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STABILITY TESTING OF COATING MATERIALS PROPOSED FOR RENOVATION OF SURFACE FINISH WINDOWS

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ABSTRACT

Several transparent coating materials were offered and applied on spruce and oak wood to renovate the surface treatment of wood windows. There were carried out experiments studying the colour stability, water resistance, and surface treatment defects on these systems after ageing. The testing of colour stability of the wood surface treated with transparent coating materials resulted in the finding that the tested surface treatment variants differed in their colour stability. The best colour stability and water resistance were found in the coating system consisting of a modified colourless impregnation material prepared based on linen seed oil and a semi-matt top glazing lacquer prepared from natural oils and waxes with anti- UV factor. Based on the experimental results, there was chosen the most appropriate configuration for the coating system intended for renewal of the surface treatment of windows originally treated with oil or alkyd coating materials. There was also proposed a system for the renovation of windows formerly treated with water-soluble coating materials.

Key words: windows, surface treatment restoration, accelerated ageing, photodegradation, colour stability, gloss, resistance to water

INTRODUCTION

In an outdoor environment, surfaces of almost all materials are exposed to different types of radiation, moisture, heat and emissions-induced effects acting in mutual interactions, under these conditions, the surface is subject to gradual degradation. The surface degradation issue is especially relevant in the case of wood. A natural organic material, very specific in comparison with other natural ones. In the case of wood products impacted by the above-discussed factors, preserving the original physical and aesthetical properties of the surface is given a high priority. Consequently, the issue has been granted particular attention, as it is evident from hundreds counting published papers, the results of which have been summarised in COGULET *et al.* (2018) and KROPAT *et al.* (2020). These works deal with wood surface degradation, it is causes and consequences, and with wood surface protection methods proposed to eliminate these degradation effects.

The most common wood protection against negative effects of environmental factors is its surface treatment (ST) with coating materials (CM). An appropriate ST should hinder as much as possible, the penetration of UV radiation to lignin and other wood constituents, slower down, in this way, the photodegradation of the surface wood layers and protect the wood surface against adverse impacts of water and emissions. In addition, several important functions are to fulfil. The practice, however, shows that the wood surface treatment itself is ageing with time because of environmental factors.

The first symptoms of degradation of a wood surface treated with coating materials are visible on the surface treatment quality, especially on altered visual properties such as colour and gloss, and later also on the overall (SAHA *et al.* 2013a, OLSSON *et al.* 2014, KÚDELA *et al.* 2016, PAVLIČ *et al.* 2020, KRŽIŠNIK *et al.* 2020).

It is necessary to separate between transparent and pigmented coatings. Several works (REINPRECHT and PÁNEK 2013, KÚDELA and KUBOVSKÝ 2016, COGULET *et al.* 2018, KÚDELA *et al*. 2018, KÚDELA 2020, KRŽIŠNIK *et al.* 2020) imply that pigmented CM have better resistance to ageing compared to transparent CM. Pigments can protect the wood surface against UV radiation. During the advanced phases of the ageing process, chalking is possible also in the case of pigmented coatings. This process causes the formation of tiny, chalk layers on the coating material surface, thereafter, water and wind remove these layers step by step, and the CM surface becomes thinner and rougher (COGULET *et al.* 2018).

Customers show preferences for transparent coatings preserving the wood's natural look and emphasising wood texture. Today, the coating materials applied on wood surfaces are expected to have the necessary longevity in fulfilling their protective and aesthetical functions. In this context, the coating materials intended for outdoor performance should meet high demanding requirements. The ST longevity is prolonged by targeted modification, of equally substrates and coatings, with different additives, nanoparticles acting on organic and inorganic bases (SAHA *et al.* 2013a, b, LANDRY and BLANCH 2012, KOCAEFE and SAHA 2012, WAN *et al*. 2014, GIRARDI *et al*. 2014, REINPRECHT *et al*. 2018, NOVÁK *et al*. 2019, KÚDELA *et al*. 2020, KÚDELA 2020, NOWROUZI *et al*. 2021, SLABEJOVÁ *et al.* 2020). Important is also protection concerning the structure performance (DONDERS 2014). Under outdoor conditions, the coating layer thickness has also an important role (SVOCÁK 2018, PAVLIČ *et al.* 2020).

In the case of transparent coatings, the discolouration of the treated wood surface may be caused by the photodegradation of these coatings as well as by the photodegradation of the wood surface substrate. Gloss alterations indicate only the degradation of the coating solely (OLLSON *et al*. 2014).

Windows are specific wood building elements. They represent important construction components for the building architecture equally as for the building performance. As boundary surfaces, windows separate and at the same time integrate the outdoor and indoor environment (JOCHIM *et al*. 2009). From the viewpoint of architecture, windows also represent an aesthetical accent finalizing the building outlook. Therefore, the surface treatment in windows is to be concerned very carefully. In the case of wood windows, the current research on their surface treatment is mainly oriented toward outdoor performance, as the external environment may have considerable negative impacts on the ST quality. There has been emerged an evident necessity to seek novel, best-fitted surface treatment possibilities in the production of new windows, but also to consider the restoration of the former surface treatment in just existing ones.

The aim of this work was to perform experimental testing of selected coating material types, concerning their colour stability and resistance to water during an accelerated ageing process. The results should contribute to the knowledge about renovation of window surface treatment and provide a base for proposing suitable coating materials for renovation of surface treatment of wood windows already serving in existing buildings and houses.

MATERIAL AND METHODS

Following the main research goal, the first phase represented a survey on windows of specified buildings and houses. The survey unveiled that the surface treatments degraded to different extents depending on different windows. The most advanced degradation was found on the windows exposed from south to west-south, especially in their bottom parts, namely on horizontal frames mostly exposed not only to solar radiation but also to the downward running water from rain and other precipitation. In the other cases, the ST degradation was much less dramatic, there were also several windows with ST preserved satisfactorily. Important as the lore of environmental factors. The examined windows were subject for 20 years to degrading outdoor conditions.

In cooperation with the firm Renojava Ltd., we developed novel coating materials intended for renovation of the windows in concern. The systems were applied on spruce and oak wood. The test specimens were 70 mm × 90 mm in size, with a thickness of 10 mm. Three tested surface treatments were applied on spruce, and three on oak wood (Table 1). Table 1 shows that the oak specimens were without the prime layer. For both wood species, the composition of the upper coatings was the same. The specimen surfaces were milled, and the coatings were applied with a brush.

Tab. 1 Coating materials proposed for surface treatment of spruce and oak wood.

Surface treatment	Primer coating	Hue	Top coating	Hue
		Spruce		
ST-1	1 × CM-1	colourless	1× CM-3	Swiss Chalet – Bohme
ST-2	1 × CM-1	colourless	1× CM-4	Oak light
ST-3	1 × CM-2	colourless	1× CM-5	Swiss Chalet – Bohme
		Oak		
ST-1´	no	–	2× CM–3	Swiss Chalet – Bohme
ST-2´	no	–	2× CM–4	Oak light
ST-3´	no	–	2× CM–5	Swiss Chalet – Bohme

CM-1 – colourless impregnation material, based on linen seed oil, effective against wood-boring insects and wood colouring fungi, highly hydrophobic, with a 27.8% content of octo-active zinc, 0.5% of dichlorfluoramide, leadless siccatives and water repellent additives.

CM-2 – oil emulsion on water base, applied directly on wood or on the primer, permeable for water vapours from the substrate, contains protective additives against biological pests

CM-3 – tung oil (China nut oil)

CM-4 – semi-matt top coating based on natural oils and waxes, with a UV factor 12, permeable for water vapours from the substrate.

CM-5 – oil emulsion on water base, applied directly on wood or on the primer coating

Accelerated ageing

Experiments testing the accelerated ageing impacts were carried out using a xenotest Q-SUN Xe-3-HS. From each group of surface-treated specimens, five specimens were selected and exposed to accelerated ageing in the directly above-mentioned equipment. The accelerated ageing conditions (parameters) in the xenotest were set according to the Standard ASTM G 155. The accelerated ageing regime simulated outdoor conditions, using the so-called „wet mode“ in which the wood is beside radiation-exposed also to rainfall. The radiation intensity was adjusted to a value of 0.35 $W \cdot m^{-2}$ at a radiation wavelength of 340 nm (Table 2). This value represents the annual mean for the moderate climatic zone. One accelerated ageing cycle comprised 120 minutes, in two steps (Table 2).

The overall ageing process duration was 700 hours, representing altogether 350 cycles. In all cases, there were examined variations in colour space CIE $L^*a^*b^*$, gloss, and resistance to water during the ageing process. After the process had finished, there was also examined the occurrence of defects on surface-treated specimens.

Tab. 2 Accelerated ageing conditions set by the Standard ASTM G 155.

Step	Mode	Radiation intensity (W/m²)	Black panel temperature (°C)	Air temperature (°C)	Relative air humidity (%)	Time (min)
1	Radiation	0.35	63	48	30	102
2	Radiation + spraying	0.35	63	48	90	18

Colour and gloss measurement on treated wood surface

Colour coordinates L^*, a^*, b^* were measured on all specimens, with a spectrophotometer Spectro – guide 45/0 gloss by BYK – GARDNER GmvH, working with spectral reflectance, wavelengths ranging 400–700 nm (STN EN ISO/CIE 11664-1).

On all the tested specimens, the colour coordinates were measured in the same way: before the ageing, and after 50, 100, 200, 300, 400, 500, 600 and 700 ageing hours. For each time interval, on each specimen, the measurements were performed at 10 measuring spots randomly chosen at least 10 mm from the specimen´s edge, representing together 50 measurements on each test series.

The differences in the particulate colour coordinates ΔL^*, Δa^*, Δb^* generated due to different irradiation modes, and the total colour difference ΔE^* were determined according to the following equations:

$$\Delta L^* = L_2^* - L_1^* \tag{1}$$

$$\Delta a^* = a_2^* - a_1^* \tag{2}$$

$$\Delta b^* = b_2^* - b_1^* \tag{3}$$

$$\varDelta E^* = \sqrt{(\varDelta L^*)^2 + (\varDelta a^*)^2 + (\varDelta b^*)^2}, \tag{4}$$

where the index “1” indicates the colour value of the surface-treated wood before ageing and the index “2” indicate the corresponding value after the ageing.

The gloss variation in the surface-treated specimens was examined with a gloss meter BYK-GARNER Micro-Tri-Gloss 20/60/85-degree Gloss Meter performing at three angles: 20°, 60°, and 85° (STN EN ISO 2813). Analogically to colour, on all specimens, the gloss was also measured before ageing and at the same ageing intervals as colour. The number of measurements performed on each specimen was 10.

There was also visually assessed ST quality before and after ageing, based on the observed defects (bubbles, craters, cracks, and similar), with the aid of a digital microscope Dino-Lite EDGE.

RESULTS AND DISCUSSION

Assessment of colour changes generated in surface-treated wood during the ageing process

The three concerned coating systems applied on spruce wood looked very similar in colour. In all three cases, the coating systems were transparent, consisting of two layers. Nevertheless, the results of the one-way variance analysis confirmed significant colour differences between the systems. With progressing time, these differences were getting more and more pronounced, as the result of qualitative and quantitative changes in the colour coordinates. The ageing also caused significant colour changes within the individual sampling series. In each tested series, however, the discolouration followed its own rate. The results of two-way variance analysis confirmed the significant influence of the two tested factors (the coating material type and the ageing time) and their interactions

The basic statistical characteristics for the colour coordinates L^*, a^* and b^* corresponding to the ageing intervals are in Table 3. The differences in the colour coordinates ΔL^*, Δa^* and Δb^* and the total colour difference ΔE^* for the tested coating materials applied on spruce wood are illustrated in Fig. 1.

Analysing the results in Table 3, we can see very small differences in average lightness L^* on specimens' surface treated with ST-1, ST-2 and ST-3, with the individual lightness values ranging from 55 to 61. The lightness was mainly affected by top coatings. This statement is backed up by the fact that there were no significant variant-dependent differences between ST-1 and ST-3 despite these two consisting of different primers but the same top coating (Table 1), while ST-1 and ST-2 consisting of the same primer but different top coatings a significant difference was confirmed.

In all the cases, the lightness values decreased with increasing irradiation time, up to the end of the ageing process. In the case of ST-1 there was a rapid decrease in L^* observed during the initial 300 hours, followed, however, by a slight increase later. After 700 ageing hours, the ΔL^* differences between the individual treatment variants were found minimum. In all three cases, the coordinates a^* and b^* values were significantly higher in wood treated with coating materials before the ageing than in the uncoated wood. This means that the wood surface treatment enhanced the saturation of red and yellow colours. In the ageing process, these coordinates varied for individual surface treatment types, not only quantitatively but also qualitatively (Fig. 1). The major change in the two coordinates was observed on the specimen series with surface treatment ST-1, with the values of both coordinates decreasing until the end of the ageing process. Due to decreasing saturation with red and yellow, the values of the to colour coordinates were shifted to the achromatic range. Also, the colour hue was altered.

Tab. 3 Basic statistical characteristics of colour coordinates L^*, a^* a b^* for the tested surface treatments applied on spruce wood (number of measurements for each series: n = 50).

Surface treatment	Colour coordinates	Basic statistical character.	Time of accelerated ageing [hours]								
			0	50	100	200	300	400	500	600	700
ST-1	L^*	$\bar{x}$	60.87	57.64	56.17	54.21	52.10	52.54	53.02	53.37	53.76
		SD	3.20	2.65	2.16	1.96	1.82	2.59	2.75	3.07	3.30
	a^*	$\bar{x}$	14.71	15.26	16.51	15.34	13.05	10.70	9.61	8.47	7.63
		SD	1.27	0.92	0.60	0.59	0.69	0.94	0.77	0.96	0.93
	b^*	$\bar{x}$	36.14	34.81	33.62	29.78	25.62	23.55	22.52	21.63	20.62
		SD	1.76	2.66	1.51	1.39	1.15	1.44	1.09	0.92	0.93
ST-2	L^*	$\bar{x}$	61.33	59.82	58.93	57.67	56.84	56.27	55.91	55.79	55.45
		SD	2.39	2.29	2.70	2.10	2.29	2.25	2.08	2.32	2.13
	a^*	$\bar{x}$	12.77	12.26	13.03	14.02	14.63	14.92	15.07	15.08	14.98
		SD	0.80	0.74	0.82	0.66	0.72	0.84	0.71	0.76	0.83
	b^*	$\bar{x}$	32.31	31.07	31.83	33.04	33.28	33.03	32.74	32.53	31.91
		SD	0.69	0.69	0.78	0.97	1.17	1.25	1.00	1.07	0.93
ST-3	L^*	$\bar{x}$	55.11	53.03	52.11	51.76	50.13	49.43	49.04	47.94	46.94
		SD	1.68	1.25	1.64	1.10	1.15	1.09	1.45	1.37	1.31
	a^*	$\bar{x}$	14.74	15.05	15.52	15.79	16.03	16.04	15.97	15.67	14.95
		SD	0.52	0.34	0.36	0.24	0.24	0.29	0.43	0.69	0.97
	b^*	$\bar{x}$	35.12	33.92	33.64	33.29	31.81	30.98	30.39	28.87	27.25
		SD	1.17	1.00	1.32	1.04	1.18	1.29	1.77	2.03	1.99

In this case, the changes in the three coordinates L^*, a^* and b^* were reflected in the overall colour difference ΔE^* (Fig. 1). As early as after 100 initial ageing hours, there could be detected a noticeable colour change, as ΔE reached a value of six. After 300 ageing hours, ΔE reached 12, which ALLEGRETTI *et al.* (2009) evaluate as a completely new colour compared to the original one. Prolonging the ageing time, the colour difference was even more pronounced. Other noticeable changes, the second ones in order, were observed in the case of the third specimen series (ST-3). After finishing the ageing process, the total colour difference values approached 12, indicating that the colour alteration in this surface treatment mode was between the degrees 5 and 6, which means a substantial colour variation or a completely new colour.

The most stable specimen series was found that treated with ST-2. Smaller changes in all three colour coordinates were also responded to by lower values of the total colour difference ΔE^* (Fig. 1). The overall colour change degree during 700 ageing hours varied from 1 to 4. This is evaluated as a small colour difference up to a difference detectable using a medium-quality filter. The tested wood surfaces before the ageing process and after 700 ageing hours are illustrated in Fig. 2.

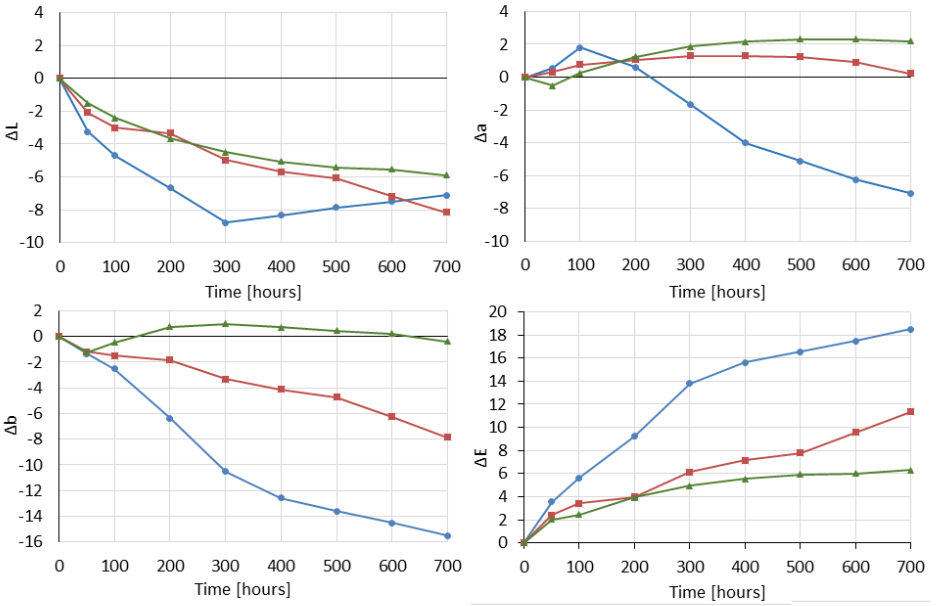


Fig. 1 Differences in colour coordinates ΔL^*, Δa^* and Δb^* and the total colour difference ΔE^* during accelerated ageing of spruce specimens treated with the tested coating systems.

ST-1 ST-2 ST-3

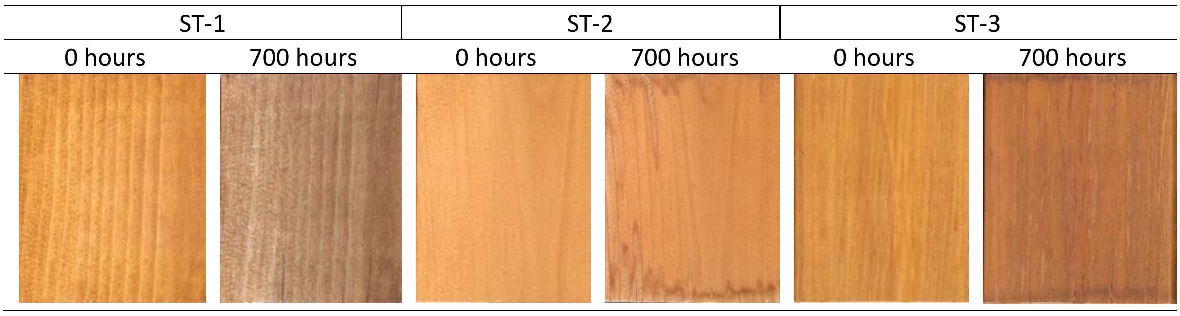


Fig. 2 Surfaces of spruce wood specimens before ageing and after 700 ageing hours. The specimen surfaces were coated with the coating systems described in Table 1.

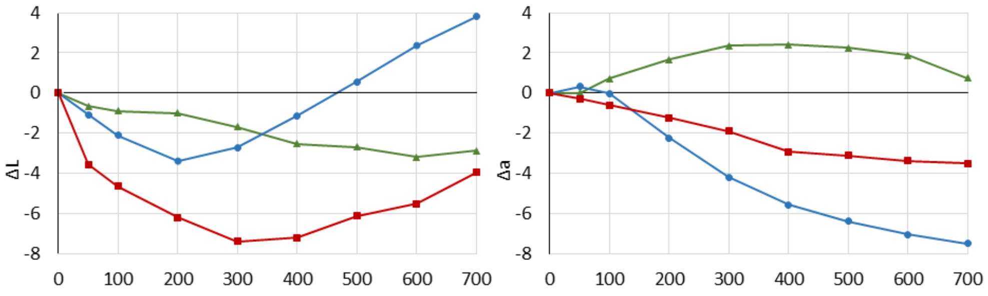
The surface of the tested oak wood was treated with the same oil and glazing/staining coatings as the spruce wood but without any impregnation primer. For this reason, there were applied two top coating layers. The basic statistical characteristics for the colour coordinates

L^*, a^* and b^* linked to the individual ageing intervals are in Table 4. The individual ST variants showed colour differences between the surface-treated spruce and oak specimens. This is due to the substrates, differing the structure, chemical composition, and natural colour itself. In all three cases, after the surface treatment, the lightness of oak specimens was higher than spruce ones.

Also in oak specimens, the detected colour differences depended on the surface treatment type, and these differences were more pronounced with ageing duration. There was confirmed that the photodegradation of the tested colour coatings applied on oak wood had different rates in different coating materials. The major discolouration was observed in the case of ST-1´ (Fig. 3). The changes in the three colour coordinates ΔL^*, Δa^* and Δb^* generated during ageing were qualitatively like the corresponding changes obtained in spruce (Fig. 3). In the case of oak wood, however, these changes were smaller, and this was also reflected in the size of the overall colour difference ΔE^* (Fig. 3). After 700 ageing hours, the ΔE^* value was 12, representing the boundary value between the degrees 5 and 6.

Table 4 Basic statistical characteristics of colour coordinates L^*, a^* a b^* for the tested surface treatments applied on oak wood (number of measurements for each series: n = 50).

Surface treatment	Colour coordinates	Basic statistical character	Time of accelerated ageing [hours]								
			0	50	100	200	300	400	500	600	700
ST-1´	L^*	$\bar{x}$	51.02	49.94	48.89	47.63	48.30	49.88	51.59	53.39	54.84
		SD	2.60	2.01	2.09	2.66	2.64	2.87	2.78	3.11	3.73
	a^*	$\bar{x}$	13.50	13.81	13.48	11.26	9.31	7.94	7.11	6.44	5.99
		SD	0.67	0.55	0.45	0.52	0.81	0.62	0.47	0.47	0.52
	b^*	$\bar{x}$	29.24	30.69	29.17	24.60	22.51	21.57	21.24	20.87	20.57
		SD	1.97	1.41	1.45	1.60	1.30	1.33	1.21	1.03	1.01
ST-2´	L^*	$\bar{x}$	50.59	49.94	49.68	49.59	48.89	48.06	47.90	47.40	47.70
		SD	1.87	1.25	1.54	1.10	1.15	0.92	1.13	1.51	1.74
	a^*	$\bar{x}$	13.17	13.18	13.89	14.84	15.52	15.58	15.41	15.05	13.90
		SD	0.47	0.22	0.28	0.22	0.35	0.39	0.58	0.78	1.04
	b^*	$\bar{x}$	28.11	28.03	28.89	29.68	29.45	28.71	28.35	27.27	25.82
		SD	1.01	1.05	1.11	0.93	1.02	0.97	0.99	1.07	1.16
ST-3´	L^*	$\bar{x}$	52.00	48.44	47.36	45.78	44.60	44.80	45.87	46.47	48.04
		SD	1.33	1.09	1.08	1.21	1.32	2.02	2.52	2.80	2.81
	a^*	$\bar{x}$	12.01	11.73	11.39	10.77	10.11	9.07	8.88	8.63	8.48
		SD	0.28	0.28	0.53	0.77	0.91	0.54	0.63	0.52	0.36
	b^*	$\bar{x}$	28.47	25.67	25.63	23.54	21.88	21.14	21.91	22.25	23.35
		SD	0.95	1.05	1.19	1.29	1.34	1.72	1.96	2.05	2.05



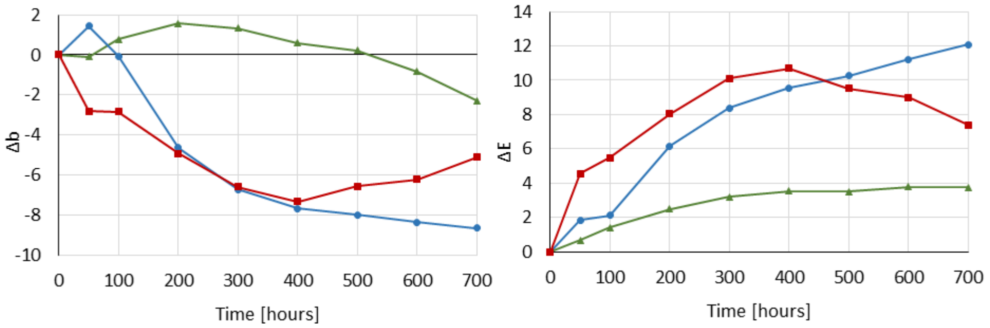


Fig. 3 Differences in colour coordinates ΔL^*, Δa^* and Δb^* and the total colour difference ΔE^* during accelerated ageing of oak specimens treated with the tested coating materials.

ST-1´ ST-2´ ST-3´

The oak series ST-3´ also exhibited significant colour changes. The courses of the individual colour coordinates were different qualitatively (Fig. 3).

The oak wood specimen series coated with the glazing lacquer applied in two layers (ST-2´) displayed the best stability from among all the series tested. The lightness decreased moderately with progressing accelerated ageing duration. In this case, however, this change was the smallest compared to the other ones. There were only very small changes in the colour coordinates a^* and b^* during ageing (Fig. 3). After 700 ageing hours, the ΔE^* value in the case of ST-2´ was 4, on average. ALLEGRETTI *et al.* (2009) has assigned this value to the colour change degree 4. We suppose this enhanced resistance to photodegradation thanks to a UV filter with a UV factor 12 admixed into the coating material.

These colour alterations were also detectable visually on specimens illustrated in Fig. 4. The colour variation occurring in the ageing of transparent surface treatments applied on spruce and oak wood is in accordance with OLLSON *et al.* (2014) who declare that these changes may be induced by photodegradation of the solid films only equally as by the degradation of the wood substrate alone.

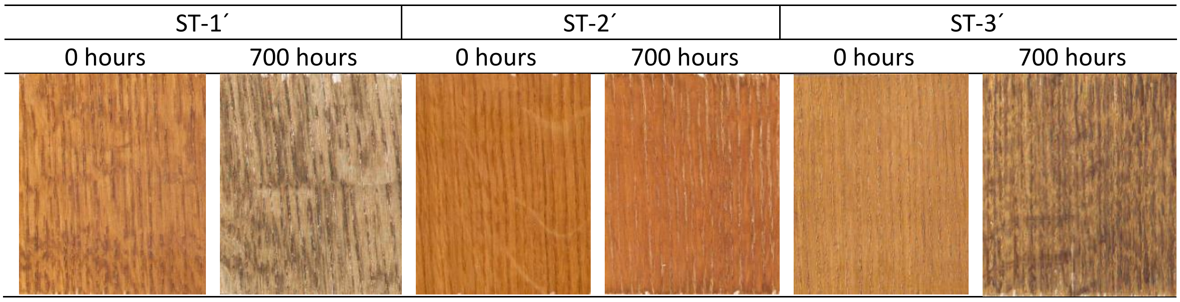


Fig. 4. Surfaces of oak wood specimens before ageing and after 700 ageing hours. The specimen surfaces were coated with the coating materials described in Table 1.

Assessment of gloss before and after ageing

The gloss was measured at three light incidence angles: 20°, 60° and 85°. The gloss values were low; therefore, the results were evaluated only for the angles 60° and 85°. The average gloss values measured on the spruce wood surface treated with the tested coating materials, together with additional statistical characteristics, are in Tables 5 and 6.

The surface treatments ST-1 and ST-3 can be classified as matt, as the gloss numbers measured at 60° were lower than 8, and at 85° they were lower than 20. In the case when the gloss numbers measured at 60° are lower than 30, gloss measuring geometry at 85° is recommended (LIPTÁKOVÁ *et al.* 2000). The mat look was getting more evident with ageing.

In terms of gloss, the two types of surface treatment (ST-2, ST-2´) applied on spruce and oak wood (Table 5 and 6) can be classified to the category of semi-gloss surface treatments.

In these treatments, the gloss was continually decreasing overall ageing time. As early as after 100 or 200 ageing hours, these surface treatments were found matt. The gloss values measured at 85° exhibited a characteristic higher variability. According to the findings reported by OLSSON *et al*. (2014), the gloss alteration appears only due to the structural changes in the coating alone. Consistently, our results imply that there was certain degradation of surface layers of the coating material during the ageing process.

Table 5 Experimentally measured gloss values on the tested surface-treatment types applied on spruce wood; before ageing and after finishing the ageing process. (n= 50).

Gloss values measured at 60°									
Basic statistical character.	before ageing	after 50 hours	after 100 hours	after 200 hours	after 300 hours	after 400 hours	after 500 hours	after 600 hours	after 700 hours
ST-1									
$\bar{x}$	4.5	4.2	4.2	3.9	3.9	3.9	4.0	3.8	3.8
SD	0.8	0.5	0.4	0.5	0.5	0.5	0.5	0.6	0.7
ST-2									
$\bar{x}$	28.2	14.9	12.3	9.5	8.3	7.5	6.8	6.7	6.5
SD	3.5	1.3	1.0	0.8	0.8	0.8	0.7	0.7	0.7
ST-3									
$\bar{x}$	4.1	3.8	3.6	3.6	3.6	3.5	3.6	3.4	3.4
SD	0.7	0.6	0.4	0.4	0.3	0.3	0.3	0.3	0.4
Gloss values measured at 85°									
ST-1									
$\bar{x}$	3.5	4.7	5.1	4.8	4.5	4.4	4.4	3.9	3.9
SD	1.1	1.0	1.0	0.9	0.8	1.0	0.7	0.8	0.7
ST-2									
$\bar{x}$	43.3	28.3	25.1	19.1	16.5	14.7	13.3	12.7	12.2
SD	10.2	5.8	5.0	3.8	3.2	2.7	2.7	2.8	2.5
ST-3									
$\bar{x}$	5.9	6.2	6.0	6.4	6.4	6.4	6.1	5.7	5.9
SD	2	2.1	1.9	1.8	1.7	1.7	1.6	1.8	1.7

Table 6 Experimentally measured gloss values on the tested surface-treatment types applied on oak wood; before ageing and after finishing the ageing process. (n= 50).

Gloss values measured at 60°									
Basic statistical character..	before ageing	after 50 hours	after 100 hours	after 200 hours	after 300 hours	after 400 hours	after 500 hours	after 600 hours	after 700 hours
ST-1′									
$\bar{x}$	3.0	1.8	1.8	1.7	2.2	1.8	1.8	1.8	2.4
SD	0.4	0.2	0.2	0.1	0.2	0.2	0.2	0.2	0.2
ST-2′									
$\bar{x}$	25.8	10.1	8.1	6.0	6.2	5.0	4.3	4.1	4.4
SD	3.7	1.2	0.9	0.6	0.6	0.3	0.3	0.4	0.4
ST-3′									
$\bar{x}$	4.5	2.8	2.8	2.7	3.0	2.5	2.5	2.4	2.8
SD	0.4	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.1
Gloss values measured at 85°									
ST-1′									
$\bar{x}$	5.9	1.2	1.0	0.9	3.2	0.6	0.6	0.6	2.9
SD	1.6	0.3	0.3	0.2	0.5	0.1	0.2	0.2	0.5
ST-2′									
$\bar{x}$	43.5	11.4	9.1	8.4	14.6	5.4	3.7	4.2	9.4
SD	8.2	2.9	1.5	1.6	2.3	1.3	1.6	2.7	1.4
ST-3′									
$\bar{x}$	7.9	0.9	0.9	0.8	5.3	0.8	0.8	0.7	4.5
SD	1.2	0.3	0.3	0.3	0.7	0.3	0.3	0.2	0.8

Resistance of the tested surface treatment types to water

The resistance of the studied surface treatments to water was tested in an accelerated ageing process, using a xenotest, simulating rainfall. The wetting of wood surfaces at different ageing intervals is documented in Fig. 5. Figure 5 shows ST-1 as the least hydrophobic. In this case, the water spread over the surface easily. The treatment ST-3 was more resistant against liquid water, this resistance, however, decreased with the ageing time. The highest water resistance was observed in spruce wood finished with a glazing coating (ST-2). After the „rain“, the water was maintained on the specimen surface in form of isolated drops, with a contact angle of 90°, or more. The surfaces treated with ST-3 were relatively resistant against water but not to such an extent than in the former case. The same was also true for the surface treatment types applied on oak wood.

Ageing process progressing, all tested specimen surfaces exhibited impaired water resistance. After 700 ageing hours, the most hydrophobic surfaces were those coated with a glazing lacquer (ST-2, ST-2´). The differences in wetting of surface-treated wood subject to ageing are directly backed up with the wood surface degradation (Landry a Blanchett 2012, Saha *et al.* 2013a). Therefore, we can declare, based on the small changes in the contact angle values that the least serious coating degradation was obtained in the case of ST-2 and ST-2´.

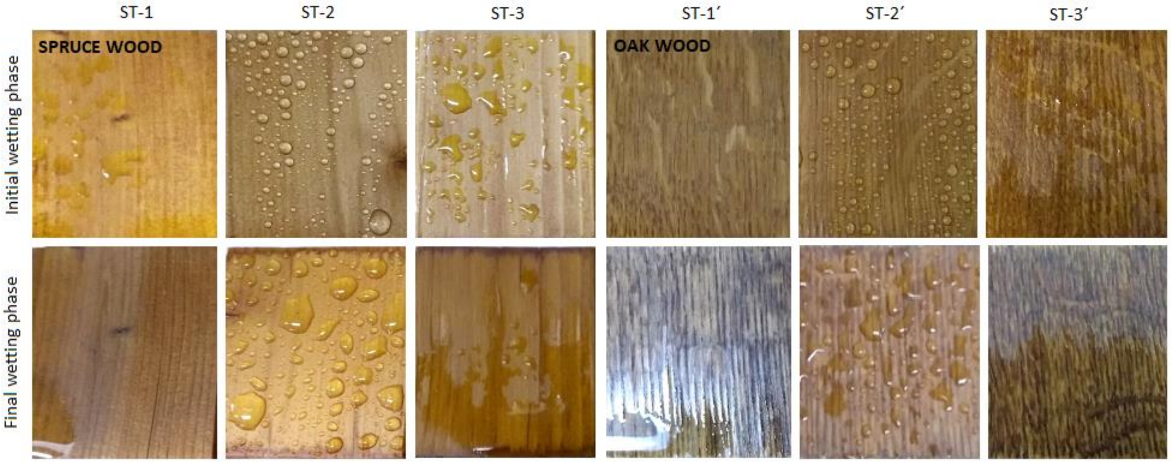


Fig. 5 Water wetting of wood surfaces treated with the tested coating materials, initial and final ageing phase.

Assessment of surface treatment quality after ending the accelerated ageing process

Ageing-induced effects impacting the surface treatment quality were assessed based on the detected defects (cracks formation, coating peeling-off). There we inspected the frequency and size of defects in ST. These defects were evaluated visually with a naked eye and with the aid of a digital microscope.

As early as immediately after the specimens’ surface treatment, the coated surfaces exhibited presence of microbubbles, craters and similar. These were generated in the process of the coating application on the wood substrate and during the coating curing process. The bubbles, especially those just under the surface act as spots of stress concentration – potentially causing cracks formation in the coating. In advanced ageing stages, there can also be impaired overall coating stability (Kúdela 2010).

The cracks observed occurring during advanced ageing phases exhibited a different character, being the cracks in wood but negatively affecting the coating material as such. These cracks were generated due to the moisture loading of the system wood–solid coating during ageing. The specimens with cracks showed visible capillary water rising along these cracks. The colour change at these spots was then more pronounced, but under a higher risk of impairment of the overall stability of the coating system.

CONCLUSIONS

From the results obtained in testing the stability of the studied coating materials proposed for restoration of the window surface treatment, the following conclusions can be drawn.

The described changes concerning the colour, gloss and defects, acted in interactions and altered the wood surface outlook considerably.

The poorest stability against photodegradation was found in ST-1, representing impregnation with linen oil (CM-1) and tung oil (CM-3). The windows with surfaces treated in this way may require frequent keeping up.

If the windows were originally coated with oil or alkyd coating materials, we recommend firstly impregnating the windows with an impregnating substance (CM-1). After drying out the impregnation, we recommend applying one layer of the protective glazing lacquer (CM-4, or CM-5) only on the window parts from which the original coating was removed. In this way, the coating is restored. After drying the first layer and soft sanding, we recommend applying the second layer on the entire window, in the hue coinciding with the original one, with the aim to attain colour uniformity. This system was revealed as the most stable in colour and the most resistant to water. By tuning the glazing to a darker hue, in accordance with the hue of the original ST, the final colour stability should be enhanced.

If the windows were originally coated with water-soluble materials, we recommend impregnating their substrate with an impregnating substance (CM-2), and for the top coating, substituting the protective glazing (CM-4, resp. CM-5) with another coating material such as WoodCare UV, applied in two layers.

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