The Effect of Varnish Type, Glue Amount, and Density on the Surface Properties of Low Density Particleboards Produced From Waste Wood Bark

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Particleboards, which are widely used in various fields, are commonly coated with solid and liquid surface coating materials to achieve better physical, mechanical, and aesthetic results. This study produced low-density particleboards from waste wood bark using different adhesive mixtures and densities. These particleboards were then coated with three types of varnish: water-based (Aq), polyurethane-based (Pu), and oil/wax-based (Ow). The color, gloss, and surface roughness values of the coated boards were determined to investigate the effect of varnish type, total adhesive usage, and density on these properties. In the board groups produced with the same glue ratio and density, the roughness values obtained with Ow varnish application were mostly higher compared to Aq and Pu. In the Ow varnish type, the roughness (R_{max}) decreased linearly with increasing total adhesive amount in particleboards produced at low density (320 kg/m^3). The highest color change (ΔE^*) values for all variations were obtained in the Ow varnish type, while the highest gloss values were achieved at 85° and in the B2 (4%-420 kg/m^3) board group. It was concluded that higher density should be preferred for smoother and glossier surfaces, which are important in terms of surface properties and aesthetics. Overall, these findings highlight the preference for higher density to achieve smoother and glossier surfaces in areas where surface properties and aesthetics are significant.

DOI: 10.15376/biores.18.4.7025-7040

Keywords: Varnish; Polyurethane; Oil/wax; Aqueous varnish; UF; Particleboard; Wood bark; Density

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INTRODUCTION

Wood materials are commonly preferred in construction and engineering due to their aesthetic appearance and ease of workability (İstek and Özlüsoylu 2016; Ergun 2021). However, the increasing population and demands have led to an insufficient supply of solid wood products. As a result, wood-based panels such as particleboards, produced by binding wood particles together with an adhesive and exposing high-temperature and pressure treatment, have been developed to replace solid wood products. Particleboards can be produced in desired thickness, have a homogeneous structure, and can be manufactured in large dimensions. They can be assembled using nails, screws, and adhesives. Particleboards can also be enhanced with surface treatments for a more decorative and aesthetic appearance (Nemli and Usta, 2004; Kevin *et al*. 2018; İstek *et al.* 2019; Kurt 2022).

The main raw materials for particleboard production are wood chips directly obtained from timber, as well as materials derived from forest pruning and wood waste (Lee *et al*. 2022). While medium and small-sized softwood species are generally preferred for particleboard production, some countries have increased hardwood species use in recent years (Pędzik *et al*. 2021). However, the reduced availability of timber resources from woodland areas presents considerable difficulties in fulfilling the escalating need for particleboards. This situation creates significant difficulties in terms of wood supply for the wood-based panel industry. Therefore, the utilization of alternative natural resources such as agricultural and lignocellulosic industrial waste and wood by-products is a preferred practice to meet the raw material demand for particleboard production (Gontard *et al*. 2018; Mirski *et al*. 2020; Auriga *et al*. 2022). The use of such raw materials is rapidly increasing due to their renewable, low-cost, and environmentally friendly characteristics. This allows both the recycling of waste materials in their discarded state and the reduction of problems arising from waste disposal. It is well known that in the disposal of waste raw materials, the most economical methods are preferred, often involving methods such as landfilling or incineration. This situation can lead to soil, water, and air pollution (Nazerian *et al*. 2016; Sugahara *et al*. 2019).

Particleboard is a significant wood-based material that can also be produced using low-quality materials. The entire wood feedstock, including bark and needles, results in a value-added product through the production process. Thus, both environmental and economic benefits are achieved (Maloney 1993; Yazici 2020; Cai *et al.* 2004). In recent years, research has been conducted on the utilization of straw (Grigoriou 2000), stalks (Taha *et al*. 2018), bran (Mendes *et al*. 2014), nutshells (Pirayesh *et al*. 2013), sunflower husks (Lenormand *et al*. 2017), leaves (Shi *et al*. 2006), grass (Nemli *et al*. 2009), palm residues (Loh *et al*. 2011), peanut hull (Guler *et al.* 2008) and tree barks (Tudor *et al*. 2021) for panel board production.

In addition to the challenge of raw material supply, the emission of formaldehyde due to the use of synthetic adhesives containing formaldehyde in wood-based panel production is a significant concern. Formaldehyde, classified as a carcinogenic substance, has adverse effects on human health and the environment. To mitigate and control these negative effects, restrictions have been imposed on formaldehyde emissions from wood-based panels, and production is carried out in compliance with these limits. Various methods and practices are being investigated to reduce formaldehyde emissions, including the addition of formaldehyde scavengers, new adhesive formulations, and the use of natural adhesives or adhesives without formaldehyde (İstek *et al.* 2018; Zhang *et al*. 2011; Hematabadi *et al*. 2012). One of these methods is the combination of binders such as MDI and P-MDI with formaldehyde-containing adhesives. Various studies have indicated that wood-based panels produced with P-MDI-modified adhesives exhibit low formaldehyde emissions and improved physical and mechanical properties (Dziurka and Mirski 2010; Wang *et al.* 2004; Wang *et al.* 2007).

Turkey has a high production capacity in wood-based panel manufacturing and ranks among the top in Europe and the world in terms of production (İstek *et al*. 2017a; FAOSTAT 2022). This high production capacity generates a significant amount of waste bark. Most of the generated bark waste is burned for energy without being transformed into a new product. In recent years, studies have been conducted on the feasibility of using bark in the production of wood-based panels such as particleboards. The chemical composition of bark differs from that of wood, characterized by relatively low cellulose content, short fiber lengths, and high extractive content (Sakai 2001; Macovei *et al.* 2021). This can result in lower mechanical properties compared to wood. However, when compared to panels produced solely from wood, composite panels made from bark alone or a mixture of wood and bark have been reported to exhibit better dimensional stability (such as water uptake, thickness swelling). Additionally, bark-based panels demonstrate better thermal insulation properties and lower formaldehyde emissions. Therefore, the utilization of bark is preferred primarily in the production of low-density panels that do not require high mechanical strength (Kain *et al*. 2014; Medved *et al.* 2019; Özlüsoylu 2022). The use of bark in wood panels reduces formaldehyde emissions when mixed with wood chips, such that bark can be regarded as a good raw material option for insulation boards (Nemli and Çolakoğlu 2005; Aydın *et al*. 2017; Tudor *et al*. 2020; Bekhta *et al*. 2021; Giannotas *et al*. 2021; Özlüsoylu 2022; Dukarska and Mirski 2023). In addition, the recycling of bark contributes to sustainability goals in the forestry industry. The recycling of bark reduces waste volume and enables more efficient utilization of natural resources (Pandey 2022).

Wood-based panels, especially particleboards and medium-density fiberboards (MDF), are produced and widely used in large quantities worldwide due to their favorable properties (Antov *et al*. 2020). A variety of solid and liquid surface coating processes are applied to a significant portion of produced wood-based panels. The surface coating enhances the aesthetic appearance of the panels and improves their physical and mechanical properties (Nemli *et al*. 2005a; Nemli and Usta 2009; Donmez Çavdar *et al*. 2013; Liu and Zhu 2014). While particleboard panels are used in interior applications, their hygroscopic nature plays a significant role in their performance due to long-term changes in relative humidity (Hızıroğlu 1999; Kılıç *et al*. 2009; İstek *et al*. 2012, 2017b). Surface properties such as surface roughness, adhesion, and the quality of the final product are important, since coating materials form the underlying layer of the panels. It is known that various factors such as the type of raw material, type of surface coating material, application method, production parameters of the panels, and moisture content of the wood affect surface roughness, color, and gloss properties (Nemli *et al*. 2007; Dündar *et al*. 2008; Kılıç *et al*. 2009; Zhong *et al*. 2013; Özdemir 2016; Bekhta *et al*. 2018; Özdemir and Bozdoğan Balcık 2019).

In this study, the effect of adhesive amount and density variation on certain surface properties of particleboards produced from waste bark was investigated. For this purpose, particleboards were produced with different ratios of UF and P-MDI adhesives and at two different densities. The surfaces of the produced boards were coated with three types of varnish: water-based, polyurethane-based, and oil/wax-based. Measurements of color, gloss, and surface roughness were conducted.

EXPERIMENTAL

Materials

Waste bark from black pine (*Pinus nigra* Arnold.) was used as the raw material, and a mixture of urea formaldehyde (UF) and polymeric methylene diphenyl diisocyanate (P-MDI) was employed as the adhesive, with varying ratios. The bark and UF (solid content 65%) were obtained from a particleboard facility, while the P-MDI was commercially purchased. Barks with high moisture content were spread on the laboratory floor and periodically mixed to remove excess moisture. Subsequently, they were placed in plastic bags for grinding and sieving processes and left to stand. The particleboard production was conducted at two different densities, namely 320 and 420 kg/m^3, with a thickness of 18 mm. A total of 24 boards were produced, with 3 repetitions for each variation. Details of the experiments are provided in Table 1.

Table 1. The Experimental Variations

Code	Board Density (kg/m^3)	Glue Type (%)		Total Glue* (%)
		UF	P-MDI	
A1	320	87.5	12.5	8
A2	420			
B1	320	75	25	4
B2	420			
C1	320	62.5	37.5	10
C2	420			
D1	320	50	50	6
D2	420			

** The total adhesive amount was determined by taking into account the solid content of the adhesive.*

Three different types of varnishes were used for surface coating in this study: water-based (Aq), polyurethane-based (Pu), and oil/wax-based (Ow). The solids contents of the Aq, Pu, and Ow varnishes were 29%, 17%, and 20%, respectively. Each varnish type was applied separately to the particleboards in each experimental variation. The purpose was to evaluate and compare the effects of these varnish types on the surface properties of the coated particleboards, including color, gloss, and surface roughness.

Bark Particleboard Production

The barks were processed through mills at the procurement facility before reaching the particleboard production site to reduce their dimensions. Upon arrival at the production laboratory, the barks underwent a secondary grinding process using a laboratory-scale grinder. Subsequently, sieving was performed using screens of different sizes (1, 3, and 8 mm). Following the sieving process, barks in the size range of 1 to 3 mm were used in the surface layers, while those in the size range of 3 to 8 mm were used in the middle layer. The production of bark particleboards involved a three-layered structure, with separate surface and core layers. The bark particles, which were sized through screening and classification, were dried in a kiln until they reached the desired moisture content of 1% to 3%. The UF and P-MDI adhesive mixtures, prepared at specified ratios, namely 4%, 6%, 8%, and 10% based on the oven-dry weight of the bark particles, were mechanically mixed. The adhesive application was carried out using a glue gun in a rotating adhesive tank. Subsequently, the manual spreading process was performed using a wooden spreading mold, and the board assembly was placed into a hot press. The hot pressing operation was conducted under the conditions of 165 °C, 25 bar pressure, and 4 minutes duration. After being released from the hot press, the boards were cooled and then conditioned at 20 ± 2 °C and 65 ± 5% relative humidity. The varnishes were applied to the board surfaces using a brush, with a targeted application rate of 110 g/m^2.

Surface Properties

The color measurements of bark particleboards were obtained using a Konica Minolta spectrophotometer (Osaka, Japan). The L^*, a^*, and b^* values were determined according to the ISO standard 7724-2 (1984) by evaluating measurements taken from randomly selected areas. The CIE Lab system was employed for the evaluation of color coordinates. For each variation, the L^*, a^*, and b^* color coordinates of the experimental boards were determined both before surface treatment (uncoated) and after surface treatment (coated). The L^* axis represents the black-white axis, where $L^* = 0$ corresponds to perfect black and $L^* = 100$ corresponds to perfect white. The a^* axis represents the red-green color spectrum, with positive values indicating red and negative values indicating green. The b^* axis represents the yellow-blue color spectrum, with positive values indicating yellow and negative values indicating blue. The changes in color coordinates (ΔL^*, Δa^*, and Δb^*) were calculated by determining the difference between the values obtained before surface treatment (uncoated) and after surface treatment (coated). The total color differences (ΔE^*) were calculated according to Eq. 1.

$$\Delta E^* = [(\Delta a^*)^2 + (\Delta b^*)^2 + (\Delta L^*)^2]^{\frac{1}{2}} \quad (1)$$

where ΔL^* represents the change in L^*, Δa^* represents the change in a^*, and Δb^* represents the change in b^*.

The gloss values were measured using a PICO GLOSS 503 photoelectric instrument according to DIN standard 67530 (1982) and ISO standard 2813 (2014), at incident angles of 20°, 60°, and 85° for both uncoated and coated samples. Five measurements were taken from each experimental board. In typical test measurements, a 20° angle is used to measure the surface gloss of matte coatings, a 60° angle is used for both matte and glossy samples, and an 85° angle is used for highly glossy surfaces. A complete mirror-like light reflection, indicating very high gloss, would have a value of 100%, while a completely diffused light reflection, indicating a matte surface, would have a value of 0%.

The surface roughness measurements of the experimental boards were conducted using a MicroProf FRT device (Fries Research & Technology GmbH, Bergisch Gladbach, Germany). The roughness parameters, including the arithmetic mean deviation of the evaluated profile (R_a), R_z, and R_{max}, were calculated by the device. All parameters were measured on a 2D profile, and four measurements were taken from each surface of the experimental board. The device had other settings, including a 50 mm evaluation length, 2.5 mm sampling length, a scanning speed of 750 μm/s, a measurement resolution of 5 μm, and a total of 10,000 points per measurement. A Gaussian filter was automatically applied to all roughness data.

RESULTS AND DISCUSSION

The calculated density values of the produced bark particleboards showed a maximum deviation of 5% for both board densities (320 and 420 kg/m^3), and the density values were within the tolerance limits specified by TS EN 312. Istek and Siradag (2013) stated that the density of particleboards is influenced by various factors, including raw material and adhesive type, as well as production conditions. They also emphasized that a variation of up to 10% in board density does not significantly affect the board properties.

Surface Roughness Values

The surface roughness values (R_a, R_z, and R_{max}) of the bark particleboards with three different (Aq, Ow, and Pu) varnish applications are presented in Table 2. Upon examining the roughness values of the board groups with the same adhesive ratio and density, it can be observed that the Ow varnish application provided higher R_{max} values compared to the Aq and Pu applications, except for the C1, D1, and D2 groups. Generally, the measured roughness values resulting from different types of varnish applications were lower for boards produced at a higher density (420 kg/m^3). For the Aq varnish application, the obtained R_{max} values for the A1, B1, 1, and D1 groups were 10.26, 9.96, 10.23, and 9.15 respectively. For the A2, B2, C2, and D2 groups, the values were measured as 4.14, 3.19, 5.83, and 5.76 respectively. Similar results were observed for Ow and Pu varnish types. In different studies, particleboards produced at a higher density have lower roughness due to their lower porosity, more compactness, and tighter structure compared to particleboards produced at a lower density (Hiziroglu 1996; Nemli *et al*. 2005b).

The roughness values showed variable values with an increase in the total amount of adhesive for boards with the same density. For the Ow varnish, a linear decrease in roughness values was observed with an increase in the total amount of adhesive in boards produced at the targeted density of 320 kg/m^3. However, no clear relationship was observed between the variation in the total amount of adhesive and roughness values in boards produced at the targeted density of 420 kg/m^3. Similarly, although the roughness changes with an increase in the P-MDI content in the total adhesive amount were not linear, the R_{max} value for the Aq varnish reached its lowest value with 50% P-MDI usage in boards produced at the targeted density of 320 kg/m^3. When the adhesive amount between the core and surface layers of the particleboards increased from 8 to 10% to 10 to 12%, the average roughness value decreased from 13.6 to 8.5 μm, which was attributed to the increased bond and contact between the wood particles (Nemli *et al*. 2007; Atar *et al*. 2014). In the present study, although the increase in the total amount of adhesive did not result in a linear decrease in average roughness for all variations, similar results were observed, especially for the Ow varnish type in boards produced at the targeted density of 320 kg/m^3. It is observed that the surfaces of bark particleboards had a more porous structure compared to those produced from wood particles. This can be attributed to the porous nature of the bark and the low density of the bark boards. Furthermore, it is mentioned in various sources that many factors, such as raw material properties and production parameters, have an influence on surface roughness (Nemli *et al*. 2007; Dundar *et al*. 2008; Ozdemir 2016; Karlinasari *et al*. 2021).

Table 2. Average Surface Roughness Values of Bark Particle Board After Coating

Codes	Varnish Type	After 3rd Treatment*		
		R_a	R_z	R_{max}
A1	Aq	6.54±2.77	39.40±2.70	10.26±0.31
	Ow	8.27±0.26	48.44±11.70	11.56±2.27
	Pu	7.67±3	36.25±11.20	9.61±3.12
A2	Aq	3.27±0.71	16.89±4.54	4.14±0.98
	Ow	9.17±0.93	49.59±5.34	11.81±1
	Pu	5.47±1.81	25.63±12.16	6.73±2.55
B1	Aq	8.01±0.86	32.22±1.28	9.96±0.63
	Ow	12.53±3.31	60.17±13.45	15.63±4.26
	Pu	8.89±0.83	42.05±4.56	11.01±1.16
B2	Aq	2.34±0.23	13.19±3.82	3.19±0.52
	Ow	8.46±2.48	44.55±12.19	10.78±2.69
	Pu	7.80±1.93	37.75±8.16	10.01±2.38
C1	Aq	8.12±2.14	37.29±11.06	10.23±3.01
	Ow	3.21±0.38	16.05±1.76	4.03±0.35
	Pu	13.55±1.03	68.51±11.69	17.63±1.96
C2	Aq	4.16±0.90	54.26±5.36	5.83±0.26
	Ow	11.71±2.32	71.13±17.15	15.52±2.94
	Pu	7.61±1.29	36.85±8.76	9.75±1.67
D1	Aq	7.10±0.90	36.29±7.16	9.15±1.32
	Ow	9.02±0.52	40.17±6.14	12.70±2.02
	Pu	15.82±5.39	27.85±3.87	21.71±3.30
D2	Aq	4.76±0.26	20.42±1.59	5.76±0.41
	Ow	6.43±2.26	26.42±7.63	8.86±3.60
	Pu	6.29±3.20	40.23±7.48	10.39±3.10

* After the application of the 1st and 2nd coat of varnish, the values could not be read on the device.
±: Standard deviation.

Color Properties

The findings regarding the color properties of bark particleboards treated with different types of varnishes are presented in Table 3. A low value of Δ*E** indicates that the color remained stable or changed only slightly. Particularly after the 2nd and 3rd varnish treatments, higher values of Δ*E** were observed. The highest Δ*E** value of 13.47 was measured for B2Ow after the 3rd treatment. However, in general, the highest Δ*E** values were predominantly obtained with the Ow varnish type. Similar results were reported in a study conducted on solid wood, where the highest Δ*E** values were observed with the OIL+WAX application (Can 2020). When the targeted density increased from 320 to 420 kg/m^3, an increase in Δ*E** values was observed for all varnish types with low glue content (4% and 6%) after the 3rd treatment. There was no significant difference between the Δ*E** obtained according to the total glue usage rate after the 1st, 2nd, and 3rd varnish treatments. On the other hand, it was observed that the values obtained in the use of 10% glue were relatively low, while the highest values were always obtained for the Ow varnish type. For the 320 kg/m^3 board group, the highest Δ*E** values obtained with 4%, 6%, 8%, and 10% total glue content were calculated as 9.38 (Ow), 8.92 (Ow), 10.64 (Ow), and 8.40 (Ow) respectively. For the 420 kg/m^3 board group, the corresponding values were 13.47 (Ow), 9.03 (Ow), 11.23 (Ow), and 8.16 (Ow). It was observed that Δ*L* values tended to decrease with increasing varnish application. It is emphasized that factors such as raw material type and characteristics, as well as application techniques, play a significant role in color changes in wood composite boards (Akkuş 2018).

It has been reported that water-based varnishes, especially on tannin-rich wood surfaces, can cause noticeable color changes. This is attributed to the weakly alkaline nature (pH 8 to 9) of water-based varnishes, which interact with tannins and undergo a one-step chemical coloring process (Sönmez and Budakçı 2004). Tannins, which are natural biopolymers with a phenolic structure, are particularly abundant in tree barks (Gönültaş and Uçar 2017). It is suggested that this characteristic may influence the color changes in the bark particleboards produced in this study.

Table 3. Color Coordinates and Total Color Changes of Bark Particle Board After Coating

Codes	Varnish Type	After 1st Treatment				After 2nd Treatment				After 3rd Treatment			
		Δ*L*	Δ*a*	Δ*b*	Δ*E*	Δ*L*	Δ*a*	Δ*b*	Δ*E*	Δ*L*	Δ*a*	Δ*b*	Δ*E*
A1	Aq	-2.99±2.52	-1.33±0.70	-0.81±0.79	3.37±2.53	-3.19±2.12	-2.12±0.08	-1.93±0.42	4.29±1.33	-3.26±2.48	-2.52±0.27	-2.91±0.32	5.05±1.44
	Ow	-7.06±4.98	-0.71±1.81	-2.59±0.76	7.55±3.54	-6.77±5.55	-1.84±0.72	-4.08±1.14	8.12±4.44	-8.90±3.37	-2.71±1.89	-5.17±1.37	10.64±2.33
	Pu	-4.18±3.93	0.19±1.46	-0.59±0.50	4.22±2.59	-6.66±2.75	-0.66±1.08	-1.89±1.16	6.95±2.78	-8.72±2.64	-0.52±1.43	-1.53±1.39	8.87±2.92
A2	Aq	-3.12±0.60	0.11±0.11	-0.15±0.56	3.13±0.59	-4.31±2.59	-0.45±0.24	-0.39±0.42	4.35±2.51	-3.26±1.92	-0.79±0.46	-1.40±1.36	3.64±2.01
	Ow	-7.23±3.31	-0.91±1.41	-2.89±1.76	7.84±3.71	-9.78±3.29	-0.71±0.25	-2.92±0.46	10.23±3.28	-10.81±4.70	-0.93±0.92	-2.92±0.87	11.23±4.60
	Pu	-3.91±0.40	0.10±0.16	-0.60±0.48	3.96±0.45	-5.80±0.53	0.08±0.14	-1.33±0.12	5.95±0.59	-5.46±1.12	-0.01±0.24	-1.27±0.79	5.61±0.90
B1	Aq	-3.60±0.99	-0.14±0.41	-1.90±0.96	4.07±1.29	-4.14±1.57	-0.67±0.49	-2.37±1.10	4.82±1.77	-3.81±1.53	-1.31±0.11	-3.50±1.29	5.34±1.93
	Ow	-7.59±2.07	-1.24±0.35	-3.45±1.14	8.43±2.29	-8.21±2.04	-1.79±0.95	-4.33±1.52	9.45±2.57	-8.46±1.70	-1.89±1.32	-3.59±1.98	9.38±2.33
	Pu	-2.83±2.81	-0.64±1.58	-1.22±1.25	3.15±1.66	-5.37±3.11	-1.21±1.46	-3.34±0.59	6.44±1.72	-6.29±1.51	-1.34±1.14	-3.78±0.23	7.46±1.04
B2	Aq	-3.31±1.50	0.28±0.18	-0.33±0.70	3.33±1.39	-4.93±1.29	-0.04±0.08	-0.76±0.44	4.99±1.35	-5.80±0.83	0.22±0.77	-0.12±1.20	5.80±0.85
	Ow	-9.43±2.50	-1.56±0.44	-3.82±1.90	10.30±2.94	-10.47±2.87	-2.01±0.51	-4.54±2.29	11.59±3.56	-12.70±3.21	-1.62±0.93	-4.19±2.51	13.47±3.68
	Pu	-4.37±1.03	0.01±0.97	-1.05±0.71	4.49±1.13	-6.21±1.43	-0.45±0.64	-2.02±1.36	6.55±1.74	-7.38±1.02	-0.46±0.66	-2.21±1.15	7.72±1.28
C1	Aq	-1.00±1.74	-0.09±0.16	1.01±0.65	1.42±1.06	-2.50±1.32	-0.78±0.19	-0.81±1.45	2.75±1.28	-2.64±1.31	-0.88±0.26	-0.78±0.81	2.89±1.13
	Ow	-7.08±2.56	0.30±1.14	-1.48±2.14	7.24±2.65	-6.67±1.13	-0.85±0.55	-2.05±0.39	7.03±1.23	-7.63±2.10	-1.36±0.92	-3.25±1.33	8.40±2.57
	Pu	-1.80±0.22	0.52±0.25	0.57±0.55	1.96±0.43	-2.44±1.12	0.12±0.09	-0.20±0.56	2.45±1.14	-3.34.±1.27	-0.10±0.02	-0.76±0.47	3.42±1.28
C2	Aq	-4.08±2.25	0.06±0.12	-0.24±1.52	4.08±2.04	-5.15±1.39	-0.06±0.34	-1.09±0.38	5.26±1.40	-4.74±1.23	-0.41±0.29	-1.22±0.98	4.91±1.41
	Ow	-5.47±1.22	-0.31±0.79	-0.42±1.08	5.49±1.22	-6.60±1.81	-0.77±0.51	-1.81±1.34	6.88±2.10	-7.98±1.24	-0.72±1.05	-1.59±1.60	8.16±1.63
	Pu	-4.05±1.09	-0.45±0.69	-1.07±0.25	4.21±1.08	-6.71±1.93	-0.53±0.59	-1.57±1.72	6.91±2.12	-6.30±2.09	-0.35±0.41	-1.03±1.38	6.40±2.21
D1	Aq	-4.17±2.58	-0.52±0.49	-1.26±0.16	4.39±2.16	-3.41±3.54	-1.28±0.50	-1.23±1.89	3.85±1.30	-3.35±2.02	-2.21±0.62	-2.73±1.04	4.85±1.61
	Ow	-6.70±3.77	-0.93±1.37	-2.80±2.60	7.32±4.39	-7.55±3.07	-2.24±1.13	-4.57±2.24	9.11±3.93	-7.70±3.27	-1.80±2.07	-4.13±2.91	8.92±4.33
	Pu	-1.50±0.72	-0.02±2.16	-0.53±0.94	1.59±0.27	-3.01±1.25	0.50±1.76	-0.92±0.88	3.19±0.88	-3.88±2.21	-0.43±1.99	-2.07±1.01	4.41±1.96
D2	Aq	-2.63±1.57	-0.32±0.78	0.47±0.56	2.69±1.40	-4.28±1.61	-0.61±1.21	-0.97±1.54	4.43±1.47	-5.17±1.16	-1.05±1.09	-1.66±0.85	5.53±1.39
	Ow	-7.38±4.04	-0.64±0.48	-2.65±2.13	7.86±4.46	-9.38±1.63	-1.73±0.21	-4.85±1.11	10.70±1.93	-8.35±3.76	-1.25±0.49	-3.20±2.54	9.03±4.21
	Pu	-3.47±0.71	-0.02±0.57	0.14±0.56	3.49±0.63	-6.74±2.21	0.19±1.31	0.05±1.86	6.74±2.04	-7.44±2.35	0.46±0.93	-0.31±1.73	7.46±2.29

Table 4. Average Gloss Values of Uncoated and Coated Bark Particle Board

Codes	Varnish Type	Uncoated			After 1st Treatment			After 2nd Treatment			After 3rd Treatment		
		20°	60°	85°	20°	60°	85°	20°	60°	85°	20°	60°	85°
A1	Aq	0.18±0.05	0.80±0.00	0.78±0.13	0.18±0.10	1.10±0.27	0.90±0.08	0.23±0.05	1.40±0.14	1.30±0.16	0.28±0.05	2.05±0.35	2.30±0.24
	Ow	0.10±0.00	0.68±0.13	0.65±0.13	0.13±0.05	0.80±0.14	0.95±0.37	0.23±0.10	1.63±0.43	1.40±0.50	0.30±0.12	2.33±0.84	3.05±0.80
	Pu	0.13±0.05	0.70±0.12	0.70±0.12	0.18±0.10	1.23±0.46	1.03±0.30	0.25±0.06	2.03±0.59	2.13±0.65	0.25±0.06	2.08±0.54	2.88±0.97
A2	Aq	0.10±0.00	0.80±0.00	1.08±0.17	0.18±0.05	1.40±0.22	1.28±0.26	0.38±0.10	2.60±0.50	2.90±0.43	0.48±0.05	4.03±0.59	6.05±1.45
	Ow	0.20±0.08	0.80±0.00	0.83±0.05	0.10±0.00	0.98±0.29	1.03±0.21	0.18±0.10	1.60±0.45	1.48±0.28	0.33±0.05	2.83±0.51	3.78±0.51
	Pu	0.18±0.05	0.78±0.05	0.90±0.18	0.18±0.05	1.35±0.19	1.28±0.19	0.35±0.10	2.30±0.61	2.55±0.44	0.30±0.00	2.63±0.33	3.80±3.47
B1	Aq	0.13±0.05	0.60±0.14	0.70±0.14	0.10±0.00	0.93±0.13	0.88±0.22	0.20±0.08	1.55±0.37	1.45±0.51	0.35±0.10	2.78±0.77	3.10±1.07
	Ow	0.10±0.00	0.68±0.15	0.83±0.15	0.10±0.00	0.78±0.10	1.13±0.26	0.18±0.10	1.30±0.53	1.65±0.90	0.35±0.13	2.35±0.70	3.25±1.55
	Pu	0.10±0.00	0.63±0.05	0.85±0.06	0.10±0.00	0.88±0.15	0.95±0.17	0.23±0.05	1.58±0.25	1.68±0.13	0.30±0.00	2.43±0.29	3.05±0.51
B2	Aq	0.15±0.06	0.88±0.10	1.68±0.26	0.20±0.00	1.43±0.05	1.65±0.13	0.30±0.00	2.68±0.30	4.15±1.38	0.68±0.15	5.73±1.18	9.18±2.10
	Ow	0.23±0.05	1.00±0.08	1.50±0.22	0.10±0.00	1.15±0.13	1.83±0.34	0.25±0.10	2.48±0.77	3.78±1.87	0.75±0.37	5.68±2.61	7.48±2.74
	Pu	0.20±0.12	0.85±0.10	1.38±0.10	0.18±0.10	1.50±0.32	2.05±0.42	0.30±0.00	2.30±0.27	3.20±0.47	0.45±0.10	3.85±0.75	6.23±0.94
C1	Aq	0.13±0.05	0.75±0.10	0.78±0.13	0.13±0.05	1.00±0.32	1.10±0.50	0.23±0.10	1.85±0.58	2.05±0.82	0.25±0.13	1.90±0.59	1.75±0.76
	Ow	0.10±0.00	0.70±0.00	0.70±0.08	0.10±0.00	0.85±0.10	0.93±0.21	0.13±0.05	1.08±0.22	1.53±0.33	0.33±0.10	2.48±0.39	3.18±0.30
	Pu	0.10±0.00	0.73±0.10	0.73±0.15	0.10±0.00	1.00±0.26	1.10±0.28	0.18±0.10	1.48±0.39	1.40±0.20	0.23±0.05	1.65±0.13	2.18±0.78
C2	Aq	0.10±0.00	0.80±0.00	1.00±0.12	0.15±0.06	1.18±0.17	1.33±0.17	0.25±0.06	1.98±0.38	2.20±0.36	0.35±0.10	2.95±0.50	3.40±0.84
	Ow	0.20±0.08	0.93±0.15	1.15±0.19	0.10±0.00	1.33±0.17	1.58±0.15	0.30±0.14	2.18±0.63	2.33±0.72	0.58±0.22	3.53±0.75	4.20±1.28
	Pu	0.10±0.00	0.80±0.00	1.15±0.13	0.18±0.05	1.45±0.19	1.48±0.24	0.30±0.00	2.40±0.08	3.00±0.34	0.45±0.10	3.13±0.29	4.03±0.33
D1	Aq	0.13±0.05	0.78±0.05	0.98±0.10	0.13±0.05	0.88±0.15	0.80±0.14	0.23±0.10	1.50±0.32	1.23±0.17	0.20±0.08	1.85±0.31	1.83±0.13
	Ow	0.10±0.00	0.78±0.05	0.98±0.15	0.10±0.00	0.85±0.06	1.03±0.22	0.15±0.06	1.38±0.22	1.55±0.10	0.38±0.10	2.88±0.29	3.38±0.29
	Pu	0.18±0.10	0.75±0.10	0.90±0.16	0.10±0.00	0.93±0.10	1.05±0.17	0.25±0.06	1.58±0.29	1.75±0.49	0.28±0.05	2.48±0.59	2.83±0.59
D2	Aq	0.25±0.06	0.93±0.10	1.73±0.26	0.20±0.00	1.48±0.25	1.93±0.15	0.30±0.00	2.35±0.26	3.00±0.64	0.60±0.18	4.78±1.10	7.95±2.49
	Ow	0.20±0.00	0.98±0.05	1.33±0.24	0.10±0.00	1.10±0.14	1.58±0.19	0.25±0.06	2.08±0.45	2.63±0.38	0.78±0.17	4.65±0.74	5.48±0.64
	Pu	0.20±0.08	0.90±0.14	1.48±0.13	0.23±0.05	1.58±0.29	1.90±0.20	0.30±0.00	2.35±0.29	3.28±0.19	0.40±0.08	3.95±1.06	5.75±1.10

Gloss Values

The gloss values of the bark particleboards are shown in Table 4. Measurements were conducted at 20°, 60°, and 85° angles on both uncoated and coated samples. In the uncoated samples, the highest gloss value (1.73) at 20°, 60°, and 85° was obtained in the D2 board group with the Aq varnish type. Among the varnish-treated samples, the maximum gloss values after the 1^{st}, 2^{nd}, and 3^{rd} treatments were measured in the B2 board group at 85°, with values of 2.05 (Pu), 4.15 (Aq), and 9.18 (Aq) respectively. The value of 9.18 was also the highest gloss value obtained across all board groups and varnish types. When examining the effect of varnish type on gloss, it was generally observed that the Aq varnish type provided the highest gloss values within the same board group. An increase in gloss values was determined as the board density increased from 320 to 420 kg/m^3. This increase, commonly observed in the 1^{st} and 2^{nd} varnish applications, was also identified at 20°, 60°, and 85° for all varnish groups after the 3^{rd} treatment. The achievement of higher gloss values can be attributed to the higher board density (420 kg/m^3), which resulted in a denser and smoother surface. Densification processes have been reported to increase gloss in wood materials and wood coatings (Krystofiak *et al*. 2014; Bekhta *et al*. 2018). The effect of total glue usage on gloss was variable, but it is noteworthy that the highest gloss values were observed in the B2 group among all varnish-treated board groups. Bekhta *et al*. (2018) stated that the surface gloss of coated MDF panels is significantly influenced by factors such as the number of layers, the amount of varnish, the orientation of wood fibers, the edge of the coating, and the compression temperature. This emphasized that gloss values increase with an increasing number of layers. Furthermore, in gloss measurements conducted perpendicular to the surface, it has been noted that the device blocks light reflection as the measurement light hits the fibers, resulting in lower gloss values for wood samples (Bekhta *et al.* 2014; Can 2020).

CONCLUSIONS

1. In the board groups produced with the same glue ratio and density, the roughness values obtained with Ow varnish application were mostly higher compared to Aq and Pu. For the Ow varnish type, there was a linear decrease in R_{max} values with an increase in total glue amount for the board groups produced at low density (320 kg/m^3).
2. Generally, it was observed that the roughness values measured after applying different types of varnish to boards produced at high density (420 kg/m^3) were lower. Therefore, high density can be preferred for smoother board surfaces.
3. In general, higher values of the total color difference (ΔE^*) were observed, especially after the third varnish treatment. When the targeted density increased from 320 to 420 kg/m^3, an increase in ΔE^* values was observed for all varnish types with low glue content (4% and 6%) after the 3^{rd} treatment. On the other hand, it was observed that the values obtained in the use of 10% glue were relatively low, while the highest values were always obtained for the Ow varnish type.
4. The highest gloss values were obtained at 85° in the B2 (4%-420 kg/m^3) group. Regarding the varnish type, Aq provided higher gloss values within the same board group.
5. The importance of board density in terms of surface properties was emphasized, particularly for areas where aesthetics are crucial. It was concluded that higher density should be preferred for smoother and glossier surfaces.

ACKNOWLEDGMENTS

This study was carried out within the scope of the Short Term Scientific Mission (STSM) carried out under COST Action FP1407 "Understanding wood modification through an integrated scientific and environmental impact approach (ModWoodLife)". In addition, the author would also like to thank Dr. Tomasz Krystofiak and Barbara Lis for their scientific and technical support in tests related to surface properties

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Article submitted: June 16, 2023; Peer review completed: July 22, 2023; Revised version received and accepted: August 2, 2023; Published: August 17, 2023.
DOI: 10.15376/biores.18.4.7025-7040