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INFLUENCE OF WOOD SPECIES ON QUALITY OF EXTERIOR TRANSPARENT ACRYLIC COATING DURING OUTDOOR EXPOSURE

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ABSTRACT

Coating systems are a popular way to protect wood against the effects of weathering when used outdoors. This study evaluates the impact of the basic wood species on the overall durability and color fastness of the selected water-based acrylic exterior paint. Spruce (*Picea abies* L.) and oak (*Quercus robur* L.) wood samples were subjected to external weathering according to EN 927-3 (2000) for 6 and 12 months. The evaluation by instrumental methods related to co changes in color, gloss, surface wettability contact angle, at which paint damage was also visually evaluated. The results showed that the durability of the tested coating was higher for spruce. Still, on the other hand, thanks to its lighter shade, a significant color change caused by the base wood's photodegradation was detected, showing that oak wood has a negative effect on the overall life of the tested coating.

KEYWORDS: Transparent coating, wood species, outdoor degradation, color stability.

INTRODUCTION

Wood, as such, has many advantages, but we also encounter the negative side of this natural material due its easy degradability (Cogulet et al. 2018). It has potential both indoors and, of course, outdoors. Wood exposed outdoors is also subjected to weather effects and changes its appearance on the order of months (Štěrbová et al. 2020). In exterior constructions, wood is popularly used for load bearing as well as decorative purposes such as gazebos, pergolas, fences, facades, terraces, bridges, etc. (Reinprecht 2008). Its pleasant original appearance and color can be preserved for a long time only with the help of transparent coating systems, especially if it is exposed to rainwater. Otherwise, photodegradation processes and leaching of the coloring components (lignins and extractives) within a few months (Feist 1990, Pandey 2005).

Subsequently, due to the growth of molds and the deposition of impurities, there is observed a known greying, which usually extends to a depth of mm (Oberhofnerová et al. 2017). Pigmented coatings on wood have a long service life, but the original appearance of the wood disappears; a variant that partially meets the requirement of maintaining the original appearance is the use of semi-transparent coating systems (Stirling and Morris 2013).

The surface treatment is not only an aesthetic matter. Coating systems protect wood against water penetration and the formation of cracks and thus prevent the attack of wood-rot fungi, which disrupt the overall mechanical functionality of structures (Hill et al. 2022). The overall service life of transparent coating systems on wood has been evaluated in several works. However, coating systems are constantly improved by producers, and the climatic conditions in each region are different (Brischke and Thelandersson 2014, Mohebby and Saei 2015), so it is important to constantly carry out further tests that would lead to a more comprehensive overview of the behavior of coatings on wood. At the same time, with their different morphological structure and the content of different extracts, wood species significantly affect the overall service life of the same coating systems (Ozgenc et al. 2012, Pánek and Reinprecht 2014, Gonzalez de Cademartori et al. 2015). A water-borne acrylate multilayer coating system, which is not harmful to health, has a low environmental impact due to its low VOC (High volatile compounds) emission, and can be easily applied by brush or spraying (de Meier 2001). Durability tests of coating systems are performed either using accelerated artificial weathering or by applying of long-term outdoor tests, during which more critical factors interact (Crewdson and Ketola 2005, Podgorski et al. 2011, Cogulet et al. 2019). Outdoor tests are performed according to EN 927-3 (2000). All commercially used coatings require a 12-month exposure period during which the layer should not be damaged.

Oak wood as a valuable natural material and spruce wood as currently the most used and cheapest wood used in Central Europe were chosen for this experiment. From the point of durability and resistance to fungi, oak heartwood is a very suitable specie, but the overall durability of exterior coatings is low compared to other wood species (Aloui et al. 2007, Sivrikaya et al. 2011). The most important properties of oak wood are strength, reasonable hardness, and durability, which has always been an important criterion (Zeidler et al. 2022). Oak is classified among very durable woods, excellently tolerating the influence of changes in the atmosphere. It is most in demand in the water construction industry because its favorable properties are further improved by soaking in water (Sarvašová et al. 2021). Spruce wood, due to climate change, it is possible to expect a reduction in its overall share in stands (Tomášková et al., 2021). Its wood is light, relatively strong, easy to split, and tough (Hýsek et al. 2021). Spruce wood is included in the group of less durable woods (class no. 4), and at the same time, it is difficult to extremely difficult to impregnate (classes 3-4) (Reinprecht et al. 2017).

This experiment aims were to determine the effect of the base wood of Oak and Spruce on the overall service life of the selected transparent water-based acrylate coating system. The partial goals were to evaluate the overall color fastness, changes in water contact angle, gloss, and the formation of surface defects of coated wood during a 12-month outdoor exposition in Prague (Czech Republic).

MATERIAL AND METHODS

Wood samples, treatment, and exposure

Heartwood samples from Oak (*Quercus robur* L.) and Spruce (*Picea abies* L.) with dimensions 378 x 78 x 20 mm (L x T x R) (Fig. 1) were prepared according to EN 927-3 (2000) from tree origin in Czech Republic. Clear samples were conditioned for a relative humidity (ϕ) 65 ± 5% and temperature (t) 20 ± 2°C to achieve their equilibrium moisture content (EMC) of 12%. Surfaces of conditioned samples were sanded (120-grit) before treatment. The average density of oak wood was 795 $kg \cdot m^{-3}$, and the density of spruce wood was 455 $kg \cdot m^{-3}$.

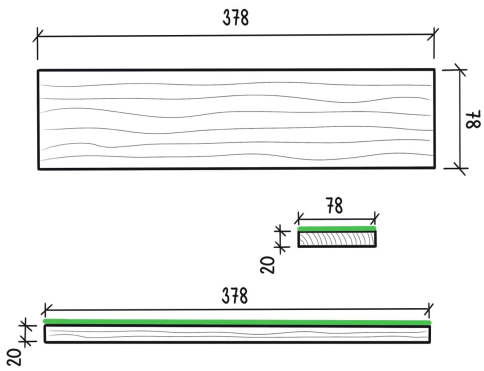


Fig. 1: A sample according to EN 927-3 (2000) (green line means a coating). Dimensions in mm.

Acrylate thick-layer transparent water-based coating with fungicide (5-chlor-2-methylisothiazol-3(2H)-on) and UV-stabilizers (based on benzotriazoles) was applied in two layers (each 120 $g.m^{-2}$) (Fig. 1). After drying in laboratory conditions, the samples were outdoors exposed in racks situated under an angle of 45° in the south direction for 12 months. References from untreated wood samples were also used. Two samples for each wood species and kind of treatment were analyzed. Changes were evaluated after six months and after the exposition. Climatic conditions during exposure were monitored, average daily temperature was 9.8°C (extremes +26.9°C, -10.1°C), total precipitation 533 mm and average daily incident solar energy 12 226 $kJ.m^{-2}$ (http://meteostanice.agrobiologie.cz).

Methods

Changes in color

The color parameters L*a*b* (CIE 1986) of the test specimens were measured after 6 and 12 months of natural weathering (NW) using a Spectrophotometer CM-600d (Konica Minolta, Osaka, Japan). The measurement was carried out at eight marked places on each sample to avoid distorting the results. Two identical samples were made for each type. For the observation of reflection, the specular component was included (SCI mode) at a 10° angle and d/8 geometry with an illumination standard of D65 (corresponding to daylight in 6500 K). Eight measurements per sample were carried out for each weathering time. Color changes evaluations were done in CIE L*a*b* color space: L^* is lightness from 0 (black) to 100 (white); a^* is chromaticity coordinate +60 (red) or –60 (green); b^* is chromaticity coordinate +60 (yellow) or –60 (blue).

The total color difference ΔE* (CIE 1986) was subsequently calculated from relative changes of color (ΔL*, Δa*, and Δb*) using Eq. 1. The dependences of the color change were also assessed by comparing the values with the EN 927 – 3 (2000) (Tab. 1).

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

Tab. 1: Table of color changes according to standard EN 927-3(2000).

$0.2 > \Delta E$	invisible difference
$0.2 < \Delta E < 2$	little difference
$2 < \Delta E < 3$	color change visible with a high-quality filter
$3 < \Delta E < 6$	color change visible with a medium-quality filter
$6 < \Delta E < 12$	high color changes
$\Delta E > 12$	different color

Changes in gloss

The gloss of the different coatings before and during weathering tests was measured based on EN ISO 2813 (2014) using glossmeter MG268-F2 (KSJ, Quanzhou, China). Four measurements at a 60° angle per sample after 6 and 12 months of NW were done to evaluate gloss changes. The change in gloss was measured in four marked areas on every sample.

Changes in hydrophobicity

The liquid (distilled water) contact angle on tangential surfaces of tested samples was measured using a goniometer Krüss DSA 30E (Krüss, Hamburg, Germany). Ten random positions on each sample were used to measure the contact angle. The sessile drop method was used; ten measurements per sample were performed before and after 6 and 12 months of NW with distilled water drops with a dosing volume of 5 µL. A surface is wettable, hydrophilic, when the angle is between 0° and 90°. A surface is not wettable, hydrophilic, when the angle is between 90° and 180°.

Statistical analyses

Statistical analyses of data were performed in MS Excel and Statistica 14 (StatSoft, Palo Alto, CA, USA) using mean values, whisker plots with mean values, and 95% two-sided confidence intervals.

RESULTS AND DISCUSSION

The measured data were evaluated based on a significance level of $p = 0.05$ and a confidence interval of 95%. Individual properties (change in color, gloss, and surface wettability) were evaluated as statistical dependencies. Color changes were compared to the values according to EN 927–3 (2000) (Tab. 1). The standard defines nominal values that determine the size of the color change.

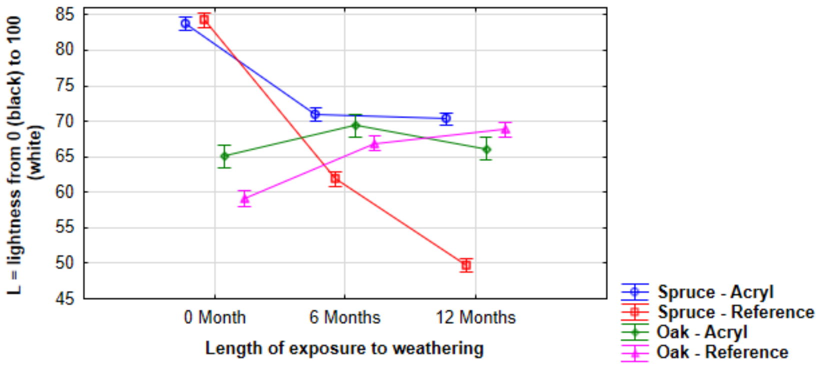


Fig. 2: Part of color spectrum, L - lightness.

In Fig. 2, the most noticeable change is in the part of the color spectrum of the reference spruce, where the value of L drops steeply, which indicates graying of the material. This fact is also confirmed by the pictures in Tab. 2. In Fig. 3 is possible to see difference of chromaticity coordinate, from red to green – except of coated spruce (Fig. 3a), and from yellow to blue (Fig. 3b). It is possible to observe a darkening of shades.

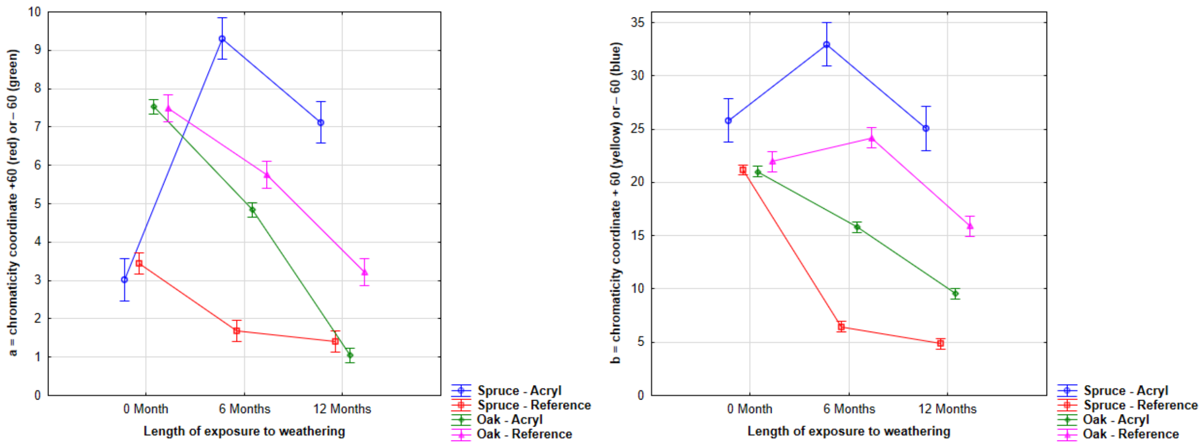


Fig. 3: Part of color spectrum, a – chromaticity coordinate (a), b – chromaticity coordinate (b).

The values of the L*a*b spectra were converted to the color change value for individual cases according to the measurement location. These values were statistically evaluated, and their averages, standard deviations, and statistical significance were determined. Fig. 4 shows that the oak, whether treated or untreated, and the reference spruce had a statistically significant color change. Spruce treated with acrylic paint did not have a statistically significant difference between six and twelve months. Still, according to the values from the EN 927-3 (2000) standard (Tab. 1), it is clear that the color was still evaluated as different. In the case of treated spruce, there is a rapid increase in color change in the first six months, and the difference is then stabilized. The other samples degrade linearly, and this process is long-term, which is also proven by the graph in Fig. 4.

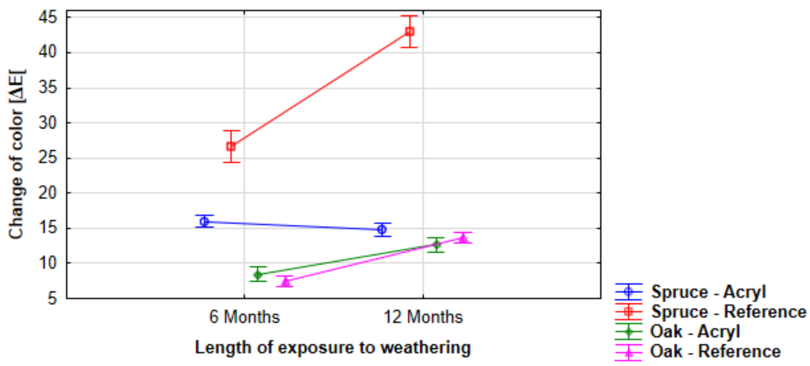


Fig. 4: Color change development.

Fig. 5 shows the evolution of the gloss change. At this value, the downward trend of the reflection coefficient can be observed. This is mainly due to the paint layer's degradation, which can no longer reflect light radiation, which is a property measured when assessing gloss development. It is interesting to observe the opposite trend in untreated spruce (Reference), where the dirt was deposited on the untreated surface, which paradoxically increased the gloss value. Due to the large dispersion of values, the spruce samples (Acrylic and Reference) could not be called statistically significantly changed, but the visual change is noticeable (Tab. 2).

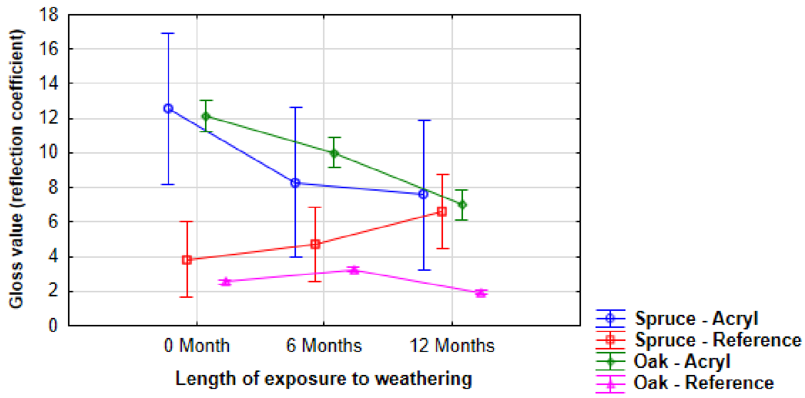


Fig. 5: Gloss change development.

The development of the free surface energy value (surface tension) expressed by the contact angle was evaluated as statistically significant for all measured samples. Some samples even absorbed liquid before it was possible to measure the contact angle. This is due to the degradation of the untreated surface. Samples treated with acrylic paint showed decreasing contact angle values (Fig. 6).

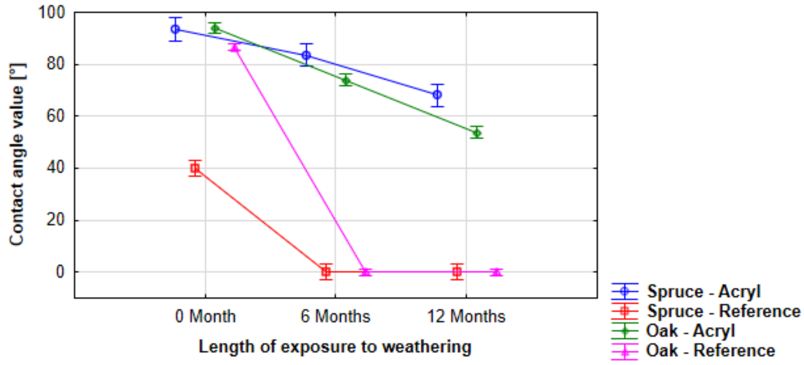
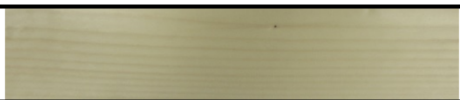
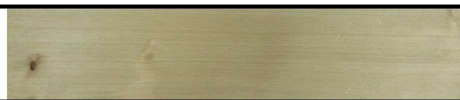
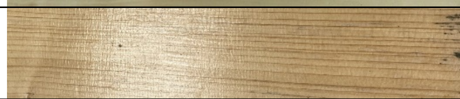
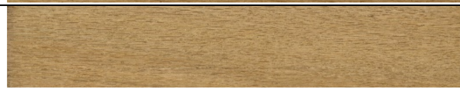


Fig. 6: Contact angle change development.

In Tab. 2, showed the visual changes in surfaces of samples. The pictures were taken with a scanner to avoid distortion by ambient light. The table confirms the statistically evaluated color changes, best demonstrated by the reference spruce sample, where even the naked eye can see the most significant color change [ΔE].

Tab. 2: Visually changes.

Weathering time	Spruce - Reference	Spruce - Acryl
0 month		
6 months		
12 months		
	Oak - Reference	Oak - Acryl
0 month		
6 months		
12 months		

The experiment results in this work confirmed that the application of the coating system could extend the overall life of selected wood species in the exterior. Water-based acrylic coatings have been evaluated as an environmentally friendly means of protecting the surface of the wood and thus improving the durability of wood in outdoor conditions, as reported by Özgenc et al. (2012) or Wang et al. (2019). In some cases, it is possible to increase the overall service life by applying an upper hydrophobic layer (oil coatings), which is in line with previous studies, e.g., for spruce and acacia (Pánek and Reinprecht 2014, 2016).

Based on several works, oak is generally characterized as a type of wood with a complex protective treatment influenced by the exterior transparency of coatings (Evans et al. 2015, Aloui et al. 2007). The effect is even more pronounced in trees with a high content of extractive substances and an uneven morphological structure (Grüll et al. 2016). The results confirm that in porous wood species with large vessels such as oak, local penetration of coatings occurs, and in these wood areas thin-layer coatings quickly degrade, and their faster restoration is necessary (Šimůnková et al. 2019). The loss of adhesion of the coating during weathering should also not be neglected, as it is a complex phenomenon related not only to the change in the surface characteristics of the substrate of individual wood species and its photodegradation (Hochmańska-Kaniewska et al. 2022), but also to the depolymerization and loss of the internal cohesion of the coating system (Evans et al. 2015). Additives, as stated by Forsthuber and Grüll (2010), or by adding flame retardants, such as Puyadena et al. (2022), can significantly affect this. Additives can also have a negative effect on the compactness of the polymer coating base.

Transparent acrylic-based coating systems can withstand outdoor conditions while achieving relatively good results, which means maintaining high surface wettability (contact angle), color fastness, and maintaining the same gloss value throughout the life of the coating. When comparing the results, we can conclude that the observed trends of coatings, when used for individual wood species, are confirmed.

CONCLUSIONS

(*1*) The influence of the underlying wood species on the overall lifespan and color fastness of the selected acrylic water-dilutable exterior paint is apparent. Transparent coatings on exterior wood, especially oak (*Quercus robur L.*), have an overall low level of durability. (*2*) Visual inspections on the painted surfaces confirmed the importance of the underlying wood species, from which it is clear that spruce achieves better results from this pair of wood species. (*3*) The effect of the underlying wood was proven for the color fastness ΔE and the gloss. Surface defects need to be visually checked during weathering. (*4*) The wettability of the surface, evaluated using the contact angle, confirms a decreasing tendency, especially in untreated samples, which were no longer measurable after a particular time. (*5*) A sufficient period of 12 or 24 months is required for outdoor testing of coating systems.

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