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Gloss of Varnished MDF Panels Veneered with Sanded and Thermally Compressed Veneer

Pavlo Bekhta [1,*], Barbara Lis [2], Tomasz Krystofiak [2,*], Maciej Tokarczyk [2] and Nataliya Bekhta [3]

[1] Department of Wood-Based Composites, Cellulose and Paper, Ukrainian National Forestry University, 79057 Lviv, Ukraine
[2] Department of Wood Science and Thermal Techniques, Poznań University of Life Sciences, 60-627 Poznań, Poland; barbara.lis@up.poznan.pl (B.L.); maciej.tokarczyk@up.poznan.pl (M.T.)
[3] Department of Design, Ukrainian National Forestry University, 79057 Lviv, Ukraine; n.bekhta@nltu.edu.ua
* Correspondence: bekhta@nltu.edu.ua (P.B.); tomasz.krystofiak@up.poznan.pl (T.K.)

Abstract: The objective of this study was to investigate the gloss of different types of commercially manufactured varnish systems, including water-based (WB), polyurethane (PUR) and UV-cured (UV), applied on veneered MDF panels with sanded and thermally densified alder and birch wood veneers. The varnishes were applied at various numbers of layers on veneered panels. The gloss was measured at three angles of incident light: 20°, 60° and 85°. Statistical analysis showed that the type of varnish, the number of layers, the pre-treatment process, the wood species and direction of wood fibers significantly affect gloss of the coatings of veneered MDF panels. The type of varnish had a dominant effect on gloss. The highest gloss values were measured for the UV-varnished surface, and the lowest for WB- and PUR-varnished surfaces. Gloss was enhanced with an increase in the number of layers. Birch veneer provided higher gloss values compared to alder veneer. The gloss values measured along the wood fibers were higher than those measured across the fibers. No significant differences were found between the coatings created on sanded and thermally densified veneers for the average gloss values measured along the fibers at angles 60° and 85°. This study could have practical applications for producing value-added furniture elements using low-value wood species pre-treated by thermal compression.

Keywords: sanding; thermal compression; waterborne varnish; polyurethane varnish; UV hardened varnish; gloss

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1. Introduction

One of the main parameters that influence the final decision of the consumer is the aesthetic and decorative properties of wood. Gloss, just like color, plays a crucial role in the appearance of various materials and is an important consumer feature. Gloss is a very important characteristic of wood, especially when it will be used for furniture production. The coatings (in particular, transparent coatings) can add beauty by enhancing the aesthetic and decorative properties of wood and improving its gloss unit [1]. The challenge is to achieve the optimal gloss required by the customer by manipulating the components and settings in the varnish application process [2].

Varnish products create coatings with different gloss which is determined by the chemical composition of the varnish coatings [3], wooden substrate [4], wood species [5,6], surface roughness [7,8], the type of varnishes [3,5,9], the number of layers [3], application method [9,10], thermal aging [11], humidity [6], moisture content of wood [11,12], substrate preparation [3,4,8] and the method of wood treatment [5,13–17].

Sanding is the most common method for wood surface machining before varnishing, which ensures sufficient smoothness before application of varnish materials [1,7,18]. Previous studies [13,14,19,20] have shown that higher surface roughness contributes to lowering the gloss of the coatings. Salca et al. [9], using different surface sanding programs for wood substrate preparation, showed that the use of sandpaper with finer grain increases the gloss of the surface. The type of varnish and method of application significantly affect the gloss of coatings. The UV-varnished samples demonstrated higher gloss than water-borne samples [21]. The method of application also has a significant impact on the gloss obtained. The same varnish applied with rollers provided a higher surface gloss than when applied by spraying [9]. In some studies, it was found that time of aging had a negative effect on the gloss [22], which is reduced over time regardless of the type of varnish used [11,21]. Gloss parallel to the wood fibers' direction was much higher than in the perpendicular direction for unaged and aged samples [23]. It was also shown [3] that the method for wood surface machining (sanding, milling and pressing) before finishing strongly influenced the gloss of the surface. The polyurethane and shellac surface coats showed reductions in gloss after exposure to ultraviolet light [24]. Results showed that gloss increased on wood samples treated with cellulose lacquer and synthetic varnish, whereas gloss decreased for wood samples treated with polyurethane varnish and water-based varnish, depending on heating temperature and time [5].

The direction of measurement affects the gloss of the wood surface [13]. There are three standardized measurement angles: 20°, 60° and 85° [25]. Generally, the 60° geometry is recommended for wooden surfaces, but it provides limited information. However, as we have demonstrated in previous work [13], the comparative measurements on the same surface using different measuring angles and the correlation of gloss between the angles can help to better estimate the wood surface.

Several authors, studying the influence of thermal and thermo-mechanical modification on the gloss, showed that heat-treated wood of various species after finishing with varnish has a higher gloss than non-treated wood [5,13,21,26]. On the contrary, several authors [15,27] reported that the gloss measured along and across the wood fibers decreases with the intensity of heat treatment.

The valuable wood species are most often used as a material for veneering of wood-based panels. However, the resources of these species are sharply depleted and have become more expensive. Therefore, different modification methods, including thermal, thermo-mechanical and thermo-hygro-mechanical treatments, have become widespread when using less valuable wood species in order to improve their properties [28–30]. These modification methods are eco-friendly without the use of any toxic chemicals.

The surface of the wood is aesthetically attractive in itself. Additionally, thermal compression gives wood an attractive darker color with clearly distinct features of its texture. Our previous studies [13,31] showed that thermal compression improves the aesthetic properties (color and gloss) of the wood surface, making less valuable wood species closer to or better in decorative properties than valuable wood species. In addition, after thermal compression, the sanding of the surface of densified wood before finishing is no longer required due to its smoothness and lower roughness [8,14].

In the process of manufacturing furniture elements, it is quite common to use medium-density fiberboard (MDF). Previous studies have demonstrated the possibility of veneering MDF boards with thermally densified veneer, thus obtaining a varnish coating with high aesthetic properties [14,32]. Currently, information on the gloss of the varnish coating on wood materials veneered with thermally densified veneer is limited [14]. Thus, the main objective of this work was to evaluate the gloss of three different varnish systems (WB, PUR and UV) applied on MDF panel veneered with sanded and thermally compressed wood veneer of black alder and birch at various numbers of varnish layers. Sanding was used as a conventional surface pre-treatment process for the comparison.

The results of this study can give better understanding of the aesthetic properties of varnish coatings of thermally densified veneers of such wood species and show their potential for veneering MDF boards for furniture production.

2. Materials and Methods

This study is a part of a large research project aimed at comparing and evaluating two different pre-treatment processes of wooden surfaces prior to varnishing by sanding or thermal compression in terms of the impact on the color characteristics and adhesion properties of the varnished surface. Recently, two articles related to color and surface roughness of varnished surfaces have been published [32,33].

2.1. Materials, the Pre-Treatment Process of the Wood Veneer, the Surface Varnishing Process and Statistical Analysis

The content of this paragraph is described with sufficient detail in our previous articles [32,33].

2.2. Gloss Measurement

The surface gloss of natural alder and birch veneer was determined after thermal compression and sanding as well as after varnishing with various varnish systems. The surface gloss measurements of all samples were recorded on the surface of veneer samples before and after relevant treatment using a PICO GLOSS 503 photoelectric apparatus (ERICHSEN GmbH & Co. KG, Hemer, Germany) in accordance with the DIN 67530:1982 and ISO 2813:1994 standards [34,35]. On each sample, five measurements were made with three measurement geometries: at 20°, 60° and 85° angles of incident light, five along (‖) and five perpendicular (⊥) to the wood fibers.

3. Results

3.1. Statistical Analysis

The results of ANOVA analysis used to analyze the impact of different factors on the gloss of varnished surfaces are summarized in Table 1. As follows from the analysis, the surface gloss was significantly influenced by the thoroughly investigated variables and their interactions. However, it should be noted that the significance of this effect is different for the values of gloss measured at various angles of light incidence. The type of varnish, then the number of varnish layers, their interaction, the wood species and the method of surface preparation have the strongest effect on the gloss in descending order. The type of varnish has a dominant effect on gloss (Table 1). Thus, the gloss is mainly provided by chemical composition of the coating. This statement is in accordance with the findings of Slabejová et al. [3], who reported that gloss is mainly given by chemical composition of the coating. However, the impact of chemical composition of the coating on its gloss may be different depending on the specific combination of wood species and varnishes. As can be seen from Table 1, the effect of interaction between wood species and type of varnish on the gloss measured at 20° and 60° was significant ($p \leq 0.05$). Figures 1 and 2 show graphical interpretation of the influence of direction of wood fibers, varnish type, number of varnish layers and method of pre-treatment on the gloss values of alder and birch varnished surfaces along and across the fibers.

Table 1. ANOVA of surface gloss for varnished samples.

Source of Variation	*F* Value					
	Gloss					
	20°(‖)	60°(‖)	85°(‖)	20°(⊥)	60°(⊥)	85°(⊥)
Wood species (WS)	22.800 *	21.537 *	14.541 *	20.912 *	12.892 *	0.867 **
Varnish (V)	1618.910 *	1821.280 *	2010.086 *	2396.335 *	2938.813 *	2204.702 *
Layers (L)	256.569 *	166.933 *	95.832 *	293.030 *	160.771 *	25.093 *
Pre-treatment (PT)	2.170 **	8.888 *	24.494 *	6.821 *	5.237 *	3.346 *
WS × V	12.279 *	7.377 *	0.457 **	9.756 *	6.616 *	0.751 **
WS × L	3.886 *	0.917 **	1.448 **	4.777 *	1.079 **	0.923 **
WS × PT	5.746 *	2.311 *	0.196 **	11.588 *	2.674 **	0.376 **
V × L	232.626 *	83.505 *	17.739 *	266.427 *	89.287 *	10.973 *
V × PT	2.298 **	18.074 *	30.552 *	4.597 *	11.734 *	10.146 *
L × PT	2.973 *	2.415 *	1.602 **	0.600 **	1.764 **	3.134 *
WS × V × L	3.015 *	0.728 **	0.640 **	3.932 *	0.426 **	0.600 **
WS × V × PT	8.815 *	5.419 *	2.109 **	14.459 *	3.797 *	0.658 **
WS × L × PT	0.359 **	1.569 **	2.374 **	2.762	0.315 **	1.433 **
V × L × PT	3.112 *	2.869 *	4.378 *	1.302 **	3.671 *	2.129 *
WS × V × L × PT	0.355 **	1.295 **	2.002 *	3.395 *	0.545 **	0.489 **

*: Significant ($p \leq 0.05$); **: non-significant; *F* value—the Fisher's criterion.

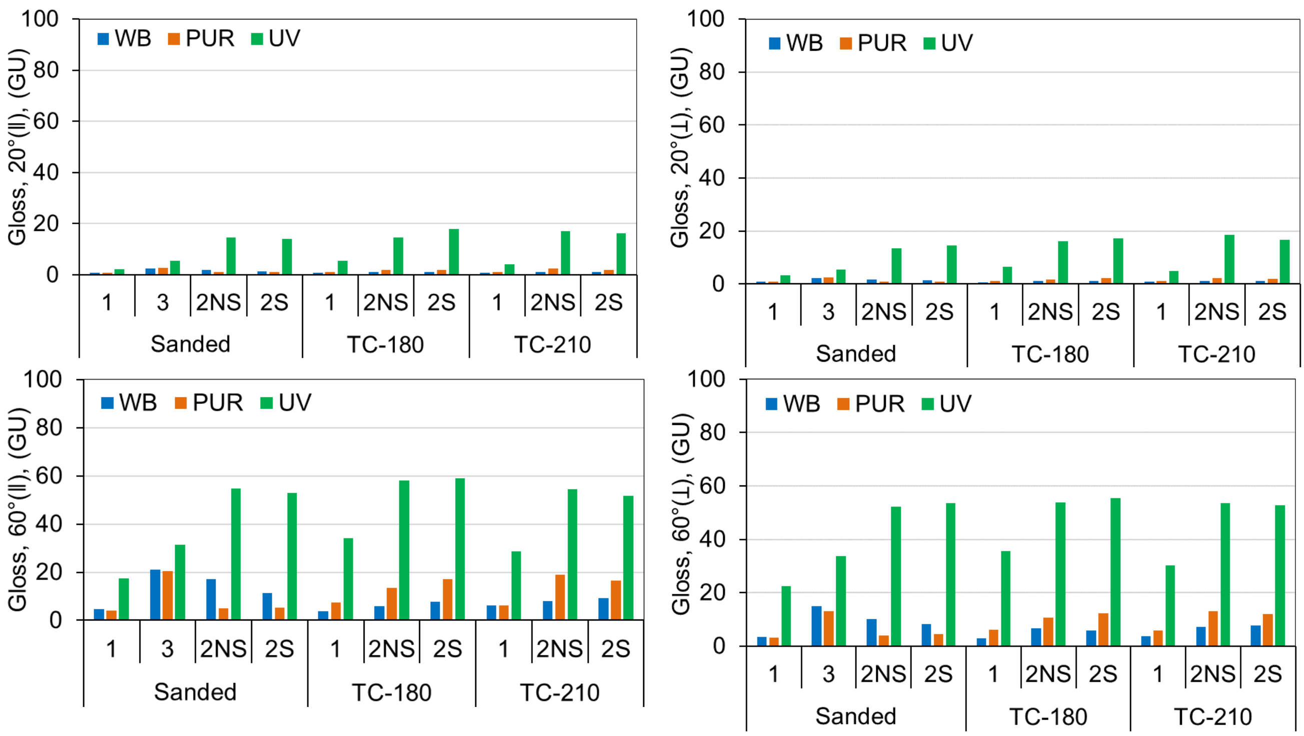

Figure 1. *Cont.*

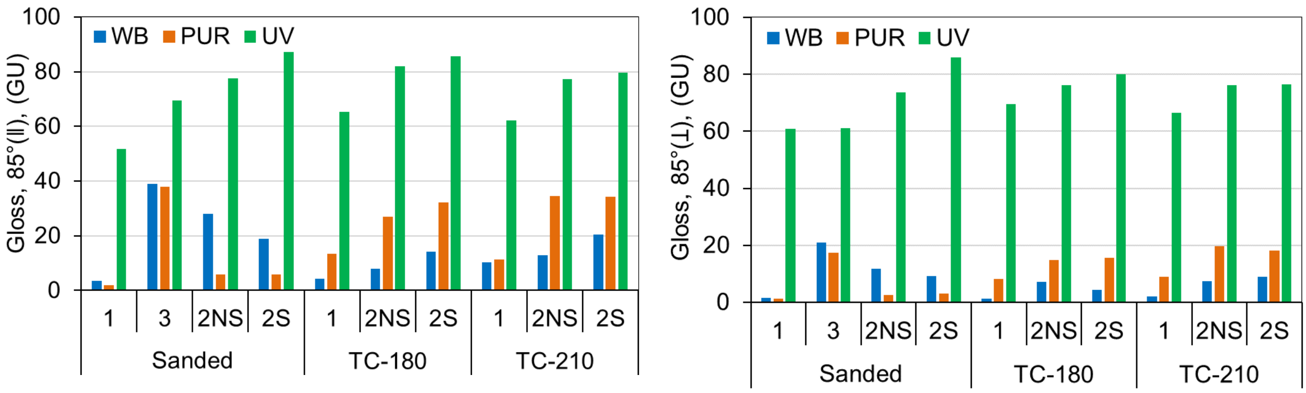

Figure 1. Impact of varnish type, number of varnish layers and method of pre-treatment on the gloss values of alder varnished surfaces along and across the fibers; (WB—water-based varnish, PUR—polyurethane varnish, UV—UV-cured varnish).

Figure 2. Impact of varnish type, number of varnish layers and method of pre-treatment on the gloss values of birch varnished surfaces along and across the fibers.

3.2. Effect of Wood Species and Direction of the Wood Fibers on the Surface Gloss of Varnished Samples

The wood species significantly affects the gloss of the varnished surface (Table 1). WB-, PUR- and UV-varnished surfaces were characterized by 1.15–1.59 times, 1.09–1.26 times and 1.04–1.30 times, respectively, higher gloss values for birch veneer than similar varnished surfaces for alder veneer (Figure 3). In our previous study, it was shown that birch veneer had higher gloss values compared to alder veneer due to thermal compression [13]. In addition, it should be noted that a greater difference in gloss values is observed for the WB-varnished surface using a thermally densified veneer than with the use of a sanded veneer. Whereas for PUR- and UV-varnished surfaces, a greater difference in gloss values is observed for sanded veneer. Thus, surface preparation by thermal compression may be an advantage over sanding, as alder and birch surfaces are homogenized and practically do not differ in gloss values in the case of PUR and UV varnishes.

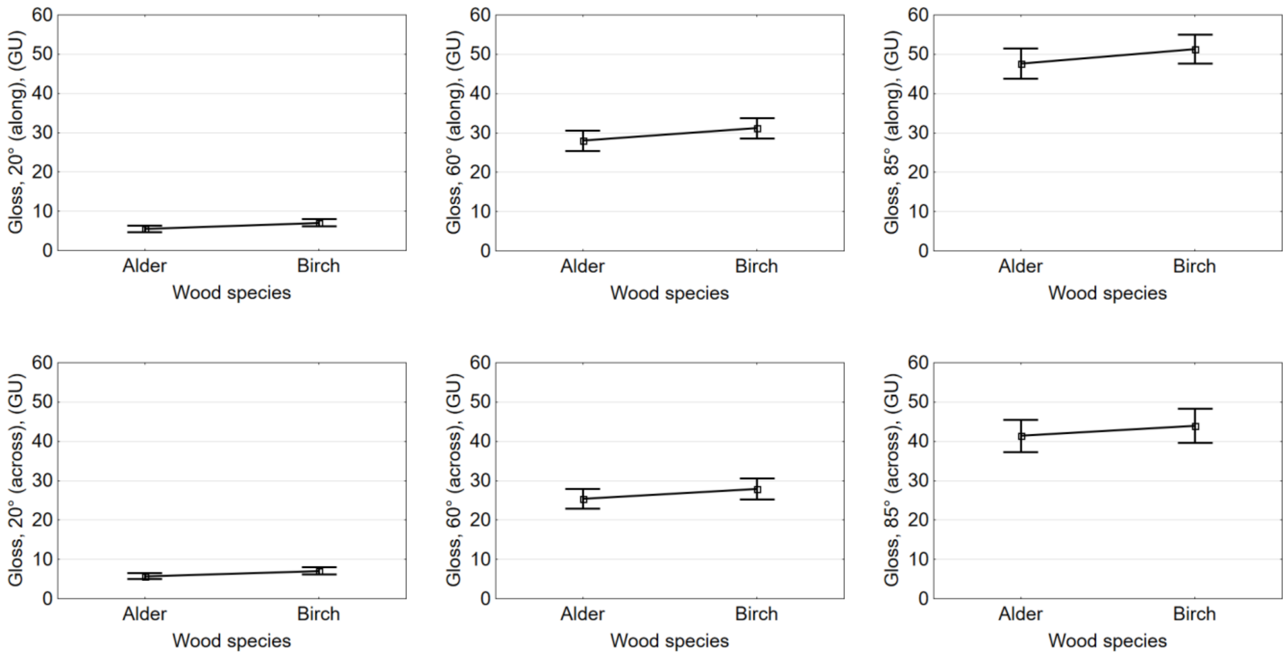

Figure 3. Main effects plot for mean gloss for different wood species for each measurement angle.

The direction of the wood fibers also significantly affects the gloss values. It was found that both wood species are characterized by the fact that the gloss values measured along the wood fibers are higher than the gloss values measured across the wood fibers (Figures 1 and 2). This trend is typical for WB- and PUR-varnished surfaces using both sanded and thermally densified veneers. In particular, the gloss values along the fibers for the WB-varnished surface using the sanded veneer are on average 1.58 and 1.83 times higher than across the fibers, respectively, for alder and birch veneer. For the WB-varnished surface using a thermally densified veneer, the gloss values along the fibers are on average 1.61–1.79 and 1.56–2.10 times higher than across the fibers, respectively, for alder and birch veneer. The gloss values along the fibers for the PUR-varnished surface using a sanded veneer are on average 1.47 and 1.39 times higher than across the fibers, respectively, for alder and birch veneer. For the PUR-varnished surface using a thermally densified veneer, the gloss values along the fibers are on average 1.31–1.37 and 1.49–1.50 times higher than across the fibers, respectively, for alder and birch veneer. The gloss values along and across the wood fibers for UV-varnished surfaces using both sanded and thermally densified veneers are virtually indistinguishable. The difference between the gloss values for these directions is within the measurement error.

It was established that the direction of the fibers has a considerably greater effect on gloss for the larger angles (60° and 85°) than for the angle 20°. The reasons for this phenomenon are described in our previous articles [13,14] and are explained by the strong influence of roughness on the distribution of the light beam, its scattering and reflection.

The higher gloss values along the fibers could be explained by the anatomical structure and irregularities on the surface of wood veneers [14]. As was demonstrated by some authors [35], for coatings of veneered MDF panels with sanded and thermally densified veneers, the roughness values measured across the fibers are several times higher than those measured along the fibers. As was shown in the previous research studies [13,14], the surface roughness more significantly affects scattering of light when measuring gloss across the fibers. This leads to greater light scattering, thus increasing the diffuse component. Some other authors [3], studying the aesthetic property of transparent coatings on beech wood surface, also found that surfaces sanded across the wood fiber had reduced gloss in comparison with surfaces sanded along the wood fiber.

3.3. Effect of Type of Varnish and Number of Varnish Layers on the Surface Gloss of Varnished Samples

Type of varnish, number of varnish layers and their interaction strongly influence the gloss of the varnished surface (Table 1). The lowest gloss values for all light incidence angles were measured for WB- and PUR-varnished surfaces, and the highest were measured for the UV-varnished surface (Figure 4). This applies to the gloss values along and across the wood fibers for alder and birch veneer. The average gloss values of the UV-varnished surface are 9.2 and 7.7, 4.8 and 4.1, 4.2 and 3.3, 10.1 and 7.9, 6.7 and 5.5, and 10.5 and 6.2 times higher than the gloss values of WB- and PUR-varnished surfaces, for light incidence angles 20°(‖), 60°(‖), 85°(‖), 20°(⊥), 60°(⊥) and 85°(⊥), respectively. One of the reasons for such a great difference in gloss values between UV and WB varnishes could be that UV-varnished and WB-varnished surfaces are characterized by the lowest and highest surface roughness, respectively [33]. It is well-known that higher surface roughness contributes to lowering the gloss of the coatings. Moreover, the high gloss of UV varnish could be related to its ability to penetrate deeply into the wood substrate [6]. Salca et al. [21] also recorded higher gloss values for UV-coated samples than for WB-coated samples. The authors explained this difference in gloss values by the structure of the UV-varnished coating, which is more cured due to the influence of UV energy when compared to WB varnish.

In another study, the gloss increased by 5–20 units with the increase in the number of layers of the water-based product compared to polyurethane [3]. These results are in accordance with the findings of some of the earliest experiments conducted [11,12,17]. Pelit et al. [17] indicated that differences in the structure of the varnishes and the methods of their application could influence the gloss. WB varnishes were reported to adversely affect the smoothness of the surface, reducing the gloss [11,12]. In another study [9], WB and UV varnishes applied by spraying were almost in the same range of gloss. On the contrary, some other authors [27] reported that the coating does not affect the gloss.

The lowest gloss values for both investigated wood species along and across the fibers were observed for surfaces covered with one layer of varnish, and the highest were observed for surfaces covered with two layers of varnish with intermediate sanding (2S) (Figure 5). It should be noted that the surfaces covered with 2S and 2NS layers do not differ significantly ($p > 0.05$). The average gloss values for surfaces covered with 2S layers of varnish are 3.5, 2.1, 1.5, 3.1, 2.0 and 1.5 times higher than the gloss values for surfaces covered with one layer of varnish, for angles of incidence light 20°(‖), 60°(‖), 85°(‖), 20°(⊥), 60°(⊥) and 85°(⊥), respectively. It is well-known that the surface roughness of the wooden substrate can affect the value of gloss; larger irregularities reduce the gloss. In a coating with one layer of varnish, its thickness is negligible; therefore, the effect of surface roughness will be more noticeable [13,14]. In the previous work [33], it was also found that roughness decreases with the number of layers in the coating. The highest values of roughness parameters were observed for surfaces with one and 2NS varnish layers, while the lowest roughness was shown by surfaces with three and 2S varnish layers.

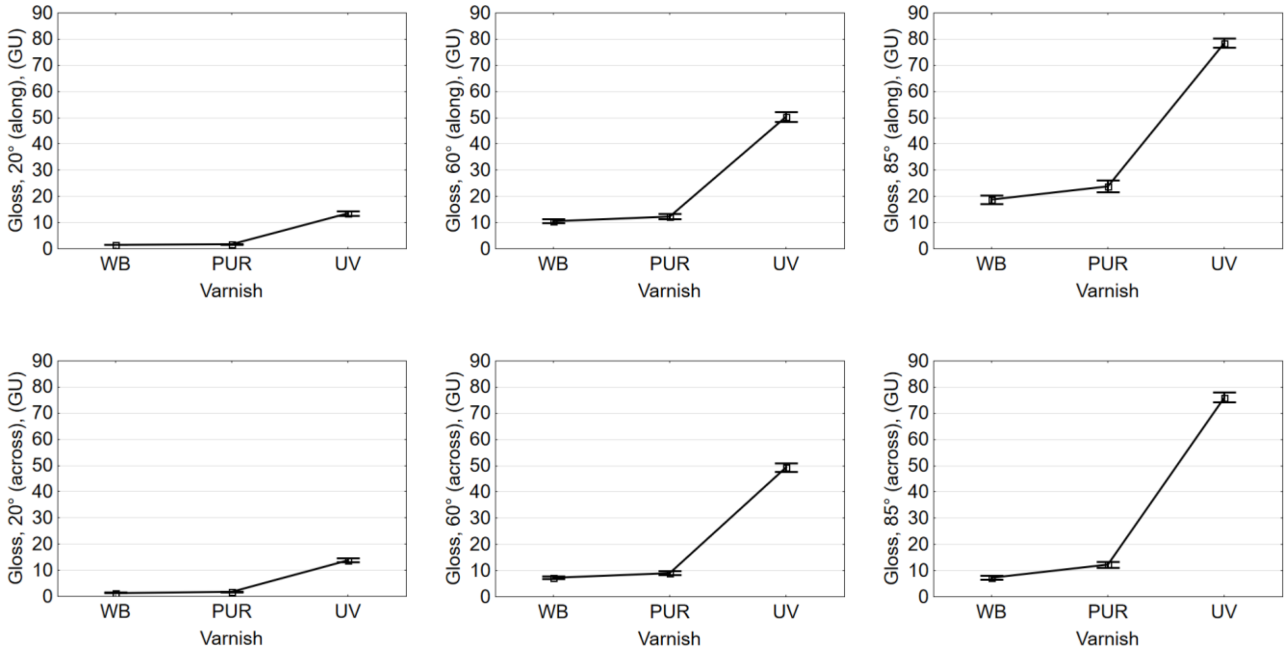

Figure 4. Main effects plot for mean gloss for different varnishes for each measurement angle.

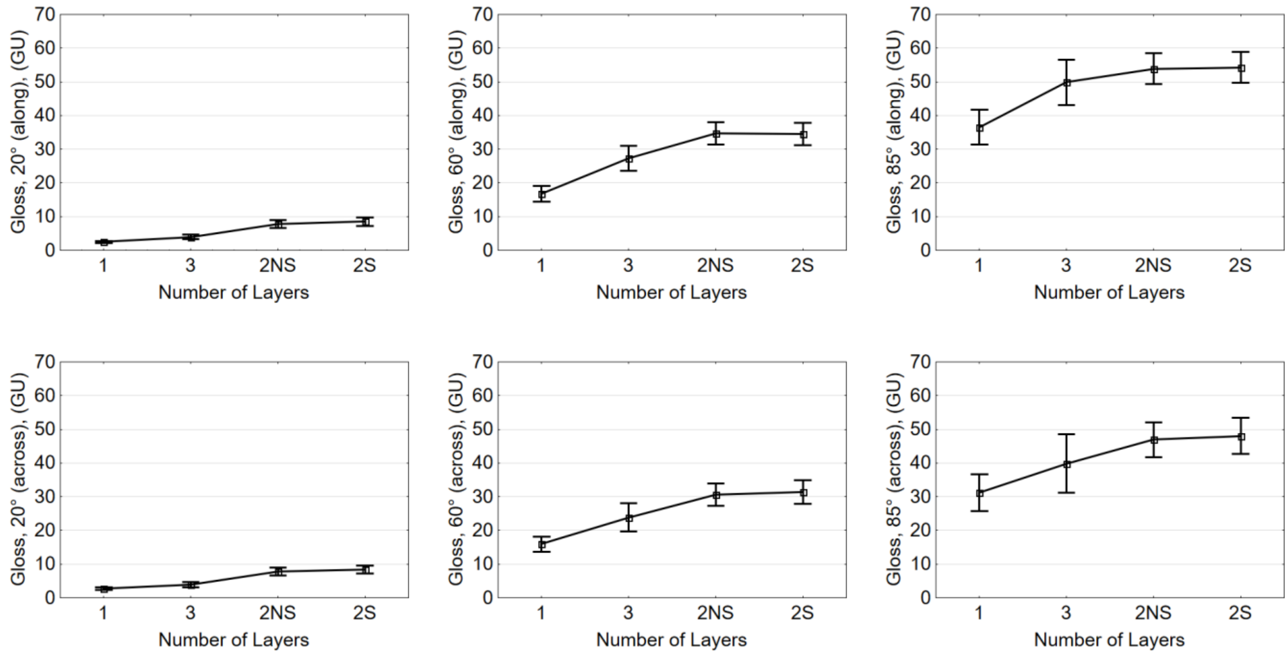

Figure 5. Main effects plot for mean gloss for different numbers of layers for each measurement angle.

Several authors [3] also observed that the gloss of coating on beech wood increases with the increasing number of layers. On the contrary, other authors [27] did not find significant differences in relation to gloss between one or two layers of coating. However, it should be considered that as the number of layers increases, the amount of volatile organic compounds (VOCs) in the atmosphere is also increasing [36] and the price of furniture is increased. Therefore, in practice, the trend is not to increase the number of layers on the wooden substrate.

3.4. Effect of the Pre-treatment Process of Wood Veneer on the Surface Gloss of Varnished Samples

The method of surface pre-treatment before varnishing significantly affects the gloss values measured for different angles of incidence light except for the angle 20°(‖). In general, it can be stated that the sanded surface provides the formation of a coating with a higher gloss than the thermally densified surface. However, it was found that for the angles 60°(‖) and 85°(‖), the varnished surfaces using sanded and thermally densified TC-210 veneer do not differ from each other for the average gloss values (Figure 6). The surfaces using sanded and thermally densified TC-180 veneer for angles of incidence light of 20°(‖), 85°(‖) and 60°(⊥) also do not differ in average gloss values. This is important from a practical point of view, as it confirms our assumption that it is possible to replace the sanding operation before varnishing with an operation of thermal densification. It is known that the springback and set recovery are very important parameters for compressed solid wood [37]. However, in our previous work [38], it was found that the thermal densification of veneers provides stable properties under normal atmosphere conditions; in particular, the thickness and contact angle values were stable for 24 hours after densification, which is important for a good coating.

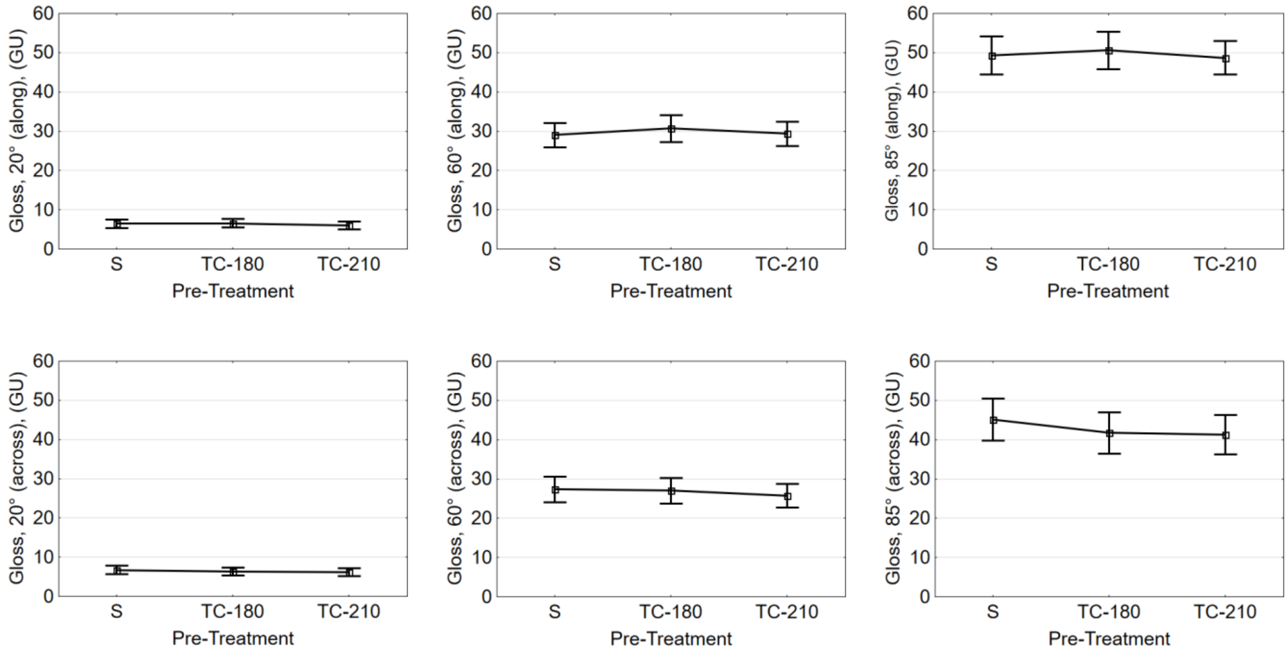

Figure 6. Main effects plot for mean gloss for different pre-treatment processes for each measurement angle.

The gloss value increases with the decrease in roughness [17,39]. During the sanding, the surface roughness decreases [1]. It was also shown that the roughness decreases during the thermal compression [8], which makes the surface more uniform, denser, smoother and glossier. However, despite the fact that the thermally densified surface has a lower roughness than the sanded surface [8,33], the latter provides the formation of coating with a higher gloss than the thermally densified surface. This indicates that the surface gloss is also determined by the lightness of the samples. It is known that after thermal densification at high temperature, the surface becomes both smoother and darker [31,32]. Therefore, the light penetrates more deeply for darker surfaces, and as a consequence, more light is absorbed by such surfaces, but their gloss is reduced. In previous studies [15,40], it was also observed that gloss values of heat-treated wood samples generally decrease with heat treatment.

4. Conclusions

The present work evaluated the gloss of coatings on veneered MDF panels with sanded and thermally densified black alder and birch wood veneers. ANOVA analysis showed that the type of varnish, the number of layers, the pre-treatment process, the wood species and direction of wood fibers significantly affect gloss of the coatings of veneered MDF panels. The type of varnish had the greatest effect on gloss. The highest gloss values were measured for the UV-varnished surface, and the lowest for WB- and PUR-varnished surfaces. Gloss was enhanced with an increase in the number of layers. The highest gloss values for both investigated wood species along and across the fibers were observed for surfaces covered with two layers of varnish with intermediate sanding (2S) and the lowest were observed for surfaces covered with one layer of varnish. Birch veneer provides higher gloss values compared to alder veneer. A typical finding for all investigated variables is that gloss values measured along the fibers are higher than those measured across the fibers. In general, it can be stated that the sanded surface provides the formation of a coating with higher gloss than the thermally densified surface. However, no significant differences were found between the coatings created on sanded and thermally densified (TC-180 or TC-210) veneers for the average gloss values measured along the fibers at angles 60° and 85°.

The findings of this study will allow the replacement of pre-varnishing sanding as one of the most time-consuming and expensive operations in the woodworking industry with thermal compression treatment.

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