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Visual properties of spruce wood coated with lacquers, changed under impact of UV radiation in indoor conditions

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Abstract: *Visual properties of spruce wood coated with lacquers, changed under impact of UV radiation in indoor conditions.* This work evaluates accelerated-ageing-induced effects imposed on colour stability of spruce wood coated with colourless polyurethane lacquers proposed for surface treatment for wood artefacts intended for the indoor. There were explored the colour and gloss variations at an accelerated ageing process representing 500 hours. Simultaneously, there was also examined the protective performance of pre-treatment with a UV radiation absorbent agent. The experimental results give evidence that in all cases, during accelerated ageing process, the influence of UV radiation on photo-degradation of the surface-treated spruce wood was significant. The tested lacquers, however, manifested diverse degrees of protective efficacy against UV radiation-induced effects to the wood surface in indoor conditions. The colour stability was found poorer for the surface treatment with lacquers without protective agents against UV radiation. The UV protective substance admixed into the coating material had an obvious decelerating effect on the photo-degradation in the surface-treated wood, but this degradation had not been inhibited absolutely. In all cases, the lightness decreased and the coordinates a* and b* increased. The result was that the treated wood surface attained yellow-brownish hue of various intensities. On the other hand, the gloss quality was preserved in all treatments.

Keywords: spruce wood, surface treatment, polyurethane lacquers, colour stability

INTRODUCTION

Surface layers of wood in outdoor conditions are degraded due to effects of several radiation types, of moisture, heat and harmful substances acting separately as well as in interactions. The first symptoms of changes during the ageing process are manifested as discolouration induced by photo-degradation of lignin and to some extent also hemicelluloses (KÚDELA *et al.* 2016). The consecutive wood surface degradation associated with ageing affects negatively this wood's morphology and other properties (WILLIAMS *et al.* 2001, TOLVAJ *et al.* 2011, HUANG *et al.* 2012, KÚDELA and IHRACKÝ 2014).

One of the ways how to protect the wood surface against outdoor conditions is surface treatment (ST) with appropriate coating materials. The outdoor environment itself, however, can influence adversely the ST quality. The first warning signs of degradation of the treated wood surface concern the surface treatment quality, primarily variations in the visual properties such as hue and gloss (SAHA *et al.* 2013a, OLSSON *et al.* 2014).

The recent research on the ageing of wood surface treated with coating materials has primarily been focused on improving the colour stability as well as the overall ST stability – by targeted modification of the substrate and of the coating material itself with nanoparticles acting on organic and inorganic base (SAHA *et al.* 2013a, LANDRY and BLANCH 2012, KOCAEFE and SAHA 2012, SAHA *et al.* 2013b, WAN*et al.* 2014, GIRARDI *et al.* 2014, REINPRECHTa ŠOMŠÁK 2015).

The authors mainly concentrate on outdoor conditions. The indoor conditions, however, also require attentiveness [14], despite weaker UV effects compared to exterior. This is also due to the strongest criteria for ST quality declared for furniture intended for interior use and for musical instruments. Consequently, the colour stability of ST with coatings for indoor use requires testing (KÚDELAandKUBOVSKÝ 2016).

The aim of this work was to study how UV radiation during accelerated ageing, under simulation of indoor conditions,changed visual properties of spruce wood surface-treated with colourless polyurethane lacquers.

MATERIAL AND METHODS

The test specimens were spruce-wood prisms, with dimensions of 100 mm × 50 mm × 10 mm (length× width × thickness). The specimens were divided in four groups, each containing five pieces. For each group, there was used a specific transparent colourless lacquer. The lacquers were polyurethane, intended for indoor furniture surface treatment, with a good mechanical and chemical resistance. The lacquers were labelled: PUR-1, PUR-2, PUR-3 and PUR-4.PUR-3 and PUR-4 were the same but the PUR-4 was improved with a UV radiation absorbent acting on organic base.

The surface treatment specimens were exposed to UV radiation in a xenotest Q–SUN Xe–3–H during 500 hours. There was used the mode simulating exterior conditions, so called dry mode under which the wood is exposed to radiation but protected against rain (Tab. 1). The indoor conditions were modelled with the aid of *Q-window Filtersrs,* simulating the outdoor daylight supply into the interior.

Table 1 The ageing parameters set according to 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-free	-	-	38	–	18

Following the Standard ASTM G 155 [15], the radiation intensity was adjusted to 0.35 $W \cdot m^{-2}$ at a wavelength of λ = 340 nm. These values represent the average radiation intensity in the temperate zone. The temperature controlled on a black panel represented the maximum surface temperature. The air temperature was determined to accelerate the changes to the wood surface. The wood discolouration was examined after 50, 100, 200, 300, 400 and 500 hours.

In all specimens, the coordinates CIE $L^*a^*b^*$ coordinates were measured before ageing and during ageing. The measuring device was a spectro-photometer Spectro-guide 45/0 gloss by BYK – GARDNER GmvH. The measure of discolouration was assessed based on the total colour difference ΔE, calculated as

$$\Delta E = \sqrt{\Delta L^2 + \Delta a^2 + \Delta b^2}\,. \qquad (1)$$

The gloss of coated surfaces was measured with a gloss-meter micro-TRI-gloss by BYK – GARDNER GmvH,under angles of 20°, 60° and 85°. The gloss evaluation was pursued following the Standard STN 67 30 64.

RESULTS AND DISCUSSION

The results of the two-way variance analysis have confirmed the significant influences of the two factors inspected (ageing time and coating material) as well as the influence of their interaction on shifting the colour coordinates L^*, a^*, b^* and on the total colour difference ΔE.

The differences in the values of the colour coordinates L^*, a^*, b^* in spruce wood treated with coating materials were evident just earlier than the ageing process started (Fig. 1). These differences were not very obvious, but summarized, they had a noticeable impact on the total colour difference. The testing results unveiled that the lacquers used were not perfect colourless. This was true especially for the lacquers PUR-1 and PUR-2 manifesting a slightly yellowish hue after their application on wood. These colour modifications, however, are not always easy to

detect instantly. They may be masked by the highly variable structure and texture of spruce wood resulting mainly from the differences between the early and the late wood.

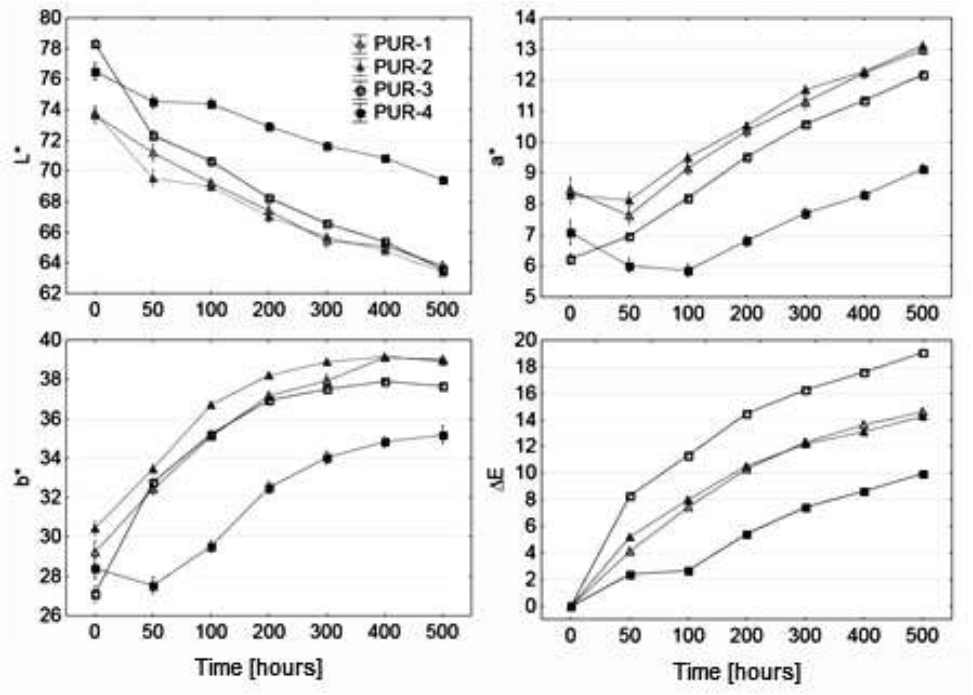

Figure 1. UV radiation-induced effects on colour coordinates *L*, a*, b** and on the total colour difference Δ*E* at accelerated ageing process.

In all cases, the lightness of surface-treated wood decreased with time. The coordinate *a** values (apart from PUR-3) showed a moderate decrease encompassing the beginning 50 hours, followed by an increase up to the end of the experiment. This means that the a* coordinate was shifting towards red. A quantitatively similar course was recorded also in the *b** coordinate with its values shifting towards yellow. As the result, the coated surfaces darkened gradually and obtained a darker yellow-brown hue in comparison with the control specimens (Fig. 2).

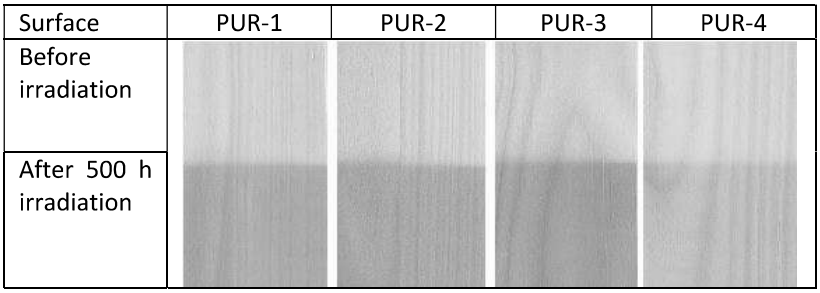

Figure 2. Colour of spruce wood surface coated with specific lacquers, before and after irradiation at accelerated ageing process.

There were also observed differences in the values of the individual coordinates and between the particular surface treatments at different phases of the accelerated ageing process. In most cases, these differences decreased with progressing accelerated ageing time.

The most conspicuous changes in the coordinates *a*, b** and in the total colour difference were recorded in the case of surface treatment with the lacquer PUR-3 without protective admixtures. In the case of PUR-1 and PUR-2, the changes were similar in quality, but proceeding slower. The smallest shifts in the colour space coordinates *L*a*b** were

observed for the lacquer PUR-4 with admixture of UV radiation absorbent acting on organic base.

The shifts in L^*, a*, b^* coordinates were also reflected in the total colour difference ΔE (Fig.1). The total colour differences for the particular surface treatments were assessed with using a six-degree evaluation scale (ALLEGRETTI *et al*. 2009). The treatment with the ST coating system PUR-3 exhibited the degree 5 (distinct colour change) as early as 100 hours from the beginning, and then there followed degree 6 meaning a total different colour. In case of the lacquers PUR-1 and PUR-2, the changes were similar, but proceeding less fast. Also in these two treatments, the final colour difference after 500 hours corresponded to the scale degree 6. The differences between these two treatments were tiny and not possible to detect with unaided eye.

The total colour difference ΔE caused by the photo-degradation process was observed for the treatment with the lacquer PUR-4. After 200 ageing hours, the treated spruce wood surface manifested the discolouration degree 4, and after finishing the ageing process, this degree was 5. The protective substance admixed into this coating system imposed significant retarding effects on the UV-induced photo-degradation; nevertheless, the protection against discolouration was not absolute. The UV-induced discolouration of the surface treated spruce wood can be to some extent caused by the photo-degradation of the coating material but primarily by the photo-degradation of the wood surface, which is in accord with the results reported in OLSSON *et al*. (2014) and also with the fact that the extent of photo-degradation of wood treated with the same lacquer was dependent on the wood species (KÚDELA and KUBOVSKÝ 2016, SIKORA 2017).

Consequently, the wood species is an important factor. In case of surface treated beech wood, the discolouration was more distinct compared to spruce, and the discolouration of oak wood was less distinct compared to spruce. It follows that the response to UV radiation is more sensitive in the natively light-coloured wood species, including spruce. The slower progressing photo-degradation in oak may be due to the contents of particular extractives showing qualitative and quantitative differences between spruce and oak. The important role of extractives has already been recognised by other authors (CHANG *et al*. 2010, PERSZE and TOLVAJ 2012).

Gloss modification induced by accelerated ageing is illustrated in Fig. 8. The individual surface treatment modes differed in gloss values, but all of them were within the semi-opaquecategory according to the standard STN 67 30 64. Very moderate gloss decrease was observed after 50 ageing hours, then no significant changes followed. Ollson *et al*. (2014) report that the gloss modification occurs exclusively on the background of the coating degradation on its surface. Consequently, in our case we may declare than this modification was negligible even after 500 hours of accelerated ageing.

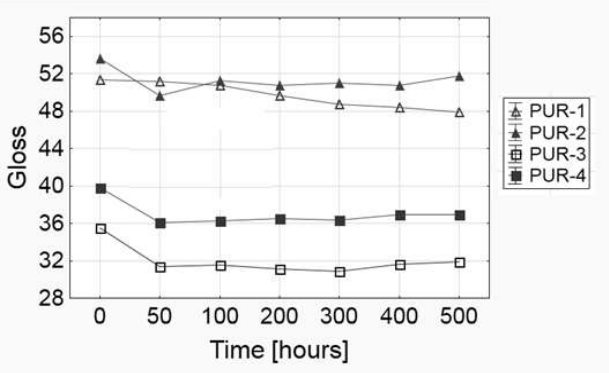

Figure 3 Gloss change during accelerated ageing

CONCLUSION

The evaluation of UV radiation-induced discoloration of the tested surface treatments, under simulated indoor conditions allows to draw the following conclusions.

In all cases, UV radiation acting in indoor conditions had negative impacts on the colour stability of the surface treated spruce wood.

After 500 accelerated ageing hours, all the four tested surfaces treated with colourless transparent polyurethane lacquers were found evidently darker and yellowish hued.

There were, however, differences in intensity of this discoloration intensity between the particular cases. The best resistance against photo-degradation was found for the PUR-4 lacquer supplemented with the UV protective filter acting on organic base.

All the four tested lacquers showed almost perfect resistance against ageing-induced changes in their original gloss.

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