Print ISBN: 978-93-5547-420-9, eBook ISBN: 978-93-5547-425-4

Selected Coating Properties of Black Alder Wood as a Function of Surface Preparation, Varnish Type, Coating System and Exposure Conditions

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DOI: 10.9734/bpi/rtcams/v5/2305C

ABSTRACT

Solid wood furniture still keeps its popularity on the market. Attributes such as reliability, environment-friendliness, appearance, and value are the main parameters to describe the overall quality of solid wood. Light-coloured species are preferred and black alder is one of them. Due to its workability, properties, and excellent grain orientation, black alder has the potential for furniture manufacturing. In this chapter selected coating properties of black alder as a function of surface preparation, varnish type, coating system and various exposure conditions are presented. The findings of various previous studies presented in this work could have practical applications in the furniture industry for producing value-added furniture units according to their specific conditions.

Keywords: Black alder; coating properties; coating system; sanding; varnish.

1. INTRODUCTION

1.1 Black Alder - Raw Material for Manufacturing Value-Added Furniture Units

The furniture industry has been rapidly developing and diversifying. It strongly leads to the implementation of a certain strategy shift from a traditional business model to a model based on value generation. Such an approach was supported by the competitive advantage of qualitative, innovative, and ecological products that are differently granted when compared to other products [1]. Furniture units manufactured from wood-based materials are commonly used on the market, but solid wood furniture still keeps its popularity. Light coloured species are preferred, but not exclusively. When compared to composites, attributes such as reliability, environment-friendliness, good looks, and value are used to describe solid wood [2]. Black alder (*Alnus glutinosa* L.) is one of the most promising short-rotation species and a major species of the riparian ecosystems in Europe. Besides the species benefits regarding the filtration and purification of waters, riverbank stabilization, black alder has potential for timber production as well [3]. Black alder is a diffuse-porous species, known mostly for its traditional uses. Due to its workability, properties, and appearance, black alder wood can be a suitable material for furniture manufacturing. Overall machining properties including splitting, turning, moulding, carving, boring, nailing, sanding, gluing, staining, finishing are important parameters influencing the effective use of this species [3]. An overview of selected coating properties of black alder wood is to be next evaluated.

1.2 Finishing. General Aspects

Finishing is one of the most utilized surfacing methods applied to wooden products and is intended to protect their surfaces, enhance their overall properties, improve their appearance, and extend the service life of the final products. The impression at first glance influences the furniture customer. Therefore, the aesthetical quality of the furniture is required. The coating of a wood surface involves a

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specific sequence of operations: preparation of the wood pieces which are to be coated, applying of the coating materials and processing of the films after curing to obtain appropriate aesthetics and operational qualities of the finished product. There are transparent coating materials, that leave the wood grain visible and opaque coating materials, which makes it possible to obtain different coloured surfaces, on which the initial grain can no longer be distinguished. Depending on the degree that the wood pores are filled, the transparent coating of the wood can be done in three ways: open-pore finish, semi-open or closed pore finish. The general classification of the materials used within a coating process is presented in Table 1.

Table 1. General classification of the materials used within a coating process [4]

Category of materials	Type of material		Observation and examples
Materials for preparing the piece of wood	Emery paper, corundum, acetone, oxalic acid		For mechanical or chemical cleaning
	Perhydrol, peroxides or other agents		For bleaching
	Stains, dyeing substances		If coloured surfaces are to be obtained
Coating materials	Clear	Transparent primers	Colourless or coloured
	Finishes	Transparent varnish	Glossy or mat; ±coloured
	Opaque finishes	Fluid materials	Primers, stains, putties, enamels, dyes
		Solid materials	Films, synthetic foils
Materials for processing of the coating films after curing	Abrasive paper Polishing liquid Wax Equaliser		

Depending on the size and shape of the coated items, as well as the nature and features of the materials used, coating materials can be applied by means of various techniques, such as curtain coating, spraying, immersion, roller coating, brushing, etc. The coating technology of a wooden piece involves several operations, that are usually carried out by a so-called finishing line.

In most cases, the wooden part is first smoothened and then the primer or the putty, stain, lacquer, enamel or dye are spread. After each coating, a drying time has to be allotted. Usually, air-nozzle tunnels or radiation (UV or IR) dryers are used. After discharge, the coated parts are stored for at least several hours in a dust-free environment with controlled parameters, for conditioning.

2.SURFACE PREPARATION OF THE SAMPLES

2.1 General Aspects of Sanding

Sanding is considered an important process prior to finishing in furniture manufacturing, among others. To implement the optimization of fabrication, two certain criteria should be simultaneously fulfilled, the best surface quality and cutting performance [5,6]. Several factors of the wood-machine—tool interaction influence the surface quality through the machining process during sanding, including properties of species, density, and moisture content, as well as cutting parameters such as pressure, belt speed, feed speed, cutting depth, processing direction, abrasive tools [7-12], cutting force, and power consumption [6,13]. Usually, a sanding process starts with a rough grit size used for rapid and deep sanding and then finer grit sizes are applied for the final finishing phases, to achieve a homogeneous substrate for subsequent coating applications [14]. The wood grain may raise, twist, and lift during the wetting and sanding, which can be reduced with a proper sanding process [15].

2.2 Materials and Methods

For the experiments, flat sawn boards of black alder were planed and then cut at dimensions of 300 mm × 6 mm × 95 mm (Fig. 1a). The samples had an average basic density of 520 kg/m^3 and a moisture content of 8%. Before their surface preparation, the samples were conditioned in a room with a temperature of 20 ± 2°C and relative humidity of 50% ± 5%.

a **b**

Fig. 1. Boards of black alder (a); Timesavers sanding machine (b) (personal photos)

The sanding of the samples was performed under industrial conditions on a wide belt-sander machine presented in Fig. 1b. The machine technical characteristics are described in Table 2.

Table 2. Technical characteristics of the Timesavers sanding machine [1]

Abrasive belt size, mm	Sanding speed, m/s	Contact pressure, bar	Feed speed, m/min
1900x1130	16	4.5	4-20

The specimens were first subjected to calibration with a 60 grit size abrasive. Two final grit sizes were selected, such as 150 and 180. Eight parallel sanding systems were applied by employing combinations of five grit size abrasives manufactured of corundum grains, such as 80, 100, 120, 150 and 180 grit sizes.

The sanding sequences applied are presented in Table 3. The calibration step and each sanding sequence were performed with the same cutting parameters, such as the feed speed of 12 m/min and cutting depth of 0.3 mm.

Table 3. The sanding sequences applied to the samples [1,16]

Final grit size	Sanding Sequence after calibration with 60 grit size			
150	80, 150	100, 150	120, 150	150
180	80, 180	100, 180	120, 180	150, 180

2.3 Surface Roughness of the Samples

The surface roughness of the sanded samples was determined by using a MicroProf FRT instrument (Fig. 2). A range of roughness parameters was calculated, such as the core roughness depth (R_k) as being the most representative indicator of processing roughness and the reduced peak height (R_{pk}) from ISO 13565-2 standard [17], along with the arithmetic mean deviation of the assessed profile (R_a) from ISO 4287 standard [18]. The reduced valley depth (R_{vk}) from R_k family was excluded from the evaluation because the anatomical roughness was not removed [19].

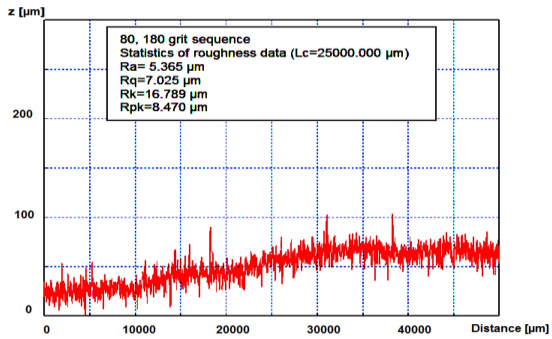
All parameters were measured in the 2D profile, perpendicular to the sanding direction.

The scanning parameters were set as follows:

- evaluation length of 50 mm,
- sampling length of 2.5 mm,
- measuring resolution of 5 µm,
- scanning speed of 750 µm/s,
- a total of 10,000 points were scanned per measurement [19].

A Gaussian filter was automatically applied to all roughness data. The roughness measurements were performed for all samples per final sanding stage before coating. The results of the roughness measurement of the samples are given in Table 4. Overall, the roughness values of the samples decreased gradually for each sanding sequence as the intermediate grit size increased.

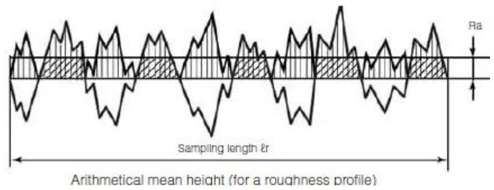
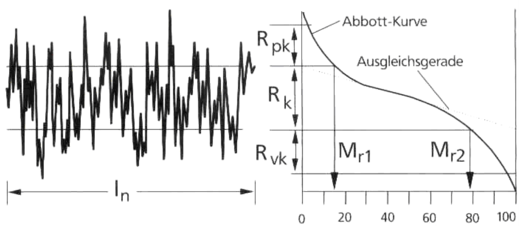
a



b

Fig. 2. MicroProf FRT device (a); a typical roughness profile [16]

Table 4. Roughness values of the sanded surfaces [1, 16]

Sanding sequence after calibration	R_a (µm)	R_k (µm)	R_{pk} (µm)	Display of roughness parameters
80, 150	6.0 (0.4) *	18.1 (1.4)	10.4 (2.8)	R_a - the arithmetic mean deviation
100, 150	6.03 (0.8)	18.6 (2.2)	8.5 (2.3)	
120, 150	6.1 (0.6)	18.4 (1.3)	10.7 (3.3)	
150	6.2 (0.9)	19.4 (2.4)	9.1 (3.5)	R_k family – the Abbot curve
80, 180	7.1 (2.0)	20.8 (5.7)	10.3 (2.7)	
100, 180	5.8 (0.9)	17.3 (2.1)	10.1 (3.1)	
120, 180	5.6 (0.8)	16.5 (2.1)	9.6 (2.9)	
150, 180	5.0 (0.2)	15.5 (0.8)	7.4 (0.9)	

** Numbers in parenthesis are standard deviation values*

Low-density species have more fuzziness on their surfaces compared to the high-density species [19]. Moreover, a tangential wood surface may contain either large or narrow areas of earlywood and latewood [19]. At the same grit size, hardwood species present better quality surfaces compared to softwood species. The wood surface roughness is inversely proportional with wood density, which plays a much more important role than the species anatomy [19]. It was proved that the wood grain orientation is not significant for grit sizes such as 60, 80, and 100, but starts to be significant for grit size over 120 [9]. A crushed wood layer on the surface is produced by sanding with 60 and 80 grit sizes; the wood tissue is forced to enter the cavities and produces their obstruction. As a result, at low feed speeds, the wood cells that remained uncut are blunt and bent, generating a better roughness, while for high feed speeds, some peaks are formed. They are considerably attenuated for finer grit sizes when applied at light feed speed [19]. In practice, such surfaces are subjected to successive sanding steps with 100, 120, 150, or 180 grit size abrasives, depending on their destination and further coating application system [1].

3. COATING OF THE SAMPLES

3.1 Varnish Products

The wood coating industry currently faces the influence of environmental regulations and there is a clear focus on water-borne systems, high solids, UV-cured coating, and powder coating. The VOC (Volatile Organic Compounds) regulations are applied for interior coatings to present abrasion and chemical resistance and to have a high gloss effect [20]. In the case of exterior woodwork, the focus is on durability and protection against humidity, sunlight, and microbiological attack [21–23]. There are several studies on coating with cellulose varnishes, solvent-borne or water-borne, which have been applied to different wood materials [24,25]. These are commonly used mostly for indoor furniture, while for humid areas such as kitchen and bath cabinets vinyl wrap has been used, but water-borne and UV varnish products are expected to be applied instead [20]. Water-based coatings and UV-cured technologies are considered efficient solutions and alternative eco-technologies for wood coating operations [26]. Waterborne coatings offer many benefits, such as the reduction of solvent emissions, lower material costs, non-toxicity, ease of application, and good gloss retention. Sometimes a poor appearance on wood caused by grain raising may limit their application [15]. Styrene/polyester and acrylic-based finishes are mostly used as UV finish layers. They offer considerable advantages over conventional systems, such as low VOC emission, rapid curing, superior wetting, immediate handling, and minimal waste. However, the high costs of raw materials and equipment may represent a problem for small companies [16].

The parameters of the UV varnish (A) and water-borne varnish (B) are presented in Table 5.

Table 5. Parameters of the coating products [1]

Varnish Code	Varnish Type	VOC-EU (Volatile Organic Compounds), g/L	Density (g/cm^3), 20 °C	Conventional Viscosity (*s*), 20 °C [27]	Organic Solvents (%)	Solid Content (%)
A	UV acrylic	55.2	1.229	42	6.5	93.5
B	Water-borne	55.2	1.024	65	5.4	27.9

The samples were subjected to finishing under laboratory conditions using the two varnish products previously mentioned by employing two coating methods (Table 6). The samples were coated in two sequential steps, namely the initial and final layers. A light 220 grit sanding was applied between the coating layers to eliminate fiber swells and to achieve surface smoothness. Dust was removed with a soft-haired brush [1, 16].

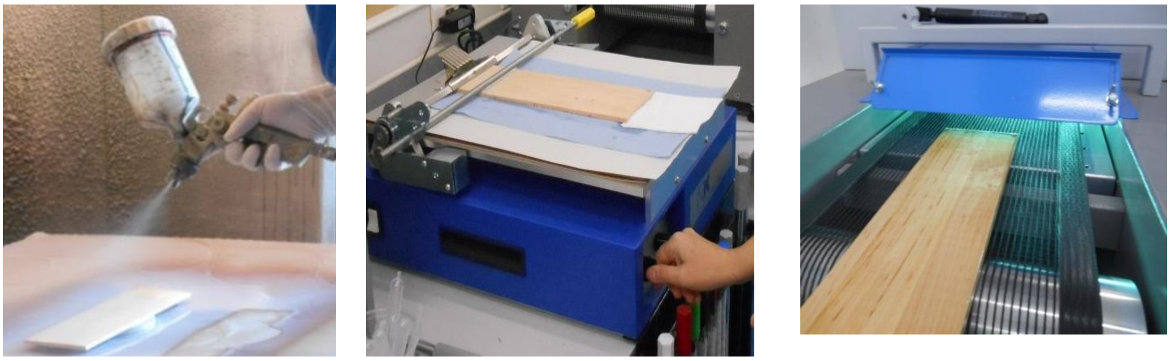
3.2 Coating Systems

An industrial low-pressure spray gun (0.25 bar) at a spread rate of 120 g/m^2 was used for both varnish products (Fig. 3a). A roller machine of RK Control Coater type was exclusively used to apply the 100% UV varnish at a feed speed of 4 m/min (Fig.3b). Two close wound meter bars with wire diameters of 0.3 and 0.08 mm were selected to individually produce 24 µm and 6 µm wet film deposits, respectively [16]. A single roller-coated layer (1A) was also applied to further evaluate and compare the coating performance for a small group of samples. The samples coated by spraying with water-borne varnish were cured at a room temperature of 20°C and 40% RH for both coating steps, while for the samples coated with 100% UV varnish (by spraying and roller) a UV curing unit system of UVC-250x2 type was used (Fig. 3 c). The transporter speed was 20 m/min, and a medium pressure mercury lamp with a high power density of 120W/cm was used [16]. The experimental schedule for coating is displayed in Table 6.

Table 6. Experimental Schedule for Coating [16]

Coating System and Device	Spraying		Roller
	Spray Gun		RK Control Coater
Varnish Product	A	100% UV Varnish	
	B	Water-borne Varnish	
2 Layers - light 220 grit sanding between layers			
Coating system			
Spraying A	Spraying B	Roller 1A	Roller A

There is a balanced relationship between the substrate, coating material, and its application system when used together to achieve the overall performance of a finished product [28]. The coating performance of the samples will be next evaluated through the adhesion strength and surface glossiness as a function of the coating system and varnish type correlated to the substrate preparation by sanding.



a b c

Fig. 3. Spray gun (a); RK control coater (b); UV 250x2 curing unit (c) [1, 16]

4. ADHESION TEST OF THE COATINGS

Surface preparation by processing influences the coating performance and the quality of the final product [28]. A rough surface produces an increase of the mechanical interlocking area between the coating and wood, while the adherence of varnish to the wood surface is reduced by the increase of wood equilibrium moisture content [29,30]. Weaker adhesion under moist conditions can result from the uptake of moisture in the coating, swelling, and hygroscopic stress [31,32]. In beech, cellulose varnish has deeper penetration and enhanced adhesion than softwoods, while waterborne coatings generally have lower wet adhesion than solvent-borne ones [32-34].

4.1 Materials and Methods

The measurements of the coating adherence were performed in ambient conditions (20°C and 40% RH) by the pull-off test with the help of the PosiTest-AT adhesion tester following the ISO 4624 standard [35]. A two-component silane-epoxy resin of Jowat 690.00 type was used to glue small steel dollies with 20 mm diameters on the film surface (Fig. 4). After one week of curing, incisions were made around the dollies to prevent failure damages close to the tested area. The adhesion strength was recorded by the PosiTest device, which involves the vertical withdrawal of the cylinders with a constant detachment speed. Five measurements were taken from each coated sample. The delamination effect was visually assessed for each coated sample.

a **b**

Fig. 4. PosiTest adhesion tester in action (a); dollies glued on the sample (b)[16]

4.2 Evaluation of the Adhesion Test

Table7 presents the results for the coating performance after spraying of the samples, expressed by the adhesion strength as a function of sanding sequence and varnish type. The cohesive failure for alder wood resulted from its distinct wood structure. Its vessels are uniformly spread throughout the wood cross section and the wood structure allows good coating penetration into the wood capillarity system. The grain raising is greater and increases the surface roughness, also affecting its wetting characteristics. It is also a fact that good wetting provides a good film performance [36]. Figure 5 shows that pull-off test failures occurred in both the wood and coating layer. The pull-off test failures of the specimens were found mostly in the wood layer as well as the varnish film. Destructions were found mostly in the substrate, while delamination between the adhesive and varnish was rarely observed. Generally, in terms of adherence, small differences were found when comparing the two varnish products.

Table 7. Average values of adherence as a function of sanding system and varnish type [1]

Sanding sequence after calibration	Varnish Type	Adherence (MPa)
80, 150	A	1.41 (0.02)*
	B	1.20 (0.01)
100, 150	A	1.29 (0.1)
	B	1.24 (0.01)
120, 150	A	1.22 (0.01)
	B	1.22 (0.2)
150	A	1.39 (0.1)
	B	1.43 (0.1)

** Numbers in parentheses are standard deviations values*

Roller-coated samples with 100% UV varnish showed similar values for adhesion strength of approximately 1.30 MPa for the first two sanding programs (Fig. 6). A noticeable difference in adherence of about 23.97% was recorded between this sequence and finer grit sequences such as the 150 and 180 grit sizes. Therefore, finer grit size sequences resulted in lower adhesion strength. One roller layer of UV varnish produced a similar variation [16].

The roller-coated samples with 100% UV varnish presented higher adhesion strength than samples spray-coated with the same product. The roller system can apply a more uniform and consistent coating layer which significantly influenced the quality of the coated surface. This is due to the roller system accuracy when compared to the spray-coating method manually applied. It is fact that a more intense coating led to a better coating adhesion [37]. Water-borne varnish by spraying generated surfaces that exhibited a better adherence than surfaces coated with UV varnish by the same application system. Water-based finishes cure by coalescing, the droplets of finish move closer together and interlock as the water evaporates [25,38]. The application of water-based varnish was found to induce greater surface roughness, therefore the area of physical contact increases and this way the coating adheres better to the wood substrate [15, 39].

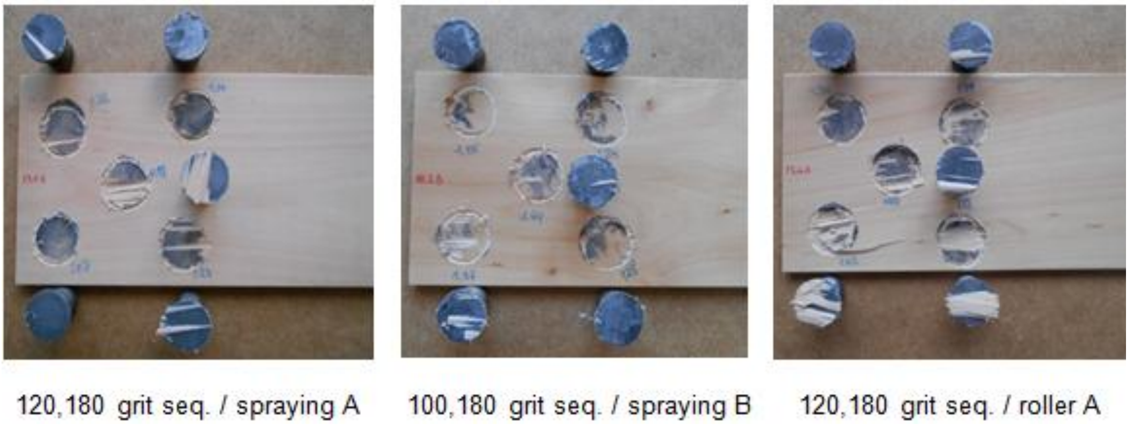


Fig. 5. Delamination of the coated layer as a function of coating system and surface preparation [16]

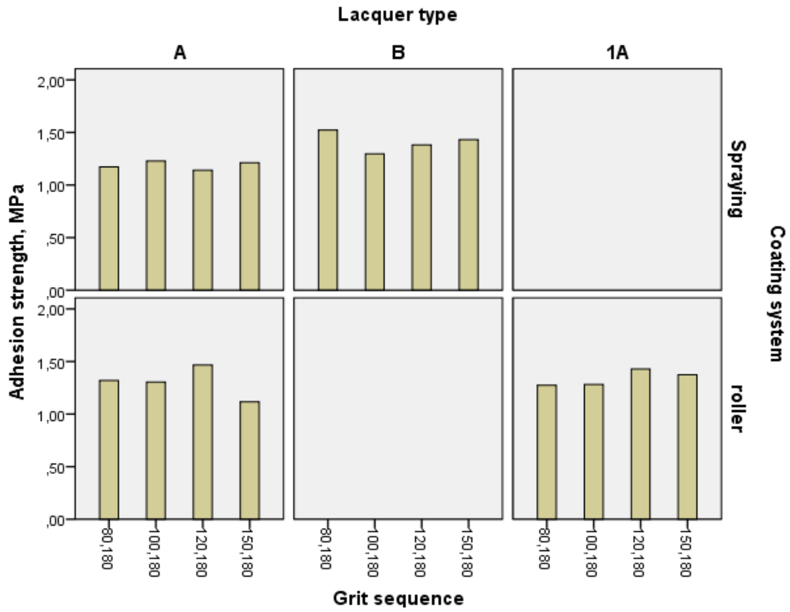


Fig. 6. Variation of adhesion strength as a function of coating system and surface preparation by sanding (180 final grit size) [16]

5. GLOSSINESS OF THE COATED SURFACES

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 [40,41]. High gloss surfaces are in demand in the furniture industry, but matte gloss still has its importance in the 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 [42]. However, recent studies have shown off the comfortable feelings given by both the coated and uncoated surfaces of wood products [43]. 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, the chemical composition of the varnish, coating system, number of layers, angle of the incident light, and the direction of gloss measurement influence the gloss quality of the finished wood product [1,16]. 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 [44]. The diameters of vessels and tracheids in the earlywood and latewood are not the same because of the annual growth rate. The roughness of the two areas of an annual ring differs under the same machining conditions and some irregular reflections of the properties appear [44]. The surface quality influences the glossiness of the wood [45]. A certain correlation may exist between the surface gloss and its roughness along with the grit sequence used for surface preparation [1]. Fig. 7 plots the main effects for the parallel gloss at 60° geometry of the spray-coated alder when using UV and water-borne varnishes.

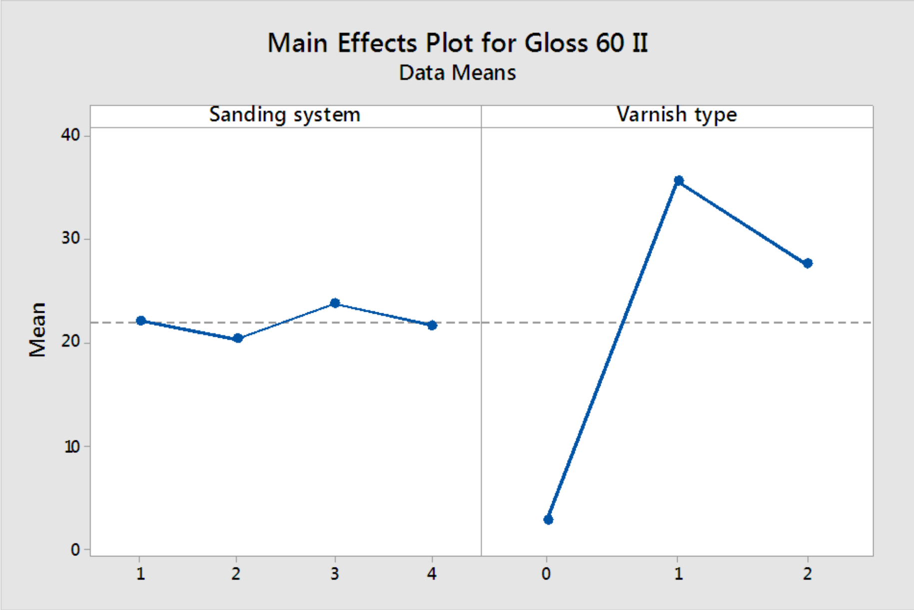


Fig. 7. Main effects plot for parallel gloss at 60° of the spray-coated samples, in which sanding systems are: 1= 60, 80, 150 grit size; 2=60, 100, 120, 150 grit size; 3=60, 120, 150 grit size; 4=60, 150 grit size; and varnish types are: 1=UVvarnish; 2=water-borne varnish

Different resin clear coatings could alter the reflection properties depending on the coating thickness [44]. Transparent coatings preserve the natural color of the 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 [46]. Different levels of gloss can be achieved as a function of varnish type and its application system [1,16]. As it was previously found, a UV varnish (A) applied by a roller system produces surfaces with a higher gloss than when applied by spraying (Fig. 8). As expected, finer grit sizes enhanced the surface glossiness. This trend was noticed for both coating systems when UV varnish was used. When applied by spraying, both varnishes were almost in the same range of glossiness, only some small differences were noticed (Fig. 8). In the case of UV varnish, the coating structure is more cured due to the influence of the UV energy when compared to water-based varnish type, which explains such differences in gloss values [16]. Water-borne varnishes were reported to affect adversely the smoothness of the surface, reducing the gloss of the layer [30]. The gloss of water-based, nitrocellulose, and polyurethane varnish has already been studied [47]. Successive layers of coating and polishing could also contribute to a higher gloss.

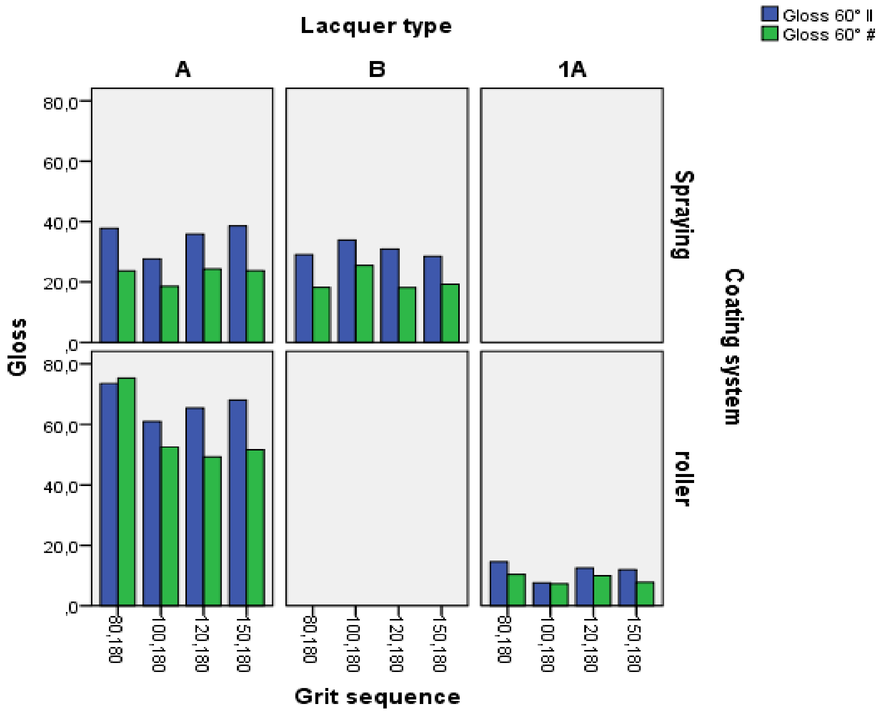


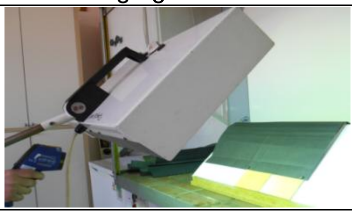
Fig. 8. Variation of surface gloss at 60° as a function of coating system and surface preparation (UV-A and water-borne varnish-B) [16]

The glossiness of spray-coated alder wood surfaces exposed to various conditions (dry heat test and artificial aging) will be next evaluated. Table 8 presents the study experimental design.

5.1 Materials and Methods

Table 8. Experimental design [48]

Wood Species	**Black Alder**	
Dimension of samples (mm) L = 300; R = 6; T = 95		- Density 520 kg/m^3 - Moisture content 8 % - 7 days conditioning before any tests
- Processing: - Planed samples were sanded with 100 and 150 grit size (sandpaper with aluminum oxide grains)		- Parallel sanding by employing a portable sander FESTOOL ETS 125.

Wood Species	**Black Alder**	
Coating system by Spraying		Dry film thicknesses of 90 ± 5 µm and 30 ± 5 µm were determined for the UV and water-borne varnishes, respectively. The two varnish products, coating system and curing have been previously described.
Varnish products and curing	A2: 100% UV varnish –2 layers	
	B2: water-borne varnish –2 layers	
A light 220 grit sanding between layers was applied		
Dry heat test	Artificial aging test	Test of cold liquids
		
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 EN 12722 standard [49]. A smaller device diameter of about 70 mm was used.	The coated samples were exposed at an angle of 45° to intensive ultraviolet light and infrared radiation (UV + IR). A special quartz lamp VT-800 of 740 W was used. The radiation was applied from 40 cm for 30 min, 1, 4 and 8 h aging time. The temperature at the coated surface was 65°C. A temperature detector DT 8662 was employed.	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 [50] have been tested. Visual surface evaluation: 1—severe damage, 2—traces with no change, 3—slight traces, 4—slight change, 5—no visible change [50].

The gloss of the control and coated samples was determined by employing a PICO GLOSS 503 gloss meter as illustrated in Fig. 9. 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 [51]. The method was applied for the samples before and after the dry heat test and artificial aging.

Fig. 9. PICO GLOSS 503 gloss meter [48]

5.2 Gloss Evaluation of the Coated Samples

The direction of viewing or measurement influences the glossiness of a wood surface [44]. 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 [16,44].

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 Fig.10. The varnish type and their structural differences influenced the glossiness of the coated samples [52]. 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 when compared to water-borne varnish due to the influence of UV energy [16]. 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. [30] 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 [53].

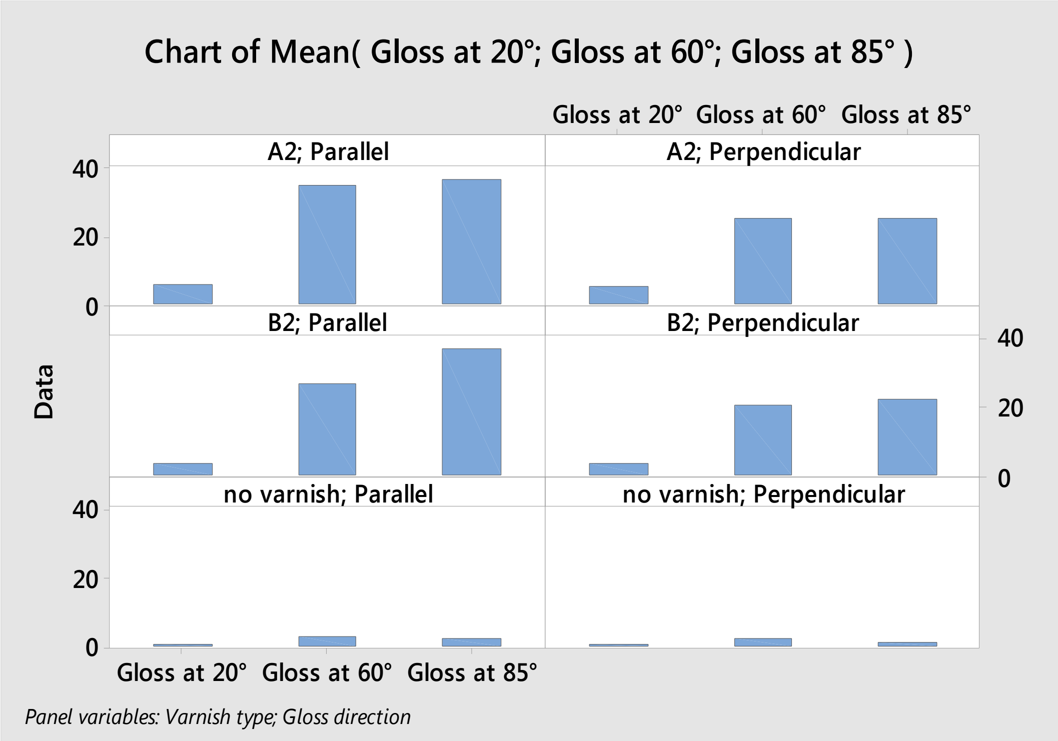


Fig. 10. Gloss variation of the coated samples as a function of incident angle, measuring direction, and varnish type [48]

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 [44]. The matrix plots of such correlations are presented in Figs. 11-13.

Table 9 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°. 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. The good correlation 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 Fig. 11. It was determined that gloss readings at 20° are practically the same in both directions [48]. 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 (Figs. 11 and 13). 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 [48]. 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) [44].

The response optimization for glossiness as a function of varnish type and gloss direction is displayed in Table 10. As already found before, the UV varnish produced the best gloss value when measured parallel to the wood grain.

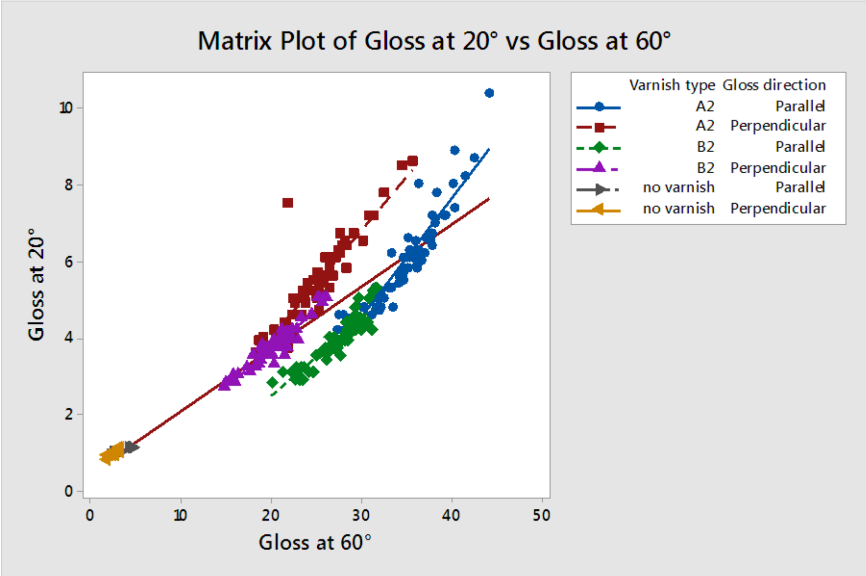


Fig. 11. Correlation of gloss at 20° and 60° geometry of the coated samples [48]

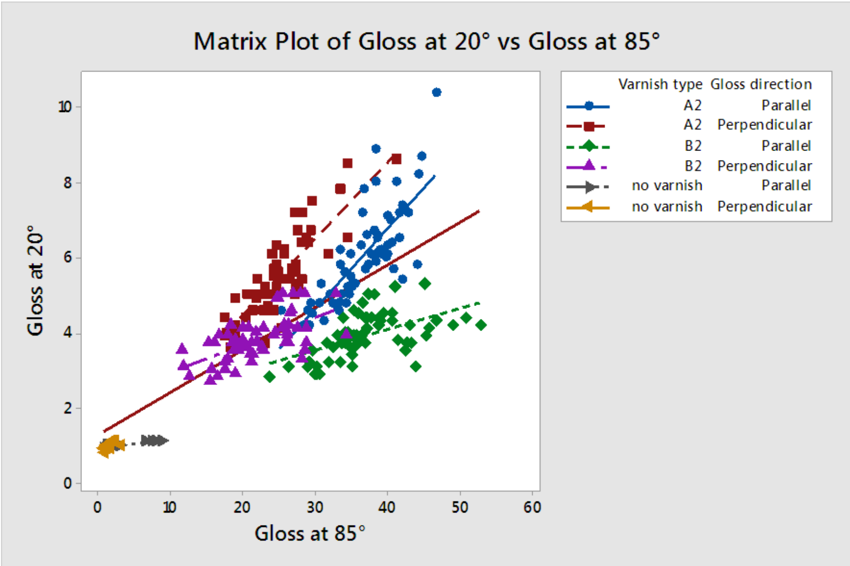


Fig. 12. Correlation of gloss at 20° and 85° geometry of the coated samples [48]

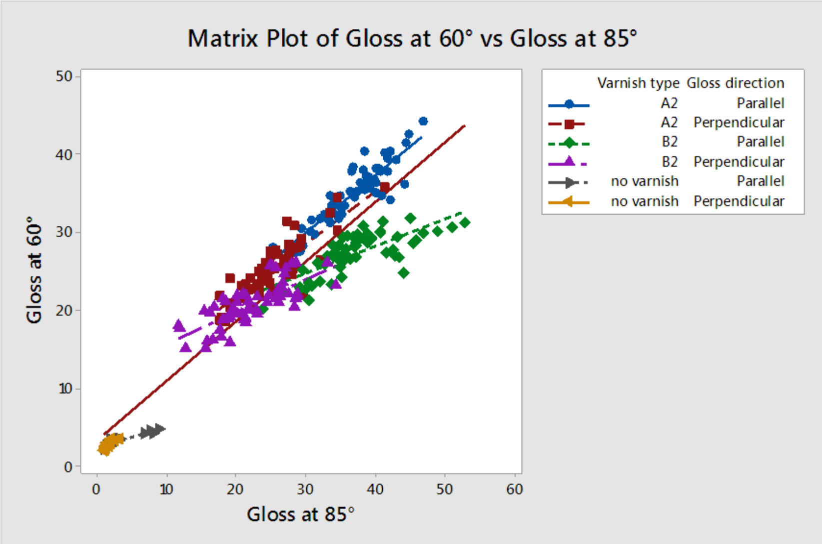


Fig. 13. Correlation of gloss at 60° and 85° geometry of the coated samples [48]

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

Resistance of the samples to 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°C. The results after the dry heat test showed that the high temperature applied to the coated wood surface influenced the surface glossiness (Fig. 14). 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. 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. The thermal test produced a high gloss in the case of polyurethane resin [54], while a low gloss was produced by powder coating [55].

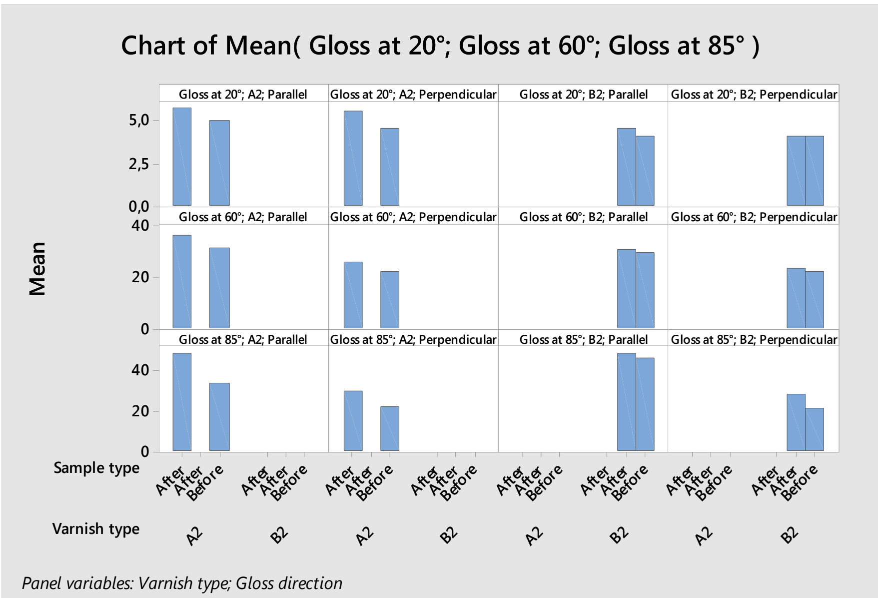


Fig. 14. Gloss variation of the coated samples before and after the dry heat tests as a function of incident angle, measuring direction and varnish type [48]

Table 9. Regression fit equations for the correlations of gloss [48]

No.	Correlation of Gloss	*R*-sq, %	Equation	Pearson Correlation Coefficient
1	Gloss at 20° and gloss at 60°	83.7	Gloss at 20° = 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° = 3.401 + 0.7658 gloss at 85°	0.940

Table 10. Response Optimization for Gloss at 85°, Gloss at 60°, and Gloss at 20° [48]

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 11. Assessment of surface resistance to cold liquids [48]

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

5.4 Gloss Evaluation of the Coated Samples after the Artificial Aging

Wood exposed to the outdoors would degrade due to the photo-degradation of the lignin and, to some extent, the hemicelluloses [56]. Changes in color and gloss, and also cracks that occur on the surface during weathering, limit the wood's utilization [57]. These changes appeared after a few hours of accelerated exposure or after a few days of natural exposure [58,59]. 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 [60]. It was shown that hardwoods underwent faster degradation than softwoods. The syringyl structure in hardwoods degraded faster than the guaiacyl structures in softwoods [61]. The natural, accelerated, and simulated weathering tests have been proved very useful in the wood protection industry [62]. When used indoors, wooden products are subjected to less intensive UV radiation than when used outdoors [63]. Slow degradation of the coating layer by changes in the surface gloss and color, apart from some fine cracks, is noticed [64]. In a previous study, it was proven that the most relevant color changes of coated beech were generated during the first 100h of artificial aging [63]. Retarding effects on the surface photo-degradation could be obtained with protective agents against UV radiation. Panek et al. [65] showed that the gloss of exposed surfaces decreased with the exposure time to radiation. The gloss variation of the coated samples before and after the artificial aging for the two measurement directions is presented in Fig. 15. 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 [48, 65]. In a previous study, Irmouli et al. [64] 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 [33,52]. 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 [33]. Kudela and Kubovski [63] 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 [65]. Reduced gloss values are usually connected with the surface micro-roughness changes and diverse formulations of the varnishes [66].

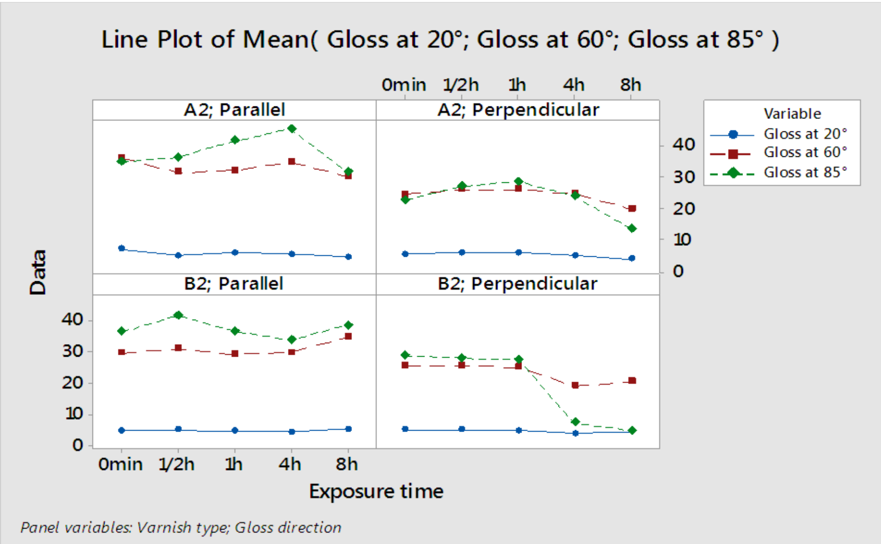


Fig. 15. Gloss variation of the coated samples before and after artificial aging [48]

5.5 Evaluation of the Coated Samples Resistance to Cold Liquids

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 [67-69]. To evaluate the chemical resistance of coatings applied to lignocellulosic materials, a rating scale, included in the standards and test procedures, is commonly used [68]. Oils enhance the natural wood appearance, but they produce limited quality in terms of resistance to various chemicals [69]. 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 [68]. It was found that the resistance to cold liquids depends on the properties of the topcoat used [68].

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 11. 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. In their study, Pavlic et al. [68] 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 [68]. In previous work, Nejad et al. [67] 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.

6. CONCLUSIONS

1. The results of this study showed a balanced relationship between substrate preparation, coating material, and its application system. Any increase in grit size for the sanding step gradually reduced the surface roughness, which further influenced the overall coating performance[16, 70, 71].
2. In terms of adherence, roller-coated samples with UV varnish presented higher adhesion strength than samples spray-coated with the same product. Water-borne varnish by spraying generated surfaces that exhibited a better adherence than surfaces coated with UV varnish by the same application system [16].
3. The varnish types and their structural differences influenced the glossiness of the coated samples. Generally, it was noticed that finer grit sizes enhanced surface glossiness. The roller system of UV varnish generated surfaces with higher glossiness than samples coated by spraying of the same product. 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 [1, 16, 48].
4. 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. 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 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 [48].
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.

ACKNOWLEDGEMENTS

We would like to thank the Poznan University of Life Sciences and Remmers Company in Poland for the support offered to perform this research.

COMPETING INTERESTS

Author has declared that no competing interests exist.

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Coatings, 11: 558, 2021.