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The colour difference of transparent surface finish on hydrothermally treated beech wood in the interior

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Abstract: *The colour difference of transparent surface finish on hydrothermally treated beech wood in the interior.* The paper deals with the influence of ageing of transparent surface finish in the dark and in the light in interior conditions. The colour difference of the tested samples with surface finishes (ΔE^*_{ab}) was measured after the ageing of native wood and hydrothermally modified wood in the dark and in the light. In the experiment, European beech wood was hydrothermally treated at a temperature of 135 °C under saturated water vapour for 6 hours. Three different types of surface finishes (acrylic-polyurethane, polyacrylic and aldehyde resin, alkyd resin) were applied on the wood surfaces. The colour parameters of the surfaces in the system *CIE* $L^*a^*b^*$, chroma ΔC^*, and hue angle Δh° were measured immediately after surface finishing and after the ageing in the dark and in the light. The samples were placed behind windows glass in the interior for 60 days. The results of the colour difference ΔE^*_{ab} showed that the colour of wood and the colour of the surface finishes was changed after ageing in the dark as well as in the light. The colour difference ΔE^*_{ab} was bigger in the light than in the dark. The colour difference was bigger on native wood than on hydrothermally modified wood.

Keywords: beech; colour; dark; surface finish; thermally modified wood

INTRODUCTION

Colour is one of the aesthetic properties of wood that can be identified subjectively with the naked eye, or measured objectively using the spectrophotometer. Changes in the colour of wood surface after applying a transparent coating material are the result of an interaction of the colour of coating film with the colour of wood surface. Various transparent finishes result in different colours of wood surfaces (SLABEJOVÁ and ŠMIDRIAKOVÁ 2020, 2021). The transparent finish can give wood materials the desired aesthetic properties, such as colour and gloss, but they are also generally essential in protecting wood. This applies to both interior uses (like furniture) and exterior applications. From the point of view of customers, the aesthetic appearance of wood coating is the main purchasing factor (SEDLIAČIKOVÁ et al. 2021).

The modification processes of wood are implemented to improve the properties of wood and change the colour of wood to produce new materials. One of the various modifications of wood is the thermally-based modifying treatment. The thermally-based modification is accompanied by chemical reactions of the cell-wall components (polysaccharides, lignin, and extractives) which cause changes in colour of wood (DZURENDA et al. 2022; 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 et al. 2016a; TOLVAJ and MITSUI 2010). The thermal treatment of wood with saturated water vapour is traditionally used in the woodworking industry, for example, in the manufacture of furniture components by solid wood bending, for production of floors and paneling for interior. DZURENDA and DUDIAK (2020) presented the changes of beech wood obtained in the targeted process of colour modification with saturated water steam.

The surface of wood, modified hydrothermally with saturated water vapour, needs to be finished with transparent coating materials to preserve the colour and an attractive appearance. Transparent finishing is designed to enhance the stability of the surface of native wood and hydrothermally treated wood and to maintain the natural aspects of wood, such as colour and texture for a long time. At the same time, the colour of finished wood surface changes due to sunlight in interior. Sunlight is the major cause of damage to a number of materials, including wood and coatings (TIMAR et al. 2016b; KUČEROVÁ et al. 2019; LEE et al. 2018; SANDBERG et al. 2017). The change in colour of surface finish is an interaction of the changed wood colour and the colour of the coating film itself (LIU et al. 2022; NOWROUZI et al. 2021; CIRULE et al. 2021; PENG et al. 2020; HERRERA et al. 2018; ŠIMŮNKOVÁ et al. 2017; KÚDELA 2017). The most commonly adopted UV protection technology is using UV protective substances that are admixed into the coating material. However, the degradation is not inhibited absolutely (SALLA et al. 2012; LIU et al. 2019; KÚDELA et al. 2020; REINPRECHT et al. 2020).

The objective of this paper is to evaluate the effects of natural light or dark on the change in colour of transparent surface finishes coated on hydrothermally modified beech wood.

MATERIALS AND METHODS

The samples of native and hydrothermally modified beech wood were prepared from the boards air-conditioned for six months (Table 1.). The boards were sanded, first transversely and then in the longitudinal direction (last sand grit P 180). The samples had 3 to 8 growth rings per cm, they were free from defects, and the growth ring orientation to the tested surface was 5° to 45°.

Table 1. Experimental set-up

Wood species	Wood treatment	Surface finishes[2]	Ageing
• European beech (*Fagus sylvatica* 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 by DUDIAK and DZURENDA (2021), DZURENDA and DUDIAK (2020), GEFFERT et al. (2020), 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 to the native and hydrothermally modified 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 living room and bedroom furniture. It was applied by spraying in two coats with spreading rate of 100-150 $ml \cdot m^{-2}$ ($g \cdot m^{-2}$). (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 spreading rate of 80-120 $ml \cdot m^{-2}$($g \cdot m^{-2}$). (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 spreading rate of 60-70 $ml \cdot m^{-2}$ ($g \cdot m^{-2}$). (Alk).

After application of the everyone coating material on one native and one hydrothermally modified wood, the samples were stored at 23 °C and 50% relative humidity (RH) in a dark room for 14 days to ensure film formation, sufficient hardening, and solvent evaporation.

Ageing test

The exposure of samples to natural sunlight was in the interior between July 2020 and September 2020 for a total of 60 days. The interior temperature varied from 20 to 25 °C, and RH varied from 50% to 55%. The daily average of total solar power density was between 336 and 535 $W \cdot m^{-2}$ (Zvolen, Slovakia). The coated and uncoated samples were stored in a room in the interior, behind a glass window (thermal-insolation double glazing, U-factor 1.1 $W \cdot m^{-2} \cdot K^{-1}$, west exposition). 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 exposition was carried out at same conditions but the samples were packed up in aluminium foil for 60 days.

Evaluation of discolouration

The colour parameters of the tested samples were measured before and after the ageing using a Color Reader CR-10 (Konica Minolta, Osaka, Japan). 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 of each tested sample and expressed in the *CIE* $L^*a^*b^*$ system (ISO 7727-3: 1984).

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

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

where: ΔL^*, Δa^*, Δb^* are the differences in individual axes (the difference between the value measured after 60 days of exposure to dark or to light and before exposure). The magnitude of the colour difference ΔE^*_{ab} can be classified according to the grading rules reported in the Table 2.

Table 2. Evaluation of color difference (ALLGERGETTI et al. 2009)

$\Delta E^*_{ab} \leq 0.2$	Not visible difference
$0.2 \leq \Delta E^*_{ab} \leq 2$	Small difference
$2 \leq \Delta E^*_{ab} \leq 3$	Colour difference visible with high quality screen
$3 \leq \Delta E^*_{ab} \leq 6$	Colour difference visible with medium quality screen
$6 \leq \Delta E^*_{ab} \leq 12$	High colour difference
$\Delta E^*_{ab} \leq 12$	Different colours

To demonstrate the colour change of the finished wood surfaces, the Scanner HP LaserJet 1536dnf MFP (Hewlett-Packard, Palo Alto in California, United States of America) was used.

Statistical evaluation

The MS excel 2013 and the statistical software STATISTICA 12 was used to analyse and present the collected data on colour parameters. Descriptive statistics deal with basic statistical characteristics.

RESULTS AND DISCUSSION

Figure 1 shows that the colour difference ΔE^*_{ab} on native beech wood, hydrothermally modified beech wood with no surface finishes, as well as HTT wood coated with transparent surface finishes after aging in the light was greater than after aging in the dark.

The Acryl-PU surface finish on HTT wood, exposed to light, resulted in the colour difference of 3.7 and the same surface finish on native wood showed the colour difference of 5.7 (Colour difference visible with medium quality screen). In the dark, the Acryl-PU on HTT wood showed the colour difference of 2.9 and on native wood of 3.0 (Colour difference visible with high quality screen).

The PAcryl-Ald surface finish on HTT wood, exposed to light, resulted in the colour difference of 5.4 (Colour difference visible with medium quality screen) and on native wood of 7.7 (High colour difference). In the dark, the PAcryl-Ald showed the same colour difference of 2.7 on HTT wood and on native wood, as well (Colour difference visible with high quality screen).

The Alk surface finish on HTT wood, exposed to light, resulted in the colour difference of 4.9 and on native wood of 7.0. In the dark, the Alk on HTT wood showed the colour difference of 3.6 and on native wood of 2.8. It follows that, in the dark, the Alk surface finish on HTT wood showed a greater colour difference than on native wood. Also on the surface with no surface finish, there was a greater colour difference on HTT wood (2.6) than on native wood (1.9). Whereas the Acryl-PU and PAcryl-Ald surface finishes, in the dark, showed a comparable colour differences on HTT wood and native wood.

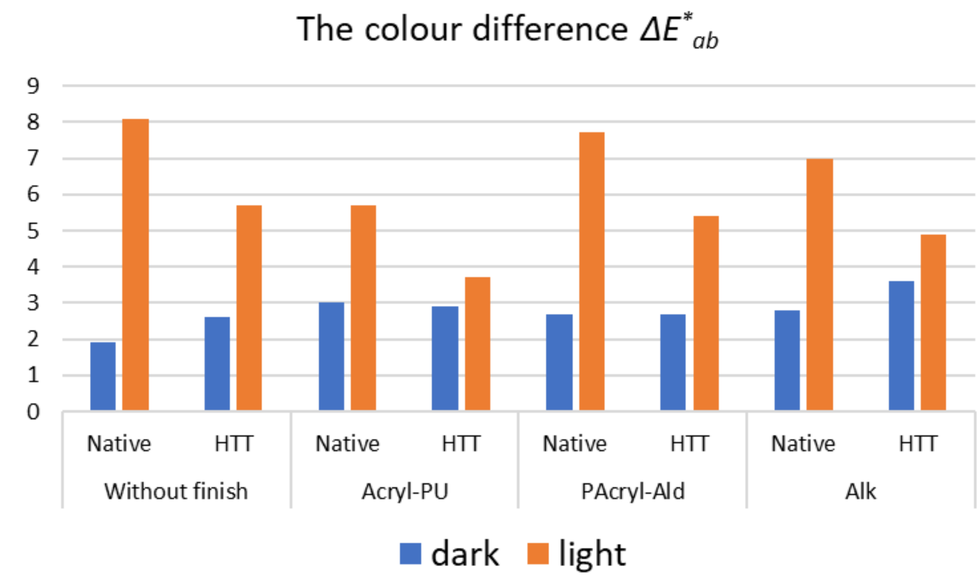
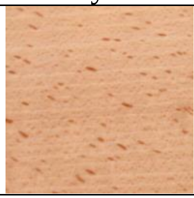
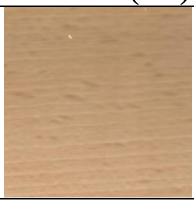
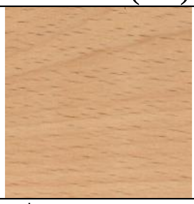
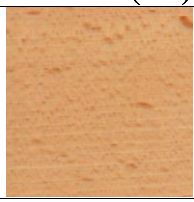


Figure 1. The total colour difference ΔE^*_{ab} on the native and hydrothermally treated wood (European beech) with surface finishes after ageing in dark or exposed to light in interior.

Darkening of native wood, with no finish and with transparent surface finish, due to light is in accordance with the opinions of experts dealing with changes in the properties of wood due to long-term exposure to sunlight in exterior and interior. They state that the surface of wood darkens and mostly turns yellow and brown (REINPRECHT 2008; CHANG et al. 2010; BAAR and GRYC 2012; KÚDELA and KUBOVSKÝ 2016; GEFFERTOVÁ et al. 2018; DUDIAK and DZUENDA 2023). Authors LIU et al. (2022) claim, that some small colour changes occurred in the surface finish, which is protected from the direct action of light; these changes were due to thermal-induced ageing.

Tables 3 and 4 show that on native wood, the surfaces were mostly darkened due to the influence of light; and on HTT wood, the surfaces were lightened.

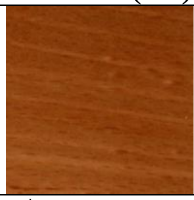
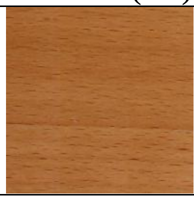
Table 3. The colour parameters (L^*, a^*, b^*, C^*, and h°) of the European beech native wood with surface finishes (ageing in dark or in light)

Exposure	Without finish	Acryl-PU	PAcryl-Ald	Alk
Before				
	L^* = 78.4 (1.3) a^* = 7.3 (0.5) b^* = 15.4 (0.3) C^* = 17.0 (0.5) h° = 64.6 (1.2)	L^* = 74.9 (0.4) a^* = 8.9 (0.2) b^* = 19.7 (0.2) C^* = 21.6 (0.3) h° = 65.3 (1.1)	L^* = 74.2 (1.3) a^* = 9.4 (0.7) b^* = 19.0 (0.6) C^* = 21.2 (0.8) h° = 63.7 (1.1)	L^* = 72.0 (0.6) a^* = 10.0 (0.3) b^* = 22.8 (0.1) C^* = 24.9 (0.1) h° = 66.3 (0.5)
Dark				
	L^* = 79.5 (0.8) a^* = 8.7 (0.3) b^* = 17.0 (0.3) C^* = 19.1 (0.4) h° = 62.8 (0.7)	L^* = 75.4 (0.9) a^* = 11.1 (0.2) b^* = 22.6 (0.5) C^* = 25.2 (0.6) h° = 63.8 (0.2)	L^* = 75.1 (0.5) a^* = 11.9 (0.2) b^* = 21.5 (0.2) C^* = 24.6 (0.3) h° = 61.1 (0.3)	L^* = 69.5 (0.4) a^* = 11.5 (0.9) b^* = 24.2 (0.2) C^* = 26.8 (0.4) h° = 64.0 (0.6)
Light				
	L^* = 72.3 (0.3) a^* = 9.4 (0.3) b^* = 20.8 (0.3) C^* = 22.8 (0.3) h° = 65.7 (0.8)	L^* = 69.4 (0.3) a^* = 9.8 (0.3) b^* = 21.2 (0.3) C^* = 23.4(0.3) h° = 65.3 (0.5)	L^* = 69.8 (0.5) a^* = 11.8 (0.5) b^* = 25.3 (0.3) C^* = 27.9 (0.4) h° = 65.1 (1.0)	L^* = 76.9 (1.7) a^* = 11.0 (0.6) b^* = 27.7 (0.5) C^* = 29.8 (0.3) h° = 68.3 (1.3)

DUDIAK et al. (2022) point to the lightening of the surface of steamed beech wood (saturated water steam at a temperature of 135 °C) during solar exposure for 36 months. DUDIAK and DZURENDA (2023) also describe lightening of the surface of steamed birch wood. SLABEJOVÁ et al. (2023) also point to the darkening of the surface of birch wood and maple wood, native and hydrothermally treated, monitored in the light in interior for a period of 2 months.

We cannot generalize that native wood gets darker in the light and HTT wood gets lighter. We can say that it changes the colour, but this change is the interaction of the changes in coordinates (ΔL^*, Δa^*, Δb^*). Just as different wood species have different content of extractive substances, different photo-degradation phenomena are happening on their surfaces. On some wood species, there is a greater change in lightness, on another species, for example, yellowing.

Table 4. The colour parameters (L^*, a^*, b^*, C^*, and h°) of the European beech, hydrothermally treated wood, with surface finishes of (ageing in dark or in light in the interior)

Exposure	Without finish	Acryl-PU	PAcryl-Ald	Alk
Before				
	L^* = 69 (0.7) a^* = 12.6 (0.3) b^* = 19.2 (0.4) C^* = 23.0 (0.4) h° = 56.7 (0.2)	L^* = 68.1 (0.3) a^* = 12.9 (0.2) b^* = 20.7 (0.2) C^* = 14.4 (0.2) h° = 58.0 (0.3)	L^* = 67.9 (0.3) a^* = 13.5 (0.2) b^* = 23.1 (0.2) C^* = 26.8 (0.3) h° = 59.7 (0.2)	L^* = 64.2 (1.0) a^* = 15.7 (0.7) b^* = 27.6 (0.4) C^* = 31.7 (0.6) h° = 60.4 (0.9)
Dark				
	L^* = 70.1 (1.0) a^* = 14.2 (0.4) b^* = 21.5 (0.4) C^* = 25.8 (0.6) h° = 56.5 (0.3)	L^* = 70.1 (1.5) a^* = 14.4 (0.6) b^* = 22.7 (0.3) C^* = 26.9 (0.5) h° = 57.7 (0.8)	L^* = 67.6 (0.9) a^* = 16.5 (0.4) b^* = 25.8 (0.2) C^* = 30.6 (0.3) h° = 57.3 (0.5)	L^* = 65.4 (1.5) a^* = 17.7 (0.8) b^* = 31.0 (0.5) C^* = 35.7 (0.8) h° = 60.3 (0.8)
Light				
	L^* = 69.8 (0.6) a^* = 10.4 (0.2) b^* = 24.8 (0.4) C^* = 26.9 (0.4) h° = 67.3 (0.5)	L^* = 70.8 (0.3) a^* = 9.9 (0.2) b^* = 23.1 (0.2) C^* = 25.2 (0.2) h° = 66.9 (0.3)	L^* = 70.5 (0.2) a^* = 11.5 (0.2) b^* = 27.9 (0.2) C^* = 30.2 (0.2) h° = 67.6 (0.3)	L^* = 69.1 (0.5) a^* = 12.0 (0.3) b^* = 27.8 (0.5) C^* = 30.2 (0.4) h° = 66.6 (0.6)

The solar radiation (daylight) initiate photo-degradation processes in wood when impacting the wood surface (photolytic and photo-oxidation reactions with lignin, polysaccharides and wood substances), and carbohydrates absorb 5–20% and 2% of the accessory substance (GANDELOVÁ et al. 2009). These reactions cleave both lignin macromolecules with the simultaneous formation of phenolic hydroperoxides, free radicals, carbonyl and carboxyl groups, as well as they cleave polysaccharides into polysaccharides with lower polymerization degree to form carbonyl, carboxyl groups, and gaseous products (CO, CO_2, H_2) (HON 2001; PERSZE and TOLVAJ 2012; BAAR and GRYC 2012; DENES and LANG 2013; GEFFERTOVA et al. 2018).

The colour of wood is created by chromophores, i.e. functional groups of the type: >C=O, -CH=CH-CH=CH-, -CH=CH-, aromatic nuclei in the chemical components of wood (lignin and extractive substances such as dyes, tannins, resins, and others), which can absorb some components of the electromagnetic radiation of daylight and thereby create the colour of wood surface perceived by the human vision (DUDIAK and DZURENDA 2023).

The smallest differences in the colour difference ΔE^*_{ab} on the wood surface, in the dark and in the light, were on the HTT wood with Acryl-PU and Alk surface finishes (Figure 1, Table 4). Table 3 illustrates that on the native wood with surface finishes, there was a shift towards shades of red and yellow on the coordinates a^*, b^* both in the dark and in the light. On HTT wood with surface finishes (Table 4) exposed to light, the coordinates a^*, b^* shift to greener (a^*) and yellower (b^*) shades.

CONCLUSION

Transparent surface finish is designed to enhance the stability of wood surface and keep the natural appearance of wood. The study has shown that surface finished wood, both native and hydrothermally modified, was susceptible to discolouration, although it was coated with transparent surface finishes (acrylic-polyurethane, polyacrylic and aldehyde resin, alkyd resin).

The hydrothermally modified wood with surface finish showed smaller colour difference than the surface finished native wood, when exposed to the light. In the dark, the colour difference of the hydrothermally modified wood with surface finish was comparable to the surface finished native wood; in some cases, the colour difference was bigger on the hydrothermally modified wood.

When exposed to the light, the acrylic-polyurethane finish (Acryl-PU) on both the HTT wood and the native wood showed the smallest colour difference. “Colour difference visible with medium quality screen“was measured on all of three surface finishes on the HTT wood On the native wood, only the acrylic-polyurethane surface finish (Acryl-PU) showed „colour difference visible with medium quality screen“. The two other surface finishes (PAcryl-Ald, Alk) on native wood achieved „high colour difference.

In the dark, only the alkyd resin (Alk) on HTT wood achieved the grade "Colour difference visible with medium quality screen". The other two surface finishes (Acryl-PU, PAcryl-Ald) on HTT wood and native wood achieved the "Colour difference visible with high quality screen".

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Streszczenie: Różnica w kolorze przezroczystego wykończenia powierzchni drewna bukowego poddanego obróbce hydrotermicznej we wnętrzu. Artykuł dotyczy wpływu starzenia przezroczystego wykończenia powierzchni w ciemności i w świetle w warunkach wewnętrznych. Różnica koloru badanych próbek z wykończeniem powierzchni (ΔE*ab) została zmierzona po starzeniu drewna rodzimego i drewna modyfikowanego hydrotermicznie w ciemności i w świetle. W eksperymencie europejskie drewno bukowe poddano obróbce hydrotermicznej w temperaturze 135 °C w warunkach nasyconej pary wodnej przez 6 godzin. Na powierzchnie drewna nałożono trzy różne rodzaje wykończeń powierzchni (akrylowo-poliuretanowe, poliakrylowe i żywice aldehydowe, żywice alkidowe). Parametry barwy powierzchni w systemie CIE L*a*b*, chroma ΔC* i kąt barwy Δh° zostały zmierzone bezpośrednio po wykończeniu powierzchni i po starzeniu w ciemności i w świetle. Próbki umieszczono za szybą okienną we wnętrzu na 60 dni. Wyniki różnicy kolorów ΔE*ab wykazały, że kolor drewna i kolor wykończenia powierzchni zmienił się po starzeniu w ciemności i w świetle. Różnica koloru ΔE*ab była większa w świetle niż w ciemności. Różnica koloru była większa na drewnie rodzimym niż na drewnie modyfikowanym hydrotermicznie.

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