

3 RESULTS AND DISCUSSION

3. REZULTATI I RASPRAVA

The results of scratch and abrasion resistance tests are given in Table 1.

Overall, both wood species and varnish type had a clear influence on surface performance, with significant differences observed between treatment groups.

3.1 Scratch resistance results

3.1. Rezultati mjerenja otpornosti na ogrebotine

High-energy UV-curable varnishes exhibited significantly higher scratch resistance compared to daylight UV-curable systems for all wood species. The highest scratch resistance was recorded in Scots pine treated with high-energy UV varnish (0.70 N), while the lowest values were observed in daylight-coated Scots pine and mahogany samples (0.10 N).

Among wood species, Scots pine and oriental beech showed relatively higher scratch resistance compared to mahogany when coated with high-energy UV systems. This suggests that both coating formulation and substrate structure play a combined role in determining surface hardness and resistance to mechanical

Table 1 Mean scratch and abrasion resistance ($\pm$ SD) of varnished wood specimens**Tablica 1.** Srednje vrijednosti otpornosti na ogrebotine i habanje ($\pm$ SD) lakiranih uzoraka drva

Wood species <i>Vrsta drva</i>	Varnish type / <i>Vrsta laka</i>	Scratch resistance, N <i>Otpornost na ogrebotine, N</i>	Abrasion mass loss, g <i>Gubitak mase nakon habanja, g</i>
Scots pine <i>borovina</i>	Daylight UV-curable varnish <i>dnevni UV lak</i>	0.10 $\pm$ 0.00	0.15 $\pm$ 0.04
	High-energy UV-curable varnish <i>visokoenergetski UV lak</i>	0.70 $\pm$ 0.07	0.09 $\pm$ 0.02
Oriental beech <i>kavkaska bukovina</i>	Daylight UV-curable varnish <i>dnevni UV lak</i>	0.24 $\pm$ 0.05	0.22 $\pm$ 0.04
	High-energy UV-curable varnish <i>visokoenergetski UV lak</i>	0.48 $\pm$ 0.04	0.18 $\pm$ 0.02
Mahogany <i>drvo mahagonija</i>	Daylight UV-curable varnish <i>dnevni UV lak</i>	0.10 $\pm$ 0.00	0.14 $\pm$ 0.02
	High-energy UV-curable varnish <i>visokoenergetski UV lak</i>	0.46 $\pm$ 0.04	0.09 $\pm$ 0.01

Table 2 ANOVA results for the effects of wood species and varnish type on scratch resistance**Tablica 2.** Rezultati analize varijance (ANOVA) za utjecaj vrste drva i laka na otpornost na ogrebotine

Sources of variance <i>Izvori varijance</i>	Sum of squares <i>Zbroj kvadrata</i>	Degrees of freedom <i>Stupnjevi slobode</i>	Mean squares <i>Srednji kvadrati</i>	F-Value <i>F-vrijednost</i>	Probability of error ($p < 0.05$) <i>Vjerojatnost pogreške ($p < 0,05$)</i>
Wood species / <i>vrsta drva</i>	0.07467	2	0.03733	17.23	0.000
Varnish type / <i>vrsta laka</i>	1.20000	1	1.20000	553.85	0.000
Wood species $\times$ Varnish type <i>vrsta drva $\times$ vrsta laka</i>	0.16800	2	0.08400	38.77	0.000
Error / <i>pogreška</i>	0.05200	24	0.00217	—	—
Total / <i>ukupno</i>	1.49467	29	—	—	—

Table 3 Multiple comparison results of scratch resistance values among wood species**Tablica 3.** Rezultati višestruke usporedbe vrijednosti otpornosti na ogrebotine ispitivanih vrsta drva

Wood species <i>Vrsta drva</i>	Mean, N <i>Srednja vrijednost, N</i>	Homogeneity group (HG) <i>Homogena skupina (HG)</i>
Oriental beech <i>kavkaska bukovina</i>	0.36	A
Mahogany <i>drvo mahagonija</i>	0.28	B
Scots pine <i>borovina</i>	0.40	A

damage. The results of the analysis of variance (ANOVA) regarding the effects of wood species and varnish type on scratch resistance are presented in Table 2.

According to the ANOVA results, the effects of wood species, varnish type, and the wood species $\times$ varnish type interaction on scratch resistance were evaluated. The results showed that all main factors and their interaction were statistically significant ($p < 0.05$), indicating that both individual and combined effects of wood species and varnish type significantly influenced scratch resistance. The results of the multiple comparison test for scratch resistance according to wood species are presented in Table 3.

According to the comparative analysis of scratch resistance values among wood species, the highest re-

sistance was recorded in Scots pine specimens (0.40 N), followed by Oriental beech (0.36 N), whereas the lowest value was obtained in mahogany samples (0.28 N). These findings indicate that scratch resistance is not solely governed by the coating system but is also strongly influenced by the anatomical and physical properties of the wood substrate.

The relatively higher performance observed in Scots pine and oriental beech may be attributed to their favorable fiber structure, higher density, and more effective varnish-substrate interaction. In contrast, the more porous structure and lower surface integrity of mahogany likely impaired coating uniformity, resulting in reduced scratch resistance.

These results are consistent with previous studies (Söğütü *et al.*, 2017; Tekin, 2009), which reported that scratch and abrasion resistance are closely related to wood species and density. Accordingly, the selection of an appropriate wood substrate is a critical factor in enhancing surface durability in UV-coated applications, particularly in furniture and mega-yacht manufacturing. The comparative results of scratch resistance based on varnish type are presented in Table 4.

The comparative analysis of scratch resistance among varnish types revealed that high-energy UV-curable systems exhibited the highest resistance (0.55 N), whereas daylight UV-curable coatings showed the

lowest performance (0.15 N). These findings are consistent with Söğütü *et al.* (2017), who reported that scratch resistance is strongly dependent on coating system characteristics.

The superior performance of high-energy UV-curable systems can be attributed to their higher degree of photopolymerization and increased crosslink density, resulting in the formation of a more compact three-dimensional network structure. This dense network enhances surface hardness and resistance to mechanical penetration, thereby improving scratch resistance (Schwalm, 2006; Salca, 2016).

In contrast, daylight UV-curable systems operate under lower energy activation conditions, which may limit the extent of polymer crosslinking. Consequently, a less densely crosslinked polymer network with higher segmental mobility is formed, leading to reduced surface hardness and lower resistance to scratch formation. As a result, these coatings are more susceptible to deformation under applied load. Table 5 presents the results of the multiple comparison test for scratch resistance values based on the interaction between wood species and varnish type.

According to the interaction analysis between wood species and varnish type, a pronounced combined effect of substrate and coating system on scratch resistance was observed. The highest scratch resistance

(0.70 N) was recorded in Scots pine coated with high-energy UV-curable varnish, whereas the lowest value (0.10 N) was observed in Scots pine and mahogany specimens coated with daylight UV-curable systems.

The homogeneity groupings indicated that high-energy UV-curable coatings consistently resulted in higher scratch resistance across all wood species. However, the magnitude of this improvement varied depending on the substrate, confirming a significant interaction between wood species and varnish type. In contrast, daylight UV-curable systems consistently exhibited lower performance, regardless of wood type.

These findings are consistent with Söğütü *et al.* (2017), who reported that coating type plays a critical role in determining scratch resistance. The lower performance of daylight UV-curable systems can be attributed to their lower curing energy, which limits the extent of photopolymerization and crosslinking. Consequently, a less densely crosslinked polymer network with higher chain mobility is formed, resulting in reduced surface hardness and lower resistance to mechanical scratching (Schwalm, 2006; Salca, 2016). Overall, the results suggest that both coating formulation and substrate characteristics influence scratch resistance; however, the curing mechanism and the resulting film structure appear to play a more decisive role under the conditions investigated.

Table 4 Multiple comparison results of scratch resistance values among varnish types

Tablica 4. Rezultati višestruke usporedbe vrijednosti otpornosti na ogrebotine upotrijebljenih vrsta lakova

Varnish type <i>Vrsta laka</i>	Mean, N <i>Srednja vrijednost, N</i>	Homogeneity group (HG) <i>Homogena skupina (HG)</i>
Daylight UV-curable varnish <i>dnevni UV lak</i>	0.15	B
High-energy UV-curable varnish <i>visokoenergetski UV lak</i>	0.55	A

Table 5 Interaction effects of wood species and varnish type on scratch resistance values

Tablica 5. Interakcijski utjecaji vrste drva i laka na otpornost na ogrebotine

Wood species <i>Vrsta drva</i>	Varnish type <i>Vrsta laka</i>	Mean, N <i>Srednja vrijednost, N</i>	Homogeneity group (HG) <i>Homogena skupina (HG)</i>
Oriental beech <i>kavkaska bukovina</i>	Daylight UV-curable varnish <i>dnevni UV lak</i>	0.24	C
	High-energy UV-curable varnish <i>visokoenergetski UV lak</i>	0.48	B
Mahogany <i>drvo mahagonija</i>	Daylight UV-curable varnish <i>dnevni UV lak</i>	0.10	D
	High-energy UV-curable varnish <i>visokoenergetski UV lak</i>	0.46	B
Scots pine <i>borovina</i>	Daylight UV-curable varnish <i>dnevni UV lak</i>	0.10	D
	High-energy UV-curable varnish <i>visokoenergetski UV lak</i>	0.70	A

3.2 Abrasion resistance results

3.2. Rezultati ispitivanja otpornosti na habanje

The results of the abrasion test are presented in Table 1. The test specimens were subjected to 5,000 abrasion cycles using a Taber abrasion testing machine, and abrasion performance was evaluated based on the resulting mass loss (g). The effects of wood species, varnish type, and their interaction on abrasion resistance were analyzed statistically, and the results are summarized in Table 6.

ANOVA results demonstrated the effects of wood species, varnish type, and their interaction on abrasion

Table 6 ANOVA results for abrasion resistance**Tablica 6.** Rezultati analize varijance (ANOVA) za otpornost na habanje

Sources of variance <i>Izvori varijance</i>	Sum of squares <i>Zbroj kvadrata</i>	Degrees of freedom <i>Stupnjevi slobode</i>	Mean squares <i>Srednji kvadrati</i>	F-Value <i>F-vrijednost</i>	Probability of error ($p < 0.05$) <i>Vjerojatnost pogreške ($p < 0,05$)</i>
Wood species / <i>vrsta drva</i>	0.048487	2	0.024243	27.14	0.001*
Varnish type / <i>vrsta laka</i>	0.018750	1	0.018750	20.99	0.001*
Wood species $\times$ Varnish type <i>vrsta drva $\times$ vrsta laka</i>	0.001460	2	0.000730	0.82	0.454
Error / <i>pogreška</i>	0.021440	24	0.000893	—	—
Total / <i>ukupno</i>	0.090137	29	—	—	—

* Indicates statistical significance at $p < 0.05$. / *Označava statistički značajnu razliku na razini $p < 0,05$.*

Table 7 Abrasion mass loss values according to wood species**Tablica 7.** Gubitak mase nakon habanja s obzirom na vrstu drva

Wood species <i>Vrsta drva</i>	Mean mass loss, g <i>Srednji gubitak mase, g</i>	Homogeneity group (HG) <i>Homogena skupina (HG)</i>
Oriental beech <i>kavkaska bukovina</i>	0.20	B
Mahogany	0.11	A
Mahogany <i>drvo mahagonija</i>	0.20	B

resistance. Wood species ($p < 0.001$) and varnish type ($p < 0.001$) showed statistically significant effects on abrasion resistance. In contrast, the interaction between wood species and varnish type was not statistically significant ($p = 0.454$), indicating that their combined effect did not contribute additional influence beyond their individual effects. Table 7 presents the comparative analysis of abrasion resistance values according to wood species.

The comparative analysis of abrasion resistance according to wood species showed that the lowest mass loss value (0.11 g) was recorded in mahogany samples, indicating the highest abrasion resistance among the tested wood species. In contrast, oriental beech and Scots pine exhibited higher mass loss values (0.20 g), corresponding to lower abrasion resistance. Since higher mass loss in abrasion tests indicates greater material removal and therefore lower performance, these results demonstrate that mahogany provided superior resistance to abrasive wear compared to the other wood species.

These findings suggest that abrasion performance is closely associated with the anatomical structure and surface characteristics of the wood substrate. The results are consistent with Tekin (2009), who reported significant variations in abrasion resistance depending on wood species. In denser and more homogeneous wood structures, improved coating–substrate interaction may enhance the integrity of the varnish film, thereby reducing material loss during abrasion testing. Conversely, more porous wood structures tend to ex-

Table 8 Abrasion mass loss values according to varnish type**Tablica 8.** Gubitak mase nakon habanja s obzirom na vrstu laka

Varnish type <i>Vrsta laka</i>	Mean mass loss, g <i>Srednji gubitak mase, g</i>	Homogeneity group (HG) <i>Homogena skupina (HG)</i>
Daylight UV-curable varnish <i>dnevni UV lak</i>	0.17	B
High-energy UV-curable varnish <i>visokoenergetski UV lak</i>	0.12	A

hibit weaker mechanical interlocking and reduced surface stability, which increases material removal under abrasive action. In this context, the superior abrasion resistance observed in mahogany can be attributed to its more favorable surface characteristics, which likely contributed to reduced mass loss during testing. The comparative results of abrasion resistance values according to varnish type are presented in Table 8.

The comparative analysis of abrasion resistance by varnish type revealed that the highest average mass loss (0.17 g) was obtained in daylight UV-curable varnish coatings, whereas the lowest mass loss (0.12 g) was recorded in high-energy UV-curable systems. Since higher mass loss indicates greater material removal and therefore lower abrasion resistance, these results demonstrate that high-energy UV systems exhibit superior abrasion resistance compared to daylight UV-curable coatings.

This improvement can be attributed to the denser crosslinked network formed under high-energy UV curing conditions, which enhances film integrity and reduces material loss under repetitive abrasion loads. These findings are consistent with Tekin (2009), who emphasized the decisive role of coating type in abrasion performance. In contrast, daylight UV-curable varnish systems, which form a less densely crosslinked and relatively more flexible/brittle film structure, are more susceptible to material removal under cyclic frictional stresses, resulting in lower abrasion resistance (Schwalm, 2006).

4 CONCLUSIONS

4. ZAKLJUČAK

This study comparatively evaluated the scratch and abrasion resistance of daylight UV-curable and high-energy UV-curable varnish systems applied to different wood species commonly used in furniture and yacht manufacturing. The findings demonstrated that both wood species and varnish type had significant effects on surface performance.

High-energy UV-curable varnish systems consistently exhibited higher scratch resistance compared to daylight UV-curable systems. The highest scratch resistance was obtained in Scots pine coated with high-energy UV varnish, indicating a notable interaction between curing energy and substrate characteristics.

In terms of abrasion resistance, lower mass loss values corresponded to higher resistance. Based on this criterion, mahogany exhibited the highest abrasion resistance, while Scots pine and oriental beech showed comparatively lower performance.

Overall, the results suggest that scratch resistance is more strongly influenced by varnish type, whereas abrasion resistance is more dependent on wood species. Accordingly, high-energy UV-curable systems may be preferred for applications requiring high scratch resistance, while daylight UV-curable systems may be suitable for less demanding surface performance conditions. The study provides practical guidance for the selection of wood substrates and UV-curable coating systems in furniture and megayacht manufacturing industries.

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