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COLOR CHANGE OF BEECH MATURE WOOD AND FALSE HEARTWOOD THROUGH ACCELERATED AGEING PROCESS

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ABSTRACT

The differences in the surface color of beech mature wood and false heartwood in the process of simulated aging induced by UV radiation in a Q-SUN Xe-3-HS xenon test chamber for 360 hours are presented in the paper. Color measurement in the color space CIE L*a*b* on exposed surfaces of beech wood samples was performed with a Color Reader CR-10 colorimeter. During exposure, the course of changes in individual coordinates (L*, a*, b*) of the color space CIE L*a*b* was recorded. The resulting change in wood color was evaluated through the overall color change. The surface of mature beech wood darkened from a light white-gray color with a yellow tinge to a red-brown color shade during exposure to UV radiation in a xenon test chamber. On the contrary, the surface of beech false heartwood slightly lightened from the original red-brown color to its paler shade. The magnitude of color changes on the surfaces of beech mature wood and false heartwood caused by UV radiation indicates the values of the total color difference for mature wood $\Delta E_{mw}^* = 15.8$ and for false heartwood $\Delta E_{fhw}^* = 10$.

Keywords: beech wood; false heartwood; mature wood; wood color; color difference; color dispersion; accelerated aging.

INTRODUCTION

The color of wood is a basic physical-optical property, which belongs to the group of macroscopic features on the basis of which the wood of individual wood species differs from each other in appearance. The color of wood is created by chromophores, i.e., functional groups of the type: >C=O, –CH=CH–CH=CH–, –CH=CH–, aromatic nuclei found in the chemical components of wood (lignin and extractives such as dyes, tannins, resins and others). Chromophores absorb certain wavelengths of daylight and thus create the color of the wood surface perceived by human vision (Hon and Shiraishi 2001; Rowell 2013; Dzurenda *et al.,* 2023).

The original color of wood changes to varying degrees due to abiotic factors (sunlight, humidity, temperature, contact with metals), biotic factors (bacteria, fungi), or targeted thermal treatments (drying, steaming, thermowood production).

From the perspective of atmospheric degradation of wood, the most important influence on color change is ultraviolet radiation (UV) and part of sunlight (wavelength < 380 nm), which induces photochemical reactions in wood (Tolvaj *et al.,* 2001; Müller *et al.,* 2003; Evans *et al.,* 2005; Dudiak *et al.,* 2022). The change in wood color is mostly caused by the absorption of UV radiation by lignin, the chemical cleavage of its bonds and the

formation of reactive free radicals (e.g., phenoxyl), which are transformed into chromophores containing carbonyl, carboxyl and quinoid structures, responsible for the changes in wood color (Fengel and Wegener 1989; Müller *et al.,* 2003; George *et al.,* 2005; Evans *et al.,* 2005; Teacă *et al.,* 2013). Extractives also participate in the photodegradation of wood, which, in addition to color changes of wood, also affect the rate of wood degradation (Chang *et al.,* 2010). Some extractives present in wood also act as antioxidants, protecting it from photodegradation (Nzokou and Kamdem 2006). Photochemical reactions within the atmospheric degradation of wood are carried out only in the surface layers of wood. UV radiation and visible light can only penetrate to depths of 75 μm and 200 μm, respectively.

The aim of the work is to compare the color changes of beech mature wood and false heartwood in the process of simulated ageing induced by UV radiation in the Xenotest Q-SUN Xe-3-H. The analyses include both changes in the individual color coordinates of the CIE L*a*b* color space at an air temperature of t = 20 °C and a relative air humidity of φ = 60%, as well as differences in the total color difference ΔE* during UV radiation.

MATERIAL AND METHODS

Lumber was produced by cutting eight beech logs with a healthy, round false heartwood by longitudinal and transverse manipulation. Blanks with a width of 100 mm and a length of 800 mm were produced from the central beech lumber with a thickness of h = 40 mm. From each central lumber with a thickness of h = 40 mm, a blank with wood around the border line of the false heartwood was randomly selected, containing both mature beech wood and false heartwood.

In order to eliminate the influence of temperature during hot air drying on the change in the color of the beech wood, the blanks were dried in a closed air-conditioned room at an air temperature of t = 20 °C and a relative air humidity of φ = 60% to a moisture content of w = 10 ± 2%.

To measure the effect of UV radiation on photodegradation, samples with dimensions: 100 × 50 × 15 mm (L × R × T) were made from beech wood, with the border line marked, and the content of mature wood and false heartwood was determined.

In the xenon test chamber Q-SUN Xe-3-HS, (Q-Lab Corporation, USA) the beech wood samples were irradiated for τ = 360 hours. During the exposure, the color of the irradiated surface was measured regularly at τ = 24 hour intervals. The dry mode was used, which simulates indoor conditions: the wood is exposed to radiation but protected from rain. The simulation of the measurement conditions was ensured by Q-window Filters, which provided outdoor daylight indoors. The samples placed in the xenotest chamber were regularly moved within the irradiated area of the xenotest to ensure uniform irradiation intensity and surface temperature of the irradiated sample (Kúdela and Kubovský 2016).

Measurement of wood color in the color space CIE L*a*b* was performed with a Color Reader CR-10 colorimeter (Konica Minolta, Japan), with a reflection spectrum of wavelengths in the range of 400 - 700 nm. A certified D65 light source with an optical sensing device diameter of 8 mm was used. Measurement of the color of mature beech wood and the color of false heartwood before UV radiation and during irradiation was performed on a radial surface created by milling. Each measured wood color value in the color space CIE L*a*b* coordinates was checked by a second measurement with the requirement that the total color difference between individual measured values was not greater than ΔE* = 2.

The measured values in the color space CIE L*a*b* coordinates are presented in the form of the average measured value $\bar{x}$ and the standard deviation s_x.

$$x = \bar{x} \pm s_x \quad (1)$$

Where: $\bar{x}$ – average value,
s_x – standard deviation.

The difference between the color of mature beech wood and the color of the false heartwood before irradiation, expressed as the total color difference ΔE_0^*, is described by the equation:

$$\Delta E_0^* = \sqrt{(L_{MW}^* - L_{FHW}^*)^2 + (a_{MW}^* - a_{FHW}^*)^2 + (b_{MW}^* - b_{FHW}^*)^2} \quad (2)$$

Where: L^*_{MW}, a^*_{MW}, b^*_{MW} – values in the color space coordinates of the surface of dried milled mature beech wood before exposure;
L^*_{FHW}, a^*_{FHW}, b^*_{FHW} – values in the color space coordinates of the surface of dried milled false heartwood beech wood before exposure.

The total color difference ΔE^* of the surface color change of mature beech wood samples in the UV radiation process is determined according to the following equation:

$$\Delta E_{MW}^* = \sqrt{(L_\tau^* - L_0^*)^2 + (a_\tau^* - a_0^*)^2 + (b_\tau^* - b_0^*)^2} \quad (3)$$

Where: L^*_0, a^*_0, b^*_0 – values in the color space coordinates of the surface of dried milled mature beech wood before exposure;
L^*_τ a^*_τ, b^*_τ – values in the color space coordinates of the surface of dried milled mature beech wood during UV radiation exposure.

The total color difference ΔE^* of the surface color change of beech wood samples with false heartwood in the UV irradiation process is determined according to the following equation:

$$\Delta E_{FHW}^* = \sqrt{(L_\tau^* - L_0^*)^2 + (a_\tau^* - a_0^*)^2 + (b_\tau^* - b_0^*)^2} \quad (4)$$

Where: L^*_0, a^*_0, b^*_0 – values in the color space coordinates of the surface of dried milled beech wood with a false heartwood before exposure;
L^*_τ a^*_τ, b^*_τ – values in the color space coordinates of the surface of dried milled beech wood with a false heartwood during exposure to UV radiation.

RESULTS AND DISCUSSION

The visual difference between the color of dry beech wood in the mature wood zone and in the false heartwood zone before and after UV irradiation is shown in Fig. 1.

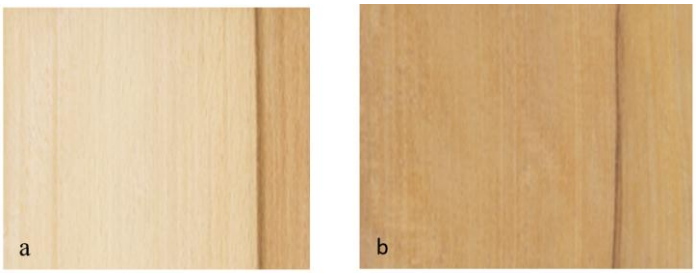

Fig. 1 View of the color of beech wood with false heartwood before (a) and after (b) UV irradiation in a xenotest.

The color of mature beech wood and false heartwood in the color space CIE L*a*b* before UV irradiation and after 360 hours of UV irradiation in the Q-SUN Xe-3-HS xenotest is shown in Table 1.

Tab. 1 Values in the CIE L*a*b* color space coordinates of beech wood.

Beech wood	Number of measurements	Color coordinates in the color space CIE L*a*b*			ΔE^*_0
		L*	a*	b*	
Mature wood before UV irradiation	30	78.5 ± 1.9	8.3 ± 1.1	18.3 ± 1,4	12.8
False heartwood before UV irradiation	30	66.6 ± 2.4	11.7 ± 1.3	19.3 ± 1.6	
Mature wood after UV irradiation	30	67.6 ± 1.5	13.8 ± 1,2	28.2 ± 0.9	1.2
False heartwood after UV irradiation	30	68.5 ± 1.7	14.0 ± 1.5	28.9 ± 0.8	

The course of changes in the lightness coordinate L* and the chromaticity coordinates of red a* and yellow b* induced by UV radiation for 360 hours in the Q-SUN Xe-3-HS Xenotest are shown in Fig. 2 and Fig. 3.

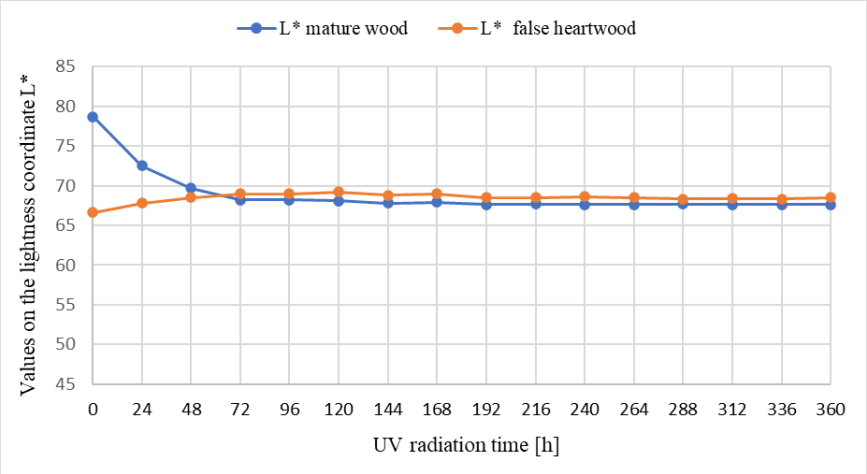

Fig. 2. Effect of UV radiation on changes in the lightness of unsteamed beech mature wood and false heartwood on the lightness coordinate L*.

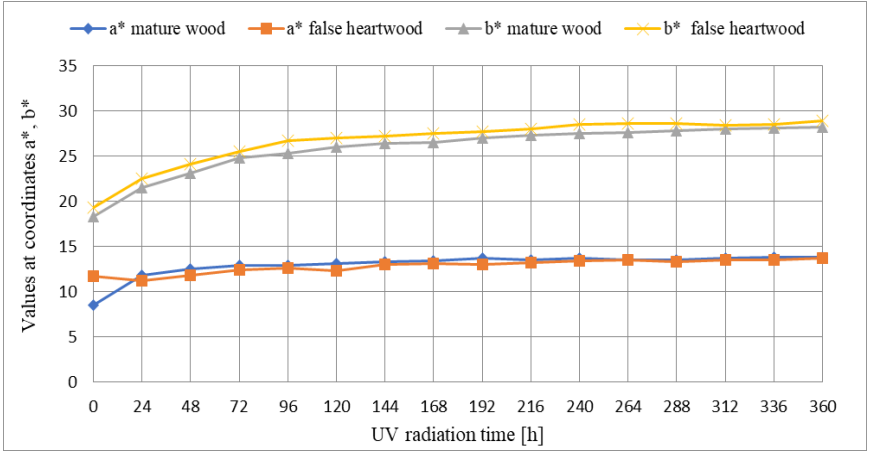

Fig. 3 Effect of UV radiation on color changes of unsteamed beech mature wood and false heartwood on chromatic coordinates a* and b*.

The color of beech mature wood is light white-gray with a yellow tinge. The values in the CIE L*a*b* color space coordinates given in Table 1 are similar to those given by the authors (Babiak *et al.*, 2004; Meints *et al.,* 2017; Dzurenda 2022).
The false heartwood has a different color: red-brown. In the CIE L*a*b* color space, it is given by the values in the individual coordinates: L* = 64.9 ± 4.9; a* = 12.9 ± 2.1; b* = 19.6 ± 1.9 (Dzurenda 2023).
The darker red-brown color of beech false heartwood differs from the light white-gray color with a yellow tinge of mature wood by a significant difference between the values of the lightness coordinate by ΔL* = -11.9 and an increase in the values of the chromatic coordinate of the red color by Δa* = +3.4 and of the yellow color by Δb* = +1.0. The difference in the color of beech false heartwood compared to the color of mature wood expressed by the total color difference is ΔE* = 12.8. According to the categorization of wood color changes presented by Cividini *et al.* (2007), the stated value of the total color difference places such the difference in wood color category ΔE > 12, i.e., different colors.

Photochemical reactions in mature beech wood and beech heartwood under UV radiation result in opposing color changes: a significant darkening and a red-brown color shade in mature beech wood, and a slight lightening of the red-brown color in beech heartwood. The magnitude of changes induced by UV radiation on individual coordinates of the color space CIE L*a*b* of mature beech wood and false heartwood induced by UV radiation is documented in Table 2.

Tab. 2 The magnitude of changes induced by UV radiation on L*a*b* coordinates.

Beech wood	Changes in values in the color space CIE L*a*b* coordinates			ΔE^*
	ΔL*	Δa*	Δb*	
Mature wood	-11.1	+5.5	+9.9	$\Delta E_{MW}^* = 15.8$
False heartwood	+1.9	+2.3	+9.6	$\Delta E_{FHW}^* = 10.1$

The total color difference $\Delta E_{MW}^* = 15.8$ during darkening and obtaining a red-brown shade of mature beech wood caused by UV radiation was achieved by significantly reducing the value on the lightness coordinate to the value L* = 67.6 ± 1.5 and increasing the value on the yellow color coordinate to b* = 28.2 ± 0.9. The red-brown shade is complemented by increasing the value of the red color to the level a* = 13.8. Similar color changes on the surface of beech wood caused by UV radiation, or. long-term exposure to daylight is presented in the works of the authors: (Kúdela and Kubovský 2016; Laskowska 2020; Dzurenda and Dudiak 2022; Vidholdová *et al.,* 2025).
The color of the false heartwood faded due to UV radiation. The lightening of the red-brown color of the false heartwood to a lighter shade was not achieved by a decrease in the value of the lightness coordinate, but by its increase by ΔL* = +1.9, an increase in the value of the red color coordinate by Δa* = +2.3 and a significant increase in the value of the yellow chromatic coordinate by Δb* = +9.6, which is mainly manifested by the yellowing of the red-brown color of the false heartwood. The value of the total color difference of the false heartwood $\Delta E_{FHW}^* = 10.1$, is 1/3 lower than the total color difference of the sapwood caused by UV radiation.
The cause of the lightening of the red-brown color of the beech false heartwood is the chromophores of polyphenolic compounds that were formed by enzymatic processes during the formation of the false heartwood (Albert *et al.,* 2003). These chromophores undergo photochemical reactions under UV irradiation, similar to the quinone-type chromophore systems formed in steamed beech wood during the steaming process (Chen *et al.,* 2014; Timar *et al.,* 2016; Hofmann *et al.,* 2025; Dzurenda 2022; Dzurenda and Dudiak, 2025).
The color changes on the surfaces of mature beech wood and false heartwood after UV irradiation are characterized by a decrease in the color contrast between the two. This is

numerically documented by low differences in the lightness ($\Delta L^* = 0.9$) and chromaticity coordinates – in the red component ($\Delta a^* = 0.2$) and yellow component ($\Delta b^* = 0.7$). The total color difference reaches a value of $\Delta E_0^* = 1.2$. According to the color difference evaluation scale by Cividini *et al.* (2007) this value falls into the category $\Delta E^* = 0.2–2.0$, which represents small color changes.
A characteristic feature of the surface of mature beech wood and false heartwood after UV irradiation is almost zero absorption of electromagnetic radiation in the red region (630–750 nm) and a significant decrease in absorption in the yellow region (570–590 nm).

The course of changes in the individual coordinates of the CIE L*a*b* color space during 360 hours of irradiation in Fig. 2 and 3 documents both the difference in their size on the brightness coordinate ΔL^*, red color Δa^* and yellow color Δb^*, as well as the temporal non-uniformity of the realizations, manifested by visible changes in the color of beech wood in the zone of mature wood and false heartwood with the naked eye.
The contradiction of color changes, darkening of mature beech wood, or lightening of false heartwood wood is shown in Fig. 2. The continuous decrease in the values on the lightness coordinate L* of sapwood is documented by a decrease from the value $L_0^* = 78.7$ to the value $L_{72}^* = 68.2$ and, conversely, the increase in the values on the coordinates of false heartwood, manifested by a lightening of the wood color, is from the value $L_0^* = 66.6$ to the value $L_{72}^* = 69.0$. The above changes are realized in the first 72 hours.
The opposite course of color changes is also on the chromatic coordinate of the red color a*. In mature beech wood, the values on the red color coordinate increase in the first 72 hours from the value $a_0^* = 8.5$ to the value $a_{72}^* = 13.9$. On the red color coordinate of false heartwood, there is a decrease in the values by $\Delta a^* = - 0.5$ in the first $\tau = 24$ hours and during the following $\tau = 48$ hours, there is an increase not only to the original value, but also an increase by $\Delta a^* = 2.0$ to the final state $a^* = 13.5$.
On the yellow color coordinate, the values of both mature beech wood and false heartwood increase simultaneously over 144 hours. The magnitude of the changes in the yellow color coordinates is $\Delta b^* \approx 9.8$.
The development of changes in the individual coordinates L*, a* and b* of mature beech wood and false heartwood during irradiation in the Q-SUN Xe-3-HS Xenotest shows that the lightness coordinate L* and the red color coordinate a* are realized in the first 72 hours and the yellow color coordinate b* within 144 hours. Subsequently, both sapwood and false heartwood were resistant to UV radiation. The fact that color changes on the wood surface due to UV radiation during testing in the xenotest is reported to occur within a time not exceeding the value $\tau \leq 150$ hours is mentioned by several authors (Kúdela and Kubovský 2016; Baar and Gryc 2011; Dudiak *et al.*, 2022). Oltean *et al.,* (2008), based on the investigation of the effect of UV radiation on softwood and hardwood of trees growing in the climatic conditions of the temperate zone of Europe concluded, that rapid changes occur during the first 24 hours of UV exposure and most of the measured wood species reached stable values after 120 hours of exposure. Subsequent irradiation caused only a slight, practically invisible to the naked eye, increase or decrease in the value of the total color difference.

CONCLUSION

The paper presents the results of color changes in beech mature wood and false heartwood induced by UV radiation in the Q-SUN Xe-3-H Xenotest. The results of the

analysis of the effect of UV radiation on wood showed that:

- The exposed surface showed changes visible to the naked eye up to 144 hours of UV radiation.
- The surface of mature beech wood darkened from a light white-gray color with a yellow tinge to a red-brown color shade with values in the color space CIE coordinates L*a*b*, lightness L* = 67.6 ± 1.5, red color a* = 13.8 ± 1.2 and yellow color b* = 22.8 ± 0.9. The mentioned change in wood darkening is indicated by a decrease in the value of the lightness coordinate by ΔL* = - 11.6 and an increase in the values of the red chromatic coordinate by Δa* = +5.5 and the yellow by Δb* = + 9.9.
- The surface of the beech wood with a false heartwood, on the other hand, lightened the original red-brown color to a lighter shade due to UV radiation. The mentioned change was achieved by a slight positive shift of the value on the lightness coordinate by ΔL* = +1.9, the red color coordinate a* = 2.3 and a significant shift of the yellow chromatic coordinate by Δb* = + 9.6.
- The color changes on the surface of the beech wood with a false heartwood in the mature and false heartwood zones caused by UV radiation are not the same. This is evidenced by the change in the total color difference ΔE*, which is ΔE_{MW}*= 15.8 for mature wood and ΔE_{FHW}*= 10.1 for the false heartwood.
- UV radiation contributes to a significant reduction in the color contrast between the color of mature wood and false heartwood. This is numerically documented by the differences in the lightness coordinate ΔL* = 0.9 and the chromatic coordinates: red color Δa* = 0.2 and yellow color Δb* = 0.7. The difference in color after irradiation between mature beech wood and heartwood expressed by the total color difference is ΔE* = 1.2, which, according to the authors' scale (Cividini *et al.*, 2007) ranks it in the small color change category (0.2 - 2.0).

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