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INFLUENCE OF ACCELERATED AGEING ON COLOUR AND GLOSS CHANGES IN TREE OF HEAVEN SURFACE TREATED WITH AN IRUXIL COATING SYSTEM

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ABSTRACT

This work investigates the influence of accelerated ageing on surface-treated wood. The assessment was carried out through evaluation of changes in visual properties (colour, gloss) in wood surface treated with water-based coating system applied in different colour hues. The system was adjusted by the manufacturer, to be used for wood surface modification guaranteeing resistance during outdoor exposure. The coating system was applied on veneers prepared of tree of heaven (*Ailanthus altissima*).

The results obtained for the studied properties demonstrate that the coating system had a high resistance against photo-degradation. Under the dry mode (UV radiation without rainfall simulation), no obvious changes to the coating occured. Under the wet mode (UV radiation with rainfall simulation), some colour changes were present, and the coating got darker and more matt. These changes, however, were not immediately observable visually.

The coating systems containing darker pigments showed more colour stability than the ligher hues. The better covering capacity of darker pigments as well as the bigger amounts of these pigments in the coatings resulted in better protection of the wood surface against UV-induced degradation.

Key words: surface treatment, wood, coating material, accelerated ageing, colour change, gloss.

INTRODUCTION

Wood is a natural organic material. Due to its chemical structure, hydrophilicity and porosity, degradation of wood is common in case of outdoor exposure in absence of protection against effects of several radiation types, humidity, heat and emissions, acting in interactions. REINPRECHT (2012) demonstrates that induced wood corrosion initiates on wood surface and afterwards proceeds inwards, reaching a depth of several millimetres.

The first changes associated with ageing process are manifested through colour alterations of wood caused by photo-degradation of lignin and to some extent also hemicelluloses. PANDEY and VUORINEN 2008, FAN *et al.* 2010, CHEN *et al.* 2012, and others observed that the wood surface photo-degradation rate and extent also depended on the wood species. The chemical reactions occurring in lignin cause wood shading, especially in light-coloured wood species. Important are also extractive substances sensitive to UV radiation (CHANG *et al.* 2010, PERSZE and TOLVAJ 2012). Extractive substances can react with hydrocarbons or with the products of lignin hydrolysis and form lignin-like compounds (TOLVAJ and FAIX 1996).

Next, the progressive wood surface degradation impairs its morphology, and the wood surface texture turns plastic (FEIST 1990). This is mainly typical for coniferous wood species as the density of their early and late wood is differing distinctly. The changes in wood structure are responded by more changes in surface properties (HON 1981, WILIAMS *et al.* 2001, KISHINO and NAKANO 2004, TOLVAJ *et al.* 2011, HUANG *et al.* 2012, IHRACKÝ 2014, KÚDELA *et al*. 2015). There is an urgent need to find out the ways how to protect wood against these unfavourable influences.

One of wood surface protection methods is application of coating materials inhibiting UV penetration to lignin and other wood constituents and, in such a way, preventing wood surface layers photo-degradation. It follows that the surface treatment of wood planned for outdoor use is a highly demanding task. The performance of coating materials with anti-degrading effects is improved through wood treatment with inorganic substances containing hexavalent chrome or its compounds, with subsequent reduction to substances containing trivalent chrome resistant against water and at the same time protecting wood against UV radiation (REINPRECHT and PÁNEK 2015). Another possibility is wood treatment with acrylate, alkyd and similar coating containing pigments or organic UV absorbents. Next one is improving the coating resistance with the aid of specific additives such as bark extract (SAHA *et al*. 2013a). The current investigation trends in area of ageing of wood, surface-treated with coating materials, are focusing on testing the stability of coatings containing various nano-particles, organic and inorganic-based coating modification, wood surface pre-treatment with plasma and similar (LANDRY and BLANCHETT 2012, KOCAEFE and SAHA 2012, SAHA *et al.* 2013a, b, OLSSON *et al.* 2014, WAN *et al*. 2014, GIRARDI *et al*. 2014, REINPRECHT and ŠOMŠÁK 2015).

The tests assessing the resistance of surface-treated wood against degradation caused by solar radiation, rain water, emissions and similar factors are time-consuming. In laboratory conditions it is possible to reduce this time, applying the accelerated ageing test.

The aim of this work was to assess the accelerated ageing influence on qualitative changes in surface-treated wood. These changes were evaluated based on changes in visual properties (colour, gloss) of wood treated with a water-based coating adjusted by the manufacturer for treating wood planned to use in outdoor conditions.

MATERIAL AND METHODS

Accelerated ageing was simulated on specimens prepared of 0.5 mm thick veneers of tree of heaven *(Ailanthus altissima)*, the specimens size was 80 × 33 mm. The ash wood structure and properties are described in (KÚDELA and MAMOŇOVÁ 2006). The veneers were firstly coated with an impregnation primer varnish Iruxil W-I colour containing fungicides and insecticides. There were used 9 colour hues of this lacquer with micronized pigments (iron oxides) protecting wood against negative UV radiation effects:

IRUXIL W-I-500 Natural
IRUXIL W-I-510 Pine
IRUXIL W-I-520 Teak
IRUXIL W-I-530 Oak
IRUXIL W-I-540 Chestnut
IRUXIL W-I-550 Walnut
IRUXIL W-I-560 Dark walnut
IRUXIL W-I-570 Mahogany
IRUXIL W-I-580 Ebony

The final surface treatment was application of the transparent top varnish Iruxil WP-600 on all specimens. The accelerated wood ageing was simulated in a xenon test chamber Q-SUN Xe-3-HS (Fig. 1).

The average thickness of the primer was 25 μm, the average thickness of the top varnish was 33 μm.

Fig. 1 Xenon test chamber Q-SUN Xe-3-HS and specimens rotation during accelerated ageing.

The surface-treated experimental material was arranged equidistantly across the xenon test chamber. To ensure the equal uniform intensity and heat dispersion for all the specimens, they were regularly shifted according to a recommended schedule (Fig. 1).

The ageing conditions in the xenon test chamber were set following the standard ASTM G 155. This standard is a fundamental one determining the conditions for accelerated ageing for non-metallic materials with the aid of a xenon discharge tube. Two modes for outdoor conditions were chosen: „dry“(without water) mode and „wet“(with water). The first mode simulates outdoor conditions in case when wood is exposed to UV radiation but protected from water, the second simulates conditions when wood is exposed to both factors, UV and rain. The test parameters are in Tables 1 and 2.

Table 1 The ageing parameters set according to the Standard ASTM G 155 “water-free mode”.

Step	Mode	Radiation intensity (W/m^2)	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

Table 2 The ageing parameters set according to the Standard ASTM G 155 “wet mode”.

Step	Mode	Radiation intensity (W/m^2)	Black panel temperature (°C)	Air temperature (°C)	Relative air humidity (%)	Time (min.)
1	Radiation	0,35	63	48	30	102
2	Radiation + water spraying	0,35	63	48	90	18

The radiation intensity was set at 0.35 W·m^{-2} with radiation wave range higher than 340 nm, following the Standard. This value corresponds to the mean annual value for the temperate climate. The temperature, controlled on a black panel, corresponds to the maximum air temperature on the panel surface. The aim of this temperature is to accelerate the changes on the wood surface.

The differences in colour coordinates ΔL^*, Δa^*, Δb^* and the total colour change ΔE^* in the individual ageing phases were calculated according to the equations:

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

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

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

$$\Delta E^* = \sqrt{\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2}} \tag{4}$$

where L* is brightness (lightness) of the colour, a* – coordinate between red and green, b* – coordinate between yellow and blue measured spectro-photometrically.

RESULTS AND DISCUSSION

The average values of colour coordinates L*a*b* measured on wood surface treated with coatings of nine colour hues and ageing in dry and wet mode are listed in Fig. 2. Figure 2 shows that the L*a*b* values of surface-treated veneers depended on the pigments used.

The influence of ageing on colour change of veneers treated with several colour hues was evaluated with the aid of three-way analysis of variance. There has been confirmed that all the three factors tested (ageing mode, ageing time, hue applied in surface treatment) were significant through inducing changes to the colour space expressed by the coordinates L*a*b*. Significant influence of interactions among these factors has been confirmed, too.

The influence of the factors inspected has been found significant. In case of dry mode, however, the changes in the colour coordinates L*a*b* were very small, without significant differences (Fig. 2a).

The changes in the individual colour coordinates as well as the total colour change ΔE are illustrated in Fig. 3 and 4. The graphs show that the colour stability over the ageing period was typical especially for darker-hued specimens (ebony, dark nut, mahogany). On the other hand, the lighter hues (pine, teak and oak) manifested less colour stability and moderate darkening due to ageing. These changes were not as distinct as the changes observed by other authors (SAHA *et al*. 2013a, OLSSON *et al*. 2014 and others). This depended on the coating system type and on the wood species used.

The colour changes were not always possible to observe easily by unaided eye. The visual observations alone did not provide a reliable base for making conclusions about occurrence and type of colour changes (Fig. 5).

In the case of the wet mode, the colour changes were similar to the dry mode, but more pronounced (Fig. 4). The coordinate a*, especially in lighter hued specimens imitating pine, teak and mahogany decreased moderately with time, shifting towards to green. Contrarily, in the case of oak, this coordinate increased. The coordinate b* moderately decreased for all hues, shifting towards blue. Fig. 4 manifests that b* decrease was steeper in case of pine, natural, oak and teak hue. Ebony and dark walnut did not manifest observable changes.

The coordinate L* also decreased with the ageing time, and this was observed for all the tested hues. The changes in ΔL* Δa* Δb* and the total colour change ΔE presented in Fig. 4 display stronger darkening and more pronounced colour change in case of lighter colour hues. Qualitatively similar results obtained for spruce wood treated with various hues can be found in REINPRECHT and PÁNEK (2015). As for the service life of wood surface intended for outdoor use, the covering capacity of coatings was found important for reflectance or absorbance of UV radiation. According to the last cited authors, the better colour stability of coating materials of darker hues can be explained by their higher absorbance of solar radiation, which prevents UV to penetrate the wood layers under the coating. Lighter hues contain less pigments, consequently, so these hues allow more UV penetrate and reach the wood surface, which results in major colour change due to more progressive lignin photo-degradation on the wood surface under the coating.

The results of this work manifest that the presented treatment of the coating system with pigments had positive impact on the system colour stability.

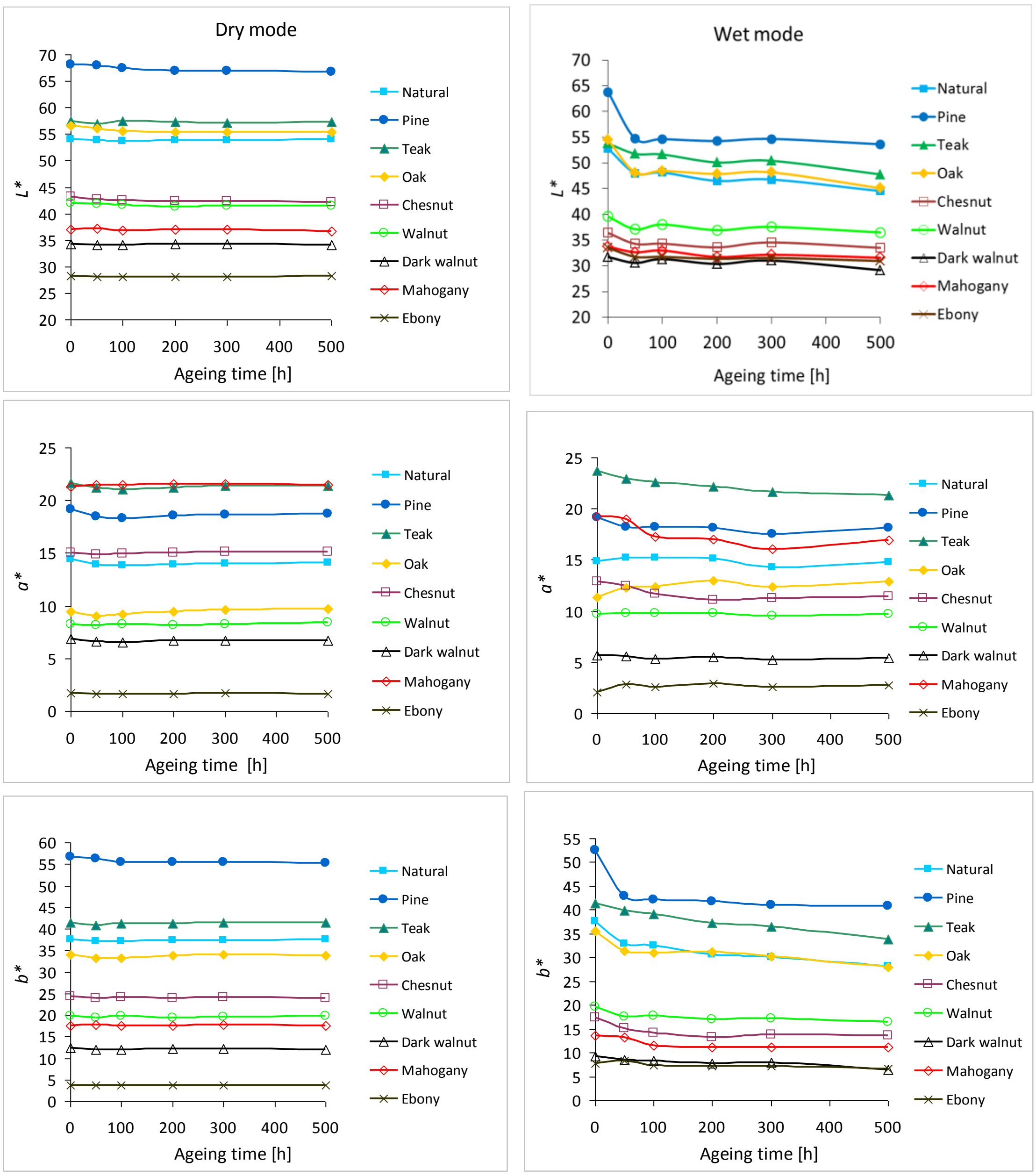

Fig. 2 Influence of accelerated ageing on colour space coordinates L*a*b*.

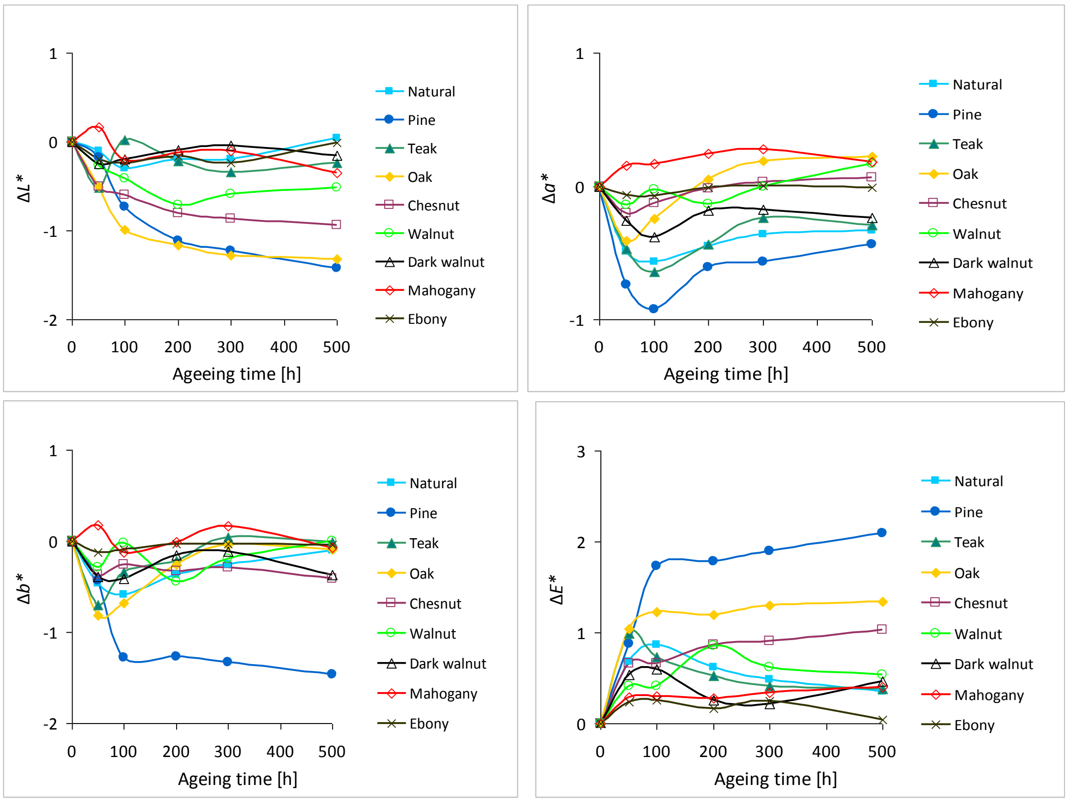

Fig. 3 Changes in colour space coordinates ΔL*Δa*Δb* and the total colour change ΔE during accelerated ageing – dry mode.

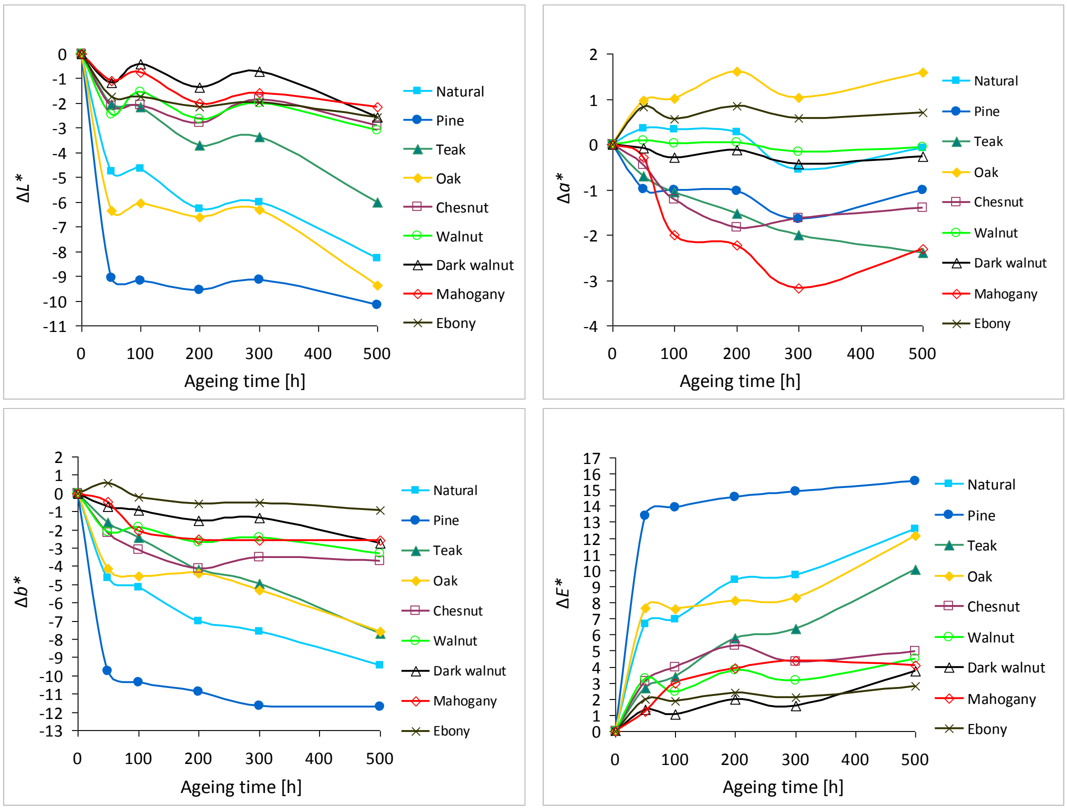

Fig. 4 Changes in colour space coordinates ΔL*Δa*Δb* and the total colour change ΔE during accelerated ageing – wet mode.

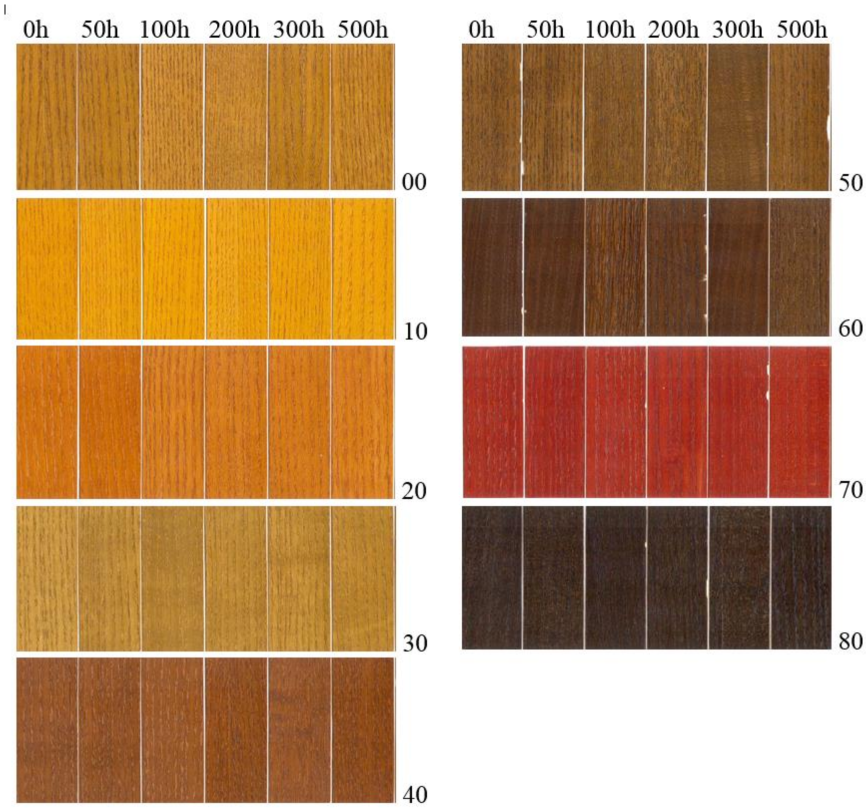

Fig. 5 Colour change during accelerated ageing – dry mode; 00-Natural, 10-Pine, 20-Teak, 30- Oak, 40-Chestnut, 50- Walnut, 60-Dark Walnut, 70-Mahagony, 80- Ebony.

The colour changes associated with the wet mode of accelerated ageing were bigger compared to the dry mode. This fact, however, was not evident with visual observations only (Fig. 6). In several cases, there were colour differences visible also in frame of a single specimen. This means that the ageing caused colour heterogeneity across the specimen. Water interacting with UV radiation induced chemical changes in the lacquer structure. In both modes, major colour changes were observed after 50–100 hours, which well corresponds to LANDRY and BLANCHETT (2012).

The results confirmed that the coating system modification with nano-particles on inorganic base was effective in protection against UV radiation; and, according to LANDRY and BLANCHETT (2012), WAN *et al*. 2014, and others, this modification is more effective than modifications on organic base.

The specimen surface treated with the tested coating system was found resistant against water, which had also been documented with the contact angle values bigger than 90° (BRIŠ 2015). This is why the coating system was well protected against water-induced effects on its surface during accelerated ageing.

The gloss change during ageing in both dry and wet mode is in Fig. 7. In case of the dry mode, the tested specimens in general preserved their original gloss. An intriguing fact is that a moderately increasing trend was observed dependent on the lacquer hue applied.
In case of the wet mode, the gloss change trend was similar, sinusoidal-shaped, in almost all the hues used. The initial decrease during the first 100 hours was followed by an increase until 300 hours, and then the trend decreased again. We may suppose this may be due to moisture content in specimens fluctuating after each cycle completed. The ageing process was stopped after 500 hours. At this moment, all the coatings were generally more matt.

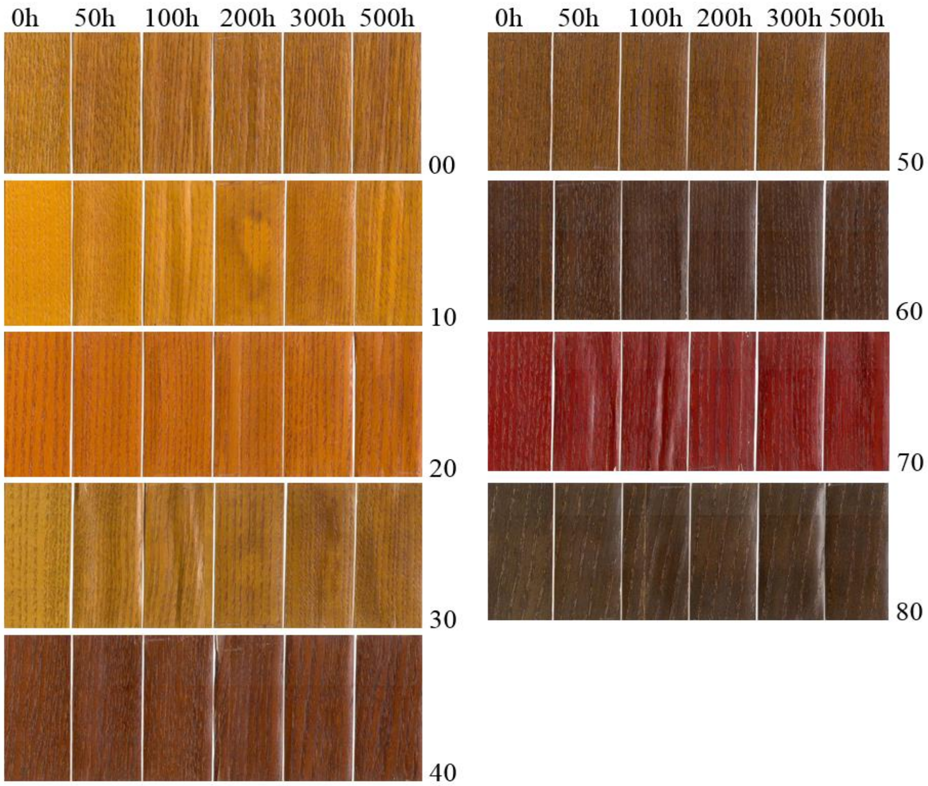

Fig. 6 Colour change during accelerated ageing – wet mode; 00-Natural, 10-Pine, 20-Teak, 30- Oak, 40-Chestnut, 50- Walnut, 60-Dark Walnut, 70-Mahagony, 80- Ebony.

The colour change can be due to degradation of the coating and equally the wood substrate (OLLSON *et al*. 2014). The gloss degradation only reflects a very moderate degradation of the coating alone.

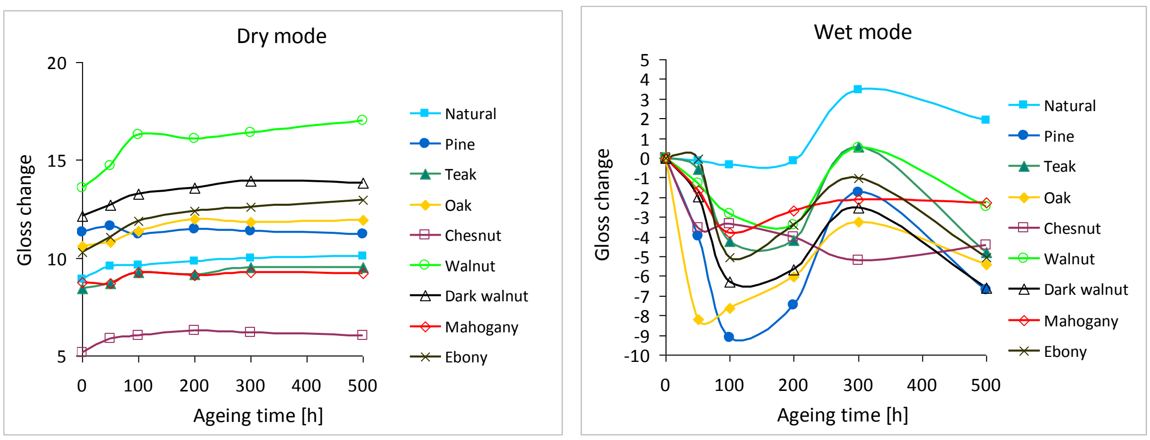

Fig. 7 Gloss change during accelerated ageing.

CONCLUSIONS

This paper reports a study of the influence of accelerated ageing on colour and gloss change in veneers prepared of tree of heaven treated with a water-based coating system Iruxil in several colour hues, intended for use in outdoor conditions.

The testing performed on colour and gloss changes showed that the coating system used was high resistant against photo-degradation.

Under the dry ageing mode, there were no obvious changes in the surface properties of the coated wood. Under the wet mode, certain changes were present: the coatings turned somewhat darker under the coupled effect of UV radiation and water, and they also got more matt. These changes, however, were not very visible.

Darker hues showed better colour stability compared to the lighter ones. The former, containing more micronized pigments, iron oxides, guaranteed better protection to the wood surface against the UV-induced effects.

REFERENCES

ASTM G155: 200: Standard Practice for Operating Xenon Arc Light Exposure of Non-Metallic Materials.

BRIŠ, A. 2015: Vplyv urýchleného starnutia na vlastnosti povrchu dreva upraveného vodou riediteľnou náterovou látkou určenou pre exteriér: Diplomová práca. Zvolen: Technická univerzita vo Zvolene. Drevárska fakulta. 73 p.

FAN, Y. *et al*. 2010: Colour responses of black locust (*Robinia pseudoacacia* L.) to solvent extraction and heat treatment. Wood Sci. Technol., 44: 667–678.

FEIST, W. C. 1990: Outdoor wood weathering and protection. In.: Rowell, R.M. and Barbour, J.R (Eds.), Archaeological Wood Properties, Chemistry, and Preservation. Washington DC: Advances in Chemistry Series 225. Proceedings of 196th meeting, American Chemical Society, 1990.

GIRARDI, F., CAPPELLETTOA, E., SANDAK, J. *et al*. 2014. Hybrid organic–inorganic materials as coatings for protecting wood. Progress Org. Coat., 77(2): 449–457.

HON, D.N. 1981. Photochemical degradation of lignocellulosic materials. In.: Grassie, N (Ed.), Developments in Polymer Degradation–3. Essex: Applied Science Ltd. Chapter 8, 1981, p. 229–281.

HUANG, X. *et al*. 2012. A spectrocolorimetric and chemical study on color modification of heat–treated wood during artificial weathering. Applied Surf. Sci., 258(14): 5360–5369.

CHANG, T. C., CHANG, H. T., WU, C. L., CHANG, S. T. 2010: Influences of extractives on the photodegradation of wood. Polym. Degrad. Stab. 95: 516−521.

CHEN, Y., GAO, J., FAN, Y., TSCHABALALA, M. A., STARK, N.M. 2012. Heat–induced chemical and color changes of extractive–free black locust (*Robinia pseudoacacia*) wood. BioResources, 2012. 7(2): 2236–2248

IHRACKÝ, P. 2014. Vplyv umelého starnutia na vybrané povrchové vlastnosti dreva. Dizertačná práca. Zvolen: Technická univerzita vo Zvolene, 142 s.

KISHINO, M., NAKANO, T. 2004. Artificial weathering of tropical woods. Part 1: Changes in wettability. Holzforschung, 58(5): 552–557.

KOCAEFE, D., SAHA, S. 2012. Comparison of the protection effectiveness of acrylic polyurethane coatings containing bark extracts on three heat-treated North American wood species: Surface degradation. Applied Surf, Sci., 258(13): 5283–5290.

KÚDELA, J., MAMOŇOVÁ, M. 2006. Tree-of-heaven wood (*Ailanthus altissima* Mill.) – structure and properties. In Wood Structure and Properties´06. (Eds. Kurjatko, S., Kúdela, J. & Lagaňa, R.), Zvolen: Arbora Publishers, p. 275–280.

KÚDELA, J., ŠMÍRA, P., MRENICA, L., NASSWETTROVÁ, A., IHRACKÝ, P. 2015. Surface treatment of wood structural elements with dry ice and its influence on wood surface properties. J. Civil Eng. Architect. Res., 2(10): 1002−1010.

LANDRY, V., BLANCHETT, P. 2012. Weathering resistance of opaque PVDF-acrylic coatings applied on wood substrates. Progress Org. Coat., 75(4): 494–501.
OLSSON, S. K., JOHANSSON, M., WESTIN M., Östmark, E. 2014. Reactive UV-absorber and epoxy functionalized soybean oil for enhanced UV-protection of clear coated wood. Polym. Degrad. Stab., 110: 405–414.
PANDEY, K. K., VUORINEN, T. 2008. Comparative study of photodegradation of wood by a UV laser and a xenon light source. Polym. Degrad. Stab., 93: 2138–2146.
PERSZE, L., TOLVAJ, L. 2012: Photodegradation of wood at elevated temperature: Colour change. J. Photochem. Photobiol. B: Biol., 108: 44‒47.
REINPRECHT, L. 2012. Ochrana dreva. Zvolen: Technická univerzita vo Zvolene, 453 pp, ISBN 978-80-228-2351-7.
REINPRECHT, L., PÁNEK, M. 2015: Effect of roughness, light pigments, and water repellent on the color stability of painted spruce subjected to natural and accelerated weathering. BioResources, 10(4): 7203–7219.
REINPRECHT, L., ŠOMŠÁK, M. 2015: Vplyv plazmy a UV-aditív v transparentných náteroch na farebnú stabilitu smrekového dreva (*Picea abies*) pri starnutí v xenoteste. Acta Facultatis Xylologiae Zvolen. 57(2): 49–59.
SAHA, S., KOCAEFE, D., BOLUK, Y., PICHETTE, A. 2013a. Surface degradation of CeO2 stabilized acrylic polyurethane coated thermally treated jack pine during accelerated weathering. Applied Surf. Sci. 276: 86–94.
SAHA, S., KOCAEFE, D., KRAUSE, C. *et al*. 2013b. Enhancing exterior durability of heat-treated jack pine by photo-stabilization by acrylic polyurethane coating using bark extract. Part 2: Wetting characteristics and fluorescence microscopy analysis. Progress Org. Coat. 76: 504–512.
TOLVAJ, L., FAIX, O. 1996: Modification of colour by steaming. In Proceedings of the 2nd international conference on the development of wood science/technology and forestry. Sopron: University of Sopron, p. 1–10.
TOLVAJ, L., PERSZE, L., ALBERT, L. 2011. Thermal degradation of wood during photodegradation. J. Photoch. Photobio. - B 105(1): 90–93.
WILLIAMS, R.S., KNAEBE, M. T., EVANS, J., FEIST, W. C. 2001. Erosion rates of wood during natural weathering: Part III. Effect of exposure angle on erosion rate. Wood Fiber Sci., 33(1): 50–57.
WAN, C., LU, Y., SUN, Q., LI, J. 2014. Hydrothermal synthesis of zirconium dioxide coating on the surface of wood with improved UV resistance. Applied Surf. Sci., 321: 38–42.

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