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COLOR CHANGES INDUCED BY CO_2 LASER IRRADIATION OF WOOD SURFACE

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ABSTRACT

The influence of color changes of wood surface with irradiation dose was examined in this work. Surface of two species - maple (*Acer pseudoplatanus,* L.) and beech (*Fagus sylvatica,* L.) was irradiated by CO_2 laser beam. The color changes were measured by spectrophotometer. Results are calculated and depicted in CIE $L^*a^*b^*$ color system. With increasing irradiation dose from 14 to 57 Jcm^{-2} we observed uniform growth of ΔE^* for both wood species, from 2,5 to 57 (maple) and from 2 to 48 (beech). Values Δa^* a Δb^* of maple at first increased until maximum 7,2. Finally decreasing was (Δa^* to -0,6 and Δb^* to -12,7) occurred. Values Δa^* of beech decreased slightly to -5,7 and Δb^* to -15,5.

KEY WORDS: maple, beech, color changes, laser, spectrophotometer, irradiation dose

INTRODUCTION

Structure and properties of wood determine its utilization. Wood is composed of cellulose, hemicelluloses, lignin and extractives. Their content and relationship affects a lot of properties of the wood, e.g. its color, which is one of the important characteristics. Wood can absorb wavelengths from width range of electromagnetic spectrum. The degradation of wood components will form chromoforic groups of lignin. These structures are responsible for the wood color changes. Color changes can be obtained by various technological processes, for example: heating, irradiation (UV, visible light, IR), steaming and drying.

Heat can cause the decrement in lightness and the increment in the color differencies resulting from heat treatment at 240-310 °C (Bourgois et al. 1991). Steaming at 92-122 °C causes decrement of lightnes greatly influenced by steaming time and temperature (Varga and van der Zee 2008). The light can induce changes of color, too. Photo-induced discoloration of sapwood of Japanese larch (*Larix leptolepis,* L.) brings lightening if wavelength is longer than 390 nm and darkening for wavelength shorter than 390 nm (Hon and Minemura 2001). The rate of color changes is usually related to the intensity of light (Mitsui 2004) or time of irradiation

(Oltean et al. 2008). UV irradiation of the wood will cause growth of the color differences with irradiation time, especially in the first 25-50 h (Tolvaj and Faix 1995). Research of color stability of heat-treated wood during artificial weathering brings knowledge how we can protect the surface of wood against UV light (Ayadi et al. 2003) and Mitsui (2006).

Interpretation of color

The color is specified by means of three color attributes: hue, saturation and lightness. This fact allows the arrangement of color in three-dimensional space. One dimension corresponds to the lightness. The other two (hue and saturation) together determine the chromacity. The color can be described by X,Y,Z tristimulus values, which are the amounts of the three reference color stimuli required for the color match with an investigated color by means of the additive mixing. There are not very useful therefore is normally used CIE $L^*a^*b^*$ (CIELAB) colorimetric coordinate system (Fig.1) established by CIE (International Commission on Illumination) in 1964. The color in CIELAB system is characterized by three parameters: L^*, a^* and b^*. Axis L^* represents the lightness, it varies from 0 (black) to 100 (white). Axis a^* and b^* are the chromaticity coordinates. In the diagram CIELAB $+a^*$ is the red direction, $-a^*$ is green, $+b^*$ is yellow and $-b^*$ is blue. The color is measured by spectrophotometers or colorimeters. Modern microcomputer controlled equipments can offer values of L^*, a^*, b^* directly.

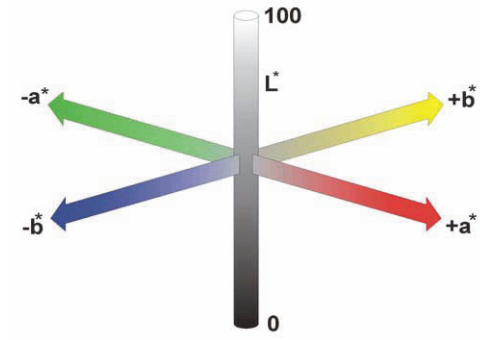

Fig. 1: Structure of axes L^*, a^*, b^* in the coordinate system CIELAB

For two colors the total color difference ΔE^* represents the distance of two points (two matched colors) in a color space. These values are calculated to the equations (1-4):

$$\Delta E^* = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2} \tag{1}$$

$$\Delta L^* = L_i^* - L_r^* \tag{2}$$

$$\Delta a^* = a_i^* - a_r^* \tag{3}$$

$$\Delta b^* = b_i^* - b_r^* \tag{4}$$

where subscript *r* denotes reference values (before exposure) and subscript *i* denotes irradiated values (after exposure).

MATERIAL AND METHODS

Experimental material

We have studied two wood species maple (*Acer pseudoplatanus* L.) and beech (*Fagus sylvatica* L.). For each species one sample of 500 x 150 x 15 mm (length x width x thickness) was obtained by tangential cut from batch. Before starting the experiment surface was sanded by glass paper with roughness No.150. Moisture content of both species was 12 %.

Irradiation

CO_2 laser was used for irradiation. Experimental equipment LCS 400 consists of CO_2 laser (wave length 10,6 μm and maximum power output 400W), positioning table system (allowed laser head positioning and raster scan of laser beam) and special PC control system. The sample was placed away from lens focus. The spread laser beam stroked on surface of the sample perpendicularly and laser head carriage moved along the width (axis x) at a certain scanning speed. After scanning all width of the sample was laser head shifted in length direction (axis y). The speed was increased and whole process was repeated. On the surface parallel band system was created. Each band was irradiated with particular value of scanning speed. Thus each band got various irradiation dose H.

All calculated values of the H ($J.cm^{-2}$) are presented in Tab. 1 and Tab. 2. For maple changed H value from 17,9 to 57,3 $J.cm^{-2}$ (23 irradiated bands, JV32-JV10, "V" is scanning speed in mms^{-1}) and for beech from 14,3 to 57,3 $J.cm^{-2}$ (16 irradiated bands, BV40-BV10).

Color measurement

The color of the surface of specimens was measured with portable spectrophotometer CM 2600d (Konica-Minolta). Measurements were made using SCI (Specular Component Included) lighting system with D65 light source by simulating the daylight in wave length range from 360 to 740 nm. The sensor head was 6 mm in diameter. The internal software contains all necessary colorimetric equations.

Before irradiation surface was measured as reference. Color of each irradiated band was measured respectively (80 measured points on whole length of band for H less than 40,1 $J.cm^{-2}$, above this value 200 measured points, 30 points on unirradiated reference surface).

The color differencies ΔL^*, Δa^*, Δb^* and total color difference ΔE^* was calculated according to the equations 1-4.

RESULTS AND DISCUSSION

All results are presented in the next tables and graphs. Values are valid for 95 % variability limit.

Color differences for maple

With increasing irradiation dose we observed continual growth of ΔE^* values for maple from 2,5 to 56,7. ΔL^* increased at first slightly until value of dose 22 $J.cm^{-2}$, then linearly until value 41 $J.cm^{-2}$, where growth was stopped. Over value 48 $J.cm^{-2}$ was observed blackening of the wood ($\Delta L^* > -52$).

Value Δa^* increased from 0,3 to 7,2 where with dose 30 $J.cm^{-2}$ started decrease until initial value.

Value Δb^* increased from 2,4 to 7,2 where with value 27 $J.cm^{-2}$ started decrease. The Δb^* changed sign (on minus sign) on value 34 $J.cm^{-2}$.

Dependency values of ΔL^*, Δa^*, Δb^* of maple with irradiation dose is depicted in Fig. 2 and total color difference ΔE^* of maple with irradiation is depicted in Fig. 3.

Tab. 1: Measured mean of ΔL^*, Δa^*, Δb^*, ΔE^* of the color space according to irradiation dose for maple

BAND	JV32	JV31	JV30	JV29	JV28	JV27	JV26	JV25	JV24	JV23	JV22	JV21	JV20	JV19	JV18	JV17	JV16	JV15	JV14	JV13	JV12	JV11	JV10
H (.Jcm^{-2})	17,9	18,5	19,1	19,8	20,5	21,2	22,0	22,9	23,9	24,9	26,1	27,3	28,7	30,2	31,8	33,7	35,8	38,2	40,9	44,1	47,8	52,1	57,3
ΔL^* (%)	-0,82	-1,39	-1,62	-2,56	-2,86	-2,79	-3,72	-5,63	-6,97	-8,81	-10,86	-13,26	-19,34	-22,66	-28,64	-32,70	-35,41	-43,29	-48,42	-52,08	-52,04	-55,71	-55,29
STD ΔL^*	0,70	1,02	0,89	0,90	0,97	1,25	1,51	2,10	1,99	2,09	2,04	2,04	3,08	2,01	2,01	1,95	2,89	2,07	2,99	1,87	3,15	1,03	2,07
Δa^* (%)	0,25	0,52	0,66	1,22	1,41	1,37	1,93	2,97	3,49	4,34	5,10	5,93	7,11	7,16	7,01	6,79	5,85	4,32	3,14	2,42	1,66	-0,57	-0,18
STD Δa^*	0,28	0,55	0,52	0,54	0,56	0,68	0,83	1,10	0,97	0,90	0,78	0,63	0,37	0,34	0,42	0,45	0,56	0,60	1,04	0,63	1,02	0,66	1,04
Δb^* (%)	2,38	2,68	3,20	3,72	4,35	3,95	4,79	5,90	6,54	6,67	7,02	7,23	6,57	5,01	2,99	1,09	-1,22	-4,90	-7,23	-8,91	-10,22	-13,96	-12,71
STD Δb^*	1,30	1,73	1,58	1,17	1,24	1,40	1,65	1,66	1,45	1,64	1,21	1,22	1,45	1,14	1,34	1,30	1,54	1,55	2,44	1,54	2,50	1,41	2,01
ΔE^* (%)	2,53	3,06	3,64	4,68	5,39	5,03	6,37	8,68	10,18	11,88	13,89	16,22	21,63	24,29	29,64	33,41	35,91	43,78	49,06	52,90	53,06	57,44	56,74
STD ΔE^*	1,24	1,58	1,45	1,06	1,14	1,32	1,55	1,81	1,68	1,84	1,73	1,76	2,80	1,89	1,95	1,92	2,85	2,06	2,97	1,86	3,13	1,06	2,07

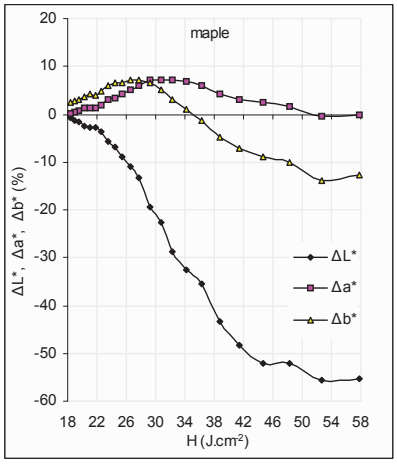

Fig. 2: Resulting values of ΔL^*, Δa^*, Δb^* of maple with irradiation dose

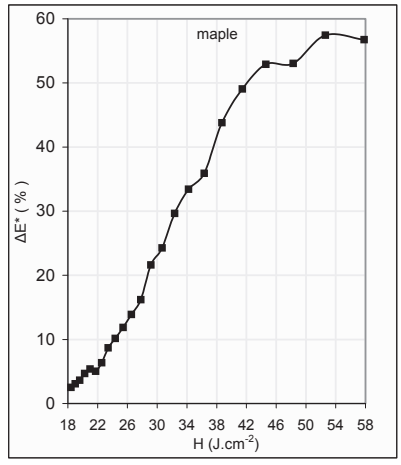

Fig. 3: Color differencies ΔE^* of maple with irradiation dose

Color differences for beech

A trend of ΔL^* is similar to that of maple. From irradiation dose of 17 J.cm^{-2} to 35 J.cm^{-2} ΔL^* increased almost linearly. Value of irradiation dose above 40 J.cm^{-2} causes marked darkening.

Considerably smaller changes of Δa^* and Δb^* comparing to maple were observed. Δa^* is quasi invariable until irradiation dose of 24 J.cm^{-2} where slightly decreased to -5,7. Δb^* decreased from value of irradiation dose 30 J.cm^{-2} to -15,5.

Dependency values of ΔL^*, Δa^*, Δb^* of beech with irradiation dose is depicted in Fig. 4 and total color difference ΔE^* of beech with irradiation is depicted in Fig. 5.

Tab. 2: Measured mean of ΔL^*, Δa^*, Δb^*, ΔE^* of the color space according to irradiation dose for beech

BAND	BV40	BV38	BV36	BV34	BV32	BV30	BV28	BV26	BV24	BV22	BV20	BV18	BV16	BV14	BV12	BV10
H ($J.cm^{-2}$)	14,3	15,1	15,9	16,9	17,9	19,1	20,5	22,0	23,9	26,1	28,7	31,8	35,8	40,9	47,8	57,3
ΔL^* (%)	-1,73	-1,98	-2,43	-3,52	-4,32	-5,40	-7,04	-8,95	-13,94	-16,38	-24,86	-30,65	-38,64	-44,95	-46,98	-45,42
STD ΔL^*	1,68	1,78	1,61	1,68	1,74	1,74	2,10	2,16	2,72	2,75	2,45	2,90	3,13	2,36	2,25	2,47
Δa^* (%)	0,48	0,50	0,64	0,80	0,90	0,94	0,94	1,14	1,32	1,10	0,96	0,16	-0,71	-2,57	-4,86	-5,68
STD Δa^*	0,65	0,72	0,65	0,66	0,67	0,67	0,69	0,68	0,68	0,66	0,89	0,94	0,90	1,05	1,16	1,23
Δb^* (%)	-0,52	-0,29	-0,42	-0,52	-0,73	-1,26	-1,32	-1,02	-0,85	-1,27	-2,28	-3,81	-6,13	-10,39	-14,55	-15,48
STD Δb^*	0,60	0,67	0,65	0,69	0,70	0,57	0,72	0,56	0,68	0,69	0,91	1,23	1,40	1,52	1,68	1,70
ΔE^* (%)	1,87	2,06	2,55	3,64	4,48	5,62	7,22	9,08	14,03	16,47	24,98	30,89	39,13	46,21	49,42	48,32
STD ΔE^*	1,57	1,72	1,55	1,63	1,69	1,68	2,05	2,13	2,71	2,74	2,44	2,88	3,10	2,33	2,20	2,39

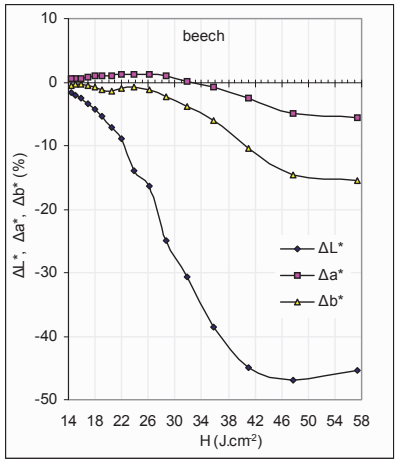

Fig. 4: Resulting values of ΔL^*, Δa^*, Δb^* of beech with irradiation dose

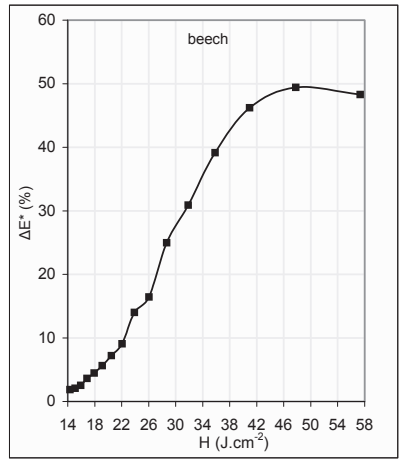

Fig. 5: Color differencies ΔE^* of beech with irradiation dose

CONCLUSIONS

The aim of these experiments was to verify a concept to change color of wood by CO_2 laser irradiation. Color changes achieved during irradiation was influenced by irradiation dose impacted on the surface of the wood. To quantify obtained results would require further experiments with another wood species.

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