





Communication Glossiness Evaluation of Coated Wood Surfaces as Function of Varnish Type and Exposure to Different Conditions

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Abstract: The objective of this study was to evaluate the glossiness of black alder wood (*Alnus glutinosa* L.) samples coated with two varnish types as a function of exposure to dry heat and artificial aging. The chemical resistance of the coated samples to cold liquids was also evaluated. Based on the findings in this work, it appears that the varnish types and their structural differences influenced the overall glossiness of the coated samples. The UV varnish exhibited higher gloss values than those coated with the water-borne product within the range of silky gloss and silky matte grades. The heat exposure influenced the surface glossiness of the overall gloss values of the samples more than the samples coated with water-borne varnish. The overall gloss values of the samples decreased with the exposure time to artificial aging, resulting in no layer cracks. The cold household liquids left less visible traces on the surfaces and alcohol was found to be the strongest agent. This study could have practical applications in the furniture industry to produce value-added furniture units according to their specific conditions of indoor use.

Keywords: artificial aging; coating; gloss; properties; varnish; black alder wood

1. Introduction

The glossiness of any surface is used to evaluate the quality of a finished product as a result of reflection due to the incident light from different directions [1,2]. High gloss surfaces are in demand in the furniture industry, but matte gloss still has its importance in a specific solid wood furniture market. A reflection structure image of high-gloss composite products was developed as an alternative method to describe the visual human perception of gloss [3]. However, recent studies have shown off the comfortable feelings given by both the coated and uncoated surfaces of wood products [4,5]. A model based on the value generation of wooden furniture has been validated by these qualitative, innovative, and ecological products. These products are used as reliable and environmentally friendly furniture [5,6].

The glossiness and color, apart from the visible wood texture, represent important aesthetic properties that influence the choice of any furniture customer. Several factors including wood species, surface roughness, chemical composition of the varnish, coating system, number of layers, angle of incident light, and the direction of gloss measurement influence the gloss quality of the finished wood product [7–10]. The anisotropic texture of the wood makes the reflection from a surface a complicated process. The variation of different structure patterns can be obtained from the most common lengthwise measurements on radial and tangential directions [11]. The diameters of vessels and tracheids in the earlywood and latewood are not the same because of the annual growth rate.



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Copyright: © 2021 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https:// creativecommons.org/licenses/by/ 4.0/). The roughness of the two areas of an annual ring differs under the same machining conditions and some irregular reflections of the properties appear [11]. The wood grain may raise, twist, and lift during machining, with effects during the finishing step [12,13]. The surface quality influences the glossiness of the wood [8,14]. A certain correlation may exist between the surface gloss and its roughness. Such a correlation is valid when the dominant effect influences the reflection originating from the surface structure of the unit.

Different resin clear coatings could alter the reflection properties depending on the coating thickness [11]. Transparent coatings preserve the natural color of wood and improve its glossiness. However, they reduce stability over time when compared to that of pigmented coatings, which are less affected by the sunlight [15–17]. However, they still maintain their popularity. Different levels of gloss can be achieved as a function of varnish type and its application system [6,9,10]. Alternative ecological products including waterbased and UV varnish are widely used due to their low emissions, rapid application, and good gloss retention. In the case of water-borne coatings, the curing time and penetration are longer because of their lower water absorption [18].

Volatile organic compounds (VOC) regulations are applied to interior coatings as well, in order to reach abrasion and chemical resistance [19]. VOC emissions from indoor materials and finishing products are still current subjects of concern among studies on indoor air quality [20,21]. The acceptable total VOC level in the air for human health ranges from 0.3 to 0.5 mg/m³ concentration [20].

The cost of the UV equipment could be considered high for small companies [10]. In terms of gloss, a UV varnish applied by a roller system produces surfaces with a higher gloss than when applied by spraying. The gloss of water-based, nitrocellulose, and polyurethane varnish has already been studied by several authors [7,22]. Successive layers of coating and polishing could also contribute to a higher gloss. They are applied on furniture parts depending on the surface visibility and exposure during use, and therefore different values of gloss are recorded [10,23]. For beech wood, the gloss level increased by 5–20 gloss units with the increase in varnish layers of the water-based product compared to polyurethane [9].

The direction of viewing or measurement influences the glossiness of a wood surface [11]. The reflection properties of a surface depend on the angle of incident light. There are three standardized measuring angles: 20° , 60° , and 85° . Generally, the 60° geometry is recommended for wooden surfaces, but it provides limited information.

Comparative measurements on the same surface using different measuring angles and gloss correlations between the angles may help to better evaluate the wood surface [8]. The scattering of the incident light strongly depends on the direction of gloss measurement relative to the wood grain; parallel gloss is higher than perpendicular gloss [10,11].

Wood exposed to the outdoors suffers due to the photo-degradation of the lignin and, to some extent, the hemicelluloses [24]. Changes in color and gloss, and also cracks that occur on the surface during weathering, limit the wood's utilization [25]. These changes appeared after a few hours of accelerated exposure or after a few days of natural exposure [26,27]. The lignin content in softwoods ranges from 25-35%, and consists mostly of guaiacyl units, while hardwoods have a lignin content of 15-28%, constituted mainly by guaiacyl and syringyl units [28]. It was shown that hardwoods underwent faster degradation than softwoods. The syringyl structure in hardwoods degraded faster than the guaiacyl structures in softwoods [29]. The natural, accelerated, and simulated weathering tests have proved very useful in the wood protection industry [30].

When used indoors, wooden products are subjected to less intensive UV radiation than when used outdoors [23]. Slow degradation of the coating layer by changes in the surface gloss and color, apart from some fine cracks, are noticed [31]. In a previous study, it was proven that the most relevant color changes of coated beech were generated during the first 100 h of artificial aging [23]. Retarding effects on the surface photo-degradation could be obtained with protective agents against UV radiation. Panek et al. [17] showed that the gloss of exposed surfaces decreased with the exposure time to radiation. The coating resistance to different chemicals has been previously studied for wooden flooring. They are the most exposed elements of an interior, along with some horizontal visible furniture parts [32–36]. To evaluate the chemical resistance of coatings applied to lignocellulosic materials, a rating scale, included in the standards and test procedures, is commonly used [34]. Oils enhance the natural wood appearance, but they produce limited quality in terms of resistance to various chemicals [35]. No major differences in the surface resistance to cold liquids such as coffee, ethanol, red wine, water, or paraffin oil have been observed for oak parquet covered with different coatings [34]. It was found that the resistance to cold liquids depends on the properties of the topcoat used [34].

Currently, there is limited information about the glossiness of varnished alder wood. Therefore, the objective of this study was to evaluate the glossiness of varnished alder wood surfaces when using two varnish types and after their exposure to various test conditions including the dry heat test and artificial aging. The resistance to different cold liquids of the coated surfaces was also tested. The results of this study can provide a better understanding of the properties of the coatings of such wood species, and show its potential for furniture manufacturing.

2. Materials and Methods

In this study, planed specimens of black alder (*Alnus glutinosa* L.) wood, supplied by a local sawmill in Buzau County, Romania, were used. Black alder wood is a native species in Romania, less-utilized but known mostly for its good workability, properties, and pleasant appearance. The average basic density of the samples was $520 \pm 10 \text{ kg/m}^3$, and their moisture content was $8 \pm 1\%$. A total of 29 samples were used for the experiment and they were grouped as presented in Table 1. The samples were conditioned for 7 days in a room with a temperature of 20 ± 2 °C and relative humidity of $50\% \pm 5\%$ before any tests were carried out.

Wood Species	Black Alder					
Dimension of samples (mm)	L = 300; R = 6; T = 95					
Number of samples and their distribution	Total: 29 5 control and 12 samples per each varnish type, and, out of them, 3 per each test and varnish type					
Processing	Planed samples were sanded with 100 and 15 grit size					
Coating System	Spraying					
Varnish Products	A2: 100% UV varnish–2 layers					
variabili i lottacto	B2: water-borne varnish-2 layers					
A light 220 grit san	A light 220 grit sanding between layers					
	Dry heat test					
Tests	Artificial aging					
	Chemical resistance					
Decorative property	Glossiness					

Table 1. Experimental design.

2.1. Surface Preparation of the Samples

The specimens (Figure 1) were subjected to parallel sanding by employing a portable sander (FESTOOL ETS 125, FESTOOL GmbH, Wendlingen, Germany) shown in Figure 2 with the technical data displayed in Table 2. Two types of sandpaper with aluminum oxide grains (FESTOOL Rubin 2) of 100 and 150 grit size were used.



Figure 1. Wood samples.



Figure 2. Festool ETS 125 sander.

			Characteristics			
Power Consumption, W	Eccentric Motion Speed, min ⁻¹	Sanding Stroke, mm	Sanding Pad Diameter, mm	Dust Extraction Connection Diameter, mm	Weight, kg	Drive Type
250	6000-12,000	2.00	125.00	27	1.20	Hand

2.2. Coating of the Samples

The sanded samples were coated by spraying with two types of varnish, namely a UV acrylic varnish (A2) and a water-borne varnish (B2) at a room temperature of 20 °C and 40% RH in two layers. An industrial low-pressure spray gun at a pressure of 0.25 bar and a spread rate of $120 \pm 5 \text{ g/m}^2$ was employed as shown in Figure 3. A light sanding using a foam pad of 220 grit size made of electrocorundum grains (Klingspor Abrasives, Bielsko-Biala, Poland) was applied between the two varnish layers. The varnish parameters are presented in Table 3. UVC-250 × 2-type UV curing equipment (MIKON UV Ltd., Warsaw, Poland) was used to cure the samples coated with the UV varnish. The samples coated with the water-borne varnish were cured at a room temperature of 20 °C and 40% RH. Dry film thicknesses of 90 \pm 5 µm and 30 \pm 5 µm were determined for the UV and water-borne varnishes, respectively [37].



Figure 3. Application with the spray gun.

Table 3. Parameters of the varnish product	ts.
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Varnish Product	VOC-EU (Volatile Organic Compounds), g/L	Density (g/cm ³), 20 °C	Conventional Viscosity (s), 20 °C [38]	Organic Solvents (%)	Solid Content (%)
UV acrylic (A2)	55.2	1.229	42	6.5	93.5
Water-borne (B2)	55.2	1.024	65	5.4	27.9

2.3. Gloss Measurement of the Samples

The gloss of the control and coated samples was determined employing a PICO GLOSS 503 gloss meter (ERICHSEN GmbH, Hemer, Germany) as illustrated in Figure 4. The gloss measurements were conducted at a degree level of 20°, 60°, and 85° geometry, both in parallel and perpendicular to the wood grain. Five measurements per sample were taken for each standardized measuring angle and direction according to the ISO 2813 standard [39]. The method was applied for the samples before and after the dry heat test and artificial aging.



Figure 4. PICO GLOSS 503 gloss meter.

2.4. Dry Heat Test of the Coated Samples

The dry heat test was carried out by employing a device, heated to the temperature of 70 °C, applied to the coated samples for 20 min according to the EN 12722 standard [40]. As the standard device did not fit the sample size, a new one with a smaller diameter of about 70 mm was used (Figure 5).



Figure 5. Hot device (70 °C).

2.5. Artificial Aging of the Coated Samples

The coated samples positioned at an angle of 45° were exposed to intensive ultraviolet light and infrared radiation (UV + IR). The artificial aging test was carried out with a special quartz lamp (VT-800, FAMED Lodz S.A., Lodz, Poland) having radiation energy of 740 W (Figure 6). The radiation was applied from a distance of 40 cm to the samples for 30 min, 1, 4 and 8 h aging time. The temperature of 65 °C at the surface of the coated samples was determined with the help of a temperature detector (DT 8662 Dual Laser Infrared Thermometer, CEM, Shenzhen, China).



Figure 6. VT-800 quartz lamp (UV + IR).

2.6. Chemical Resistance of the Coated Samples

The chemical resistance of the coated surfaces was determined by using four types of liquids, namely water and fat (liquid paraffin) applied for 24 h and alcohol (48%) and coffee for 6 h, according to the EN 12720 standard [41]. Soft filter paper disks of 25 mm diameter were soaked for 30 s in the above mentioned liquids and then placed on the coated samples and each covered with a glass rim (Figure 7). After the exposure time, the glass rims and paper disks were removed and the samples were carefully cleaned with a soft paper towel. The surfaces were evaluated visually under the laboratory light environment according to an assessment scale from 1 to 5 for the varnish structure (1—severe damage, 2—traces with no change, 3—slight traces, 4—slight change, 5—no visible change) [41].



Figure 7. Test of cold liquids.

2.7. Processing of the Data

All data in this study have been processed using the Minitab 17.0 software. The mean values of the gloss have been used to represent the variation for each test. The regression fit equations, along with the gloss correlations and the response optimization, have also been provided.

3. Results and Discussion

3.1. Gloss Evaluation of the Coated Samples

The glossiness for the 20° , 60° , and 85° geometry was determined for the control and coated samples by respecting two measurement directions, parallel and perpendicular to the grain direction. The gloss variations of the control and coated samples are displayed in Figure 8. The varnish type and their structural differences influenced the glossiness of the coated samples [42]. The gloss values of the samples coated with the UV varnish for both directions of measurement were found to be higher than the gloss values obtained when using the water-borne product to varnish the samples. As expected, the UV-cured varnish produced an enhanced coating layer [10]. The coating structure of the UV varnish was more cured due to the influence of the UV energy when compared to the water-based varnish, and this can therefore explain the gloss differences. The direction of the gloss measurement at a 20° angle did not influence the gloss values of the same sample type and varnish, while in the case of the gloss at 60° and 85° , the values from along the grain were found higher than those from across the grain. The parallel gloss value at 60° geometry increased after coating from 2.95 to 34.87 gloss units (GU) in the case of the UV varnish, while the surfaces coated with water-borne varnish reached 27.21 GU. For the 85° geometry the gloss did not show much difference between the two varnishes when considering the same gloss direction. Sonmez et al. [12] reported that the water-borne varnish reduced the glossiness of the coated wood surface. Similar results have been found in a previous study for beech samples [9].

To obtain good interpretations and to give insights into the diversity of the results, it is best to use the correlations of gloss. Such correlations present interest in terms of their practical applications in furniture manufacturing [11]. The matrix plots of such correlations are presented in Figures 9–11. Table 4 also displays the general regression equations for the correlations of gloss. It appears that strong correlations were obtained for the gloss at 20° and 60°, and 60° and 85° (R-sq = 0.83 and R-sq = 0.88, respectively). A moderate correlation between the gloss at 20° and the gloss at 85° (*R*-sq = 0.6) was noticed. These results are also supported by the Pearson coefficients displayed in Table 4 (p-value = 0.000). The good value of correlation presented in Figure 9 could be explained by the incident angles used, which were large enough to be released from the surface microstructure effect. There was very little difference between the gloss readings of the samples for each varnish type and gloss direction, as depicted in Figure 9. It was determined that gloss readings at 20° are practically the same in both directions. The gloss along and across the grain for the UV varnished samples varied over a wide range, corresponding to the silky gloss grade (25–40 GU), while the water-borne varnish produced a perpendicular gloss of silky matte grade (15-25 GU), but silky gloss along the grain (Figures 9 and 11). The gloss

readings perpendicular to the grain changed in a narrower range and they were much lower than the ones parallel to the grain for each varnish type (Figure 11). The literature provides information on the gloss correlations mainly for old oil and wax-treated furniture or flooring with a clear high-gloss resin. An oak-veneered old cabinet having a thin clear coating presented a gloss in the range of a silky matte grade (15–25 GU), while an old Biedermeier cabinet polished with shellac in several layers showed a high gloss grade (70–100 GU) [11].

The response optimization for glossiness as a function of varnish type and gloss direction is displayed in Table 5. As already found before, the UV varnish produced the best gloss value when measured parallel to the wood grain.



Figure 8. Gloss variation of the coated samples as a function of incident angle, measuring direction, and varnish type.



Figure 9. Correlation of gloss at 20° and 60° geometry of the coated samples.



Figure 10. Correlation of gloss at 20° and 85° geometry of the coated samples.



Figure 11. Correlation of gloss at 60° and 85° geometry of the coated samples.

Table 4. Regression fit equations for the correlations of gloss.

No.	Correlation of Gloss	R-sq, %	Equation	Pearson Correlation Coefficient
1	Gloss at 20° and gloss at 60°	83.7	Gloss at $20^{\circ} = 0.4365 + 0.1627$ gloss at 60°	0.915
2	Gloss at 20° and gloss at 85°	60.7	Gloss at 20° = 1.287 + 0.1128 gloss at 85°	0.779
3	Gloss at 60° and gloss at 85°	88.4	Gloss at $60^{\circ} = 3.401 + 0.7658$ gloss at 85°	0.940

Solution	Varnish Type	Gloss Direction	Gloss at 20° Fit	Gloss at 60° Fit	Gloss at 85° Fit	Composite Desirability
1	A2	parallel	5.9	33.4	36.5	0.648015

Table 5. Response Optimization for Gloss at 85° , Gloss at 60° , and Gloss at 20° .

3.2. Gloss Evaluation of the Coated Samples after the Dry Heat Test

The test for resistance to dry heat was carried out to evaluate the effect produced by the contact of the coated surface with a hot object heated to a temperature of 70 $^{\circ}$ C.

The results after the dry heat test showed that the high temperature applied to the coated wood surface influenced the surface glossiness (Figure 12). Overall, very little or no increase in glossiness values between the samples coated with both varnish types and the tested samples at 20° gloss geometry was found. The parallel gloss at 60° and 85° geometry for the UV-coated samples was highly influenced by the dry heat test when compared to water-borne varnish samples; a gloss increase of 15.83% and 43.4% for UV, and 4.79% and 5.21% for water-borne, respectively, were found. In regards to the perpendicular gloss at an 85° angle, the dry heat test produced a gloss increase in the same range for the two varnish types. In another study, the thermal test produced a high gloss in the case of polyurethane resin [43], while a low gloss was produced by powder coating [44].



Figure 12. Gloss variation of the coated samples before and after the dry heat tests as a function of incident angle, measuring direction and varnish type.

3.3. Gloss Evaluation of the Coated Samples after the Artificial Aging

The gloss variation of the coated samples before and after the artificial aging for the two measurement directions is presented in Figure 13. The gloss measurement direction and the exposure time to radiation had almost no influence on the gloss values at 20° geometry. However, there were small differences in glossiness between the two varnish products. The gloss values recorded at 60° and 85° geometry for the coated samples showed a subsequent decrease and increase in a parallel direction with the increase of the exposure time to radiation. The gloss in the perpendicular direction was almost constant for 1 h radiation, and it then decreased for the next 8 h of exposure. Overall, the gloss of the coating layer decreased with the exposure time to radiation, predicting the degradation of the surface layer [17]. In a previous study, Irmouli et al. [31] estimated the surface

degradation by quantifying the cracks at the surface layer. In the present study, no cracks were found on the coating. The findings of this test are similar to the results determined in two past studies [14,42]. The temperature plays an important role in the degradation of the varnish molecules on the surface. It is also stated that the changes on the surface are due not only to changes in the coating layer but also in the wood [14].



Figure 13. Gloss variation of the coated samples before and after the artificial aging.

Kudela and Kubovski [23] found the best color stability after aging in the case of the pre-treated beech samples before coating with a varnish-containing UV filter. Another study showed that the UV-accelerated weathering of the coated beech and spruce wood samples produced significant degradation of the oil-based coating compared to the acrylic coating [17]. Reduced gloss values are usually connected with the surface micro-roughness changes and diverse formulations of the varnishes [45].

3.4. Evaluation of the Coated Samples Resistance to Cold Liquids

The chemical resistance of the coated surfaces was determined by using four types of liquid: paraffin, water, alcohol, and coffee. The cold liquids used in the household left both visible and less visible traces on the tested surfaces. Alcohol was noticed to be the strongest agent because it produced surface deterioration very fast, while coffee, paraffin, and water did not produce much change, as displayed in Table 6. The results of the resistance to chemical tests are similar to other findings in the literature for wood surfaces coated with UV and water-borne varnishes [36]. Even though oils enhanced the wood's natural appearance, they had limited resistance to chemicals [35]. In their study, Pavlic et al. [34] showed that the resistance to cold liquids including coffee, ethanol, red wine, water, and paraffin oil, among others, depended on the properties of the topcoat. In terms of surface chemical resistance, no major differences were found [34]. In previous work, Nejad et al. [32] showed that household chemicals including vegetable oil, ketchup, and mustard increased the gloss of coated oil-heat-treated samples made of maple, beech, and hemlock.

Cold Liquids	Time, h	Varnish Type	Scale 1–5	Description	
Paraffin	24 b	A2 B2	4	Slight change on the varnish layer, only	
Water	27 11	A2 B2	4	visible under reflected light	
Alcohol (48%)	6 h	A2 B2	1	Severe damage on the varnish layer	
Coffee		A2B2	4	Slight change on the varnish layer, only visible under reflected light	

Table 6. Assessment of surface resistance to cold liquids.

4. Conclusions

The present work evaluated the glossiness of alder wood surfaces coated with two varnish types and the effect of their exposure to the specific conditions of dry heat and artificial aging on the gloss. The chemical resistance of the coated surfaces was also assessed. The findings of this work are useful in furniture manufacturing for selecting the best varnish type. The specific conclusions of this study are presented as follows:

- 1. The varnish types and their structural differences influenced the glossiness of the coated samples tested in this study. The samples coated with the UV varnish exhibited higher gloss values than the samples coated with the water-borne product in both gloss directions. The gloss readings across the grain were found lower than those recorded along the grain for each varnish type. The two varnish types produced glossiness in the range of silky gloss and silky matte grades. The incident angles used were large enough to be relieved of the surface microstructure effect, and therefore very good correlations were found for the gloss at 20° and 60°, and 60° and 85°.
- 2. The high temperature applied to the coated wood surface influenced the surface glossiness. The parallel gloss at the 60° and 85° geometry for the UV-coated samples was highly influenced by the dry heat test when compared to the samples coated with the water-borne varnish.
- 3. The overall gloss values of the samples decreased with the exposure time to artificial aging, predicting the degradation of the surface layer. No cracks were noticed on the coating layer. The glossiness in the parallel direction at the same geometry for both varnish types showed a subsequent decrease and increase with the increase of the exposure time to radiation.
- 4. The cold liquids used in the household left both visible and less visible traces on the tested surfaces. Alcohol was found to be the strongest agent because it produced surface deterioration very fast.
- 5. The findings of this study could have practical applications in the furniture industry for producing value-added furniture units according to their specific conditions of indoor use.

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