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PROPERTIES OF WOOD SURFACE COATED WITH OIL WAX

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ABSTRACT

The research is aimed at establishing the changes in colour, gloss, hydrophobicity, and roughness of wood surfaces after treatment with hard wax oil, as well as the number of layers and the appropriate amount of liquid system required to achieve an effective coating. The water permeability of the coating was used as a criterion. Commercial hard wax oil was applied to the wood of spruce (*Picea abies* Karst.), aspen (*Popolus tremula* L.), beech (*Fagus sylvatica* L.), ash (*Fraxinus excelsior* L.), and European oak (*Quercus robur* L.). Changes in the colour of the wood substrates were evaluated visually. Gloss was measured using a gloss meter in accordance with ISO 2813:2014. Changes in roughness were assessed through the parameters *Rz* and *RSm*. Measurements were conducted with a contact surface roughness tester. Hydrophobicity was evaluated using the sessile drop method. It was found that a two-layer coating is optimal, and that the density, composition, and structure of the substrate influence the amount of liquid system required to form a coating with uniform colour and gloss. The coating was classified as unstable. Changes in colour, roughness, gloss, and hydrophobicity of the treated surfaces were established. No raising of the wood grains was found. The characteristics of the substrate had a significant impact on the coating properties.

Keywords: hard wax oil; wood surface; water permeability; contact angle; gloss.

INTRODUCTION

Products based on vegetable oils and natural waxes provide an effective, environmentally friendly protective coating for wooden surfaces (Teacă *et al*., 2019). Vegetable oils are natural, renewable raw materials obtained by esterification of glycerol with saturated or unsaturated fatty acids (Guner *et al.,* 2006). Depending on the degree of saturation of the fatty acids they contain, oils are classified as drying, semi-drying, or non-drying. The first two types are used as binders in coating systems. Through radical chain oxidation, they harden upon contact with air, forming spatially cross-linked structures. To accelerate the process, siccatives are used (Bulian and Graystone, 2009). Linseed, tall, soybean, nut, and hemp oils are most effective in protecting wood from microorganisms and insects (Teacă *et al*., 2019). Coatings containing tall oil, linseed oil, or tung oil reduce water absorption and consequently increase the dimensional stability of treated wood surfaces (Koski, 2008; Humar and Lesar, 2013).

Waxes are used as an additive in coating systems to preserve the appearance (gloss) and softness of wood. They are easy to apply and impart hydrophobic properties to the treated surfaces (Liu *et al*., 2011). They are used for non-biocide protection of outdoor wood structures, to increase water resistance, and to reduce photochemical degradation. They contain waterborne or organic solvent-soluble, long-chain, lipophilic compounds that form a coating while preserving the substrate's original appearance and structure (Bulian and Graystone, 2009).

The most effective method for imparting hydrophobicity to a wood surface, recommended by Janesch *et al*. (2020), is a combination of oil penetrating the wood surface to a certain extent with wax.

Colour and gloss are essential decorative properties for any coating. Colour evaluation is based on spectral estimates of the background colour's wavelength, its saturation, and its brightness. Gloss is determined by the degree of orientation of the rays reflected by the coating (Kavalov and Angelski, 2014). Gloss quality depends on several factors, including wood species, chemical composition, coating system type, number of layers, and substrate preparation (Bekhta *et al*., 2014).

Roughness reflects the presence, number, and size of surface irregularities at a micro level. For wood surfaces, roughness is a combination of the anatomical roughness specific to each particular wood species and the conditions of their processing (Kavalov and Angelski, 2015). It is evaluated using different groups of roughness parameters, depending on the materials and technological processes under investigation.

Hydrophobicity is an indicator of the degree of wetting of a solid substrate by a liquid. An indispensable tool for characterizing wetting is the measurement of the water contact angle (WCA) (Arminger *et al*., 2022). According to Shi and Gardner (2001), in addition to the stage of creating a contact angle at the boundary interfacial surfaces, wetting also includes the stages of spreading the liquid phase onto the surface of the solid phase and of the liquid phase penetrating into the porous solid phase. Hydrophobicity depends on many factors, including surface tension in the contact zone, chemical composition and heterogeneity of the phases, roughness of the contacting surfaces, etc.

The permeability of coatings to water and water vapour is a major factor in their wood protection function. Permeability determines the flow of liquids or gases through a solid surface. Liquid water and water vapour uptake are determined by coating film thickness, the number of coats, and the coating system formulation (Angelski and Atanasova, 2021).

The wood of each tree species is characterized by an individual structure. Its composition includes up to 30% of various extractive substances: tannins, resins, polyphenols, waxes, fats, starch, essential oils, and minerals (Spiridon, 2020), which influence the properties of the coating formed on its surface. In this regard, the aim of the present study is to assess the water permeability of a multilayer coating to establish the optimal number of layers and the appropriate amount of liquid system to obtain an effective coating, as well as the changes in colour, gloss, hydrophobicity, and roughness of wood surfaces as a result of the coating application.

MATERIALS AND METHODS

For the treatment of the specimens, a colorless gloss version of hard wax oil (Hartwachs-Öl Original, OSMO, Germany), intended for interior use, was chosen According to the manufacturer, the product contains renewable plant-based raw materials: sunflower oil, soybean oil, thistle oil, carnauba wax and candelilla wax, paraffin, siccatives and water-repellent additives, as well as unscented white spirit (benzene-free). The product complies with the requirements of Directive 2004/42/EC. It is recommended for all types of wood flooring and furniture. Application is possible by brush, roller, or pad. A two-layer liquid system is recommended, with 30–40 g/m^2 per layer applied after the previous layer has solidified. The coating is safe for people, animals, and plants.

Wood of spruce (*Picea abies* Karst.), aspen (*Popolus tremula* L.), beech (*Fagus sylvatica* L.), ash (*Fraxinus excelsior* L.), and European oak (*Quercus robur* L.) without flaws and visible discolourations was selected for the experiment. The specimens were manufactured in accordance with EN 927-5:2023, with six specimens of each wood species and an additional 18 spruce specimens, of which six were used as controls. The density of each specimen was measured. The average density of wood from different tree species, the dimensions of the specimens, and the orientation of the wood grains are presented in Tab. 1.

Tab. 1 Density of wood from different tree species. Dimensions and orientation of specimens.

Tree species	Density, kg/m^3	Dimensions L x B x δ, mm	Surface orientation
Spruce (*Picea abies* Karst.)	460	150×70×20	Tangential
Aspen (*Popolus tremula* L.)	600	150×70×20	Radial-tangential
Beech (*Fagus sylvatica* L.)	740	150×70×20	Radial-tangential
Ash (*Fraxinus excelsior* L.)	750	150×70×20	Radial
Oak (*Quercus robur* L.)	770	150×70×20	Radial-tangential

The wood samples were sawn and milled into flat surfaces. The moisture content of all control specimens ranged from 8% to 10%, as measured with a contact hydrometer (Hydromette Compact, Gann, Germany).

The test specimens were conditioned for a month at 23 ± 2 °C and 50 ± 5 % R.H. Before treatment, the surfaces were sanded with P120 sandpaper. The liquid system was applied with a pad until a uniform and homogeneous layer was obtained. The specimens were cured for 24 hours. The experiments were conducted seven days after the coating had dried. Application of the liquid system, coating curing, and subsequent conditioning were performed at a controlled temperature of 23 ± 2 °C and relative humidity of 50 ± 5%. The surfaces were not sanded before applying the next layer of the coating system.

The water permeability test was carried out in accordance with EN 927-5:2023.

The weight of the specimens after 72 hours of drying was also measured.

The amount of applied liquid system (Q) was calculated using equation (1):

$$Q = \frac{m_a - m_b}{A} \quad (\text{g.m}^{-2}) \qquad (1)$$

Where: m_a – weight of the specimen after coating(g); m_b – weight of the specimen before coating (g); A – area of the treated surface (m^2).

Colour changes were assessed visually.

Gloss was measured with a gloss meter GM 100 (Deutschland GmbH, Germany) according to ISO 2813:2014. Three measurements were made on each specimen, along the wood grain length.

To assess the roughness, a surface roughness tester model SJ-210 (Mitutoyo, Japan) with a diamond V-shaped probe tip with a radius R = 5 µm was used, with the following settings:

- profile – R, profile filter – Gauss;
- evaluation length l_e = 15 mm;
- number of section lengths n_{sc} = 6;
- section length l_{sc} = 2.5 mm,
- measuring speed 0.25 mm/s.

Measurements were taken across the wood grain at the same evaluation lengths after each layer of the coating was applied, as well as on the initial (sanded) surface. Six measurements were made on each specimen. The following parameters were selected for observation and analysis:

- arithmetic mean height of the assessed profile *Ra*;
- maximum height *Rz*;
- mean profile element spacing *RSm*.

Parameters are defined by ISO 21920-2:2021.

Hydrophobicity was assessed with a contact-angle measuring system, according to the principles and procedures described in EN 828:2013. The OneAttension software, Version 4.1.4 (r 9753) from Biolin Scientific, was used. Measurements were performed along the wood grains with a drop volume of 7.3 µl at a temperature of 20 °C. Deionized water was used as the test liquid. The change in the mean water contact angle *WCA mean* (°), and the change in the *baseline* (mm) were evaluated. Twelve measurements were carried out on one specimen of each tree species.

Preliminary experiments were conducted to determine the flow time and the system's solid content. A flow time of 56 s was measured using a 6-mm flow cup, according to ISO 2431:2019, and a solid content of 65% for a single-layer coating.

Excel was used for statistical processing of the measured data and graphical presentation of the results.

RESULTS AND DISCUSSION

Water permeability of the coating

After conducting the water permeability test, no cracks or defects were found on the surfaces of the specimens. The results of the measurements for single-layer, double-layer, and triple-layer coatings are presented in Table 2.

Tab. 2 Average values of the weight of spruce specimens before and after the water permeability test, and after 72 hours of drying. Amount of water absorbed.

Coating layers	Weight before the test, g	Weight after the test, g	Weight after 72 hours of drying, g	Amount of water absorbed, $g.m^{-2}$
One layer	102.47	110.95	105.32	818
Two layers	96.39	101.94	98.6	491
Three layers	100.48	106.84	103.09	494

The results show that, according to EN 927-2:2022, this coating system is non-stable. It can be used indoors or outdoors for end-use categories such as overlapping cladding, fencing, garden sheds, open cladding, and ventilated rain screen (EN 927-1:2013). The significant reduction in water permeation observed after applying a second layer of the coating system and the insignificant change after applying a third layer indicate that the two-layer coating is optimal.

The decrease in the mass of absorbed water 72 hours after removing the test specimens from the water indicates that the coating is permeable to water vapour.

Amount of oil wax system applied

Figure 1 shows the dependence of the amount of applied oil required to form a two-layer coating on the substrate density.

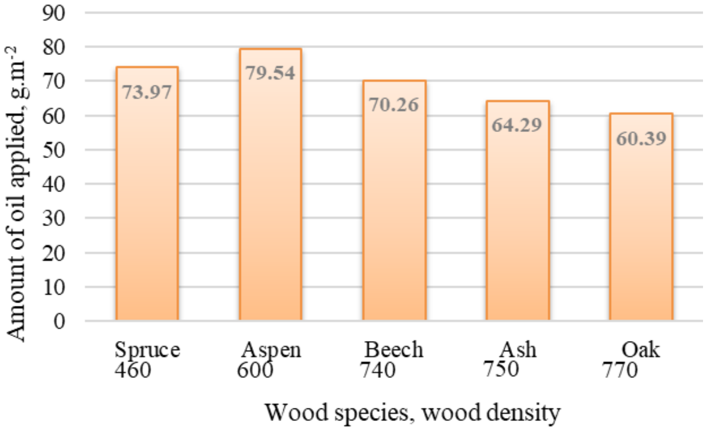

Fig. 1 Influence of wood density on the amount of oil applied (for a two-layer coating).

The graph in Figure 1 shows an inverse relationship between the amount of liquid system applied (*Q*) and the density of the wood substrate. The exception is spruce wood, which shows that the treated surface orientation (Atanasova and Savov, 2023) and wood composition (in this case, the presence of resin) also influence the results. It can be observed that *Q* for ring-porous wood is compared to that of diffuse-porous wood. When comparing the amount of liquid system applied to beech and ash, as well as to ash and oak, it can be argued that wood structure has a more significant influence on *Q* than density. However, this conclusion is conditional, as the two parameters are interdependent.

Changes in colour and gloss

It was found that the surfaces with a two-layer coating were pleasant to the touch, changed colour to varying degrees (Fig. 2), and acquired a gloss (Table 3). The texture was visible and clearly expressed. No grain-raising of the wood was felt.

Spruce (*Picea abies* Karst.) Aspen (*Popolus tremula* L.) Beech (*Fagus sylvatica* L.) Ash (*Fraxinus excelsior* L.) Oak (*Quercus robur* L.)

Fig. 2 Change in the colour of the specimens due to the formation a two-layer coating: 0 – initial surface; 2 – two-layer coating.

The significant changes in the colour and texture contrast of the specimens from hardwood (Fig. 2) indicate a reaction between the oil that has penetrated the substrate and the wood's natural colourants. No migration and redistribution of the colourants was observed. It suggests that the coating system reacts more slowly with the colourants in the wood substrate than water and that its movement is limited (Angelski and Atanasova 2021). The observation is consistent with studies by Demirel et al. (2016) and Zhang and Song

(2024), which indicate that oil penetration into the substrate occurs through conducting vessels, not through cell walls.

Tab. 3 Change in the gloss values of the specimens due to the formation of a two-layer coating.

Tree species	Average values, GU						Change, %		
	Initial surface			Two-layer coating					
	20°	60°	85°	20°	60°	85°	20°	60°	85°
Spruce	2.78	5.23	4.80	3.40	12.25	18.68	22	134	289
Aspen	2.63	5.07	6.06	3.68	15.60	31.68	40	208	423
Beech	2.55	3.83	11.10	5.92	25.42	53.63	132	563	383
Ash	2.75	4.53	8.10	4.18	17.93	34.63	52	296	328
Oak	2.02	3.17	10.22	2.93	11.68	28.13	45	269	175

Based on the results presented in Table 3, surfaces with a two-layer hard wax oil coating are described as matte to semi-gloss (ISO 2813:2014). For different substrates, the gloss unit values have increased to various degrees. The increase was most significant for beech. The least noticeable change was for spruce. Similar minimal changes in colour and glosses of spruce wood treated with oil-wax emulsion were also reported by Janesch *et al.* (2020).

Surface roughness

Table 4 presents the arithmetic mean values of the parameters *Rz* and *RSm*, the variation coefficients, and the accuracy indicators in the three consecutive phases of processing.

Tab. 4 Average values of the roughness parameters after each processing phase, variation coefficients *V*, %, and accuracy indicators *p*, %.

Tree species	Roughness parameter	Average values, µm			Variation coefficient *V*, %			Accuracy indicator *p*, %		
		Initial surface	Single layer coating	Two-layer coating	Initial surface	Single layer coating	Two-layer coating	Initial surface	Single layer coating	Two-layer coating
Spruce	*Ra*	5.68*	5.56	5.02*	5.10*	5.09	6.02*	2.28*	2.27	2.69*
	Rz	43.22	42.96	37.79	10.38	4.74	10.04	4.64	2.12	4.49
	RSm	237.98*	240.98	337.80*	7.69*	15.01	16.62*	3.44*	6.71	7.43*
Aspen	*Ra*	5.67*	5.26	4.48*	5.70*	3.47	6.08*	1.47*	0.90	1.57*
	Rz	41.41	38.82	30.53	6.86	7.03	6.63	1.77	1.81	1.71
	RSm	248.36*	309.77	427.15*	9.49*	8.79	16.04*	2.45*	2.27	4.14*
Beech	*Ra*	5.52*	4.31	3.67*	13.64*	11.04	15.93*	3,52*	2.85	4.11*
	Rz	39.44	28.91	23.20	15.48	9.22	14.89	4.00	2.38	3.85
	RSm	285.92*	431.99	625.75*	12.35*	25.41	25.48*	3.19*	6.56	6.58*
Ash	*Ra*	9.88*	8.95	7.20*	19.55*	19.77	21.64*	5.05*	5.10	5.59*
	Rz	75.76	67.56	52.29	18.83	16.83	19.86	4.86	4.35	5.13
	RSm	481.47*	676.07	769.46*	16.13*	24.61	20.68*	4.65*	6.35	5.53*
Oak	*Ra*	8.36*	7.43	7.32*	19.99*	16.40	22.91*	5.16*	4.24	5.91*
	Rz	69.36	63.03	57.14	26.54	21.62	24.20	6.85	5.58	6.25
	RSm	430.35*	454.86	581.07*	37.85*	17.82	17.88*	9.77*	4.60	4.62*

* Atanasova (2025)

The presented data show that during the formation of a multilayer coating, the arithmetic mean height of the profile *(Ra*) and the maximum height *(Rz*) decrease, while the mean profile element spacing *(RSm*) increases, indicating that the surfaces become less rough. No raising of the wood grains was detected. The increase in the values of the coefficient of variation and the accuracy index after forming the second layer of the coating is impressive. This shows that with the chosen application technology, surfaces with a single-layer coating have a more homogeneous structure than surfaces with a double-layer coating. A similar trend was found for the coefficient of variation and the accuracy indicators for processing the gloss measurements. These results can be explained by the nano-structured surface of the wax emulsion coating (Arminger *et al.,* 2022). The values of the coefficient of variation and the accuracy index for the Rz parameter for aspen wood are an exception to this trend, which can be explained by the fuzzy structure of the aspen surface.

Hydrophobicity

Table 5 presents the changes in the average water contact angle *WCA mean* and the *baseline B* for the initial surfaces, and for the surfaces with a two-layer coating 5 seconds after the start of the test.

Tab. 5 Evaluation of the change in the hydrophobicity of surfaces due to the formation a two-layer coating through the changes in the water contact angle *WCA mean* (°), and the *baseline B* (mm).

Tree species	Average values				Change, %	
	Initial surface		Two-layer coating			
	WCA mean, °	*B*, mm	*WCA mean*, °	*B*, mm	*Δ WCA*	*Δ B*
Spruce	78.742	3.546	81.592	3.308	3.62	-6.71
Aspen	23.957	6.347	101.917	2.858	325.42	-54.97
Beech	61.072	4.193	88.046	3.184	44.17	-24.06
Ash	67.718	3.992	100.108	2.839	47.83	-28.88
Oak	70.675	3.842	98.230	2.830	38.99	-26.34

The presented results show a clearly pronounced hydrophobicity of the treated surfaces. The most significant change is for aspen. The values for spruce have changed the least.

Figure 3 presents the dynamics of the change in the mean water contact angle for the initial surfaces over the course of 30 seconds.

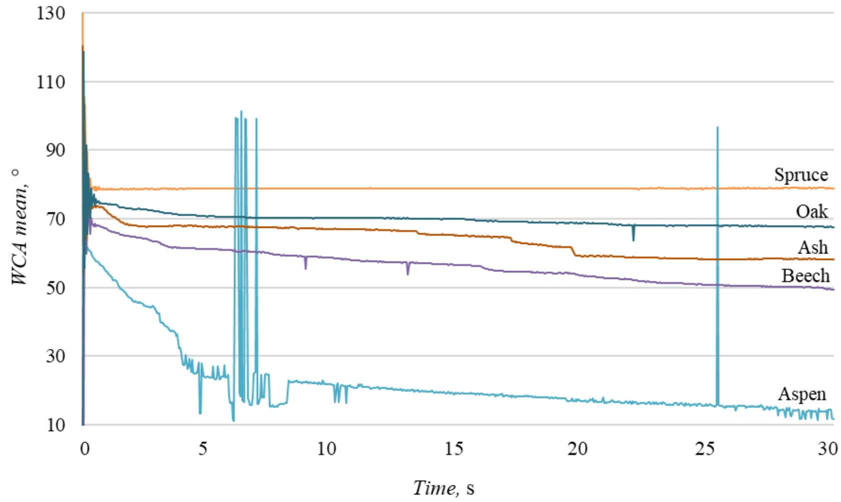

Fig. 3 Time dependence of the static contact angle with water over the course of 30 s for the initial surfaces.

Figure 4 presents the dynamics of the change in the baseline length for the initial surfaces in the first 5 seconds of the measurement.

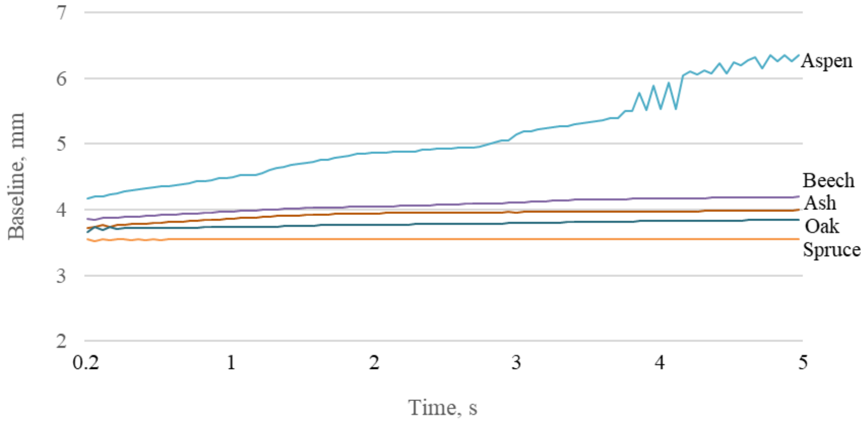

Fig. 4 Time dependence of the baseline over the course of first 5 s of the measurement for the initial surfaces.

The presented graphs show that the decrease in the contact angle upon wetting of the various wood substrates is due first to water penetration into the substrate and then to liquid spreading over the surface. The highest penetration rate occurs in aspen. Given the relatively constant values of the angle for the surface of spruce wood, it can be argued that under the conditions of the measurements, evaporation is negligible. The sharp changes in the curve for aspen wood reflected the presence of partially detached wood grains characteristic of its sanded surface.

Figure 5 shows the dynamics of the change in the mean water contact angle for the treated surfaces over the course of 30 seconds. The changes in the baseline after the first second range from 0.001 to 0.005 mm.

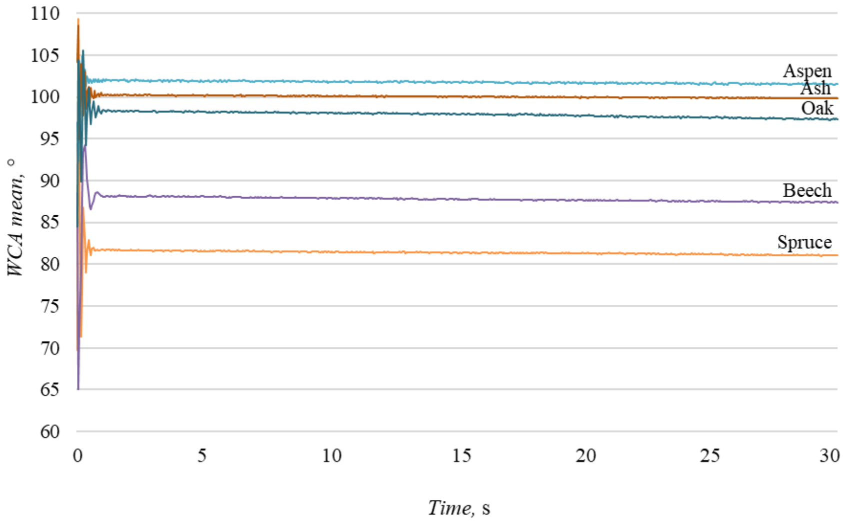

Fig. 5 Time dependence of the static contact angle with water over the course of 30 s for the treated surfaces.

From the graphs presented in Figures 3 and 5, it can be concluded that treatment with hard wax oil homogenizes wood surfaces, limits wetting and water spreading by creating a nano-structured surface, and significantly reduces water penetration into the substrate.

These results extend the conclusions made by Arminger *et al.* (2022) for super-hydrophobic surfaces obtained by treating beech with aqueous wax dispersion, and for oil wax emulsions applied to surfaces of various wood species. They also confirm the influence of surface pretreatment on the size of the *WCA* and on the degree of hydrophobicity achieved.

CONCLUSION

The goal of the presented study was to determine the changes in colour, gloss, hydrophobicity, and roughness of sanded surfaces of spruce, aspen, beech, ash, and European oak after treatment with hard wax oil, as well as the number of layers and the appropriate amount of liquid system applied to obtain an effective coating. The water permeability of the coating was used as a criterion.

It was found that a two-layer coating was optimal. The two-layer coating was classified as unstable in accordance with EN 927-2:2022.

Changes in colour, reductions in roughness, and increases in gloss and hydrophobicity of the treated surfaces were established. No raising of the wood grains was found. In the case of ring-porous wood species, the coating was coloured and had increased texture contrast due to the reaction of the coating system with colouring substances in the substrate. The gloss and hydrophobicity of the coating were influenced by the structure and composition of the substrate. The density of the treated wood also influenced the amount of liquid system needed to form a layer with uniform colour and gloss.

The results of this study can be used to optimize the process of treating different types of wood surfaces with hard wax oil.

REFERENCES

Angelski, D., Atanasova, K., 2021. Water permeability of nano water-based coatings applied on wood. Proceedings of the first international „Salzburg Conference for Smart Materials ", September 16-17, Kuchl, Austria: 79-84.

Arminger, B., Gindl-Altmutter, W., Hansmann C., 2022. Efficient recovery of superhydrophobic wax surfaces on solid wood. European Journal of Wood and Wood Products 80 (2) https://doi.org/10.1007/s00107-022-01793-8

Atanasova, K., Savov, V., 2023. Effect of process conditions on waterborne wood coating performance applied by dipping. Bulletin of the Transilvania University of Brasov, Series II: Forestry, Wood Industry, Agricultural Food Engineering 16(65) Special Issue: 1-22. https://doi.org/10.31926/but.fwiafe.2023.16.65.3.1

Atanasova, K., 2025. The surface roughness of wood after hard wax oil treatment. Bulletin of the Transilvania University of Brasov, Series II: Forestry, Wood Industry, Agricultural Food Engineering 18(67), 55-64 https://doi.org/10.31926/but.fwiafe.2025.18.67.1.4

Bekhta, P., Proszyk, S., Lis, B., Krystofiak, T., 2014. Gloss of thermally densified alder (*Alnus glutinosa* Gaertn.), beech (*Fagus sylvatica* L.), birch (*Betula verrucosa* Ehrh.), and pine (*Pinus sylvestris* L.) wood veneers. European Journal of Wood Products 72 (6), 799-808. https://doi.org/10.1007/s00107-014-0843-3

Bulian, F., Graystone J. A., 2009. Wood Coating: Theory and Practice, First Edition, Elsevier, Amsterdam.

EN 828:2013. Adhesives - Wettability - Determination by measurement of contact angle and surface free energy of solid surface. European Committee for Standardization.

EN 927-1:2013. Paint and varnishes - Coating materials and coating systems for exterior wood - Part 1: Classification and selection. European Committee for Standardization.

EN 927-2:2022. Paint and varnishes - Coating materials and coating systems for exterior wood. Part 1: Performance specification. European Committee for Standardization.

Demirel, G. K., Temiz, A., Demirel, S., Jebrane, M., Terziev, N., Gezer, E. D., Ertas, M., 2016. Dimensional stability and mechanical properties of epoxidized vegetable oils as wood preservatives. Proceedings COST Action FP1407, 2nd Conference on Innovative Production Technologies and Increased Wood Products Recycling and Reuse, 29-30th September 2016, Brno, Czech Republic, pp. 49-50.

Directive 2004/42/EC of the European Parliament and of the Council of 21 April 2004 on the limitation of emissions of volatile organic compounds due to the use of organic solvents in certain paints and varnishes https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2004:143:0087:0096:EN:PDF

EN 927-5:2023. Paints and varnishes - Coating materials and coating systems for exterior wood - Part 5: Assessment of the liquid water permeability.

Guner, F.S., Yagci, Y., Erciyes, A.T., 2006. Polymers from triglyceride oils. Progress in Polymer Science 31:633–670. https://doi.org/10.1016/j.progpolymsci.2006.07.001

OSMO, Product information. http://www.osmobg.com/userfiles/product_files_shared/PI-DIY_HWO_GB_LR-0117_R.pdf POLYX®-OIL ORIGINAL

Humar, M., and Lesar, B., 2013. Efficacy of linseed- and tung-oil-treated wood against wood-decay fungi and water uptake, International Biodeterioration & Biodegradation 85, 223-227. https://doi.org/10.1016/j.ibiod.2013.07.011

ISO 2813:2014. Paints and varnishes - Determination of gloss value at 20°, 60° and 85°

ISO 2431:2019. Paints and varnishes - Determination of flow time by use of flow cups

ISO 21920-2:2021. Geometrical product specifications (GPS) - Surface texture: Profile. Part2: - Terms, definitions and surface texture parameters

Janesch, J., Armingera, B., Gindl-Altmuttera, W., Hansman, C., 2020. Superhydrophobic coatings on wood made of plant oil and natural wax. Progress in Organic Coatings 148:105891 https://doi.org/10.1016/j.porgcoat.2020.105891

Kavalov, A., Angelski, D., 2014. Furniture Technology. Publishing House of the University of Forestry, Sofia, ISBN 978-954-332-115-5 (in Bulgarian).

Kavalov, A., Angelski, D., 2015. Alternative methods for friction smoothing of wood surfaces. Publishing House of the University of Forestry, Sofia, ISBN 978-954-332-137-7 (in Bulgarian).

Koski, A., 2008. Applicability of Crude Tall Oil for Wood Protection. Academic dissertation, University of Oulu, Oulu University Press, Oulu, Finland.

Liu, C., Wang, S., Shi, J., Wang, C., 2011. Fabrication of superhydrophobic wood surfaces via a solution-immersion process, Applied Surface Scence 258(2), 761-765. https://doi.org/10.1016/j.apsusc.2011.08.077

Shi S. Q., Gardner, D. J., 2001. Dynamic adhesive wettability of wood. Wood and Fiber Science 33(1): 58-68.

Spiridon, I., 2020. Extraction of lignin and therapeutic applications of lignin-derived compounds. A review. Environmental Chemistry Letters 18:771– 785. https://doi.org/10.1007/s10311-020-00981-3

Teacă, C.-A., Roşu, D., Mustaţă, F., Rusu, T., Roşu, L., Roşca, I. and Varganici, C.-D., 2019. Natural bio-based products for wood coating and protection against degradation: A Review. BioResources 14(2), pp.4873-4901. https://doi.org/10.15376/biores.14.2.Teaca

Zhang, D., Song K., 2024. Effects of Photoinitiators on Curing Performance of Wood Wax Oil Coating on Wood, Coatings 14(1), 2. https://doi.org/10.3390/coatings14010002

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