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Modification of wood surfaces with nanomaterials having hydrophobic and hydrophilic properties

Hidrofobik ve hidrofilik özelliklere sahip nano malzemelerin ahşap yüzeylerdeki modifikasyonu

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Modification of Wood Surfaces with Nanomaterials Having Hydrophobic and Hydrophilic Properties

Highlights

- *Nanocoating was applied to improve the water resistance of wood surfaces.*
- *The hydrophobicity performances of different nanocoatings were compared.*
- *SH-5 coating showed the best water repellency by providing the highest contact angle.*

Graphical Abstract

In this study, three different coatings (AS-54, HL-31 and SH-5) were applied to Scotch pine, Turkish beech and Cedar wood species and the properties of the surfaces obtained were investigated.

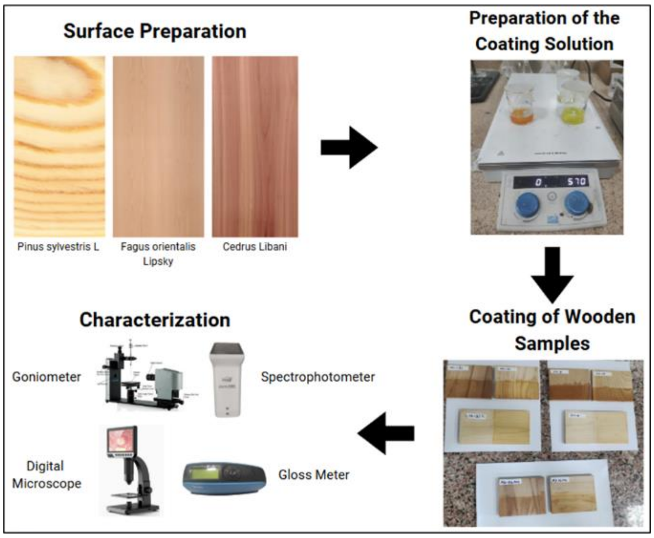

Figure. Schematic Representation of the Surface Modification Process and Characterization of Nanocoated Wooden Samples.

Aim

This study aims to improve wood performance by modifying surfaces with hydrophobic or hydrophilic nanomaterials, enhancing properties like water resistance and durability. It supports the development of sustainable, high-performance wood products through eco-friendly nanotechnology.

Design & Methodology

In this study, three different solutions were prepared and applied to wood surfaces. Afterwards, water repellency of the surfaces was examined, contact angle measurements, color change, gloss and microscopic analysis were carried out.

Originality

It offers an original approach that addresses the effect of nanotechnology on the protection of wooden surfaces against water in a multidimensional way.

Findings

The findings showed that SH-5 provided the highest contact angle and best hydrophobic performance, while HL-31 showed the lowest. Control samples remained hydrophilic due to wood's natural water absorption. Overall, SH-5 significantly improved water resistance and stain protection of the wood surfaces.

Conclusion

These results highlight that SH-5 is the most effective coating for improving water resistance, making it a promising solution for extending the lifespan of wooden materials.

Declaration of Ethical Standards

The authors of this paper affirm that neither ethical committee nor legal-special permission is needed for the materials and procedures utilized in this investigation.

Modification of Wood Surfaces with Nanomaterials Having Hydrophobic and Hydrophilic Properties

Araştırma Makalesi / Research Article

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ABSTRACT

Surface modification of wood materials covers various methods to increase durability, performance, aesthetics and lifespan. These techniques, which are widely used in areas such as furniture, structural wood and decoration, are further developed with the innovations offered by nanotechnology. In particular, nanotechnology offers an effective solution in creating stain-proof and hygienic surfaces by applying hydrophobic coatings to wood surfaces, preventing water permeation and extending their lifespan.

In this study, three different nanocoating solutions (AS-54, HL-31 and SH-5) were created to increase the hydrophobic properties of wood surfaces and applied to Scotch pine (*Pinus sylvestris* L.), Turkish beech (*Fagus orientalis* Lipsky) and cedar (*Cedrus libani* A. Rich.) wood species. Then, color, gloss, contact angle (wettability) and FTIR tests of the coated surfaces were performed. Experimental results show that SH-5 nano solution synthesis applied to oriental beech samples gives the best result with a contact angle of 103,51°, creating a hydrophobic (water repellent) and stain-resistant surface. This research highlights the critical role of nanomaterials in protecting wooden surfaces and ensuring hygiene conditions.

Keywords: Wood material, hydrophobic surfaces, nano coatings, contact angle.

Hidrofobik ve Hidrofilik Özelliklere Sahip Nano Malzemelerin Ahşap Yüzeylerdeki Modifikasyonu

ÖZ

Ahşap malzemelerin yüzey modifikasyonu, dayanıklılık, performans, estetik ve kullanım ömrünü artırmaya yönelik çeşitli yöntemleri kapsar. Mobilya, yapısal ahşap ve dekorasyon gibi alanlarda yaygın olarak kullanılan bu teknikler, nanoteknolojinin sunduğu yeniliklerle daha da gelişmektedir. Özellikle nanoteknoloji, ahşap yüzeylere hidrofobik kaplamalar uygulayarak su geçirimini engelleyip ömrünü uzatırken, leke tutmaz ve hijyenik yüzeyler oluşturmada etkili bir çözüm sunmaktadır.

Bu çalışmada, Ahşap yüzeylerin hidrofobik özelliklerini artırmak için üç farklı nano kaplama çözeltisi (AS-54, HL-31 ve SH-5) oluşturuldu ve sarıçam (*Pinus sylvestris* L.), Doğu kayını (*Fagus orientalis* Lipsky) ve Sedir (*Cedrus libani* A. Rich.) ağaç türlerine uygulandı. Deney sonuçları, doğu kayını örneklerine uygulanan SH-5 nano solüsyon sentezinin 103,51° temas açısı ile en iyi sonucu verdiğini, hidrofobik (su itici) ve leke tutmaz bir yüzey oluşturduğunu göstermektedir. Bu araştırma, ahşap yüzeylerin korunması ve hijyen koşullarının sağlanmasında nano malzemelerin kritik rolünü vurgulamaktadır.

Anahtar Kelimeler: Ahşap malzeme, hidrofobik yüzeyler, nano kaplamalar, temas açısı.

1. INTRODUCTION

Nanotechnology is an interdisciplinary science related to nanoscale technology and research in terms of material science, physics, chemistry, biology, bioengineering and pharmacology. The concept of "nano" is expressed dimensionally as the measure of one in billion pieces of the matter (10-9 m) in other words nanometer (<100 nm). This manipulation allows for the creation of materials with unique physical, chemical, and biological properties that differ significantly from their bulk counterparts. The application of nanotechnology spans various domains, including medicine, electronics, and materials science, with particular emphasis on enhancing the functionality and performance of coatings through the development of nanocoatings [1,2].

Nanocoatings, which are thin layers of material engineered at the nanoscale, have gained prominence due to their ability to impart desirable properties such as hydrophobicity, hydrophilicity, and antimicrobial effects to surfaces. These coatings are typically composed of nanoparticles or nanostructured materials that can modify the surface characteristics of substrates, thereby improving their resistance to environmental factors, enhancing durability, and providing aesthetic benefits [3,4]. For instance, the incorporation of engineered nanoparticles into coatings can significantly enhance mechanical strength, thermal stability, and chemical resistance, making them suitable for a wide range of applications, from automotive to biomedical fields [5,6].

The importance of nanocoatings is particularly evident in their role in surface engineering. Self-assembled

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monolayers (SAMs) made from silanes are a prominent example of nanocoatings that provide effective surface modification. These SAMs can create hydrophobic or hydrophilic surfaces depending on the chemical nature of the silane used, thus allowing for tailored surface properties that meet specific functional requirements [3,4]. Moreover, the use of nanocoatings can lead to significant improvements in the performance of materials by enhancing their resistance to corrosion, wear, and microbial adhesion, which is critical in applications such as dental implants and medical devices [6,7].

Wood material maintains its importance in many areas of use today due to its superior properties. The increase in per capita consumption and the decrease in forest areas make it necessary to use the wood material produced for a long time. Depending on the environmental conditions, the wood material ages and degrades due to chemical and biological factors. Drying, impregnation and surface treatments are applied against these drawbacks [8]. Especially these processes are processes such as varnishing and impregnation. Nowadays, wooden surfaces are coated with nano technological chemicals and modified products. Nanotechnology enters our lives in different fields. These fields are especially informatics and communication, defense industry, aerospace and aircraft technologies, molecular biology. Thanks to the developments in nanotechnology, new materials can be produced or the properties of existing materials can be improved. Nanomaterial technology, as in many areas, has been used in wood materials, chemicals and varnishes used for protection purposes, as well as in order to gain some additional and new features in processes etc [9].

In the context of wood coatings, the application of nanotechnology can revolutionize the way wood surfaces are treated. By employing silane-based nanocoatings, it is possible to achieve enhanced water repellency and improved color stability, which are essential for maintaining the aesthetic and functional qualities of wood products [4,12]. The ability to engineer wood surfaces at the nanoscale not only extends their lifespan but also contributes to sustainability by reducing the need for frequent replacements and maintenance [11].

The study of wood surface coatings has garnered significant attention in recent years, particularly with respect to enhancing the functional properties of various wood species such as Scotch pine, Cedar, and Turkish beech. The application of silane groups and alkoxides in the formulation of coatings presents a promising avenue for achieving desired surface characteristics, including hydrophobicity. These modifications not only improve the aesthetic appeal of wood but also enhance its durability against environmental factors such as moisture and UV radiation. The integration of nanotechnology into wood coatings has been shown to provide additional benefits, including increased color stability and gloss retention, which are critical for maintaining the visual and structural integrity of wood products over time [12,13,14].

The hydrophobic properties of wood surfaces are primarily influenced by their chemical composition and surface morphology. The introduction of silane compounds can significantly alter the wettability of wood surfaces. For instance, studies have demonstrated that the application of low-surface free-energy materials, such as alkoxysilanes, can transform wood surfaces into hydrophobic entities, thereby reducing water absorption and enhancing resistance to biological degradation [13,14]. This transformation is crucial, as untreated wood is highly susceptible to moisture-related issues, which can lead to dimensional instability and fungal growth. Furthermore, the incorporation of nanoparticles, such as TiO2 and ZnO, into coatings has been shown to provide UV protection, thereby prolonging the lifespan of wood products by mitigating the photodegradation processes that typically lead to color fading and surface deterioration [12,15].

Color stability is another vital aspect of wood coatings, particularly for applications where aesthetic qualities are paramount. The interaction between the coating materials and the wood substrate can lead to significant changes in color parameters, which are quantitatively assessed using color analysis techniques. Research indicates that coatings containing UV absorbers and photostabilizers can effectively minimize color changes, thus preserving the natural beauty of wood surfaces [16,17]. The gloss of coated wood surfaces is also an important factor, as it contributes to the overall appearance and perceived quality of the product. Gloss measurements can provide insights into the surface smoothness and the effectiveness of the coating in protecting the wood from environmental degradation [18,19].

In addition to the chemical and physical properties of the coatings, the application techniques and the preparation of the wood substrates play a critical role in the performance of the final product. Surface treatments, such as sanding and plasma treatment, can enhance the adhesion of coatings to wood surfaces, thereby improving their durability and effectiveness [20]. The choice of coating formulation, including the concentration of active ingredients and the method of application, can also influence the performance characteristics of the coated wood. For instance, the use of waterborne coatings has been shown to provide a balance between environmental safety and performance, making them an attractive option for both manufacturers and consumers [21,22].

Today, the primary use of nanomaterials is in studies on antimicrobial properties. The use of nanomaterials in wooden products has increased, especially in terms of surface hygiene. Generally, wood surfaces are used to improve surface properties and provide protection with nano-additive liquid coatings [23]. In recent years, some studies have been conducted on the modification of wood materials with nanoparticles. In the study conducted by Cansu et al. (2024), 0.1% and 0.3% nanoboron and nanosilver were applied together with synthetic and water-based varnishes on Scotch pine, oak and Turkish beech tree species and the antimicrobial effect of the surfaces was determined. Staphylococcus aureus, Staphylococcus epidermidis, Klebsiella pneumoniae, and Escherichia coli were the four microorganisms that were employed. It was shown that using nanoparticles where antibacterial qualities are sought improves both human and environmental cleanliness and health [24]. Four tree species (Scotch pine, Austrian pine, Turkey oak, and cedar) were impregnated with a silane-siloxane-based water-repellent compound (S-WR) using the immersion method for brief, medium, and extended periods of time. The wood's retention, contraction, expansion, water intake rate, specific gravity, and other physical characteristics were assessed after impregnation. In conclusion, it was discovered that a water-repellent impregnation compound based on silane and siloxane was successful in giving wood dimensional stability [25].

The present study aims to systematically investigate the effects of various silane groups and alkoxides on the functional properties of coated Scotch pine, Cedar, and Turkish beech wood surfaces. By employing contact angle measurements, color analysis, and gloss assessments, we seek to elucidate the relationships between coating composition, surface characteristics, and the resultant performance of the wood substrates. This research not only contributes to the existing body of knowledge regarding wood surface treatments but also provides practical insights for the development of advanced, durable, and environmentally friendly wood coatings that meet the demands of modern architectural, industrial, and decorative applications.

In conclusion, the exploration of functional coatings for wood surfaces represents a significant area of research that intersects materials science, chemistry, and environmental sustainability. The findings from this study will be instrumental in advancing the understanding of how different chemical modifications can enhance the performance of wood products, ultimately leading to more durable and aesthetically pleasing materials for a variety of applications.

2. MATERIAL and METHOD

2.1 Preparation of Wood Samples

The test samples prepared according to ISO 3129 were prepared from sapwoods that were not damaged by insects and fungi, did not contain defects such as knots, cracks and arcs, did not have discoloration and had a uniform fiber structure [26]. A total of 10 samples were prepared for 1 control, 3 different coating solutions and 3 wood species. In order to reduce the sample moisture to 12±2%, the samples with net dimensions of 100x100x10 mm (longitudinal direction × radial direction × tangential direction) were acclimatized at 20±2°C / 65±5% to bring the air to dry humidity [27]. For the cutting of these materials, Afyon Vocational School furniture and decoration workshop facilities were utilized.

2.2 Preparation of Coating Solutions

Three different solvent solutions (AS-54, SH-5 and HL-31) prepared by sol-gel method. Firstly, titanium alkoxide or zinc was added to the IPA and ethanol used as solvents in the solutions and mixed with VELP Multi HS-6 magnetic stirrer (Figure 3) for 2 hours, then acetyl acetone, purified water and binder silane compounds were added in certain amounts and the mixing process continued for 6 hours. The solution contents are given below.

SH-5: IPA (Solvent), Zinc-Acetate, Bonding Silane Agents.

HL-31: IPA (Solvent), Titanium (IV) Propoxide, Bonding Silane Agents.

AS-54: Ethanol (Solvent), Titanium (IV) Propoxide, Bonding Silane Agents.

Figure 1. Preparation of coating solutions (Magnetic stirrer).

2.3 Applying the Coating to Wooden Surfaces

Sandpaper numbers 80 and 120, respectively, were used to sand the sample surfaces, and compressed air was used to remove any remaining dust. Using an air pistol with a 1.8 mm tip opening, the produced liquid nano solutions were applied in four layers at 2 (28 atm) atm pressure [28] at a rate of 125 g per m², perpendicular and parallel to the fibers. They were then allowed to dry for 48 hours at ambient temperature (23 °C). The surface coating procedure was based on the ASTM-D 3023 standard [29]. Thus, the coating was ensured to interact well with the surface and to form a sufficient film layer. The coated wooden surfaces are given in Figure 2.


Figure 2. Coated wood surfaces.

2.4 Characterization

2.4.1 Contact angle measurement

Contact angle measurements were carried out in accordance with the ASTM D7334-08 standard. This standard outlines a procedure for evaluating the surface wettability of coatings, substrates, and pigments using an advancing contact angle method with an automated goniometer. In this study, a defined volume of deionized water was carefully deposited onto each sample surface, and the contact angles were measured after droplet stabilization to assess the hydrophilic or hydrophobic character of the surface. This method enabled a quantitative evaluation of the influence of surface modification on wettability.

The contact angle was recorded using a high-resolution goniometer (Attension/Theta Lite), with measurements taken at 1-second intervals to capture the evolution of wettability over time.

Figure 3. Goniometer.

2.4.2 Microscopic analysis

The surfaces of the coated wood samples were examined using a Kentfaith GW45.0029 model 7-inch high-definition microscope to observe microstructural changes due to the nanocoating application. This analysis provided detailed visual data on the uniformity of the coatings, particle distribution, and how well the nanocoatings adhered to the wood fibers. The microscopic imaging offered insights into the variations in performance of the different coatings, revealing details about surface morphology that contributed to their hydrophobic or hydrophilic behavior.

Figure 4. 7-inch high definition microscope.

2.4.3 Color measurement

Colorimetry measurements were performed to determine the color changes of coated wood surfaces according to ASTM D 2244 principles [30]. Color measurements were evaluated using L* (lightness), a* (red-green axis) and b* (yellow-blue axis) values in CIELAB color space. This method is widely used to quantitatively determine color changes before and after coating [31,32,33]. The data obtained were statistically interpreted to evaluate the visual impact of the coating on the surface and to analyze its aesthetic suitability.

Figure 5. Colorimeter.

2.4.4 Gloss testing

The gloss properties of coated wood surfaces were determined using a glossmeter according to TS EN ISO 2813 [34]. Gloss measurement provides information about the surface smoothness and optical properties of the coating by determining how much of the light sent to the surface at a certain angle is reflected. The instrument was calibrated according to ASTM-D-523. Glossmeter measurements were performed at an angle of 60°. The 60° angle used in the measurement is generally accepted as the standard measurement angle. A measurement angle of 20° is preferred for high gloss surfaces and 85° for low gloss surfaces [35].

Gloss values are expressed in Gloss Units (GU) and higher values indicate that the surface is more glossy. The measurement results were used to compare the effect of different coating recipes on gloss. The surface morphology of the coating, the optical properties of the components in the recipe and the application method are the main factors affecting the gloss values [31]. In this study, glossmeter measurements were used as a critical analysis method to evaluate the aesthetic and functional performance of coatings. In particular, processes such as homogeneous dispersion of the coating on the surface, solvent evaporation and film formation play an important role in gloss [36].

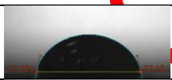
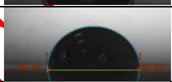
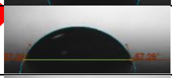
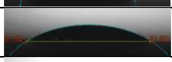
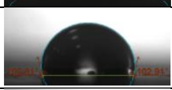
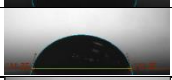
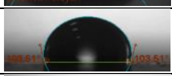
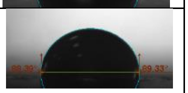
Figure 6. Glossmeter.

3. RESULTS AND DISCUSSION

3.1 Contact Angle Results

In this study, the effect of different nanocoatings on the hydrophobic properties of wood surfaces was evaluated through detailed contact angle measurements, as presented in Table 1. The contact angles of the uncoated wood samples were found to be quite low, clearly indicating that these surfaces exhibited a high affinity for water and were therefore classified as highly water-absorbent, or hydrophilic. This behavior reflects the natural tendency of untreated wood to absorb moisture due to its porous structure and polar chemical groups, which can significantly limit its durability and performance in humid or outdoor environments.

Table 1. Contact angle results

Wood Type	Solution	Contact Angle	Image
Scotch pine	Uncoated	77.13	
	SH-5	97.15	
	AS-54	92.58	
	HL-31	67.28	
Cedar	Uncoated	31.92	
	SH-5	102.91	
	AS-54	88.81	
	HL-31	75.11	
Turkish beech	Uncoated	45.59	
	SH-5	103,51	
	AS-54	87,25	
	HL-31	88,39	

It was determined that the contact angle increased in all coated specimens. SH-5 coating showed the best hydrophobic properties by providing the highest contact angle in all wood species (Highest contact angle: Turkish beech 103,51°). The AS-54 coating provided a lower but still significant hydrophobicity compared to SH-5 (Highest AS-54 contact angle: Scotch pine 92,58°). The HL-31 coating showed weaker water repellency compared to the other coatings, giving the lowest contact angle values (Lowest HL-31 contact angle: Scotch pine 67,28°).

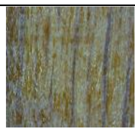
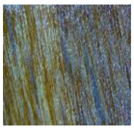
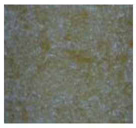
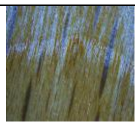
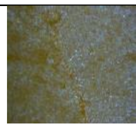
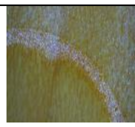
In general, the SH-5 coating provided the best hydrophobic effect, while the uncoated surfaces had the lowest contact angles. These results indicate that nanocoatings significantly reduce water absorption on wood surfaces and contribute to surface protection.

It has been shown that nanomaterials used to obtain superhydrophobic properties on wood surfaces are effective in increasing the dimensional stability, durability, and UV resistance of wood. In these studies, techniques such as sol-gel methods, graft copolymerization, and chemical vapor deposition have been employed, producing similar surface effects to those achieved by the nanomaterials used in this study. These methods contribute to the development of functional coatings that not only enhance water repellency but also improve the overall performance and longevity of wood in various environmental conditions. [37].

3.2 Microscope Images

In order to examine the morphological changes of the wood surfaces after coating, analyses were carried out using a 7-inch high-resolution digital microscope. It was observed (Table 2) that the surfaces of the uncoated samples were rough and porous, while the uncoated surfaces had a more natural and irregular texture.

Table 2. Microscope images

	Turkish Beech	Scotch Pine	Cedar
Uncoated			
SH-5			
AS-54			
HL-31			

It was determined that the surfaces of the coated specimens had a smoother and homogenous structure. SH-5 coating formed a more holistic film layer on all wood species and prevented the formation of water stains on the surface to a great extent. AS-54 and HL-31 coatings, on the other hand, provided a relatively homogeneous coating, but significant staining was observed especially in the areas in contact with water in HL-31 coating.

Microscope images support the interaction of the coatings with wood surfaces and their hydrophobic properties. It was observed that the SH-5 coating provided the best water repellent property, while the other coatings offered relatively lower hydrophobicity. In particular, the formation of distinct marks in the areas in contact with water in the HL-31 coating reveals that this coating shows less resistance to water. In a similar study, high contact angles were obtained against water, ethylene glycol and sunflower oil by applying fluorine-containing silica nanoparticles to pine wood surfaces. The coating showed low sliding angles and good durability. These properties were effective in making the wood surfaces stain-resistant [38].

3.3 Colour Measurement Results

The effect of different coatings applied to the wood surfaces on the colour change was evaluated with the colour parameters L (light-dark), a (red-green) and b (yellow-blue) (Table 3).

Table 3. Colour measurement results.

		L	a	b	ΔE
Scotch pine	Uncoated	81.42	6.18	24.43	-
	SH-5	75.26	9.37	37.20	14.53
	AS-54	76.11	8.81	39.21	15.92
	HL-31	60.59	13.45	27.69	22.30
Cedar	Uncoated	77.09	7.96	20.99	-
	SH-5	62.68	13.23	33.91	20.06
	AS-54	67.50	12.14	32.04	15.22
	HL-31	67.19	12.07	31.87	15.27
Turkish beech	Uncoated	64.82	11.73	19.80	-
	SH-5	62.92	13.49	32.42	12.88
	AS-54	52.49	13.95	24.41	13.35
	HL-31	60.59	13.45	27.69	9.12

When evaluated in terms of L value (lightness), it was determined that the uncoated samples had the highest L values, thus the lightest tone. When the coatings were applied, a significant decrease in L values was observed, especially in SH-5 and AS-54 coatings, and it was determined that the surfaces became darker.

When analysed in terms of a value (red-green axis), it was observed that the red tones increased in all samples with the application of coatings and the highest a values belonged to SH-5 and AS-54 coatingshe b-value (yellow-blue axis) results show that the coatings created a significant change on the yellow tones. SH-5 and AS-54 coatings increased the b values, especially in Scotch pine and Turkish beech samples, causing the surfaces to gain a more yellowish tone.

In general, the coating application caused significant changes in the colour characteristics of the woods, especially SH-5 and AS-54 coatings showed a darkening and yellowing tendency. In the case of HL-31 coating, the colour change remained at a relatively low level.

When the data were evaluated in terms of total color change (ΔE); SH-5 coating created a significant color difference in all three species, especially on cedar with ΔE > 20, which produced the highest difference. This suggests that SH-5 creates a stronger pigment or gloss effect on light-toned coniferous trees.

AS-54 application produced similar and high ΔE values in all three species. This shows that the color effect of AS-54 is more homogeneous and creates similar visual changes in different species. However, the ΔE value in Scotch pine is the highest.

HL-31 produced a very high ΔE (22.30) value, especially on Scotch pine, and provided the most significant visual change in this species. However, it showed a relatively lower effect on Turkish beech with ΔE = 9.12. This suggests that HL-31 has a more limited effect on broadleaf species (especially beech) in terms of fiber structure and color absorbency, while it creates intense pigmentation and brightness effects on conifers.

In this study, acacia hybrid wood samples were impregnated with TiO_2 nano sol and exposed to UV rays. The results showed that the color changes (ΔE*) of TiO_2-treated woods were less than those of untreated samples. This is due to the fact that TiO_2 absorbs UV rays and slows down lignin oxidation [39]. The coating formed by the combination of epoxy resin and ZnO nanoparticles increased the resistance of wood surfaces to UV rays. In coated samples, total color change (ΔE) values during UV exposure were found to be lower than in uncoated samples. This was associated with the ability of ZnO to absorb UV rays [40]. In similary study, photographic properties of wood surfaces were investigated using microencapsulated polydimethylsiloxane (MP-PDMS) composite coating. When exposed to UV rays, significant changes were observed in the color parameters (L*, a*, b*) of coated woods and the total color change (ΔE*) increased. This indicates the sensitivity of the coating to UV rays and color changes [41].

3.4 Gloss Measurement Results

Gloss changes of wooden surfaces after coating were evaluated (Table 4). Gloss value gives information about the smoothness and brightness of the surface by determining the amount of light reflection from the surface.

Table 4. Gloss measurement results.

		Gloss Value
Scotch pine	Uncoated	6.1
	SH-5	9.6
	AS-54	5.2
	HL-31	6.9
Cedar	Uncoated	2.5
	SH-5	8.4
	AS-54	8.0
	HL-31	2.5
Turkish beech	Uncoated	2.1
	SH-5	12.1
	AS-54	6.5
	HL-31	6.9

The lowest gloss values were measured in uncoated samples. While the gloss values of uncoated surfaces in Turkish beech and cedar samples ranged between 2.1-2.5, this value was determined as 6.1 in the Scotch pine sample.

SH-5 coating provided the highest gloss values in all wood species. In particular, it was observed that the surfaces gained a brighter appearance with a gloss value of 12.1 in Turkish beech, 9.6 in Scotch pine and 8.4 in cedar. AS-54 coating increased the gloss values in Turkish beech and cedar, but decreased the gloss in Scotch pine. The HL-31 coating provided a moderate gloss value for Turkish beech and Scotch pine, while it remained at the same value as the uncoated surface in cedar. In conclusion, the SH-5 coating provided the highest gloss values in all wood species and showed that the surface became smoother. AS-54 and HL-31 coatings gave variable results in terms of gloss.

In similar study, polyurethane coating modified with lignin nanoparticles provides UV resistance on wood, while a decrease in gloss was observed over time. Loss of gloss was attributed to oxidative degradation of lignin and changes in surface morphology [42]. The addition of nano-SiO_2 maintained the gloss at a moderate level while improving the mechanical properties. Nano additives at optimum rates provide advantages in terms of both durability and aesthetic appearance [43].

4. CONCLUSION

In this study, the effects of different coatings on the surface properties of Scotch Pine, Cedar, and Turkish beech woods were investigated. Various characterization techniques, including contact angle measurements, gloss analysis, color evaluation, and digital microscope imaging, were employed to examine the coatings' impact on hydrophobicity, aesthetic appearance, and surface morphology. The findings provide valuable insights into the potential of these coatings for improving the performance of wooden materials in various applications.

The contact angle measurements revealed that all coatings significantly enhanced the hydrophobic properties of the wood surfaces compared to the uncoated samples. Among the coatings, SH-5 exhibited the highest contact angle values, indicating superior water repellency. The other coatings, AS-54 and HL-31, also improved the hydrophobicity of the wood surfaces, though to a lesser extent. The difference in contact angles suggests that the chemical composition and interaction of each coating with the wood substrate play a crucial role in determining surface wettability.

The gloss analysis demonstrated that the coatings had varying effects on surface reflectivity. SH-5 coating provided the highest gloss values, particularly in Turkish beech wood, indicating a smoother and more uniform surface. AS-54 also contributed to increased gloss in some wood types, whereas HL-31 had a more moderate effect, with results closer to uncoated surfaces in certain cases. The variation in gloss values across different wood types suggests that the inherent surface roughness and porosity of each species influence the final appearance after coating.

The color measurements indicated noticeable changes in the L (lightness), a (red-green), and b (yellow-blue) values after coating application. Generally, the coatings caused a darkening effect, particularly in SH-5 and HL-31 coatings, which resulted in lower L values. The a and b values also shifted, indicating changes in the hue and saturation of the wood surfaces. AS-54 coating, in contrast, maintained a color appearance closer to the uncoated samples in some cases, which may be preferable for applications requiring minimal color alteration.

Microscopic surface morphology analysis confirmed that all coatings formed a homogeneous layer on the wood surfaces, demonstrating good adhesion and uniform coverage. However, during contact angle measurements, water droplets left stains on the surfaces of all coated samples except SH-5, further supporting its superior hydrophobic performance. These stains were clearly visible in the microscope images, reinforcing the idea that SH-5 provides better protection against moisture absorption.

Overall, the results highlight the effectiveness of different coatings in modifying the surface properties of wood. SH-5 was identified as the most effective coating, offering the highest water repellency, enhanced gloss, and improved surface homogeneity. AS-54 and HL-31 also contributed to better surface properties, though their effects varied depending on the wood type. These findings emphasize the importance of selecting appropriate coatings based on the desired characteristics, ensuring enhanced durability, aesthetic quality, and long-term performance of wooden materials in various applications.

DECLARATION OF ETHICAL STANDARDS

The author(s) of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

AUTHOR'S CONTRIBUTIONS

Abdi ATILGAN: Conducted the preliminary preparation of the wood materials and contributed to the interpretation of the results. Jointly contributed to the writing of the manuscript.

Oğuzhan EVCİN: Prepared the coating solutions, applied them to the surfaces, and carried out the experimental work. Jointly contributed to the writing of the manuscript.

CONFLICT OF INTEREST

There is no conflict of interest in this study.

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