ИНОВАЦИИ В ГОРСКАТА ПРОМИШЛЕНОСТ И ИНЖЕНЕРНИЯ ДИЗАЙН, 1/2012 (1): 31–37

DISCOLOURATION OF COATED MODIFIED OAK WOOD DURING SIMULATED INDOOR SUNLIGHT EXPOSURE

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ABSTRACT

The aim of this work was to establish a degree to which UV irradiation causes discolouration of heat-treated and ammonium-treated wood. Discolouration of uncoated samples and of those treated with commercial transparent coatings (oil, UV varnish, water-based and polyurethane varnish) was measured. The most significant colour changes (ΔE*) was recorded between uncoated samples and those coated with water-based varnish, whereas other coatings, most of all two-component polyurethane varnish, had helped reduction of discolouration. The ammonium-treated oak wood showed superior stability to discolouration.

Key words: heat-treated wood, ammonium-treated wood, discolouration, accelerated weathering, wood coatings

1. INTRODUCTION

When it comes to wood for interior then its colour and colour stability play a very important role. It is widely known that UV light is one of the natural factors most responsible for discolouration of wood surface (Oltean et al. 2008). Of all the complex compounds in wood lignin is most sensitive to UV light because it absorbs it most (Padney 2005). Some wood species under UV light turn whiter or greyer, some become yellow, red-orange or brown depending on wood composition (Oltean et al. 2008; Sandermann and Schlumbom 1962). In addition to being an aesthetic defect, this light-attributable discolouration indicates degradation of wood surface (Schaller and Rogez 2008). A degree of discolouration depends on light intensity, colour stability of lignin and of the extractives, duration of exposure to light, moisture and temperature.

Oak (*Quercus robur* L.) is a wood species which is, unlike other commercial kinds of wood, characterized by good colour stability in the indoor environment (Jirouš-Rajković and Turkulin 2003). Owing to its mechanical properties and attractive appearance oak wood has many interior uses.

Due to its dark colour, resembling tropical kinds of wood, modified wood is increasingly popular in the production of wood flooring. Modification of wood is a procedure by which its physical and mechanical properties are changed i.e. which by changing wood compounds improves its dimensional stability and reduces its mechanical properties as well (Yildiz et al. 2006; Weigl et al. 2009). Modification of wood also increases the value of wood with certain aesthetic defects. Heat- and ammonium treatment is most applied modification of oak which give it darker shade (Weigl et al. 2009; Ayadi et al. 2003). Darkening which occurs by heat-treatment is due to the coloured compounds developed during degradation of hemicelluloses and the extractives (Estevez et al. 2008), whereas in ammonium-treatment darkening of wood is attributable to ammonium-tannin reaction (Parameswaran and Roffael 1984).

Transparent coatings are applied to emphasise and preserve characteristic appearance of wood. However, not being UV-absorbing they cannot prevent penetration of light to wood surface and the consequential photodegradation (Aloui et al. 2007; Chang and Chou 1999; Jirouš-Rajković et al. 2004). The protection of the coating-wood system is very complex due to different absorption spectra of the both components and the difficulty to find the corresponding absorbents (Jirouš-Rajković et al. 2003). Increasingly stringent environmental regulations have become very important in the selection of wood coatings. This explains more frequent use of oil and water-based coatings for finishing of wood flooring (Miklečić and Jirouš-Rajković 2009).

The present work was aimed at testing colour stability of the modified oak wood treated with different coating systems.

2. MATERIALS AND METHODS

The samples used in the present study were wood flooring of the two established Croatian manufacturers i.e. two groups of samples of modified oak wood (*Quercus robur* L.). One (marked „H“) was heat-treated at 180 °C and the other one (marked „A“) was ammonium-treated. The both had predominantly radial texture and even colour. Finished and unfinished samples sized 150 x 75 x 18 mm (L x R x T), priorly conditioned in the conditioning chamber at 20 °C and 65 % RH to constant weight, were exposed to light.

Finishing of the samples was performed by four systems: 1) one-component water-based coating (acrylic-urethane copolymer emulsion) containing 32 % dry-solid content (marked „AQ“); 2) oil (marked „O“); 3) UV high-solid acrylic varnish (marked „UV“), and 4) two-component polyurethane varnish („2k PU“) containing 38 % dry – solid content (marked „PU“). Oil and UV varnish were applied on a large scale with a roller-coating machine. Oil was applied in one layer in spreading rate of 25–45 g/m² and then dried in the warm air. Finishing with UV varnish comprised a water-based priming coat (10–15 g/m²), acryl-based sealer (40–45 g/m²), sanding of sealer with 240 grid paper, acryl- based priming coat (28–30 g/m²), sanding of a priming coat with 280 and 320 grid paper, the first layer of top coat (8–10 g/m²) and the second layer of top coat (5–8 g/m²). Water-based coating and 2k PU were applied by a brush in two layers each in spreading rate of 120 g/m². The second layers were applied after sanding the first one with 240 grit paper and leaving it to dry over 24 hours. Mean thickness of the hardened film of UV coat was 64 μm, of the water-based varnish 89 μm, and of 2k PU varnish 96 μm. There was no oil film left on wood surface.

Accelerated exposure of the samples to UV light through window glass was performed in the QUV Accelerated Weathering Tester (by Q-Panel) equipped with the UVA-351 fluorescent lamps. These lamps are recommended for simulation of sunlight through window glass for interior applications. Three equal samples, one for each coating system, were kept in the QUV Weathering Tester over 32 days (for 768 hours). The fourth sample was the unexposed reference sample. Temperature of the black panel was 60±2 °C and irradiation was 0,77 $Wm^{-2}nm^{-1}$.

The first measurement of colour had been performed prior to exposure of the samples, while further measurements were performed after 1, 2, 4, 8, 16 and 32 days of exposure. The measuring was performed with a portable spectrophotometer Microflash 100d (Datacolor) with d/8° measuring geometry, 10° viewing standard, D_{65} light source always on the same points on the samples. Calculated was arithmetic mean of

18 measurements for every group of the samples. The overall colour change (ΔE*) was calculated according to the CIEL*a*b* colour measuring system where, L* describes brightness, a* and b* describe chromatic coordinates on the red-green and yellow-blue axis. ΔE* is the colour difference between the initial colour of the sample and the colour of the sample after exposure and it was calculated using the following formula:

$$\Delta E^* = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2} \quad (1)$$

where ΔL* describes the difference in brightness (+ light, – dark), Δa* and Δb* describes differences in chromaticity coordinates ((Δa*: + redder, – greener; Δb*: + yellower, – bluer). The measurement of gloss was made with a portable glossmeter Glosmaster Erichsen 507 with 65° measuring geometry on the three locations on sample.

3. RESULTS AND DISCUSSION

Figure 1 show the results of samples' discolouration (ΔE*) during their accelerated exposure to UV light. The increasing change in colour of all the samples is quite obvious. In addition, the trend is more pronounced in the heat-treated than in the ammonium-treated samples. This may be attributed to chemical reactions between ammonium and the compounds from wood which ensured better stabilisation of wood surface (Weigl et al. 2007).

Table 1. L*, a*, b* parameters for modified oak samples before exposure to UV light

Type of treatment	Colour parameters [a]		
	L*	a*	b*
AC	38,82 (0,98)	4,43 (0,07)	10,36 (0,31)
AO	27,90 (0,12)	3,59 (0,12)	4,78 (0,13)
AUV	31,12 (1,44)	4,33 (0,84)	6,57 (1,78)
APU	30,35 (0,31)	3,41 (0,13)	4,04 (0,25)
AAQ	33,94 (0,42)	4,30 (0,29)	7,89 (0,54)
HC	41,47 (4,46)	7,26 (0,44)	14,79 (1,34)
HO	31,44 (1,68)	9,26 (1,15)	11,14 (2,30)
HUV	35,67 (2,76)	8,04 (0,79)	11,46 (2,70)
HPU	34,77 (1,18)	7,76 (0,57)	10,15 (1,57)
HAQ	38,01 (2,88)	7,91 (0,39)	13,74 (2,44)

[a] *Values in parenthesis are standard deviations*

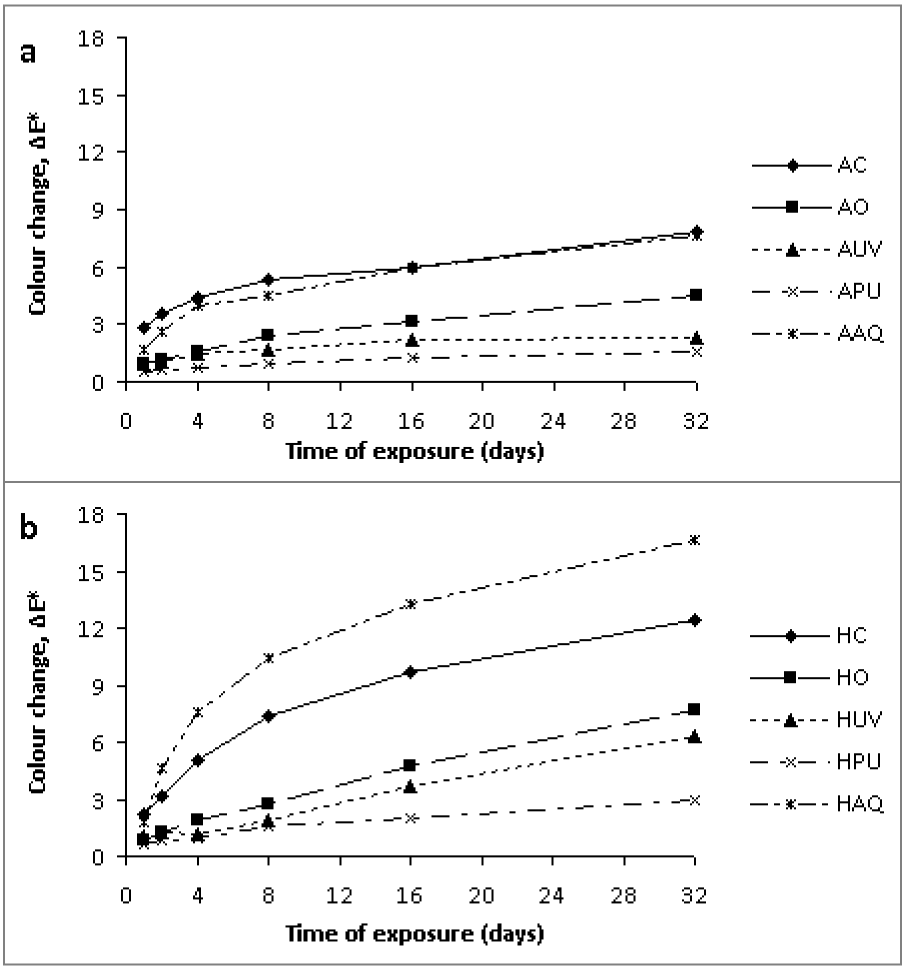

Fig. 1. Colour change (ΔE*) of ammonium-treated (a) and heat-treate (b) oak wood during exposure to UV light

In Figure 1 can bee seen that the uncoated modified samples (AC and HC) underwent discolouration as early as 24 hours following their UV exposure. Discolouration (ΔE*) of the ammonium-treated and heat-treated samples was 2,86 and 2,33 respectively and was visible with the naked eye. After two days of exposure to UV light the uncoated heat-treated samples underwent more intense discolouration unlike the uncoated ammonium-treated samples. In both groups of the modified samples coated with 2k PU varnish discolouration (ΔE*) during exposure was the slightest. Total discolouration (ΔE*) of the heat-treated samples coated with this varnish was 2,9 and of the ammonium-treated samples coated with this varnish was 1,53. Hon and Feist (1986) established that discolouration above 3 ΔE* is unacceptable on the large-scale. The biggest discolouration of both groups of the modified coated samples was recorded on the samples treated with water-based coating. Up to day 8 of exposure to UV light the heat-treated and ammonium-treated samples coated with oil and UV varnish (marked „HO“ and „HUV“; „AO“ and „AUV“) exhibited very similar changes in the ΔE* parameter (Figures 1a and 1b) which was then followed by increasing discolouration trend of the heat-treated samples. After 32 days of the accelerated exposure to UV light total discolouration (ΔE*) of the ammonium-treated samples coated with UV varnish was three times smaller than of the heat-treated samples coated with the same varnish. The least striking discolouration visible with the naked eye in the study was within the range ΔE* =1,5–2.

Table 1 show the initial values of colour parameter for all the samples. They are apparently different, depending on whether the samples were coated or not. It must be pointed out that coating, irrespective of its transparency, changes colour of wood by filling in cellular air gaps with substances of higher refraction index (Jirouš-Rajković et al. 2003).

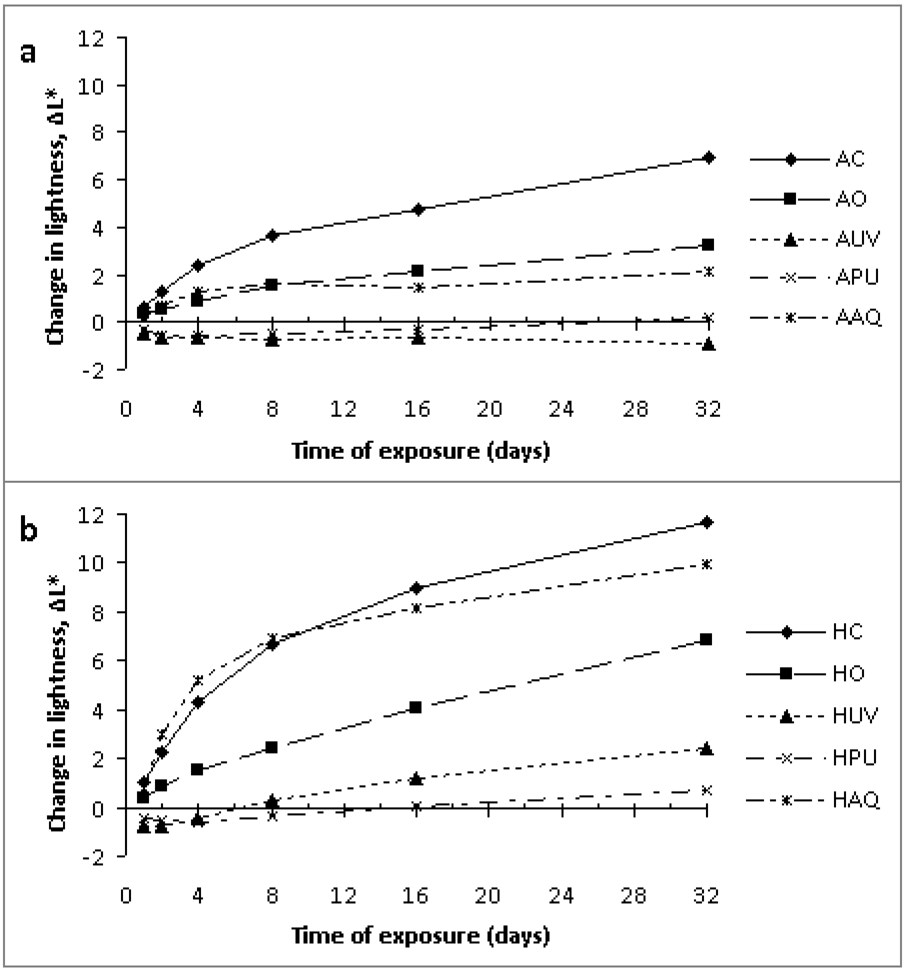

Fig. 2. Change in lightness (ΔL*) of ammonium-treated (a) and heat-treate (b) oak wood during exposure to UV light

Figure 2 show the changes in lightness of the samples during accelerated exposure to UV light. The greatest changes on both groups of the modified samples were recorded on the uncoated wood (AC and HC), wood with water-based coating (AAQ and HAQ) and oil (AO and HO). During exposure to UV light the ammonium-treated wood turned darker (- ΔL*) (Figure 2a). The heat-treated wood coated with the same varnish during the first 8 days of exposure to UV light turned darker and thereafter lightered (+ ΔL*) (Figure 2b). With 2k PU varnish, at the beginning of exposure to UV light there was also darkening of wood surface, whereas the prolonged exposure resulted in increased lightness.

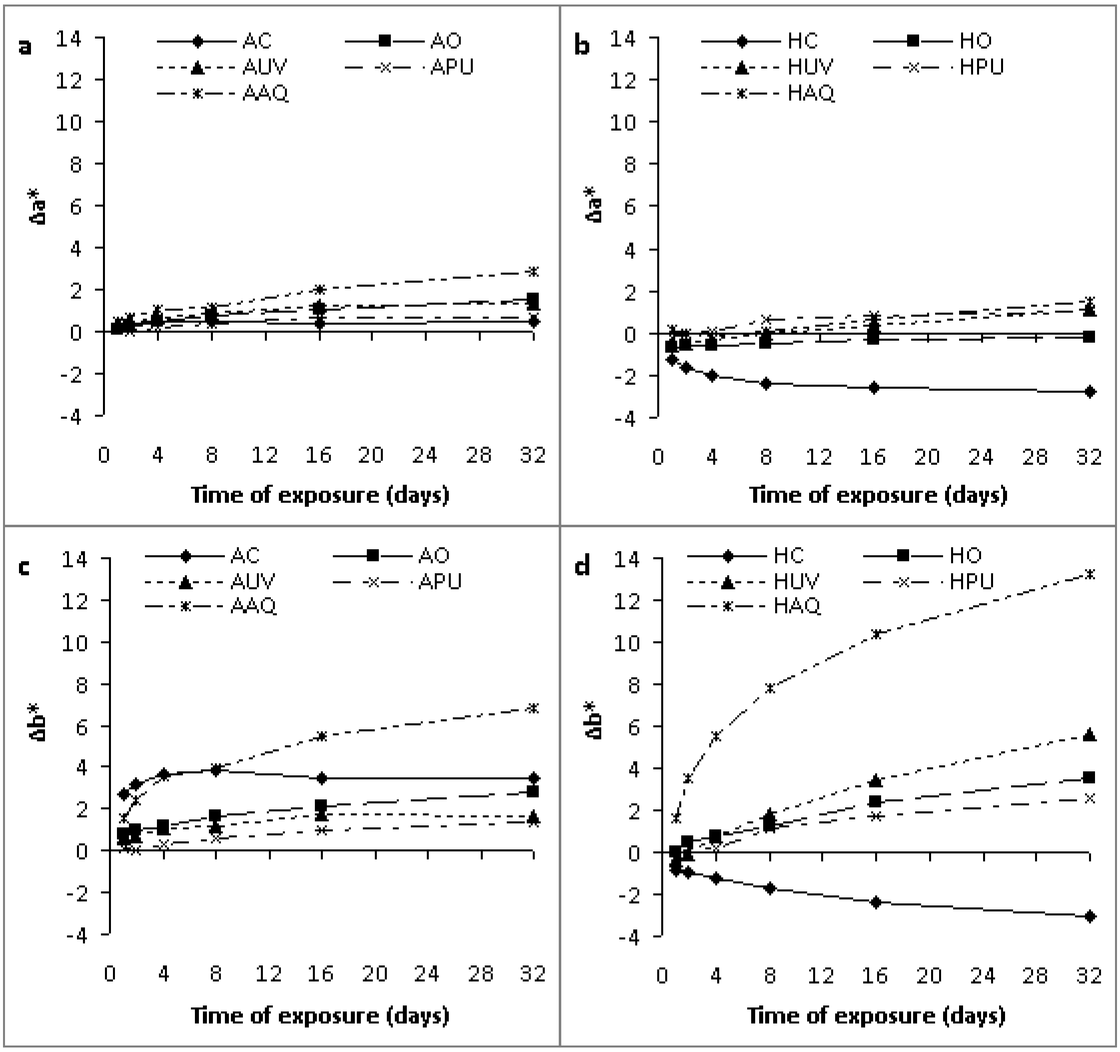

Fig. 3. Change in chromatografhic coordinate Δa* of ammonium-treated (a) and heat-treate (b) oak wood and in chromatografhic coordinate Δb* of ammonium-treated (c) and heat-treate (d) oak wood during exposure to UV light

Figure 3 show the changes in chromatographic coordinates of colour Δa* and Δb*. Changes in the parameters Δa* were significantly smaller than in the parameters Δb*. The parameters Δb* showed the greatest changes in the samples with water-based coating the surface of which turned yellow (+ Δb*) (Figure 3c and 3d). Yellowing developed in all studied samples, except in the uncoated ones of the heat-treated wood.

4. CONCLUSION

All studied samples developed discolouration after 32 days of accelerated exposure to UV light. Different finishing systems exhibited different behaviour on various surfaces. All of them provided better colour stability of the ammonium-treated samples than of the heat-treated samples. The highest colour stability during accelerated exposure to UV light was recorded in the samples treated with 2k PU varnish and then in those with UV varnish and oil. The greatest discolouration developed in the samples with one-component water-based coating.

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