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HEAT TREATMENT EFFECT ON COLOUR CHANGES OF BEECH (FAGUS SYLVATICA) WOOD

Andromachi MITANI
PhD Canditate, Aristotle University of Thessaloniki, Faculty of Forestry and Natural Enviroment, Laboratory of Wood products and Furniture Technology Address: 54124 Thessaloniki, Greece
E-mail: amitani@for.auth.gr

Ioannis BARBOUTIS
Assosiate Professor, Aristotle University of Thessaloniki, Faculty of Forestry and Natural Enviroment, Laboratory of Wood products and Furniture Technology Address: 54124 Thessaloniki, Greece
E-mail: jbarb@for.auth.gr

Abstract:
In this study the effects of thermal modification of beech wood (Fagus sylvatica) on color changes after heat treatment were determined. The heat treatment of beech wood was conducted in a temperature of 180°C and 200°C for five different durations ranging from 2 to 10h. It was observed a gradual color change of treated samples whereas after 4h treatment no significant changes were recorded, measured with a colorimeter. The greatest reduction of lightness indicator L was observed between 2 and 4 hours whereas the most intense color differences compare to untreated samples were occurred in 8h and 10h treatments. Comparing the two treatment conditions there is an obvious colour difference. Moreover, at 4h treatments time the differences were approximately 27.92 units more. Finally, radial direction gave higher values regarding lightness and longitudinal the lowest.*

Key words: *beech wood; colour; Fagus sylvatica; heat treatment.*

INTRODUCTION

Wood is considered to be very important material due to its boundless assets. As a renewable natural resource, and a decreasing factor for the global climate's change rating, wood defines a vast number of products. This requires the urgent development of new technologies to ensure the more efficient use of the recourse by extending the life of timber-based products. Wood modification represents a process that is used to improve the wood properties or to ameliorate one or more of its drawbacks (Hill 2006). Heat treatment is one of the most popular ways of modifying timber and possesses higher dimensional stability and decay resistance while its strength is considerably reduced. Since no chemicals are required and only heat is used, this process is environmentally friendly. During heat treatment, the colour of the wood products tends to darken in different ways which depend on wood species, density, treatment duration and temperature. The higher the temperature is, the darker the appearance. The colour change is related to the change of the conjugated double bound chemical systems. These bounds can be found in lignin and in the extractives. Thus, the colour changes in the examined temperature range originate mostly from the alterations of the extractives. Flavonoids play a significant role in the discoloration of wood (Tolvaj and Molnár 2006). In the field of heat treatment, several researches have been conducted so far. Poplar wood (Wikberg and Maunu 2004, Olek and Bonarski 2008, Ábraham *et al*. 2010, Kocaefe *et al*. 2008 etc.), Chestnut wood (Ates *et al*. 2010 etc.), Oak wood (Wikberg and Maunu 2004, Ohnesorge *et al*. 2008 etc.) as well as beech wood (Hakkou *et al*. 2006, Arnold 2007, Bachle *et al*. 2010, Niemz *et al*. 2010 etc.). Todorovic *et al.* (2012) estimated the beech wood properties by colour change in 170ºC, 190ºC and 210ºC for four hours. This study showed that higher temperatures caused a rise in mass loss and a reduction of mechanical properties whereas the effect on MOE was small. Akgul and Korkut (2012) studied the colour change of Scots pine and Uludag fir wood after heat treatment at varying temperatures (120, 150 and 180ºC) for 2, 6 and 10h. They conclude that the two wood species showed a darker colour and a reduction of lightness especially at 180ºC for 10h. Li *et al*. (2011) investigated the visual colour changes and they mentioned that more distinct changes were observed above 180ºC and that the temperature has greater effect than duration. Gunduz *et al*. (2010) examined the colour changes of Uludag fir wood and noted that if darker colour tone is desired, the treatment duration may be required to last more than 8h. Behkta and Niemz 2003 investigated the change in colour of spruce at 200ºC for 2, 4, 8, 10 and 24h and they concluded that heat treatment induced extensive darkening and reddening of wood.

This research was conducted with the aim to determine the colour changes (ΔL, Δa, Δb, ΔE, ΔC) after heat treatment of beech (*Fagus sylvatica)* wood at 180ºC and 200ºC for 2, 4, 6, 8 and 10 hours and to present the comparison of the two different treatment conditions.

MATERIAL AND METHODS

Beech sawn wood (*Fagus sylvatica*) timber used in this research was of Greek origin, obtained from the market. The timber was naturally dried for 1 year. Initially, lumber was cut in sawn samples of dimension 65x50x25mm in cross section and only those without any wood defects were used for the tests. The samples had short length because they indented only for colour measurement and not for other properties. The average density (oven dry weight/volume at 10.26% moisture) of timber used were 0.68g/cm3 (SD 0.02), while the average moisture was 10.26% (SD 0.15) after conditioning at 20±2^{o}C and 60±5% relative humidity. Thermal treatment of the specimens applications were carried out in a temperature controlled small laboratory heating unit (80x50x60cm). Five different durations (2h, 4h, 6h, 8h and 10h) were applied at 180^{o}C and 200^{o}C under atmospheric pressure in the presence of air. Although the industrial process of thermal modification of wood is normally taking place in a closed poor oxygen environment, we use this method because it could be applied to small structures which are intending to decorative purposes in joinery and in some small parts of furniture. The specimens were placed in the unit after the desired temperature had reached.

The colour measurements of all specimens were recorded on the surface of wood specimens before and after heat treatments in radial, tangential and longitudinal directions with a colorimeter Minolta Croma-Meter CR-400. CIELAB was the colour system that was used for the measurements (Fig. 1). Where L* describes the lightness, a* and b* describe the chromatic coordinates on the green-red and blue yellow axis, respectively.

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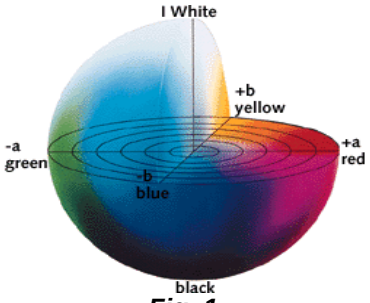

Fig. 1

Three-dimensional model of CIELAB coordination system pictured the color changes in L*, a* and b* coordinates (www.linocolor.com).

From the L*a*b* values, the difference in the lightness (ΔL*) and chroma coordinates (Δa* and Δb*), saturation (C*) (ΔC*) and total colour differences (ΔE) were calculated using the following equations:

$$\Delta L^* = L^*t - L^*ut \quad (1)$$
$$\Delta a^* = a^*t - a^*ut \quad (2)$$
$$\Delta b^* = b^*t - b^*c \quad (3)$$
$$C^* = (a^{*2} + b^{*2})^{½} \quad (4)$$
$$\Delta E = (\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2})^{½} \quad (5)$$
$$\Delta C^* = C^*t - Cut \quad (6)$$

where, Ct, L*t, a*t, b*t are L*, a* and b* of the heated specimens Cut, L*ut, a*ut, b*ut are L*, a* and b* of the control specimens, respectively. The measurements of color were determined according to EN 7224-3:2003. The values reported are average values with standard deviation. Twelve replicates for each variable (treatment) was carried out to compute the color changes of beech wood.

RESULTS AND DISCUSSION

In order to estimate the colour change of the specimens, the three colour coordinates, L*, a*, and b* were recorded before and after heat treatment. The effect of colour changes induced by heat treatment can be observed after a few hours of treatment. The samples become visibly darker and the colour changes to more alluring tones. According to Fig. 2 it appears that wood affected lightness L properties. Darkening after heat treatment was clearly and increased with temperatures and duration. The samples treated at 200ºC were found to be darker than the samples treated at180ºC. Concerning samples treated at 200ºC the greatest reduction of L* indicator was observed between 2 and 4 hours. On the other hand, specimens treated at 180ºC present a smooth decrease of lightness.

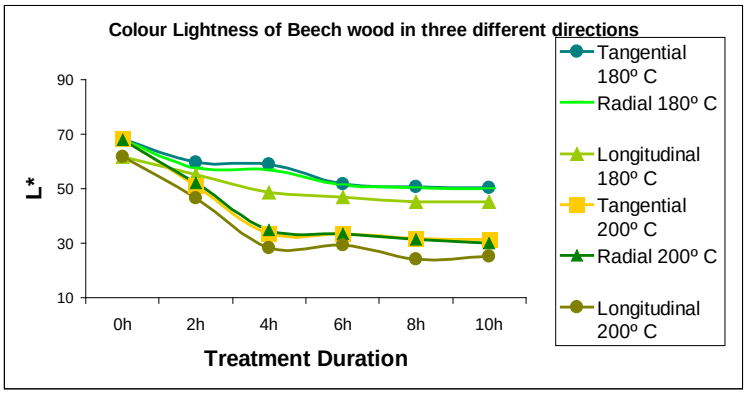

Fig. 2

Effect of heat treatment duration in three different directions on L*.

The a* (green-red) coordinate was also changed significantly particularly at 200ºC where the reduction was more visible. This reduction means that the colour of beech wood converted to red. Less intense course present the specimens treated at 180ºC. More specifically, for both treatments conditions coordinate a*

increased until 2h but decreased continually till 10h. Regarding 180ºC temperature it is observed a small increase between 8h and 10h.

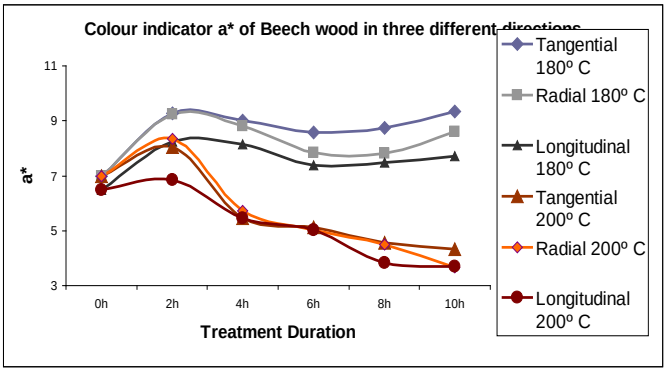

Fig. 3
Effect of heat treatment duration in three different directions on a*.

The colour coordinates of yellow to blue (b*) presented a variation in treated samples especially in those which were treated at 180ºC, with increasing yellow tones initially and decreasing later for more intense treatments. As it is observed after 2 hours of treatment the differences between two separate treatment conditions are obvious and seem to be important. These three chromaticity coordinates (L*, a* and b*) were used in order to compute the color difference (ΔE) and saturation index (ΔC) of total color change.

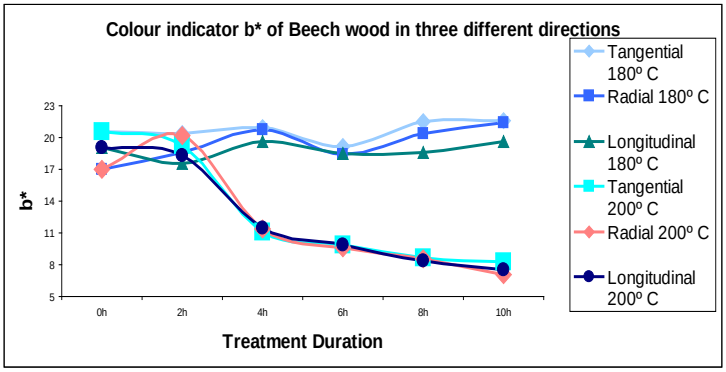

Fig. 4
Effect of heat treatment duration in three different directions on b*.

Table 1 shows the results of colour changes for different temperatures (180 and 200ºC) and durations (2, 4, 6, 8 and 10h) of treated Beech wood. According to the results it appears that the duration heat treatment influenced color values. As it is obvious from Table 1 the differences between two treatment conditions (180-200ºC) are remarkable and in most cases the samples treated at 200ºC present twofold values compare to 180ºC treatment. The progress of colour change values concerning the different directions (tangential, radial and longitudinal) for the above two treatment conditions is similar.

Table 1
The effect of heat treatment for different temperatures and durations on colour difference in Beech wood

Time (h)	Direction	Temperature	Fir wood				
			Color change values				
			ΔE	ΔL	Δa	Δb	ΔC
2h	Tangential	180º C	9.09(0.89)	-8.77(0.94)	2.31(0.24)	-0.3(0.06)	0.70(0.12)
		200 º C	17.69(1.32)	-17.17(1.59)	1.08(0.14)	-1.54(0.12)	-1.09(0.13)
	Radial	180º C	11.27(0.99)	-10.44(0.84)	2.27(0.37)	1.64(0.21)	1.77(0.23)
		200 º C	16.64(1.60)	-15.87(1.92)	1.64(0.19)	2.99(0.55)	3.14(0.70)
	Longitudinal	180º C	7.06(0.89)	-6.74(0.93)	1.78(0.32)	-1.48(0.24)	-0.59(0.16)
		200 º C	14.09(0.74)	-14.08(0.75)	0.28(0.07)	-0.44(0.13)	-0.33(0.09)
	Tangential	180º C	9.48(1.30)	-9.42(1.31)	2.02(0.27)	0.34(0.08)	1.07(0.08)
		200 º C	37.40(0.63)	-36.14(0.43)	-1.59(0.34)	-9.30(0.85)	-9.23(0.88)

4h	Radial	180º C	11.58(0.51)	-10.92(0.51)	1.85(0.26)	3.76(0.45)	3.70(0.42)
		200 º C	34.56(0.93)	-34.03(0.93)	-1.25(0.15)	-5.84(0.71)	-6.59(0.68)
	Longitudinal	180º C	13.37(0.62)	-13.25(0.61)	1.68(0.19)	0.61(0.18)	1.27(0.15)
		200 º C	33.31(0.80)	-32.45(0.47)	-1.03(0.20)	-7.05(0.45)	-6.97(0.60)
6h	Tangential	180º C	16.84(0.90)	-16.73(0.87)	1.69(0.46)	-1.29(0.15)	-0.65(0.11)
		200 º C	34.98(0.61)	-33.80(0.55)	-1.18(0.14)	-8.66(0.72)	-8.42(0.71)
	Radial	180º C	16.84(0.87)	-16.75(0.87)	0.88(0.16)	1.45(0.16)	1.19(0.11)
		200 º C	34.71(0.84)	-33.84(0.75)	-1.52(0.37)	-6.31(0.85)	-6.63(0.66)
	Longitudinal	180º C	14.44(0.63)	-14.40(0.63)	0.91(0.09)	-0.52(0.09)	-0.17(0.07)
		200 º C	32(0.9)	-30.79(0.76)	-1.51(0.13)	-8.57(0.68)	-8.45(0.68)
8h	Tangential	180º C	17.68(0.83)	-17.78(0.89)	1.76(0.18)	0.92(0.11)	1.48(0.15)
		200 º C	37.46(1.03)	-35.77(0.86)	-1.69(0.33)	-10.98(0.74)	-10.77(0.71)
	Radial	180º C	18.14(0.78)	-17.66(0.94)	0.83(0.09)	3.46(0.25)	2.91(0.25)
		200 º C	36.55(1.44)	-35.74(1.41)	-2.41(0.24)	-8.02(0.58)	-8.82(0.68)
	Longitudinal	180º C	16.61(0.69)	-16.58(0.69)	0.99(0.11)	-0.44(0.10)	-1.10(0.07)
		200 º C	37.24(1.13)	-35.29(1.34)	-3.19(0.38)	-11.43(0.54)	-11.83(0.61)
10h	Tangential	180º C	18.19(0.57)	-18.01(0.56)	2.35(0.22)	1(0.22)	1.73(0.16)
		200 º C	39.48(0.75)	-37.11(0.68)	-3(0.59)	-13.12(0.65)	-13.28(0.84)
	Radial	180º C	18.65(0.65)	-18.04(0.69)	1.63(0.17)	4.44(0.15)	4.13(0.15)
		200 º C	37.23(1.73)	-35.98(1.36)	-2.96(0.39)	-10.60(0.89)	-11.39(0.75)
	Longitudinal	180º C	16.80(0.57)	-16.74(0.58)	1.23(0.14)	0.57(0.09)	0.98(0.10)
		200 º C	37.44(1.76)	-35.94(0.93)	-1.84(0.24)	-11.82(0.62)	-11.45(0.45)

Average; standard deviation in parenthesis

CONCLUSIONS

According to the results, it was found that the beech wood got darker with the increasing durations and temperatures of the heat treatment. Additionally, ΔE, ΔL, Δa, Δb and ΔC values affected more at 200ºC than at 180ºC. However, the higher reduction of lightness observed for the heat treatment conditions of 200ºC and 10h. Furthermore, between 0h and 4h treatment it was observed an intense decrease of all colour parameters. Concerning 180ºC the colour difference (ΔE) appears to increases with the treatment intensity. On the contrary, saturation index (ΔC) presents a proportional decrease to treatment severity. The most intense color differences were occurred in 8h and 10h treatments at 200ºC but their differences are not worth mentioning. Additionally the colour measurement of the three different surfaces presented smaller differences at 200ºC than at 180ºC. Finally, heat treatment may be a good, environmentally friendly way to alter the colour of wood without any paintings.

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