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CHANGE IN THE COLOUR OF TRANSPARENT SURFACE FINISH ON HYDROTHERMALLY TREATED WOOD

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ABSTRACT

The paper deals with the influence of ageing in the dark and in the light on the colour of a transparent surface finish. In the experiments, Paper birch (*Betula papyrifera Marsh*) and Norway maple wood (*Acer pseudoplatanus L.*) were hydrothermally treated at 135 °C under saturated water vapour for 6 hours. The colour parameters were measured after native wood and thermally treated wood were surface finished. Three different types of surface finishes (acrylic-polyurethane, polyacrylic and aldehyde resin, and alkyd resin) were applied on the wood surfaces. The colour parameters of the tested surfaces (system CIE L*a*b*, chroma C*, hue angle h°) were measured immediately after surface finishing and ageing. The tested samples were aged either in the dark or in the sunlight behind windows glass, in the interior, for 60 days. The results showed that the colour of the wood and the colour of surface finishes changed after ageing in the dark and the light. The changes were different. The surfaces mostly lighten up in the dark and darken in the light.

Keywords: birch; colour; maple; surface finish; hydrothermally modified wood.

INTRODUCTION

Coatings can give wood materials desired aesthetic properties, such as colour and gloss. However, they are also generally essential in protecting wood from environmental influences, such as moisture, radiation, biological damage, or damages of mechanical or chemical origins. It is applied to both interior uses (like furniture) and exterior. From the viewpoint of customers, the aesthetic appearance of the wood coating is the main purchasing factor (Sedliačiková *et al.*, 2021).

Transparent finishing is designed to enhance the stability of wood surfaces and maintain the natural aspects of wood, such as colour, grain, and texture, for a long time. Transparent finishing films on wood surfaces perform poorly during interior or exterior exposure. In fact, these types of coatings cannot absorb UV light, and treat the wood surface (Bulian and Graystone 2009). This phenomenon leads to the photodegradation of the wood substrate. A visible colour change of wood is the first sign of its chemical modification when exposed to light, even in diffuse indoor light conditions. The change in the colour due to the surface finishing is an interaction between the changed wood colour and the colour of the coating film itself. It is generally known that, under the influence of light, coating films exposed in interiors turn yellow. The most commonly adopted UV protection technology is using UV protective substances that are admixed into coating material. However, this degradation of colour was not inhibited absolutely (Salla et al. 2012, Liu *et al.*, 2019, Kúdela *et al.*, 2020, Reinprecht *et al.*, 2020).

Wood modification processes are exciting because they are implemented to improve the properties of wood and to produce new materials. The hydrothermal treatment of wood with saturated water vapour is traditionally used in the woodworking industry, for example, in the manufacture of furniture components with solid wood bending, for the production of floors and paneling for the interior. Dzurenda and Dudiak (2020) presented the changes in beech wood obtained in the targeted process of colour modification with saturated water steam at temperatures from 105 °C to 137,5 °C. The changes in density, acidity, and colour of beech wood were analyzed. The thermally-based modification treatment is also accompanied by chemical reactions of the cell-wall components (polysaccharides, lignin, and extractives) which cause changes in the colour of wood (Sandberg *et al.*, 2021, Dudiak and Dzurenda 2021, Dzurenda and Dudiak 2020, Dzurenda *et al.*, 2020, Kminiak *et al.*, 2020, Vidholdová *et al.*, 2019, Timar and Varodi 2016, Tolvaj and Mitsui 2010). Increasing the temperature of the hydrothermal reaction from 100 °C to 150 °C causes deepening of the chemical and physicochemical changes of all components of the wood substance (Solár 1997). The change in the colour of the wood depends on the steaming conditions and ~~it~~ is closely related to changes in its chemical characteristics (Geffert *et al.*, 2020).

Colour is one of the aesthetic properties that can be identified subjectively with the naked eye, or measured objectively using a spectrophotometer. The surface of wood, hydrothermally treated with saturated water vapour, needs to be finished with transparent coating materials to preserve the colour and an attractive appearance (Vidholdová *et al.*, 2019). The transparent coating is designed to enhance the light stability of the wood surface but not to cover the wood texture. The impact of transparent finishes on emphasizing the aesthetic properties of root textures was dealt with by Reinprecht and Vidholdová (2011). Transparent coating films can visibly change the colour of wood. Change in the colour of the wood surface after a transparent coating material has been applied is an interaction between the colour of the coating film and the colour of the wood surface. Different transparent finishes result in different colour of wood surfaces (Slabejová and Šmidriaková 2020, Slabejová and Šmidriaková 2021).

At the same time, the colour of the finished wood surface changes due to sunlight. The light is the major reason for damage to a number of materials, including wood and coatings (Kučerová *et al.*, 2019, Lee *et al.*, 2018, Sandberg *et al.*, 2017). The change in the colour of surface finish is an interaction of the changed wood colour and the colour of the coating film itself (Nowrouzi *et al.*, 2021, Cirule *et al.*, 2021; Peng *et al.*, 2020, Herrera *et al.*, 2018, Šimůnková *et al.*, 2017, Kúdela 2017). It is generally known that coating films turn yellow under the influence of light. The most commonly adopted UV protection technology uses UV protective substances that are admixed into the coating materials. However, the degradation has not been inhibited absolutely (Liu *et al.*, 2015, Salla *et al.*, 2012, Kúdela *et al.*, 2020, Reinprecht *et al.*, 2020).

The aim of this paper was to evaluate the change in the colour of transparent surface finishes applied on hydrothermally treated wood, in the dark and the natural light.

MATERIALS AND METHODS

Wood and the surface finishes

The samples of mature native wood and hydrothermally treated wood of two wood species (Table 1) were prepared from the boards, air-conditioned for six months. The boards were sanded, transversely first and then in the longitudinal direction (last sandpaper grit P

180). The samples had three to eight growth rings per cm, they were free from defects, and the growth ring orientation to the tested surface was 5° to 45°.

Tab. 1 Experimental set-up.

Wood species	Wood treatment	Surface finishes[2]	Ageing
• Paper birch (*Betula papyrifera* Marsh) • Norway maple (*Acer pseudoplatanus* L.)	Native (untreated) HTT -Treated (with saturated water vapour at 135 ± 2.5 °C for 6 hours)[1]	Without finish Acryl-PU PAcryl-Ald Alk	• light • dark

Note:
[1] The parameters for the modification process are described in more detail in the works by Dudiak and Dzurenda 2021, Dzurenda and Dudiak 2020, Geffert *et al.*, 2020, and Dudiak 2021.
[2] Acryl-PU = One-component water-based acrylic-polyurethane dispersion surface finish; PAcryl-Ald = Two-component surface finish with polyacrylic and aldehyde resin; Alk = Single-component wood sealer with alkyd resin.

Three transparent surface finishes for interiors were applied on the native wood and hydrothermally treated wood samples, according to the producer's recommendations:

- One-component water-based acrylic-polyurethane dispersion surface finish, Aqua TL-412-Treppenlack/50. It is recommended for use on solid wood, veneers, wooden stairs, and furniture. It was applied by spraying in two coats with a spreading rate of 100-150 ml·m^{-2}, with an average film thickness of 30 ± 10 μm. The coating material has a density of 1.03 g·cm^{-3} and VOC content of < 140 g·l^{-1}. (Acryl-PU);
- Two-component surface finish with polyacrylic and aldehyde resin, PUR SL-212-Schichtlack/30. It is recommended for use on solid wood, veneers, tables and worktops, and kitchen and bathroom furniture. It is highly scratch-resistant and full-built. It was applied by spraying in two coats with a spreading rate of 80-120 ml·m^{-2}. The coating material has a density of 0.94 g·cm^{-3}. (PAcryl-Ald);
- Single-component wood sealer with alkyd resin, HWS-112-Hartwachs-Siegel/clear. It is recommended for use on furniture, tables and worktops, bathroom and sauna elements, floors and stairs, cork floors, and bamboo components. It was applied by spraying in two coats with a spreading rate of 60-70 ml·m^{-2}. The coating material has a density of 0.88 g·cm^{-3} and VOC content < 500 g·l^{-1}. (Alk).

After application, samples were stored at 23 °C and 50% relative humidity (RH) in the dark room for 14 days to ensure film formation, sufficient hardening, and solvent evaporation.

Testing for light fastness

The exposure to natural sunlight behind the window glass was carried out between July 2020 and September 2020 for 60 days. The coated and uncoated samples were stored in a room in the interior, behind a glass window (thermal-insolation double glazing with U-factor 1.1 W·m^{-2}·K^{-1} with west direction). The interior temperature varied from 20 to 25 °C, and RH varied from 50% to 55%. The daily average total solar power density was between 336 and 535 W·m^{-2} in Zvolen, Slovakia. The geographical data for Zvolen are: longitude 19°07′03″ East; latitude 48°34′15″ North; and an altitude of 283 m. The natural dark exposure was carried out at the same conditions but samples were packed up in aluminium foil for 60 days.

Evaluation of discolouration

The colour parameters of the tested samples were measured using a Color Reader CR-10 (Konica Minolta, Osaka, Japan) after surface finishing and after exposition in the dark or in the light. The device was set to an observation angle of 10°, with d/8 geometry, and a D65 light source. The colour changes of the sample surfaces were measured after 60 days. The colour values (lightness L^*, redness + a^*, yellowness + b^*, chroma C^*, hue angle h°) were measured on the 10 given positions on each of the tested samples (Figure 1) and expressed in the CIE $L^*a^*b^*$ system (ISO 7727-3: 1984).

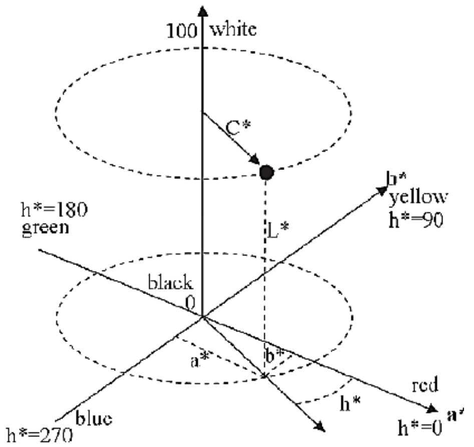

Fig. 1 CIE $L^*a^*b^*$ system (Ruiz *et al.*, 2012).

Total colour difference, ΔE^*_{ab}, was subsequently calculated as the Euclidean distance between the points representing them in the space using the following equation (ASTM D2244-16:2016 and ISO 7727-3:1984):

$$\Delta \boldsymbol{E}^*_{\boldsymbol{ab}} = \sqrt{\Delta \boldsymbol{L}^{*2} + \Delta \boldsymbol{a}^{*2} + \Delta \boldsymbol{b}^{*2}}, \quad (1)$$

where: ΔL^*, Δa^*, Δb^* are the differences in individual axes (the difference between the value measured after 60 days of exposure in dark and sunlight and before exposure).
To demonstrate the colour change of the coated wood surfaces, the Color Laser Jet Pro MFP M477fdw was used before and during the exposure of the specimens to natural sunlight ageing.

Statistical evaluation

The MS Excel 2013 and statistical software STATISTICA 12 were used to analyse and present the collected data on colour parameters. Descriptive statistics deal with basic statistical characteristics (arithmetic mean, standard deviation) and analysis of variance (ANOVA) at 0.05 significance level.

RESULTS AND DISCUSSION

We assume that hydrothermal wood treatment (HTT) eliminates colour changes caused by light. The change in the colour of the wood or the change in the colour of transparent surface finishes is significantly reflected in the lightness L^*.

Figure 2 shows that, in the dark, the lightness L^* of HTT birch wood with no surface finish almost did not change; and the native surface lightened up. It was also confirmed by the Duncan test (Table 2). The change in lightness was statistically insignificant (< 95%). In the dark, the change in the lightness of native birch wood was statistically highly significant (>99.9%). In the light, the surface of HTT birch wood with no surface finish darkened slightly and the native surface darkened markedly. It was confirmed by the Duncan test (Table 2).

In the dark, the surface of HTT maple wood with no surface finish lightened up and the native surface remained almost unchanged. The change in the lightness on native wood was statistically insignificant (< 95%). In the light, the surfaces of the native wood and HTT maple wood with no surface finish darkened significantly. This was also confirmed by the Duncan test (Table 3). Similar behaviour was observed by Pandey (2005) for photo-induced changes of uncoated softwood and hardwood. Salcă and Cismaru (2011) reported that, under sunlight radiation that penetrates the window glass, wood surfaces change the colour and darken with increasing exposure time.

The measurements show that the change in lightness of the wood surface occurs even if no light affects the surface. In our case, the native birch wood surface and the HTT maple wood surface became lighter in the dark and they became darker in the light. These changes in colour of all wood species resulting from the hydrothermal treatment are considered to be permanent and irreversible. Irreversibility of the changes in wood colour is confirmed by the differences in lignin-carbohydrate complex of HTT wood as well as native wood, and by the presence of monosaccharides, organic acids and basic structural elements of guaiacyl-syringyl lignin in the condensate (Sandberg *et al.,* 2021, Dzurenda and Dudiak 2020, Dudiak 2021, Kminiak *et al.,* 2020, Dudiak *et al.,* 2021, Vidholdová *et al.,* 2021). But we cannot consider the changes in colour of HTT wood surface to be constant over time or in exposure to light. It was proven by our measurements and the results by other authors, as well. Miclečić *et al.,* (2011) reported that in the first ten days of sunlight exposure, the surfaces of uncoated thermally modified ash, beech, and hornbeam samples discoloured slowly compared to uncoated native samples.

From the viewpoint of surface finishes applied on both HTT wood and native wood, the Alk surface finish showed the most stable lightness on birch wood (native and HTT); on HTT wood the Acryl-PU surface finish, as well. The change in the lightness of the Acryl-PU on HTT birch wood was insignificant (< 95%), so it remained constant in the dark and in the light. The native birch wood with the Acryl-PU showed both lightenings in the dark and darkening in the light highly significantly (> 99.9%). The surface of HTT birch wood with the PAcryl-Ald lightened up both in the dark and in the light highly significantly (> 99.9%). The change in lightness of the surface of native birch wood with the PAcryl-Ald was insignificant in the dark (< 95%); and the surface darkened highly significantly in the light (> 99.9%).

The surface of HTT birch wood with the Alk surface finish did not show any significantly change in the lightness both in the dark and in the light. The change in lightness was of a low significance in the light (> 95%) and insignificant in the dark (< 95%). The surface of native birch wood with an Alk surface finish darkened low significantly in the dark (> 95%); it darkened high significantly in the light (> 99.9%). Decker and Zahouily (1999) report that a polyurethane-acrylic coating film is more resistant to accelerated QUV weathering than high-strength clearcoats used as automotive finishes. The study by Durmaz *et al.,* (2020) reports that waterborne acrylic coatings can improve the weatherability of wood–plastic composites and minimize colour changes – lightness difference ΔL^*. It follows that the light resistance of acrylic films and acrylic-polyurethane films is satisfactory.

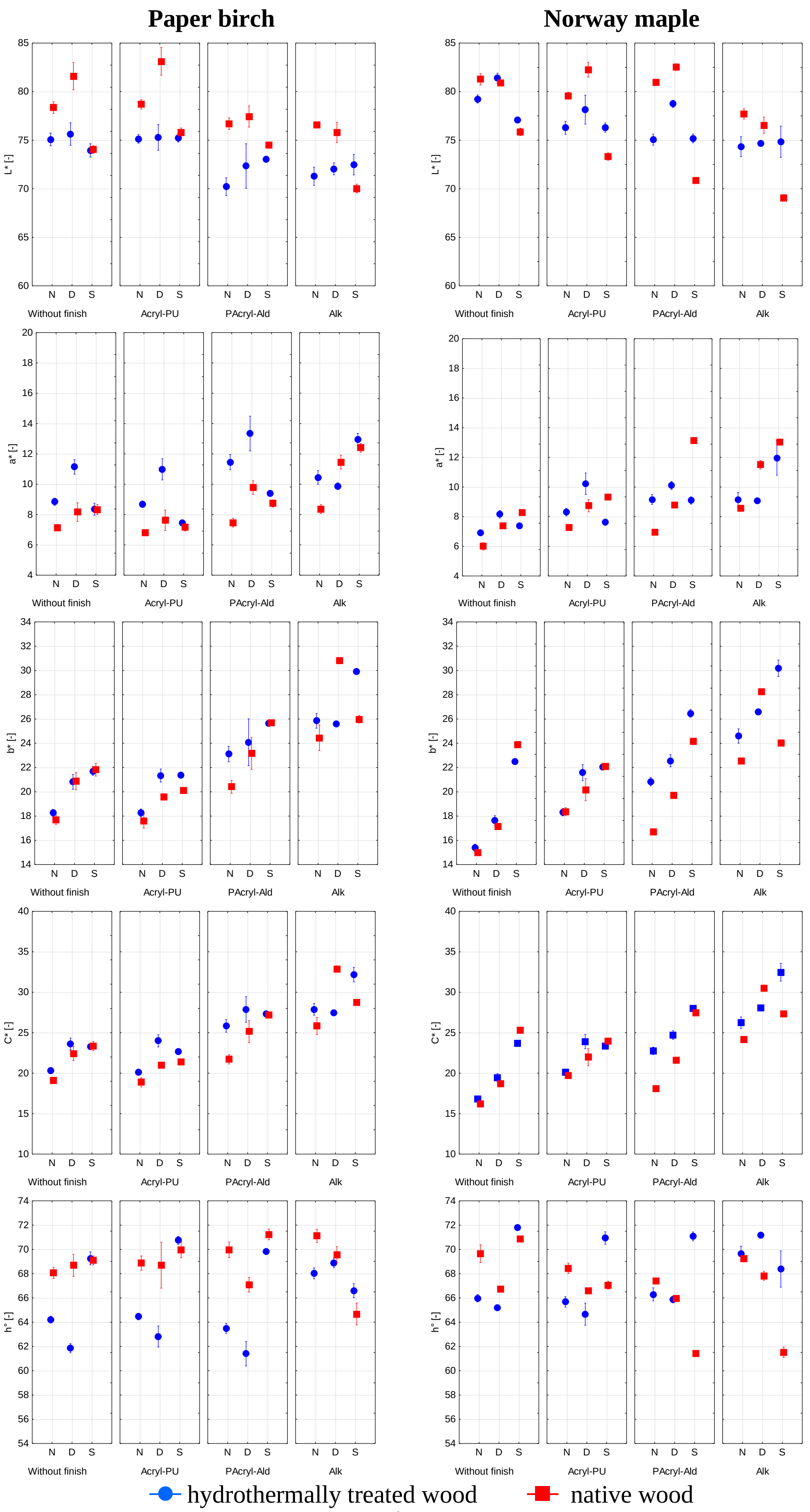

Fig. 2 Colour coordinates L*, a*, b*, C* and h° for native and hydrothermally treated wood; Paper birch (*Betula papyrifera* Marsh), Norway maple (*Acer pseudoplatanus* L.)
Note: before exposition (N) and after exposition in the dark (D) and in the light (S).

The change in the lightness of both HTT and native birch wood surfaces with Acryl-PU surface finish was very similar to the change in lightness of wood with no surface finish. It follows that the change in lightness was mainly caused by changes of the wood itself. A decrease in the lightness of native wood and thermally modified wood is in compliance with the knowledge about changing colour of wood, its darkening, during processes of natural sunlight weathering (Liu *et al.*, 2019, Pandeley 2005, Salcă and Cismaru 2011, Tolvaj and Mitsui 2010, Miklecic *et al.*, 2011).

Figure 2 shows that the surfaces of HTT maple wood coated with Acryl-PU and PAcryl-Ald lightened up highly significantly in the dark (> 99.9%) and did not change the lightness in the light. The surface of HTT maple wood with an Alk surface finish did not change the lightness both in the dark and in the light. Native maple wood surfaces with Acryl-PU and PAcryl-Ald lightened up highly significantly in the dark (> 99.9%) and became darker in the light highly significantly (> 99.9%). The Alk surface finish on native wood significantly darkened in the dark (> 99%) and highly significantly darkened in the light (> 99.9%).

The coordinates a^*, b^*, C^* and the angle h° for all the tested samples both in the dark and in the light are shown in Figure 2. The results of Duncan test for coordinates a^*, b^*, C^* and angle h° are summarised in Table 2 (Paper birch) and Table 3 (Norway maple).

Tab. 2 The Duncan test for Paper birch wood.

Colour coordinates	Exposition	Without finish		Acryl-PU		PAcryl-Ald		Alk	
		Native	HTT	Native	HTT	Native	HTT	Native	HTT
L^*	dark	•••	-	•••	-	-	•••	•	-
	light	•••	•	•••	-	•••	•••	•••	•
a^*	dark	•••	•••	•••	•••	•••	•••	•••	•
	light	•••	-	-	•••	•••	•••	•••	•••
b^*	dark	•••	•••	•••	•••	•••	••	•••	-
	light	•••	•••	•••	•••	•••	•••	•••	•••
C^*	dark	•••	•••	•••	•••	•••	•••	•••	-
	light	•••	•••	•••	•••	•••	•••	•••	•••
h°	dark	-	•••	-	•••	•••	•••	••	••
	light	•	•••	•	•••	••	•••	•••	•••

Notes: indexes of the Duncan test characterizing the significance level of colour coordinates in relation to the state before exposure: ••• high significant decrease > 99.9%, •• significant decrease > 99%, • low significant decrease > 95%, - insignificant decrease < 95%.

For birch wood (Table 2), the statistically insignificant change in coordinate a^* was determined for HTT birch wood with no surface finish in the light and for native birch wood with Acryl-PU in the light. Statistically insignificant change in the coordinate b* was determined for HTT birch wood with an Alk surface finish in the dark. Statistically insignificant change in the coordinate C^* was determined for HTT birch wood with Alk surface finish in the dark. Statistically insignificant change in the angle h° was determined for native birch wood with no surface finish in the dark and for native birch wood with Acryl-PU in the dark. Figure 2 shows that the coordinate a^* on (native) birch wood, with surface finishes and with no surface finish, changed towards shades of red more significantly in the light than in the dark. The coordinate a^* on HTT birch wood, with no surface finish and also with each of the surface finishes, changed towards shades of red in the dark; in the light, the coordinate a^* changed towards shades of green. The coordinate b^* on (native) birch wood and HTT (birch wood) changed towards shades of yellow in the dark and in the light, as well. Only the Alk surface finish on native yellowed more significantly in the dark and on HTT (birch wood) yellowed more significantly in the light; in the dark, the coordinate b* did not change. A visual comparison of the colour of the surfaces and the colour difference ΔE^*_{ab} can be seen in Tables 4 and 5.

Tab. 4 Scans and the colour difference ΔE^*_{ab} on the surface finishes on Paper birch wood exposed to the light and to the dark.

Exposition		Without finish	Acryl-PU	PAcryl-Ald	Alk
Paper birch - native	before exposition				
	light	 $\Delta E^*_{ab} = 6.0$	 $\Delta E^*_{ab} = 3.8$	 $\Delta E^*_{ab} = 5.7$	 $\Delta E^*_{ab} = 6.7$
	dark	 $\Delta E^*_{ab} = 4.5$	 $\Delta E^*_{ab} = 4.9$	 $\Delta E^*_{ab} = 2.8$	 $\Delta E^*_{ab} = 6.4$

Tab. 5 Scans and the colour difference ΔE^*_{ab} on the surface finishes on HTT Paper birch wood exposed to the light and to the dark.

Exposition		Without finish	Acryl-PU	PAcryl-Ald	Alk
Paper birch - HTT	before exposition				
	light	 $\Delta E^*_{ab} = 3.6$	 $\Delta E^*_{ab} = 3.1$	 $\Delta E^*_{ab} = 3.8$	 $\Delta E^*_{ab} = 4.2$
	dark	 $\Delta E^*_{ab} = 2.6$	 $\Delta E^*_{ab} = 3.1$	 $\Delta E^*_{ab} = 2.3$	 $\Delta E^*_{ab} = 0.8$

For maple wood (Table 3), the statistically insignificant change in coordinate a^* was determined for HTT maple wood with PAcryl-Ald in the light and for HTT maple wood with an Alk surface finish in the dark. The change in coordinate b^* was determined as highly significant for all the tested maple wood samples both in the dark and in the light. The change in coordinate C^* was determined as highly significant for all the tested maple wood samples except HTT maple wood with an Alk surface finish in the dark. Statistically insignificant change in the angle h° was determined for HTT maple wood with PAcryl-Ald in the dark.

Tab. 3 The Duncan test for Norway maple wood.

Colour coordinates	Exposition	Without finish		Acryl-PU		PAcryl-Ald		Alk	
		Native	HTT	Native	HTT	Native	HTT	Native	HTT
L^*	dark	-	•••	•••	•••	•••	•••	••	-
	light	•••	•••	•••	•••	•••	-	•••	-
a^*	dark	•••	•••	•••	•••	•••	••	•••	-
	light	•••	••	•••	•	•••	-	•••	•••
b^*	dark	•••	•••	•••	•••	•••	•••	•••	•••
	light	•••	•••	•••	•••	•••	•••	•••	•••
C^*	dark	•••	•••	•••	•••	•••	•••	•••	••
	light	•••	•••	•••	•••	•••	•••	•••	•••
h°	dark	•••	•	•••	•	•••	-	•••	••
	light	•••	•••	•••	•••	•••	•••	•••	•

Notes: indexes of the Duncan test characterizing the significance level of colour coordinates in relation to the state before exposure: ••• high significant decrease > 99.9%, •• significant decrease > 99%, • low significant decrease > 95%, - insignificant decrease < 95%.

Tab. 6 Scans and the colour difference ΔE^*_{ab} on the surface finishes on Norway maple wood exposed to the light and to the dark.

Exposition		Without finish	Acryl-PU	PAcryl-Ald	Alk
Norway maple - native	before exposition				
	light				
		ΔE^*_{ab} = 10.4	ΔE^*_{ab} = 7.3	ΔE^*_{ab} = 12.6	ΔE^*_{ab} = 8.8
	dark				
		ΔE^*_{ab} = 2.2	ΔE^*_{ab} = 3.2	ΔE^*_{ab} = 3.4	ΔE^*_{ab} = 5.8

Figure 2 shows that the coordinate a^* on (native) maple wood with Acryl-PU and PAcryl-Ald changed towards shades of red more significantly in the dark than in the light. The coordinate a^* on HTT maple wood, with no surface finish and with each of surface finish, changed towards shades of red in the dark; in the light, the coordinate a^* did not change. The Acryl-PU slightly changed towards shades of green in the light. The b^* coordinate changed towards yellow on both (native) and HTT (maple wood) in the dark and, even more notably, in the light. Only the Alk surface finish on native yellowed more significantly in the dark and on HTT maple wood yellowed more significantly in the light. A visual comparison of the colour of the surfaces and the colour difference ΔE^*_{ab} can be seen in Tables 6 and 7.

Tab. 7 Scans and the colour difference ΔE^*_{ab} on the surface finishes on HTT Norway maple wood exposed to the light and to the dark.

Exposition		Without finish	Acryl-PU	PAcryl-Ald	Alk
Norway maple - HTT	before exposition				
	light				
		ΔE^*_{ab} = 7.4	ΔE^*_{ab} = 3.7	ΔE^*_{ab} = 5.6	ΔE^*_{ab} = 5.6
	dark				
		ΔE^*_{ab} = 3.1	ΔE^*_{ab} = 3.7	ΔE^*_{ab} = 4.1	ΔE^*_{ab} = 2.0

CONCLUSION

The wood colour is very important quality feature, and it is required to be maintained during the long-term life of wood products. The study has shown that thermally modified wood – Paper birch wood (*Betula papyrifera* Marsh) and Norway maple wood (*Acer pseudoplatanus* L.) – considerably differ from unmodified (native) wood regarding the changes in lightness L^* when exposed to natural sunlight behind the window glass or exposed to dark.

The hydrothermal treatment of birch wood ensured the stability of the lightness of the surfaces both in the dark and in the light.

The hydrothermally treated maple wood did not show better stability of lightness than the native wood when exposed to light. In the dark, the hydrothermally treated maple wood showed poor lightness stability. The native maple wood showed good stability of lightness.

The alkyd surface finish (Alk) had excellent stability on hydrothermally treated birch wood and hydrothermally treated maple wood, as well. The finish retained its original lightness in the dark and in the light.

The water-based acrylic-polyurethane dispersion surface finish (Acryl-PU) on the hydrothermally treated birch wood kept its original lightness in the dark and in the light.

The polyacrylic-aldehyde surface finish (PAcryl-Ald) on native birch wood kept its unchanged lightness in the dark. On the hydrothermally treated maple wood, this surface finish kept its unchanged lightness when exposed to light.

REFERENCES

Bulian, F.; Graystone, J.A. 2009. Wood Coatings—Theory and Practice; Elsevier: Amsterdam, The Netherlands.

Cirule, D.; Sansonetti, E.; Andersone, I.; Kuka, E.; Andersons, B. 2021.Enhancing thermally modified wood stability against discoloration. Coatings, 11, 81.

Decker, C., Zahouily, K. 1999. Photodegradation and photooxidation of thermoset and UV-cured acrylate polymers. Polymer Degradation and Stability, 64(2), 293–304, https://doi.org/10.1016/S0141-3910(98)00205-5

Dudiak, M.; Dzurenda, L. 2021. Changes in the physical and chemical properties of alder wood in the process of thermal treatment with saturated water steam. Coatings, 11, 898.

Dudiak, M. 2021. Modification of maple wood colour during the process of thermal treatment with saturated water steam. Acta Fac. Xylologiae Zvolen, 63, 25–34.

Durmaz, S., Özgenç, Ö., Avci, E., Boyaci, I.H. 2020. Weathering performance of waterborne acrylic coating systems on flat-pressed wood–plastic composites. J. Appl. Polym. Sci., 137, 48518, https://doi.org/10.1002/app.48518

Dzurenda, L., Dudiak, M. 2020. Changes in wood tree species Fagus sylvatica L. and characteristics of the thermal process of modifying its color with saturated water steam. Appl. Ecol. Environ. Res., 5, 142–156.

Dzurenda, L., Geffert, A., Geffertová, J., Dudiak, M. 2020. Evaluation of the process thermal treatment of maple wood saturated water steam in terms of change of pH and color of wood. BioRes., 15, 2550–2559.

Geffert, A., Geffertová, J., Výbohová, E., Dudiak, M. 2020. Impact of steaming mode on chemical characteristics and color of birch wood. Forests, 11, 478.

Herrera, R., Sandak, J., Robles, E., Krystofiak, T., Labidi, J., 2018. Weathering resistance of thermally modified wood finished with coatings of diverse formulations. Progress in Organic Coatings, 119, 145-154. https://doi.org/10.1016/j.porgcoat.2018.02.015

Kminiak, R., Orlowski, K.A., Dzurenda, L., Chuchala, D., Banski, A. 2020. Effect of thermal treatment of birch wood by saturated water vapor on granulometric composition of chips from sawing and milling processes from the point of view of its processing to composites. App. Sci., 10.21: 7545.

Kučerová V., Lagaňa R., Hýrošová T. 2019. Changes in chemical and optical properties of silver fir (Abies alba L.) wood due to thermal treatment. J Wood Sci, 65, 1–10. https://doi.org/10.1186/s10086-019-1800-x

Kúdela, J., Sikora, A., Svocák, J. 2020. Colour stability of spruce wood surface coated with a polyurethane lacquer without and with a UV absorber admixture. In XIII: Konference Pigmenty a Pojiva: sbornik/Conference Preceedings; Chemagazín: Pardubice, Czech Republic, pp. 28–30, ISBN 978-80-906269-5-9.

Kúdela, J. 2017. Accelerated ageing-induced effects on surface properties of wood veneers treated with a modified water-based coating system. Ann. WULS-SGGW, For. and Wood Technol, 98, 59–65.

Lee S.H., Ashaari Z., Lum W.C., Halip J.A., Ang A.F., Tan L.P., Chin K.L., Tahir, P.M. 2018. Thermal treatment of wood using vegetable oils: A review. Constr Build Mater, 181, 408‒419. https://doi.org/10.1016/j.conbuildmat.2018.06.058

Liu, R., Zhu, H., Li, K., Yang, Z. 2019. Comparison on the aging of woods exposed to natural sunlight and artificial Xenon Light. Polymers, 11, 709.

Miklecic, J., Jirouš-Rajković, V., Antonović, A., Španić, N. 2011. Discolouration of thermally modified wood during simulated indoor sunlight exposure. BioResources, 6, 434–446.

Nowrouzi, Z., Mohebby, B., Ebrahimi, M. Petrič, M., 2021. Effects of different additives in a waterborne polyacrylate coating on selected surface properties of heat-treated finished wood. Drewno: prace naukowe, doniesienia, komunikaty, 64. https://doi.org/10.12841/wood.1644-3985.377.08

Pandeley, K.K. 2005. Study of the effect of photo-irradiation on the surface chemistry of wood. Polym. Degrad. Stab., 90, 9–20.

Peng, Y., Wang, Y., Chen, P., Wang, W. Cao, J., 2020. Enhancing weathering resistance of wood by using bark extractives as natural photostabilizers in polyurethane-acrylate coating. Progress in Organic Coatings, 145, p.105665. https://doi.org/10.1016/j.porgcoat.2020.105665

Reinprecht L., Vidholdová Z. 2011. Thermowood. Šmíra – Print, s.r.o.: Ostrava, Czech Republic, 89.

Reinprecht, L., Tiňo, R., Šomšák, M. 2020. The impact of fungicides, plasma, UV-additives and weathering on the adhesion strength of acrylic and alkyd coatings to the Norway spruce wood. Coatings, 10, 1111. https://doi.org/10.3390/coatings10111111

Ruiz, F.J., Agell, N., Angulo, C., Sánchez, M., 2012. A qualitative learning system for human sensory abilities in adjustment tasks. In 26th International workshop on qualitative reasoningAt: Playa Vista, California, Estados Unidos de América.
Salcă, E.A., Cismaru, I. 2011. Colour changes evaluation of freshly cut alder veneers under the influence of indoor sunlight. Pro Ligno, 7, 15–24.
Salla, J., Pandey, K.K., Srinivas, K. 2012. Improvement of UV resistance of wood surfaces by using ZnO nanoparticles. Polym. Degrad. Stab., 97, 592–596, https://doi.org/10.1016/j.polymdegradstab.2012.01.013
Sandberg D., Kutnar A., Mantanis G. 2017. Wood modification technologies-a review. IForest, 10, 895−908. https://doi.org/10.3832/ifor2380-010
Sandberg, D., Kutnar, A., Karlsson, O., Jones, D. 2021. Wood Modification Technologies: Principles, Sustainability, and the Need for Inno-vation, 1st ed.; CRC Press, Taylor and Francis Ltd.: Abingdon, UK, 450p; ISBN 978-1-138-49177-9.
Sedliačiková, M., Aláč, P., Moresová, M. Sedliačik, I., 2021. Mapping the wood colour preferences among potential customers. Acta Facultatis Xylologiae Zvolen res Publica Slovaca, 63(2), pp.163-173. https://doi.org/ 10.17423/afx.2021.63.2.14
Slabejová, G.; Šmidriaková, M. 2020. Colour of thermally modified wood finished with transparent coatings. Trieskové a beztrieskové obrábanie dreva (Chip and Chipless Woodworking Processes), 12, 97–102.
Solár, R. 1997. Lignin Changes in Hydrothermal Wood Treatment Processes, 1st ed.; Technical University in Zvolen: Zvolen, Slovakia, p. 57.
Šimůnková, K., Pánek, M. Zeidler, A., 2018. Comparison of selected properties of shellac varnish for restoration and polyurethane varnish for reconstruction of historical artefacts. Coatings, 8(4), p.119. https://doi.org/10.3390/coatings8040119
Timar, M.C., Varodi, A.M, Hacibektasoglu, M., Campean, M. 2016. Color and FT-IR analysis of chemical changes in beech wood (Fagus sylvatica L.) after light steaming and heat treatment in two different environments. BioResources, 11, 8325–8343.
Tolvaj, L., Mitsui, K. 2010. Correlation between hue angle and lightness of light irradiated wood. *Polym. Degrad. Stab.*, *95,* 638–642. https://doi.org/10.1016/j.polymdegradstab.2009.12.004
Vidholdová, Z., Sandak, A., Sandak, J. 2019. Assessment of the chemical change in heat treated pine wood by near infrared spectroscopy. Acta Fac. Xylologiae Zvolen, 61, 31–42.

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