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THE SURFACE ROUGHNESS OF WOOD AFTER HARD WAX OIL TREATMENT

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Abstract: *The article presents a study on the surface roughness change of spruce (Picea abies Karst.), aspen (Popolus tremula L.), beech (Fagus sylvatica L.), ash (Fraxinus excelsior L.), and European oak (Quercus robur L.) after treatment with commercial hard wax oil. For the spruce specimens, measurements were also made after a water permeability test, according to CSN EN 927–5:2007, as well as after 72 hours of drying. Before coating application, the surfaces were sanded with P120-grain sandpaper. The second layer of coating was applied without intermediate sanding. A contact surface roughness tester model SJ-210 and a standard Gaussian filter were used for roughness evaluation. It was found that after the application and solidification of hard wax oil, the treated surfaces were less rough but with increased heterogeneity. The substrate properties (structure, density, hardness) had a major impact on the investigated parameter values and changes. The beech wood roughness changed to the greatest extent. The most significant change was observed in the parameter RSm (119 - 35%). The coating was also found to impart form stability to the treated surfaces without being watertight. No grain raising was found.*

Key words: *oil, wax, wood, roughness, bio-based coating.*

1. Introduction

Modern products based on natural oils and waxes are being used more often in interiors due to their protective properties and characteristic appearance. The main part of their composition are non-toxic environmentally friendly renewable vegetable oils, which provide effective protection of the treated wood against insects, fungi, and bacteria, while giving it water-repellent properties and UV resistance [12, 16]. Vegetable oils are triglycerides obtained by glycerol esterification with saturated or unsaturated fatty acids with different saturation percentages [20]. They solidify through oxidation upon contact with air, forming cross-linked structures. To accelerate hardening, siccatives [4] or photoinitiators [21] are included in the liquid system formulation. The oils cover

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the wood surface and occupy the pore structures of the wood, acting as a barrier to water [14]. To improve the natural vegetable oils' performance, they are modified through thermal or chemical methods.

Another approach to increase the oil coatings' performance is to add waxes in the oil system [22]. Wax coatings on wood protect the substrate mainly from lignin degradation and the formation of carbonyl-containing chromophores. The characteristic surface of the coating depends primarily on its composition [19]. A mixed wax emulsion slows the bound water adsorption by the substrate [5]. The phenomenon was explained by the presence of textured surfaces in the inner lumen surface of the wood cells and on the external surfaces of the samples. The observed continuous film consisted of paraffin wax with carnauba wax micropillars embedded in it.

Wood surface roughness is a universal measure of processing efficiency. It can be used for technological control after each processing phase. When coatings are formed, the roughness depends on the substrate structure [21], the treatment before coating [17, 21], and the liquid system formulation [18].

The surface movement after wetting can be observed by the changing values of the roughness parameters. The change trend due to wetting is identical for each wood species, but there are differences in the magnitude of the surface movement [21].

In this regard, the aim of the present study is to determine the change in the surface roughness of different wood species after hard wax oil treatment.

2. Material and Methods

A hard wax oil for interior application manufactured by OSMO, Germany, was used. According to the manufacturer [15], the product contains: sunflower oil, soybean oil, thistle oil, carnauba wax, candelilla wax, paraffin, siccatives, water-repellent additives, and dearomatized white spirit (benzene- free). The product complies with Directive 2004/42/EC on the VOCs limitation (Annex 2 of 2010 [8]). It is suitable for coating wooden floors, such as solid wood, plank, strip, OSB, and cork flooring, as well as furniture surfaces. A two-layer liquid system application is recommended, with an amount of 30-40 g/m^2 per layer applied after the previous layer has solidified. Treated surfaces are easy to maintain and clean. They do not stain when wet.

For the purposes of this study, specimens with dimensions of 150 x 70 x 20 mm were made of spruce (*Picea abies* Karst.) with a density of 460 kg/m^3, aspen (*Popolus tremula* L.) with a density of 600 kg/m^3, beech (*Fagus sylvatica* L.) with a density of 740 kg/m^3, ash (*Fraxinus excelsior* L.) with a density of 750 kg/m^3, and European oak (*Quercus robur* L.) with a density of 770 kg/m^3. Before waxing, the specimens were sanded with P120 grain size sandpaper. The coating was applied with a pad according to the manufacturer's recommendations. The specimens were cured for 24 hours at 23 ± 2°C and 50 ± 5 % R.H. The surfaces were not sanded in between layer applications.

Preliminary experiments were conducted to establish the basic characteristics of the liquid system and the resulting coatings. A flow time of 56 s using a 6-mm flow cup, according to EN ISO 2431:2019 [10], and a system solid content of 65% were determined. The two-layer coating was found to be water permeable according to CSN EN 927 – 5:2006 [7], and was classified as unstable according to CSN EN 927 – 1:2013 [6]. It was discovered that part of the hard wax oil system penetrated deeply into the substrate and caused colour changes, while another part remained on the surface affecting the gloss. Wood grain raising was not detected.

A Mitutoyo SJ-210 surface roughness tester, according to EN ISO 3274:1996 [11], was used for roughness evaluation, at the following settings:

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

Eight measurements were taken of each specimen, perpendicular to the wood grains, in the same evaluation lengths before and after the application of the two-layer coating. In this study, the initial surfaces (before coating) were the sanded surfaces. Measurements for the spruce surfaces were also made after the water permeability test. The following parameters were selected for observation and analysis: arithmetic mean height of the assessed profile (*Ra*), mean profile element spacing (*RSm*), core height (*Rk*), reduced peak height (*Rpk*) and reduced pit depth (*Rvk*) according to EN ISO 21920-2:2022 [9], and the composite parameter *Rpk+Rk+Rvk*.

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

3. Results and Discussion

The average values of the roughness parameters for the initial (sanded) surfaces and for the two-layer coated surfaces of the five wood specimens are presented in Table 1.

The results presented in Table 1 show that after waxing, the values of the parameters *Ra*, *Rk*, *Rvk,* and *Rpk+Rk+Rvk* decreased, and the *RSm* parameter values increased. The *RSm* parameter was most affected. The change for the tree species with different structures (softwood, diffuse porous wood, and ring porous wood) was different:

- in spruce, aspen, and beech, the *ΔR* charge increased as the density increased;
- in ash and oak, *ΔR* decreased as the density increased.

The *Rpk* change does not correspond to this general trend because this parameter was not affected by the substrate structure. The beech wood surface parameter values changed to the greatest extent. This is due to its relatively homogeneous structure, high density, and hardness. The similar values of the researched parameters for the initial surfaces of spruce, aspen, and beech made it possible to evaluate the complex influence of the substrate properties on the two-layer hard wax oil coating parameter values. They also show that in these wood species, the sanded surface profiles were greatly influenced by the tools and modes of the last sanding with the influence of the wood structure being secondary (Table 1, Figures 1 to 3). Similar results were reported by Gurau et al. [13].

Roughness parameter values, variation coefficient V [%], and accuracy index p [%] for the sanded surfaces and for the two-layer coated surfaces of the five wood specimens Table 1

Wood species	Roughness parameter [µm]	Average values		ΔR [%]	Variation coefficient, V [%]		Accuracy index, p [%]	
		Sanded surface	Two-layer coating		Sanded surface	Two-layer coating	Sanded surface	Two-layer coating
Spruce (*Picea abies* Karst.)	$\overline{Ra}$	5.61	5.02	-11	5.10	6.02	2.28	2.69
	$\overline{RSm}$	237.98	337.80	42	7.69	16.62	3.44	7.43
	$\overline{Rpk}$	6.49	8.35	29	13.97	26.00	6.25	11.63
	$\overline{Rk}$	17.66	16.01	-9	3.46	5.36	1.55	2.40
	$\overline{Rvk}$	10.19	7.09	-30	9.42	28.56	4.21	12.77
	$\overline{Rk}+\overline{Rpk}+\overline{Rvk}$	34.34	31.45	-8	5.85	7.3	2.62	3.26
Aspen (*Popolus tremula* L.)	$\overline{Ra}$	5.67	4.48	-21	5.70	6.08	1.47	1.57
	$\overline{RSm}$	248.36	427.15	72	9.49	16.04	2.45	4.14
	$\overline{Rpk}$	6.70	6.85	2	17.87	16.57	4.61	4.28
	$\overline{Rk}$	17.47	14.11	-19	5.37	7.92	1.39	2.04
	$\overline{Rvk}$	10.80	7.10	-34	18.75	10.85	4.84	2.80
	$\overline{Rk}+\overline{Rpk}+\overline{Rvk}$	34.97	28.05	-20	8.78	5.20	2.27	1.34
Beech (*Fagus sylvatica* L.)	$\overline{Ra}$	5.52	3.67	-34	13.64	15.93	3.52	4.11
	$\overline{RSm}$	285.92	625.75	119	12.35	25.48	3.19	6.58
	$\overline{Rpk}$	5.66	5.78	2	19.04	34.09	4.92	8.80
	$\overline{Rk}$	17.31	11.49	-34	14.83	14.41	3.83	3.72
	$\overline{Rvk}$	10.60	5.48	-48	27.02	30.46	6.98	7.86
	$\overline{Rk}+\overline{Rpk}+\overline{Rvk}$	33.57	22.75	-32	17.48	28.58	4.51	4.89
Ash (*Fraxinus excelsior* L.)	$\overline{Ra}$	9.52	6.91	-27	14.64	16.27	3.91	4.35
	$\overline{RSm}$	481.47	741.48	54	16.13	15.83	4,65	4.57
	$\overline{Rpk}$	7.76	7.21	-7	17.42	21.66	4.65	5.79
	$\overline{Rk}$	22.01	15.93	-28	9.59	11.06	2.56	2.96
	$\overline{Rvk}$	34.17	26.10	-23	19.66	24.44	5.26	6.59
	$\overline{Rk}+\overline{Rpk}+\overline{Rvk}$	63.94	49.24	-23	13.12	16.94	3.51	4.53
European oak (*Quercus robur* L.)	$\overline{Ra}$	8.17	7.20	-12	19.07	23.22	5.10	6.20
	$\overline{RSm}$	396.44	463.08	17	25.22	18.47	6.74	4.94
	$\overline{Rpk}$	8.39	8.57	2	24.30	34.22	6.94	9.15
	$\overline{Rk}$	22.05	18.67	-15	13.38	18.55	3.58	4.96
	$\overline{Rvk}$	26.56	25.45	-7	37.14	45.41	9.93	12.14
	$\overline{Rk}+\overline{Rpk}+\overline{Rvk}$	56.99	52.69	-8	23.89	31.07	6.39	8.30

The increase in the *RSm* values in combination with the decrease in the *Rvk* values, as well as other height parameters, means that part of the liquid system remained on the substrate surface and filled the micro irregularities. Similar results were obtained by He et al. [14] and Chen et al. [5]. For softwood and diffuse porous wood, *Rvk* changes to a greater extent than *Rk*, while for ring porous wood, it is the opposite. This means that for ash and oak wood the effect of waxing is greatest in the *Rk* zone (Figure 4 and 5), while for spruce, aspen, and beech the *Rvk* zone is also affected.

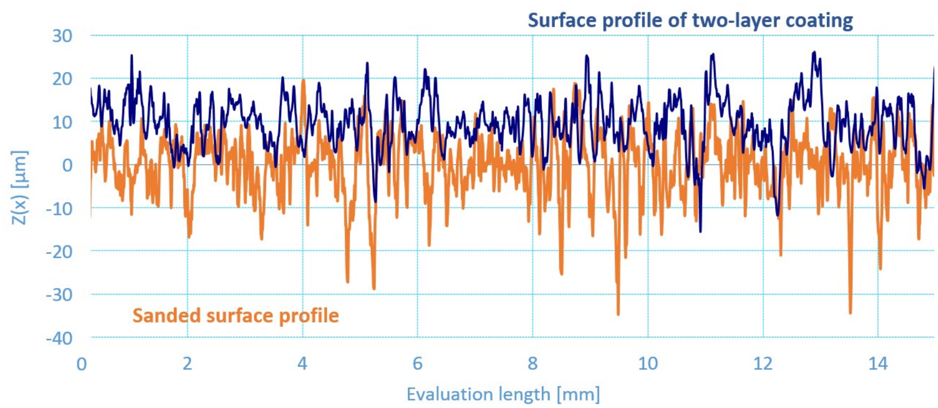

Fig. 1. *Comparison graph of the sanded surface profile and the two-layer coating surface profile on spruce*

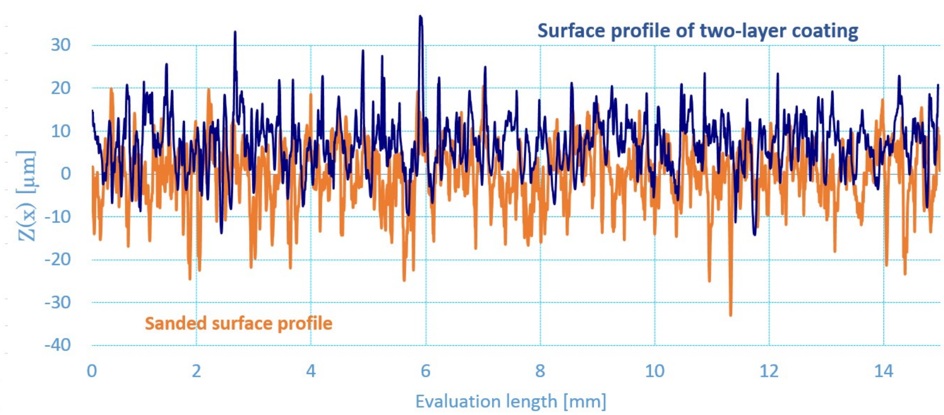

Fig. 2. *Comparison graph of the sanded surface profile and the two-layer coating surface profile on aspen*

In the figures presented, it can be seen that in the case of spruce and diffuse porous wood species, the coating system unevenly filled the micro irregularities, significantly changing the surface profiles (Figures 1 to 3). In ash and oak, the liquid system entered the pores due to their large diameter, and filled parts of them reducing the surface roughness, but the profile remained recognizable (Figures 4 and 5).

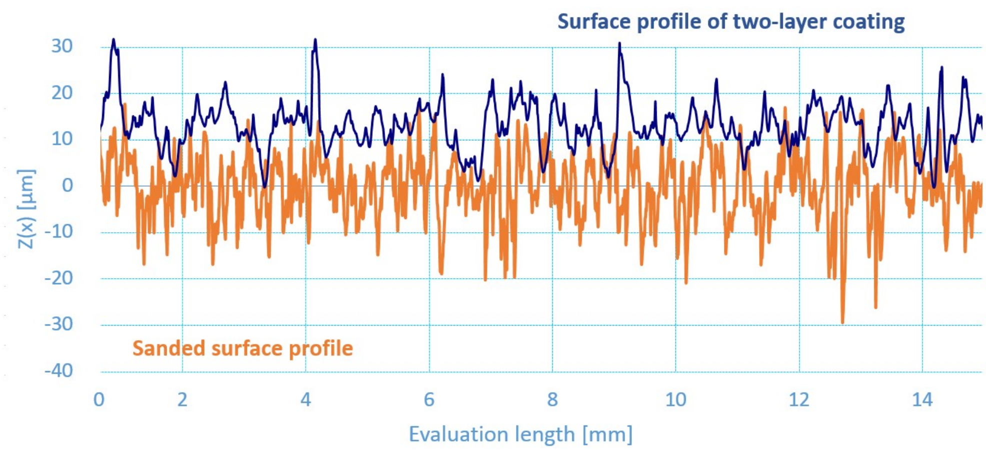

Fig. 3. Comparison graph of the sanded surface profile and the two-layer coating surface profile on beech

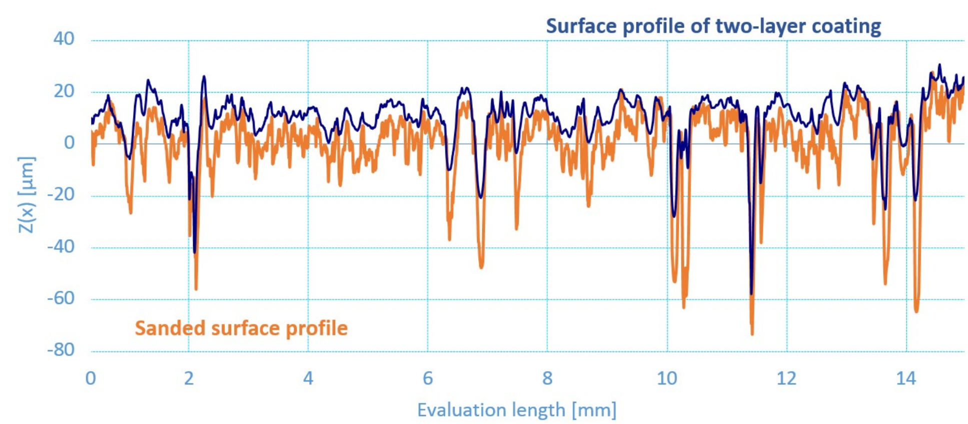

Fig. 4. *Comparison graph of the sanded surface profile and the two-layer coating surface profile on ash*

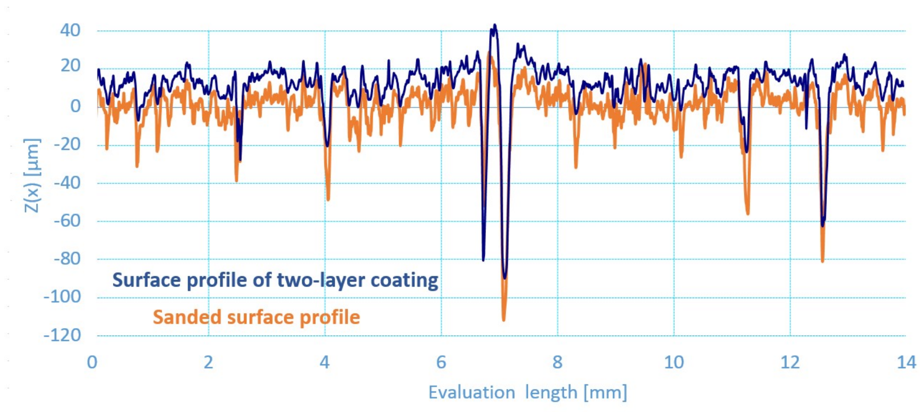

Fig. 5. *Comparison graph of the sanded surface profile and the two-layer coating surface profile on European oak*

For the researched system, as well as for waterborne systems for outdoor application [2], a similar trend of changes in the *Ra*, *Rk,* and *Rpk+Rk+Rvk* parameters was observed. In contrast to waterborne systems, the oil coating parameter values are smaller than the initial surface parameter values, which is an indicator of the absence of grain raising when wooden surfaces are treated with hard wax oil.

The changes in the *Rpk* parameter for spruce were 29%, 2% for diffuse porous wood were, and less than 2% for ring porous wood. At the same time, the accuracy index for two-layer coating for aspen decreased slightly, while for hardwoods and spruce, it increased. In general, the trend of increasing the parameter value dispersion for two-layer coating was valid for all measured parameters. This means that despite the small *Rpk* change as a result of the treatment, the surface non-uniformity increased. This result is consistent with results obtained by Chen et al. [5].

After carrying out a water permeability test (according to EN 927 – 5:2006 [7]), the specimen surfaces kept their good appearance. No stains were found after drying. The results of measuring the researched roughness parameters before and after the water permeability test, as well as after 72 hours of drying at 23 ± 2°C and 50 ± 5% R.H. are presented in Table 2.

The minimal changes found in the values of the investigated parameters during the water permeability test indicate that the hard wax oil created a coating permeable to water and water vapour, which protects the surface profiles from significant changes when exposed to water. Such protection cannot be provided by nano-based acrylic waterborne products classified as stable according to CSN EN 927-1:2013 [1, 6].

When compared with the results of a similar study for a waterborne bio-based system determined to be unstable, [2] it was found that as a result of water absorption during the water permeability test, various roughness parameters were affected, and in a different direction (compared to the results in Table 2).

This means that the mechanism of wood surface protection in the two coatings is different. The relatively rapid decrease in parameter values after 72 hours of drying (Table 2) is an indicator of water entering the wood micro capillaries and not the cell walls. This statement is consistent with a publication by Zhang and Song [22], according to which hard wax oil prevents water from entering the cell walls, thereby limiting grain raising both at the surface and deep within the substrate.

Table 2

Average values and percentage change of the roughness parameters for spruce surfaces before and after the water permeability testing, as well as after 72 hours of drying

Roughness parameter [µm]	Before the test, R_i	After the test, R_p	72 h drying R_{72}	$\Delta R_p = R_i - R_p$ [%]	$\Delta R_d = R_p - R_{72}$ [%]
$\overline{Ra}$	5.37	5.92	5.52	10	-7
$\overline{RSm}$	472.51	645.68	633.81	37	-2
$\overline{Rbk}$	9.47	10.74	9.81	13	-9
$\overline{Rk}$	16.10	17.65	16.79	10	-5
$\overline{Rvk}$	7.98	8.63	7.76	8	-10
$\overline{Rk}+\overline{Rpk}+\overline{Rvk}$	33.55	37.03	34.36	10	-7

4. Conclusions

In the presented study, the roughness changes of spruce, aspen, beech, ash, and oak surfaces after treatment with hard wax oil were established and analysed. For the spruce specimens, measurements were also made after a water permeability test, according to CSN EN 927-5:2006 [6], as well as after 72 hours of drying. Before the coating application, the surfaces were sanded with *P120*-grain sandpaper. The second layer of coating was applied without intermediate sanding. It was found that after hard wax oil application and solidification, the treated surfaces were less rough but with increased heterogeneity. The beech wood roughness changed to the greatest extent. The type of changing roughness parameters, their values, and the degree of change were determined by the wood substrate characteristics (structure, density, hardness). The *RSm* parameter changed most significantly. It was also found that the coating imparts form stability to the treated surfaces without being watertight. No grain raising was found.

It was confirmed that the wood substrate hardness influences the degree of roughness change due to sanding.

This research may contribute to increasing the use of bio-based coatings in interiors.

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