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INFLUENCE OF THERMAL MODIFICATION ON COLOUR OF POPLAR (*POPULUS X EURAMERICANA*) ROTARY CUT VENEER

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ABSTRACT

This paper presents the results of poplar (*Populus x euramericana*) veneer colour change caused by one-hour long thermal treatments at temperatures of 190, 200, 210 and 215°C. There were three veneer zones included in this experiment: Veneer from sapwood, veneer from heartwood and veneer from intermediate zone - mixed. The measurement results by CIELAB colour system confirmed that there were significant colour differences among the three groups of veneer before thermal treatments. Of all thermal treatments, only the treatment at 210°C contributed to a significant decrease in difference of colour among of all observed veneers. Based on more intensive color change in veneer formats from sapwood, it could be assumed that there were differences in chemical composition between the peripheral and core zones of poplar wood.

KEYWORDS: Poplar peeled veneer, thermal modification, colour, sapwood, heartwood.

INTRODUCTION

Development of ecological weariness lead to a higher demand for ecologically accepted materials. Wood is just such renewable material with a variety of applications in building construction and furnishing of objects for people. The main problem in wood exploitation, for most wood species, is the high period between seeding to harvesting (rotation period), so there is a tendency for using fast growing species.

Poplar is a fast growing species with short rotation period of 10 to 20 years and it is common used - which leads to 90 000 000 ha of plantations covered with poplar (FAO 2012). Poplar wood is mostly used in veneer and plywood production, as cellulose material, for lumber production, as bio fuel, and in the production of packaging material.

Annual world production of different poplar products is 70 350 000 m^3, most of which are plywood panels 42 919 000 m^3, only in China 38 000 000 m^3 (FAO 2012). One of the main products from poplar wood is rotary – cut veneer. During poplar veneer production there is an obvious colour difference. Veneer produced from zone of sapwood is lighter than veneer produced from heartwood zone (wetwood). This might cause some problems, especially in the production of veneer formats for face or back of plywood panels, where the difference in colour might diminish the plywood class.

This difference in colour might be reduced using bleaching solvents such as hydrogen peroxide, or some solvents based on chloric or oxalic acids. An ecologically more appropriated approach might be the thermal wood modification. In contrast to bleaching solvents, thermally modified wood became darker than normal wood, depending on the temperature and treatment duration.

The process of thermal modification is based on high temperatures which cause the decomposition of basic chemical wood components, mainly hemicelluloses and cellulose - Alen and Zaman (2002), Tjeerdsma and Militz (2005), Boonstra and Tjeerdsma (2006), Windeisen et al. (2007), Rowell et al. (2009), etc.

One of the main effects of thermal wood modification is the colour change. With an increase in treatment duration and an increase in temperature, wood becomes darker. This colour change might be used as an indicator of mechanical properties of treated wood, as discussed in some papers: Schnabel et al. (2007), González-Peña and Hale (2009), Welzbacher et al. (2010), Todorović (2012), etc.

The main objective of this paper was to establish whether the choice of proper thermal treatment regime might annul, or significantly reduce the difference in colour of poplar veneer produced from sapwood and heartwood.

MATERIAL AND METHODS

In this study, 15 Euramerican polar clone bolts were converted into 3.2 mm thick rotary - cut veneer by the mill company "Novi drvni kombinat" from Sremska Mitrovica. From rotary - cut veneer mat, the peaces 100x80 cm were cut on the veneer clipper. In this experiment only full formats were used (without splicing), to avoid possible additional defects.

Clipped veneer formats were dried by standard drying procedure on BSH Babcocck thermo-jet veneer dryer to final moisture content of 6-8 %. After drying, the veneer formats were classified into three classes: white, mixed and dark. Maximum allowed part of false heartwood in white formats was 25 %, in mixed was 25 to 75 % and in dark formats above 75 %. The classification was performed by visual assessment by the same observer.

Groups for thermal modification and the control group were formed and each group consisted of 56 dark formats, 16 mixed formats, and 16 white formats. Such prepared material was shipped to the company "Tarkett" from Backa Palanka. The material was thermally treated under atmospheric pressure in laboratory-scale chamber Baschild (model ATK). Steam generated from the water reservoir inside the chamber was used as vapour membrane to prevent cracking of the wood and also in the second stage of treatment, to prevent the burning of wood. Four thermal treatment regimes were performed at 190, 200, 210 and 215°C, all in duration of one hour.

To determine the influence of thermal treatments on veneer colour of all formats, colour measurements were performed before and after thermal treatments. Colour measurements were conducted by colorimeter BYK Gardner GmbH. Colorimeter was calibrated at D65 lighting and observing angle of 10°. The range of wavelengths was from 400 to 700 nm, and sensor diameter was 11 mm.

The colour of every format was measured at 5 spots (Fig. 1, 1a) and the result was calculated as the average value of five measurements. The measuring spots were in the format centre and in four corners (each at the distance of 10 cm from every edge). In case of some deviation in the veneer format at measuring spots, the measurement was performed at the nearest clear part. The average MC of veneer sheets at the moment of colour measurement was between 2.84 % (for treatment at 215°C) and 4.70 % (for treatment at 200°C).

Fig. 1, 1a: Veneer formats before and after thermal modification. Colour measuring spots are marked by X.

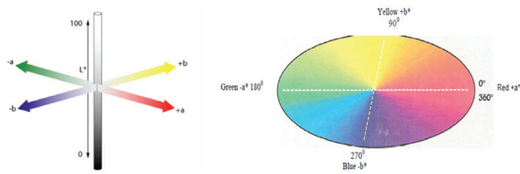

Fig. 2, 2a: Colour distribution in the CIELAB coordinate system.

The results of colour measurements by BYK colorimeter are presented in CEILAB colour system. In this coordinate system (Fig. 2, 2a), the value of L* presents colour intensity from 100 for light colour to 0 for dark colour, the value of a* from red (+a*) to green (– a*), and the value of b* from yellow (+b*) to blue (-b*).

On the basis of measured values of coordinates L*, a* and b* (before and after thermal treatments), the effect of thermal treatments to colour change was calculated (Eqs. 1-4) as follows:

$$\Delta L = L^*_m - L^*_0 \tag{1}$$

$$\Delta a = a^*_m - a^*_0 \tag{2}$$

$$\Delta b = b^*_m - b^*_0 \tag{3}$$

$$\Delta E = \sqrt{(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2} \tag{4}$$

where: ΔL – change of coordinate L* before thermal treatment (L^*_0) and after thermal treatment (L^*_m);
Δa - change of coordinate a* before thermal treatment (a^*_0) and after thermal treatment (a^*_m);
Δb - change of coordinate b* before thermal treatment (b^*_0) and after thermal treatment (b^*_m);
ΔE – measure of total colour change.

To classify the effects of thermal treatments on colours equalizing among dark, mixed, and white veneer formats, we used Tab. 1 (Allegretti 2009).

Tab. 1: Colour difference classification by ΔE (Allegretti 2009).

No.	Colour change - ΔE	Description
1.	$\Delta E < 0.2$	No noticeable difference
2.	$0.2 \leq \Delta E < 2$	Small difference
3.	$2 \leq \Delta E < 3$	Colour differences noticeable at high quality screen
4.	$3 \leq \Delta E < 6$	Colour differences noticeable at middle quality screen
5.	$6 \leq \Delta E < 12$	Great difference
6.	$\Delta E \geq 12$	Different colours

RESULTS AND DISCUSSION

Colour before thermal modification

Average results of colour measurements of dark, mixed, and white veneer formats and basic statistics are presented in Tab. 2.

Tab. 2: Basic statistics of colour parameters of non-treated veneers in CIELAB coordinate system.

STATISTICS	DARK			MIXED			WHITE		
	L*	a*	b*	L*	a*	b*	L*	a*	b*
N	224	224	224	64	64	64	64	64	64
$\bar{x}$	76.71	4.63	22.34	80.06	3.68	24.01	83.33	2.42	25.59
SD (σ_{n-1})	2.24	0.83	1.19	2.03	0.77	1.35	1.44	0.75	1.02
KOV (υ)	2.92	18.01	5.32	2.54	20.85	5.63	1.72	31.15	3.97
SG ($\varphi_{\bar{x}}$)	0.15	0.06	0.08	0.25	0.10	0.17	0.18	0.09	0.13

In the comparison of colour parameters, it is noticeable that the values of colour coordinate L* and b* increase from dark to white formats, while the value of colour coordinate a* decreases. At the same time, all changes are very uniform: coordinate L* increases approximately for 3.3; coordinate a* decreases approximately for 1; and coordinate b* increases approximately for 1.6 units.

Analyzing the calculated values of standard deviations (SD), it can be noticed that parameter L* (lightness) has the greatest variation related to average value. This is the consequence of the fact that the measuring points were defined in advance no meter whether included white or dark part of the veneer. Because the difference in veneer colour from sapwood and heartwood can be rather qualified as darker or brighter (but not as more yellow or less yellow, or more red and less red), the impact on parameter L* was most significant. Tab. 3 confirms the differences in colour among dark, mixed, and white veneers by parameter ΔE, comparing with values in Tab. 1.

Tab. 3: Calculated values of the difference in colour (ΔE) between dark, mixed, and white veneer formats of untreated samples.

Comparison	ΔE	Description
Dark-Mixed	**3.86**	Colour differences noticeable at middle quality screen
Mixed-White	**3.84**	Colour differences noticeable at middle quality screen
Dark-White	**7.69**	Great difference
Average	**5.13**	Colour differences noticeable at middle quality screen

According to scale 1-6 (Tab. 1), the calculated values of difference in colour among dark and mixed veneers and mixed and white veneers belong to category 4. When it compares dark with white formats, it belongs to category 5. Average difference in colour of all produced formats belongs to category 4. Based on this data, it can be concluded that there was a significant difference in colour between veneer formats produced from sapwood and heartwood before thermal treatments.

Colour of veneer formats after thermal treatments

Tabs. 4-7 present the results of colour changes of polar veneers after thermal treatments at different temperatures. Two main patterns are noticed. The first one: with increasing temperature all three colour components decreased (L*, a*, b*) for all three veneer categories. The second one: in comparison with non-treated veneer (Tab. 2), the changes in veneer colour occurred, so that the values of colour components L* and b* decreased from dark to white formats (exception was b* at 210°C), while colour component a* varied depending on the temperature treatment. If colour component L* is analysed separately, it can be noticed that white veneer formats after treatments become darker than mixed and dark one. Also, mixed veneer formats after treatments become darker than veneers from the hardwood zone.

Tab. 4: Colour of poplar veneers after thermal treatment at 190°C.

STATISTICS	TREATMENT - 190°C								
	DARK			MIXED			WHITE		
	L*	**a***	**b***	**L***	**a***	**b***	**L***	**a***	**b***
N	56	56	56	16	16	16	16	16	16
$\bar{x}$	**45.19**	**11.90**	**24.50**	**39.36**	**12.53**	**22.74**	**37.82**	**12.61**	**22.06**
SD (σ_{n-1})	4.60	0.69	1.95	3.19	0.65	2.30	1.66	0.72	1.85
KOV (υ)	10.17	5.82	7.98	8.11	5.20	10.13	4.40	5.70	8.37
SG ($\varphi_{\bar{x}}$)	0.61	0.09	0.26	0.80	0.16	0.58	0.42	0.18	0.46

Tab. 5: Colour of poplar veneers after thermal treatment at 200°C.

STATISTICS	TREATMENT - 200°C								
	DARK			MIXED			WHITE		
	L*	**a***	**b***	**L***	**a***	**b***	**L***	**a***	**b***
N	56	56	56	16	16	16	16	16	16
$\bar{x}$	**36.09**	**10.83**	**19.77**	**30.94**	**9.85**	**16.10**	**29.73**	**10.16**	**15.93**
SD (σ_{n-1})	2.28	0.76	2.01	1.48	0.89	1.70	1.12	0.82	1.53
KOV (υ)	6.32	7.06	10.15	4.78	9.02	10.58	3.76	8.10	9.62
SG ($\varphi_{\bar{x}}$)	0.30	0.10	0.27	0.37	0.22	0.43	0.28	0.21	0.38

Tab. 6: Colour of poplar veneers after thermal treatment at 210°C.

STATISTICS	TREATMENT - 210°C								
	DARK			MIXED			WHITE		
	L*	**a***	**b***	**L***	**a***	**b***	**L***	**a***	**b***
N	56	56	56	16	16	16	16	16	16
$\bar{x}$	**29.74**	**8.71**	**14.73**	**28.19**	**8.61**	**13.72**	**27.62**	**8.90**	**14.14**
SD (σ_{n-1})	2.18	1.01	2.05	2.44	1.42	2.80	2.01	1.26	2.26
KOV (υ)	7.35	11.62	13.89	8.67	16.44	20.40	7.27	14.16	15.98
SG ($\varphi_{\bar{x}}$)	0.29	0.14	0.27	0.61	0.35	0.70	0.50	0.31	0.56

Tab. 7: Colour of poplar veneers after thermal treatment at 215°C.

STATISTICS	TREATMENT - 215°C								
	DARK			MIXED			WHITE		
	L*	a*	b*	L*	a*	b*	L*	a*	b*
N	56	56	56	16	16	16	16	16	16
$\bar{x}$	**28.87**	**8.22**	**13.75**	**27.20**	**8.07**	**12.98**	**24.98**	**7.34**	**11.29**
SD (σ_{n-1})	1.71	0.79	1.70	1.43	0.85	1.70	1.13	0.80	1.46
KOV (υ)	5.94	9.66	12.36	5.26	10.55	13.07	4.50	10.86	12.92
SG ($\varphi_{\bar{x}}$)	0.23	0.11	0.23	0.36	0.21	0.42	0.28	0.20	0.36

In graphic presentation of colour parameters (Fig. 3, 3a), it is obvious that only colour component L* continually decreases. This means that during thermal modification only lightness of treated veneers decreases with increasing temperature, while proportion of red and yellow colour increase at the beginning, and later on decreases (the same was concluded by González-Peña and Hale (2009)).

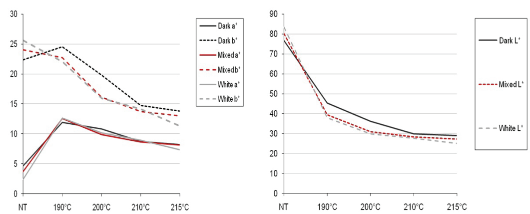

Fig. 3, 3a: Changes of colour components of treated poplar veneers after thermal modification.

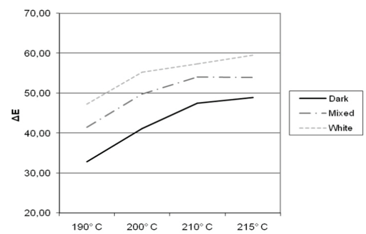

Fig. 4: Colour change of dark, mixed, and white veneer formats depending on temperature.

It should be noticed that this research refers only to the temperature range from 190 to 215°C, so the first portion of the graphs may be different if lower temperatures than 190°C were included. At the lower temperatures, the rapid colour change could be achieved by steaming, but it depends on extractives content in treated material and treatment duration. Tolvaj et al. (2012a) stated that black locust (as species rich with extractives) rapidly change colour during the steaming even at temperature of 70°C, while that temperature is not enough to initiate substantial chemical changes for spruce and Scots pine.

In other paper Tolvaj et al. (2012b) stated that black locust colour can be modified to a very dark by steaming at a temperature above 100°C, and that temperatures from 80 to 120°C are suitable to homogenize the colour of white and red heartwood of Turkey oak and beech. Authors explaining this colour change by forming of new chemical components during steaming, coursed by degradation of the extractives being present in treated wood samples.

On the contrary, according Sundqvist (2004), chemical changes of extractive substances begin only at temperatures above 100°C, while temperatures above 150°C significantly influence the hemicelluloses content.

The greatest change of colour components during thermal treatments refers to colour component L* (lightness) (Fig. 3a), and this component has the greatest influence on total colour change (ΔE). The difference in colour among veneer groups before and after thermal modification (ΔE) is shown in Fig. 4.

The greatest change in colour in all treatments was shown in the white, followed by mixed formats and the smallest colour change was observed in the dark veneer formats (Fig. 4). As colour change could be a good indicator of physical and mechanical properties of thermally modified wood (Schnabel et al. (2007), González-Peña and Hale (2009), Todorović (2012), etc.), it leads to a conclusion that poplar veneer produced from sapwood have different properties than veneer produced from heartwood.

Statistical analysis by SPSS computer software was performed to determine if there was a significant difference in colour change of white, mixed, and dark veneer formats during the thermal treatments. Games-Howell post hoc test was used for the analysis of the difference in average values. This test was used because compared groups with normal distribution, but with different number of samples, and because Levene test showed that veneers treated at 210 and 215°C had no homogeneous variance:

210° - $F(2.85)= 3.99$, $p<.05$;   215° - $F(2.85)=3.67$, $p<.05$.

Statistical analysis showed significant difference in colour change (at confidence level of 95 %) in all treatments for all observed couples (white-mixed, mixed-dark and white-dark):

190° - $F(2.85)=68.03$, $p<.05$;   200° - $F(2.85)=144.79$, $p<.05$;
210° - $F(2.85)=57.42$, $p<.05$;   215° - $F(2.85)=77.96$, $p<.05$.

Statistical analysis suggested that there were different influences of thermal treatments on veneer produced from heartwood and sapwood caused by the difference in wood structure from heartwood and sapwood. Glavaški (1982) stated in his research that some mechanical properties were worse in the samples from the darker part of the tree (heartwood) than in the part from sapwood. Fang and Yang (2003) also confirmed the differences in wood structure of heartwood and sapwood. They stated that in nine poplar clones there were increases in density, fibre dimensions and cellulose contents, going from pith to bark.

As cellulose is more sensitive to thermal treatments than lignin, just more cellulose content in peripheral parts of the trunk may be the reason for greater change of colour in veneers produced from sapwood. It can be assumed that hemicelluloses content (as the cellulose escort) is greater in the peripheral parts, but there are not relevant data.

Colour equalization

The presented data showed that the veneer formats with predominant amount of sapwood were changed more intensively than veneer with predominant amount of heartwood. The calculated values of colour difference (ΔE) among dark, mixed, and white veneer formats before (column marked with NT) and after thermal treatments at different temperatures are presented in Tab. 8.

Tab. 8: Calculated values of colour difference (ΔE) among dark, mixed, and white veneer formats before and after thermal treatments.

Comparison (ΔE)	NT	190°C	200°C	210°C	215°C
Dark-Mixed	3.86	6.13	6.40	1.84	1.84
Mixed-White	3.84	1.68	1.26	0.77	2.88
Dark-White	7.69	7.80	7.46	2.21	4.68
Average	5.13	5.20	5.04	1.61	3.13

Data presented in Tab. 8 shows that treatments at 190 and 200°C did not change significantly the difference in colour of compared veneers (average ΔE stayed in category 4-. Colour differences noticeable at middle quality screen). Further increasing of temperature to 210°C significantly decreased ΔE, so the average value could be classified into category two - Small difference in colour. The highest treatment at 215°C again increased ΔE into category 4 ($3 \leq \Delta E < 6$).

Also, it can be seen that after treatments at 190 and 200°C, the difference in colour between mixed and white veneer formats was smaller, in the same time the difference in colour between dark and mixed veneer formats was higher. These treatments did not have significant influence on colour difference between dark and white formats.

If we compare the values of colour parameters for non-treated veneer formats (Tab. 2) and veneer formats modified at temperatures 190 and 200°C (Tab. 4 and 5), it can be seen that in all three types of veneers, colour component L^* decreased, and veneer colour component a^* and b^* increased after thermal modification. However, in non-treated veneer formats (where values of colour parameters of mixed veneers were approximately between dark and white), after these thermal treatments, the values of colour parameters of mixed veneer formats were much closer to values of colour parameters of white veneer formats. It caused the lowering of the colour change between white and mixed veneer formats, but at the same time it increased the difference between dark and mixed veneer formats.

After treatment at 210°C, the colour of dark veneer formats became closer to colour of white and mixed veneer formats (Tab. 6). Consequently, it caused that the average difference in colour decreased to the category of a small difference in colour. From the point of colour equalization, treatment at 210°C could be accepted as satisfactory.

The highest treatment - 215°C, contributed to further increasing of colour difference. In contrast to treatments at 190 and 200°C (where the values of colour parameters for white and mixed veneer formats were similar), after this treatment, the colour parameters for dark and mixed veneer formats were similar (Tab. 7). Also, it contributed to increasing the difference of colour parameters of dark-white and mixed-white veneer formats (Tab. 8).

CONCLUSIONS

The results of colour measurements by CIELAB colour system showed significant differences in the colour of non-treated poplar veneer formats produced from zone of sapwood, zone of heartwood, and intermediate zone.

Thermal modification contributed to the change in all colour parameters in such a way that with increasing of treatment temperature, all three colour components (L^*, a^*, b^*) decreased, for all three veneer categories. Thereby, only the colour component L^* constantly decreased, while colour components a^* and b^* increased at the beginning and then decreased.

The applied thermal treatments changed the distribution of lightness of the compared veneer formats. After treatments, veneer formats from sapwood zone became the darkest, and the lightest ones were from heartwood zone. Statistical analysis performed by Games-Howell post hoc test confirmed that the difference in colour was significant. Based on more intensive colour change in veneer formats from sapwood, it could be concluded that there were differences in structure between the peripheral and core zones of poplar wood, which was confirmed by Glavaški (1982) and Fang and Yang (2003).

The treatments at 190 and 200°C did not affect the total colour equalization of treated veneer formats, but they reduced the difference in colour of white and mixed veneer formats. At the same time they increased the difference in colour between white and mixed veneer formats on one hand and dark veneer formats, on the other hand.

The thermal treatment at 210°C contributed to the decrease in the average colour difference of treated veneer formats and dropped into the category of small colour difference. From the point of view of colour equalization, this treatment could be accepted as satisfactory.

The highest thermal treatment at 215°C again increased the difference of colour parameters of observed veneer formats.

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