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THE EFFECT OF SUNLIGHT ON THE CHANGE IN COLOR OF NATIVE AND STEAMED MAPLE WOOD WITH SATURATED WATER STEAM

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ABSTRACT

The differences in the color changes of native and steamed maple wood with saturated water steam caused by the action of sunlight on the surface of the wood in interiors for 36 months were presented in the paper. The pale shade of white-yellow of native maple wood darkened under the influence of sunlight, and the wood took on a pale brown-yellow color. The degree of darkening and browning is quantified by the value of the total color difference ΔE^* = 19.1. The opposite brown-red color of the steamed maple wood brightened during the exposure due to sunlight, and the surface of the wood took on a brown-yellow color. The degree of lightening of the color of steamed maple wood in the color space CIE $L^*a^*b^*$ is quantified by the value of the total color difference ΔE^* = 10.4. A comparison of the color changes of native and steamed maple wood caused by solar radiation through the total color differences ΔE^* shows that the surface of steamed maple wood shows 45.5 % fewer color changes than the surface of native dazzled maple wood. This fact points to the fact that steaming maple wood with saturated water steam has a positive effect on the color stability and partial resistance of steamed maple wood to the initiation of photolytic and photolytic reactions induced by UV + VIS wavelengths of solar radiation.

Key words: maple wood, steaming, saturated water steam, sunlight, wood color

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 woody plants differs visually. The color of the wood is formed 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 extractive substances such as dyes, tannins, resins and others), which absorb some components of the electromagnetic radiation of daylight and thus create the color of the wood surface perceived by human vision.

Wood exposed to long-term exposure to sunlight changes color on its surface. The surface of the wood darkens and mostly yellows and browns. This fact is described, mentioned in professional literature as natural aging (HON 2001, REINPRECHT 2008, BAAR and GRYC 2012).

Solar radiation is electromagnetic radiation with wavelengths in the range from 100 to 3000 nm (HRVOĽ and TOMLAIN 1997), which consists of ultraviolet radiation, visible radiation (light) and infrared radiation. Ultraviolet radiation (UV) with wavelengths of 100 – 380 nm makes up about 2 % of the daylight spectrum. According to the effect of UV radiation on biological materials and their effects on these materials, UV radiation is divided into: UV-A radiation with a wavelength of 320 – 380 nm, UV-B radiation with a wavelength of 280 – 320 nm and UV-C radiation with a wavelength below 280 nm. The spectrum of UV radiation falls on the Earth's surface from solar radiation, which is made up of 90 – 99 % UV-A radiation and 1 – 10 % UV-B radiation. The most dangerous UV-C radiation is completely absorbed by the atmosphere. The visible light spectrum, referred to as VIS with wavelengths from 380 to 780 nm, represents approximately 49 % of the daylight spectrum. The rest consists of infrared IR radiation with wavelengths of 780 – 3000 nm. The wavelengths of visible and infrared radiation are absorbed or reflected by the wood surface. The reflected wavelengths of the visible spectrum allow a person to perceive its color when looking at a given object. The absorbed wavelengths of infrared solar radiation change to heat on the surface (HRVOĽ and TOMLAIN 1997).

UV + VIS components of solar radiation upon impact on the wood surface initiate photodegradation processes of wood (photolytic and photooxidation reactions with lignin, polysaccharides and accessory substances of wood). Of the chemical components of wood, lignin is the most subjected to photodegradation 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 polysaccharides into polysaccharides with a lower degree of polymerization 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, GEFFERTOVÁ *et al.* 2018.

The aim of this work is to compare the effect of solar radiation on the surface of thermally treated maple wood with saturated steam (steaming) and native (unsteamed) maple wood. Through changes in the coordinates L^*, a^*, b^* of the color space CIE $L^*a^*b^*$ and the total color difference ΔE^*, the surface color changes of native and thermally treated maple wood caused by UV + VIS components of solar radiation are evaluated.

MATERIALS AND METHODS

Blanks with the dimensions of 32 × 60 × 600 mm made of maple wood had moisture content w_p = 57.8 ± 4.8 % and they were divided into 2 groups. The first group of blanks were not thermally steamed prior to drying. The blanks of the second group were steamed with saturated water steam at a temperature of t = 135 ± 2.5 °C in order to modify the color of the maple wood to a dark red color. Steaming was performed in an APDZ 240 pressure autoclave (Himmasch AD, Haskovo, Bulgaria) installed at Sundermann s.r.o. Banská Štiavnica (Slovakia). The steaming mode of beech wood with saturated steam is shown in Fig. 1 and technological parameters of the steaming mode are given in Table 1.

Tab. 1 Mode of colour modification of maple wood with saturated water steam.

Mode	Temperature of saturated water steam [°C]			Time of operation [hours]		
	t_{min}	t_{max}	t_4	τ_1 -phase I	τ_2-phase II	Total time
Mode	132.5	137.5	100	6.0	1.0	7.0

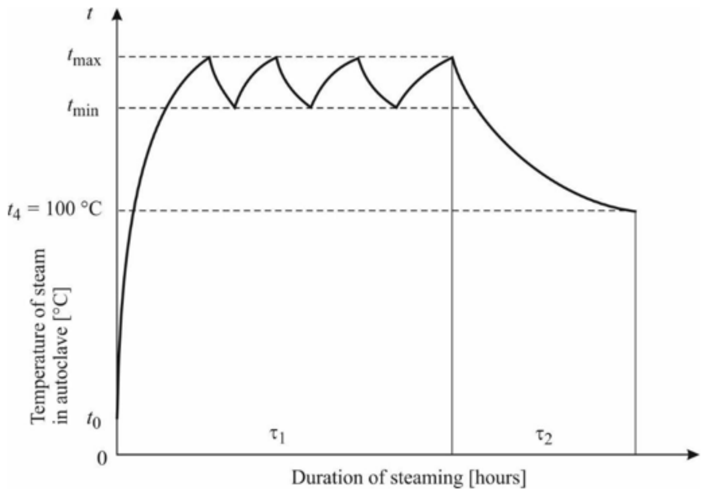

Fig. 1 Mode of color modification of maple wood with saturated water steam.

Native and steamed maple blanks were dried by a low-temperature drying mode (DZURENDA 2020) preserving the original wood color to moisture content w_k = 12 ± 0.5 % in a conventional hot air dryer: KC 1/50 (SUSAR s.r.o).

The samples with dimensions: 20 × 50 × 400 mm were produced from dried unsteamed and steamed maple wood blanks. The planed surface of unsteamed and steamed maple wood samples was exposed at an angle of 45° to daylight in the northern temperate zone - Slovakia locality for 36 months. Indoor temperature and relative humidity during exposure was t = 20 ± 2.5 °C, φ = 50 ± 10 %.

The average density of incident solar radiation in Slovakia is 1100 kWh/m^2 per year. The intensity of the sun rays changes throughout the year. The highest intensity of solar radiation is in the summer months of June and July when it reaches a value of 5.9 to 6.0 kWh/m^2 per day. During the autumn, the intensity of sunlight decreases and the lowest one is during winter. In December, the intensity of solar radiation is the weakest with an approximate value of 1.7 kWh/m^2 per day.

The surface color of the maple samples before and during the exposure was evaluated in the color space CIE *L*a*b** at monthly intervals using a Color reader CR-10 colorimeter (Konica Minolta, Japan). A D65 light source and an 8 mm diameter optical scanning aperture were used.

The total color difference ΔE^* of the maple wood surface color change during the 36-month exposure to sunlight was determined according to the following ISO 11 664-4 equation:

$$\Delta E^* = \sqrt{\left(L_2^* - L_1^*\right)^2 + \left(a_2^* - a_1^*\right)^2 + \left(b_2^* - b_1^*\right)^2} \qquad (1)$$

Where: L^*_1, a^*_1, b^*_1 the coordinates of the color space CIE *L*a*b** on the surface of the dried, milled maple wood before exposure,

L^*_2, a^*_2, b^*_2 the coordinates of the color space CIE *L*a*b** on the surface of the dried, milled maple wood during exposure.

The measured values on the luminance coordinate *L** and the chromaticity coordinates *a*, b**, as well as the calculated values of the total color differences ΔE^* during the observed exposure periods were statistically and graphically evaluated using EXCEL and STATISTICA 12 programs (V12.0 SP2, USA).

RESULTS AND DISCUSSION

Maple wood, according to (MAKOVINY 2010, KLEMENT *et al.* 2010), has a white color, or pale shade of white-yellow color. In the steaming process, as reported by: (TREBULA 1986, DZURENDA 2018, BANSKI and DUDIAK 2019, DZURENDA and DUDIAK 2020, VIDHOLDOVÁ and SLABEJOVÁ 2021) depending on the temperature of the saturated water steam and the length of the wood treatment darkens and takes on shades of pale pink-brown to brown-red. Table 2 shows the coordinates of the color space CIE $L^*a^*b^*$ of native and steamed maple wood at moisture content of w = 12 % on the planed surface before and after 36 months of glare.

Tab. 2 Coordinate values of color space CIE $L^*a^*b^*$ of native and thermally treated maple wood.

Maple wood	Native wood			Thermally treated wood		
	Color space coordinates CIE $L^*a^*b^*$					
	L^*	a^*	b^*	L^*	a^*	b^*
Before dazzling	86.0 ± 2.6	5.9 ± 1.3	16.4 ± 1.7	60.7 ± 1.6	12.2± 1.5	18.9 ± 1.5
After dazzling	70.4 ± 1.1	12.8 ± 0.9	26.8 ± 0.8	68.5 ± 0.9	12.0 ± 0.5	25.9 ± 0.6

The values of the luminance coordinates L^* and the chromatic coordinates of red a^* and yellow b^* of the color space CIE $L^*a^*b^*$ of native maple wood given in Table 2 are similar to those given by the authors: (BABIAK *et al.* 2004, MEINTS *et al.* 2017, DZURENDA 2018, KÚDELA *et al*. 2020).

The color of native and steamed maple wood before and after exposure to daylight dazzling is shown in Fig. 2.

Fig.2 View of maple wood: native before and after exposure; thermally treated before and after exposure.

The waveforms of the measured values of the maple wood color on the coordinates: L^*, a^*, b^* of the color space CIE $L^*a^*b^*$ in individual months, during 36 months of dazzling by the sunlight of daylight are shown in Fig. 3, 4.

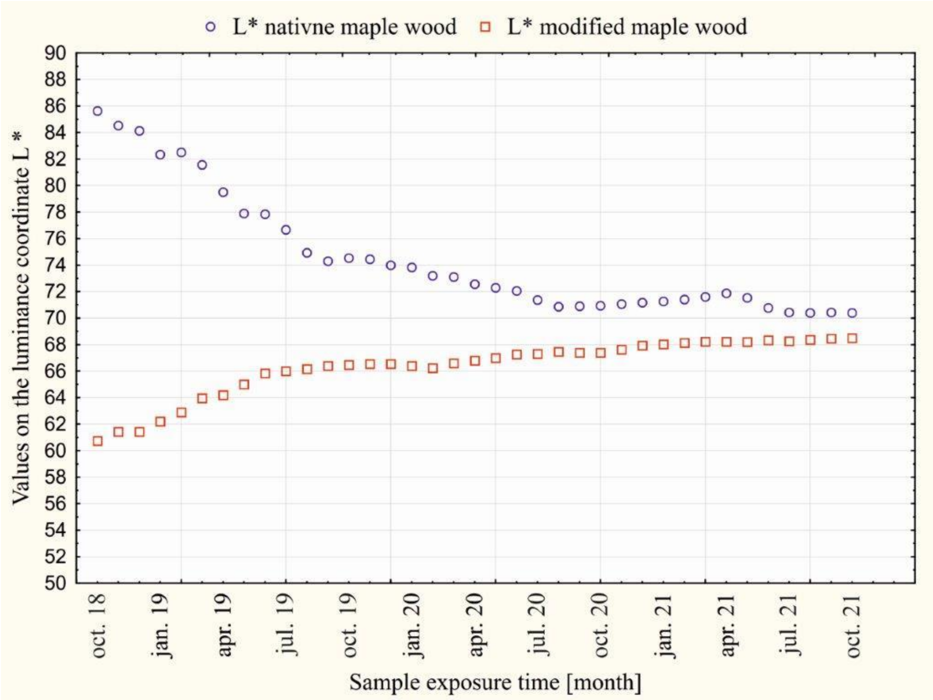

Fig. 3 Values on the luminance coordinate *L of dazzling native and thermally treated maple wood over a period of 36 months (October 2018 to October 2021).**

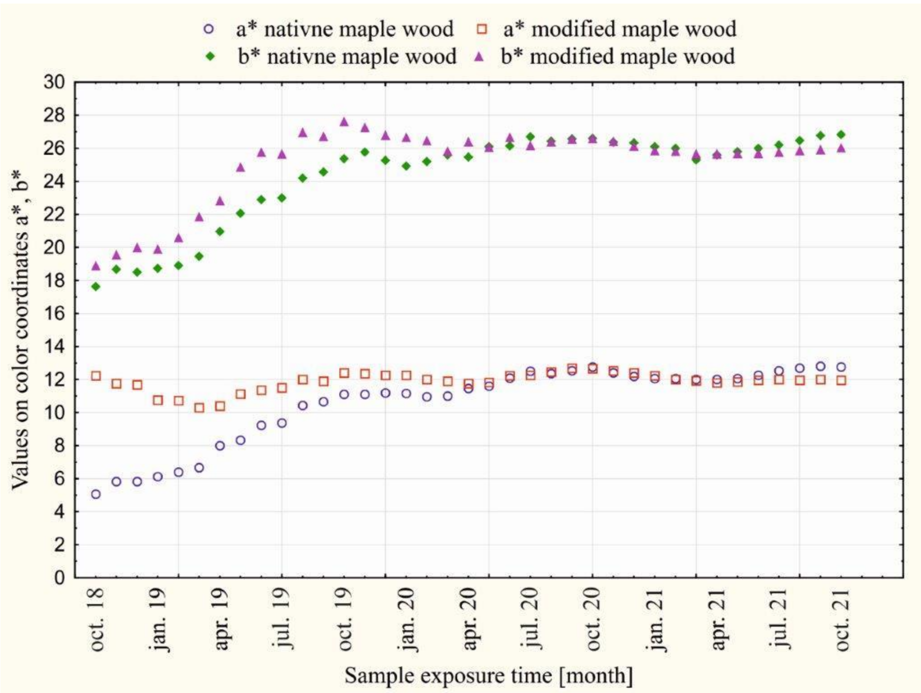

Fig. 4 Values on chromatic coordinates of red color *a and yellow color *b** of dazzling native and thermally treated maple wood for 36 months (October 2018 to October 2021).**

The course of the measured values on the light coordinate L^* and the chromatic coordinates of the color a^* and the yellow color b^* in Fig. 3 and 4 during 36 months of dazzling is not smooth. The fluctuations are attributed to the influence of the intensity of solar radiation during the individual seasons, causing photolytic and photooxidative reactions of UV radiation with wood. In Fig. 5 and 6 show the magnitudes of changes in the average values of Δ*L**, Δ*a** and Δ*b** in individual seasons during the exposure.

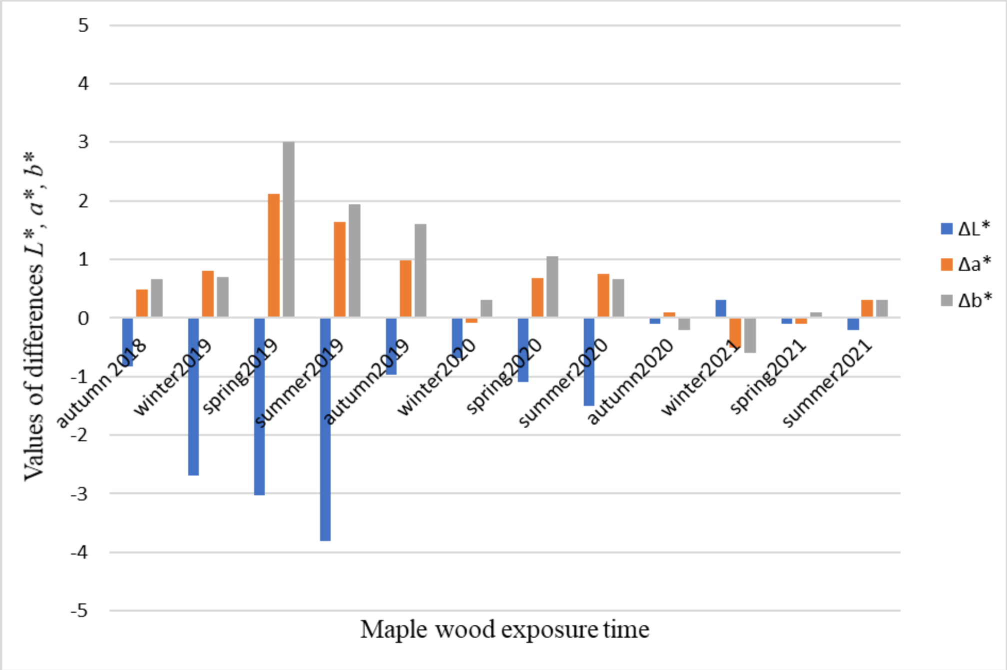

Fig. 5 The magnitudes of changes in the values of Δ*L, Δ*a**, Δ*b** in the color space CIE *L*a*b** of native maple wood during the 36-month exposure to sunlight, depending on the season.**

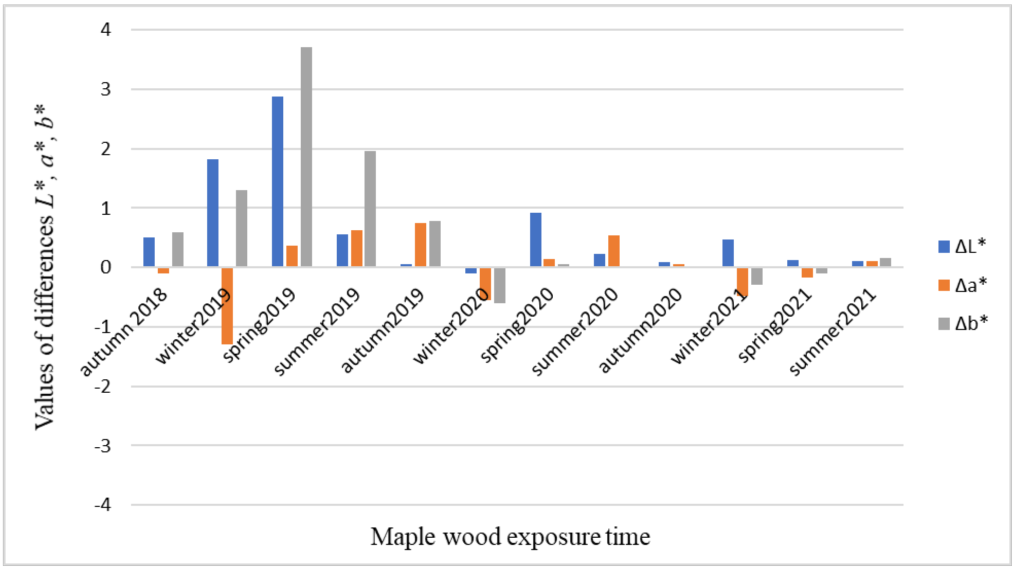

Fig. 6 Amounts of changes in the values of Δ*L, Δ*a**, Δ*b** in the color space CIE *L*a*b** of steamed maple wood during the 36-month exposure to sunlight, depending on the season.**

In Fig. 7, the degree of color change of the surface of unsteamed and steamed maple wood induced by sunlight over a period of 36 months is documented by the total color difference Δ*E**.

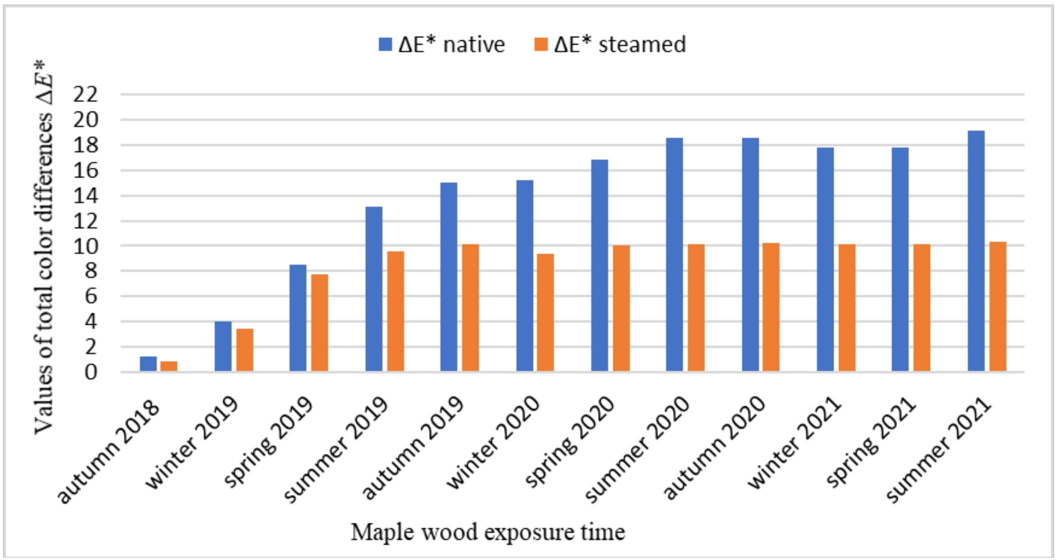

Fig. 7 Values of the total color difference Δ*E of native and steamed maple wood during 36 months of dazzling (October 2018 to October 2021).**

From the comparison of wood colors in Fig. 2 and the values presented at the L^*, a^*, b^* coordinates of native and steamed maple wood during the exposure in Fig. 3 and 4 show that while the surface of the native maple wood darkened and browned, the brown-red color on the surface of the porous wood lightened.

The darkening and browning of unsteamed maple wood numerically documents the shift on the luminance coordinate L^* from the value $L_0^* = 86.0$ to $L_{36}^* = 70.4$ i. by the value $\Delta L^* = -15.6$ and changes in chromatic coordinates: red color a^* from $a_0^* = 5.9$ to $a_{36}^* = 12.8$ i.e., by value $\Delta a^* = +6.9$ and yellow b^* from $b_0^* = 16.4$ to $b_{36}^* = 26.8$ i.e., by the value $\Delta b^* = +10.2$. The largest darkening of native maple wood occurred during the first year of dazzling, when changes in the luminance coordinate ΔL^* reached 68.0 % of the total change in luminosity of maple wood caused by UV + VIS radiation of daylight, in the second year it is 27.5 % and in the third 4.5 %. The browning of native maple wood occurred due to changes in chromatic coordinates: red a^* and yellow b^*. The change in the red coordinate in the first year of glare was 72.5 % of the total change Δa^*, in the second year of glare 36.2 % and in the third year 1.3 %. On the yellow coordinate, the change in Δb^* in the first year of glare was 63.7 % of the total value of the change in Δb^* maple wood, in the second year 35.3 % and in the third year 1.0 %. The changes in the red a^* and yellow b^* coordinates of the color space CIE $L^*a^*b^*$ in the third year, as measured by measurements, are small and, moreover, the different seasons are contradictory, while in winter they show a decrease in both spring and summer in at the time of more intense sunlight their growth. The darkening of wood due to solar radiation is in line with the opinions of experts dealing with changes in the properties of wood due to long-term exposure to sunlight, who state that the surface of wood darkens and mostly yellows and browns (REINPRECHT 2008, CHANG *et al.* 2010, BAAR and GRYC 2012, KÚDELA and KUBOVSKÝ 2016, GEFFERTOVÁ *et al.* 2018, DZURENDA 2020, DZURENDA *et al.* 2020).

Steamed maple wood under the influence of sunlight for 36 months compared to native wood showed the opposite character of the color change, the surface of the wood faded. Visually, this is documented in Fig. 2, as well as the shift on the luminance coordinate L^* from the value $L_0^* = 60.7$ to $L_{36}^* = 68.5$ i.e. on the value $\Delta L^* = +8.2$ and on the chromatic coordinates: red a^* by $a_0^* = 12.2$ to $a_{36}^* = 12.0$ i.e. by the value $\Delta a^* = -0.2$ and the yellow color b^* from the value $b_0^* = 18.9$ to $b_{36}^* = 25.9$ i.e. by the value $\Delta b^* = +7.0$. On the basis of a comparison of individual changes ΔL^*, Δa^*, Δb^* on the coordinates of the color space CIE $L^*a^*b^*$ of steamed maple wood caused by exposure to solar radiation with changes ΔL^*, Δa^*, Δb^* on the coordinates of the unsteamed it can be stated that the values expressing the magnitude of changes in steamed maple wood are smaller. The magnitude of the changes in the luminance coordinate L^* and the yellow color b^*, similarly to unsteamed maple wood, are the largest in the first year of exposure. The changes in the red coordinate a^* oscillated around the value $a^* = 12.0$. In winter, at low sunlight intensity, the values at the red coordinate a^* decrease, and from spring to autumn they increased at higher sunlight intensity. The rate of decline, or the increase in red coordinate values decreases over the years. Based on the above findings, it can be stated that the functional groups of the maple wood chromophore system with absorption of the electromagnetic radiation spectrum with a red wavelength of 630 – 750 nm causing reddening of steamed maple wood were eliminated by steam due to UV-induced photochemical reactions on the steamed maple surface.

The authors point out the effect of brightening the surface of steamed wood under the action of UV radiation: (DZURENDA 2019, VARGA *et al.* 2021). Dzurenda in work: "*The effect of UV radiation in Xenotest 450 on the color of steamed beech wood during the process of simulated aging"* shows the lightening of the surface color of steamed beech wood after its irradiation in Xenotest with a 450-xenon lamp emitting UV radiation with a wavelength of 340 nm, intensity 42 ± 2 W/m^2 for 7 days. The lightening of the red-brown color of steamed beech wood is declared by the increase of the values on the lightness coordinate from $L_1^* = 62.6$ to the value of $L_2^* = 69.3$, i.e. by $\Delta L^* = +6.7$, the increase of the value on the chromatic coordinate of the yellow color from $b_1^* = 17.1$ to the value of $b_2^* = 29.4$ i.e. by $\Delta b^* = +12.3$, with a slight change in the red coordinate value from $a_1^* = 10.9$ to $a_2^* = 10.8$ i.e. by $\Delta a^* = -0.1$.

The effect of UV radiation on steamed agate wood is discussed in (VARGA *et al.* 2021) states that while the surface of steamed agate wood darkened slightly at a steaming temperature $t = 100$ °C, the surface of agate wood brightened at a steaming temperature $t = 120$ °C.

The contribution of the influence of maple wood steaming on the color fastness and resistance to the effects of sunlight declares a decrease in the value of the total color difference ΔE^* in Fig. 7. While the change in the color of unsteamed maple wood caused by solar radiation expressed by the value of the total color difference for 3 years is $\Delta E^* = 19.1$, then the change in the total color difference of steamed maple wood in the same period is $\Delta E^* = 10.4$ which is the decrease in color changes by 45.5 %. This fact points to the fact that maple wood steaming has a positive effect on changes in the chromophore system of steamed maple wood and the partial resistance of steamed maple wood to the initiation of photolytic and photolytic reactions induced by UV + VIS wavelengths of solar radiation.

CONCLUSIONS

The results of the color change of the surface of native and steamed maple wood with saturated water steam in a pressure autoclave APDZ 240, which was exposed to daylight indoors for 36 months were presented in the paper. The results of the analyses of the effect of solar radiation on native and steamed maple wood showed:

1. The color of the surface of native maple wood under the influence of daylight during the exposure changed, the wood darkened and took on a brown-yellow hue. The opposite tendency, i.e., lightening occurred on samples of steamed maple wood.

2. The measured changes in values at the coordinates of the color space CIE $L^*a^*b^*$ caused by solar radiation in native maple wood are: ΔL^* = - 15.6; Δa^* = + 5.9; Δb^* = + 10.2 and for steamed maple wood: ΔL^* = + 8.2; Δa^* = - 0.2; Δb^* = + 7.0.
3. The evaluation of the color change of maple wood in the form of the total color difference ΔE^* shows that the surface of steamed maple wood shows a reduction of color change due to aging by 45.5 %.
4. Minor changes in the values of ΔL^*, Δa^*, Δb^* and the overall color difference ΔE^* of steamed maple wood indicate a positive effect of steamed wood on the partial resistance of steamed maple wood to the initiation of photolytic reactions induced by UV + VIS wavelengths of solar radiation.

REFERENCES

BABIAK, M., KUBOVSKÝ, I., MAMOŇOVÁ, M. 2004. Color space of selected local woods. In: interaction of wood with various forms of energy. Technická univerzita vo zvolene. 113 – 117. ISBN 80-228-1429-6.

BANSKI, A., DUDIAK, M. 2019. Dependence of color on the time and temperature of saturated water steam in the process of thermal modification of beech wood. In AIP conference proceedings. ISSN 0094-243X. DOI: 10.1063/1.5114731

BAAR, J., GRYC, V. 2012. The analysis of tropical wood discoloration caused by simulated sunlight. In Europen journal of wood and wood products. 70: 1-3, 263-269. doi: 10.1007/S00107-011-0551-1

DENES, L., LANG, E.M. 2013. Photodegradation of heat-treated hardwood veneers. In Journal of Photochemistry and Photobiology B: Biology 118: 9-15.

DZURENDA, L. 2018. Hues of *Acer platanoides* L. resulting from processes of thermal treatment with saturated steam. In Drewno 61(202): 165-176. DOI: 10.12841/wood.1644-3985.241.11

DZURENDA, L. 2019. The effect of UV radiation in Xenotest 450 on the colour of steamed beech wood during the process of simulated ageing. In Annals of Warsaw University of Life Sciences. Forestry and Wood Technology. No 106: 114-119. ISSN 1898-5912.

DZURENDA, L., DUDIAK, M. 2020. The effect of the temperature of saturated water steam on the colour change of wood *Acer pseudoplatanus L*. In Acta Facultatis Xylologiae Zvolen, 2020, 62(1), 19–28. DOI: 10.17423/afx.2020.62.1.02

DZURENDA, L., DUDIAK, M., BANSKI, A. 2020. Influence of UV radiation on color stability of natural and thermally treated maple wood with saturated water steam. In Innovations in woodworking and engineering design: international scientific journal. pp. 36-41. ISSN 1314-6149.

DZURENDA, L. 2020. Drying of Steaming Maple Timber in Drying Kilns, While Preserving the Color Acquired by the Wood Steaming Process., In MATEC Web of Conferences 328, 04004 (2020), XXII. AEaNMiFMaE-2020.

GANDELOVÁ, L., HORÁČEK., P., ŠLEZINGEROVÁ., J. 2009. Nauka o dřevě. Mendelova zemědělská a lesnická univerzita v Brně, 176 p. ISBN 978-80-7375-312-2.

GEFFERTOVÁ, J., GEFFERT, A., VÝBOHOVÁ, E. 2018. The effect of UV irradiation on the colour change of the spruce wood. In Acta Facultatis Xylologiae Zvolen, 2018, 60(1), 41–50.

HON D.S.N. 2001. Weathering and photochemistry in wood. In Hon D.S.N., Shiraishi, N. Wood and cellulosic chemistry. 2nd edition. New York: MarcelDekker, p. 513 – 546. ISBN 9780824700249.

HRVOĽ, J., TOMLAIN, J., 1997. Žiarenie v atmosfére. [Radiation in the atmosphere],1 vyd. Bratislava, Univerzita Komenského v Bratislave, 136 p. ISBN 80-223-1088-3.

CHANG, T. C., CHANG H. T., CHANG S. T. 2010. Influences of extractives on the photodegradation of wood. In Polymer Degradation and Stability, (95). 516–521. DOI: 10.1016/j.polymdegradstab.2009.12.024

KÚDELA, J., KUBOVSKÝ, I. 2016. Accelerated-ageing-induced photo-degradation of beech wood surface treated with selected coating materials. In Acta Facultatis Xylologiae Zvolen: Technická univerzita vo Zvolene. 2. s. 27-36. DOI: 10.17423/afx.2016.58.2.03

ISO 11 664-4:2008 Colorimetry - Part 4: CIE 1976 L*a*b* Colour space.
KÚDELA, J., KUBOVSKÝ, I., ANDREJKO, M. 2020. Surface Properties of Beech Wood after CO_2 Laser Engraving. In Coatings, 10(1): 77. DOI: 10.3390/coatings10010077
KLEMENT, I., RÉH, R., DETVAJ, J. 2010. Základné charakteristiky lesných drevín – spracovanie drevnej suroviny v odvetví spracovania dreva. [Basic characteristics of forest trees - wood raw material processing in the wood processing industry], (Národné lesnícke centrum, 2010), 82 p.
MAKOVÍNY, I. 2010. Úžitkové vlastnosti a použitie rôznych druhov dreva. [Useful properties and use of different types of wood]. Zvolen: Technická univerzita Zvolen, 104 p.
MEINTS, T., TEISCHINGER, A., STINGL, R., HANSMANN, C. 2017. Wood colour of central European wood species: CIELAB characterisation and colour intensification, Eur. In J. Wood Prod., 75: 499-509.
PERSZE, L., TOLVAJ, L. 2012. Photodegradation of wood at elevated temperature: Colour change. In Journal of Photochemistry and Photobiology B: Biology 108: 44-47.
REINPRECHT, L. 2008. Ochrana dreva [Wood protection] Zvolen Technická univerzita Zvolen, 450 p.
TREBULA P. 1986: Sušenie a hydrotermická úprava dreva [Wood drying and hydrothermal treatment], Technická univerzita vo Zvolene. Zvolen. 255 p.
VARGA, D., TOLVAJ, L., PREKLET, E. 2021. Colour stability of steamed black locust, beech and spruce timbers during short-term photodegradation. In Wood Research 66(4): 544-555. DOI: 10.37763/wr.1336-4561/66.4.5544555
VIDHOLDOVÁ, Z ., SLABEJOVÁ,G. 2021. Colour Stabilisation of Surface of Four Thermally Modified Woods with Saturated Water Vapour by Finishes. In Polymers 13(19), 3373. DOI: 10.3390/polym13193373

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