Modification of Hardwood Veneers by Heat Treatment for Enhanced Colors

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This research involved the most widely used wood-species of veneers in Hungary (oak, ash, beech, cherry, and maple). The resulting changes in color produced at treatment temperatures between 80 and 200 °C in different treatment times were evaluated using the CIELab color stimulus evaluation system. For higher temperature treatments, a tight functional relationship was observed between the treatment time and the difference in color stimulus. Heat treatments within a temperature range above 160 °C produced visually perceptible results, while color change resulting from heat treatments at lower temperatures was almost imperceptible. For higher temperature treatment a tight functional relationship was observed between the difference in color stimulus and treatment time (r^2>min. 0.84). Different tree species produced different extents of change in hue depending on the treatment parameters. Among the color components, the perceptible discoloration was mostly produced by the change in the lightness factor (*L**). As the treatment temperature rose, the change in the red (*a**) and yellow (*b**) components was less significant regardless of the species.

Keywords: Veneer; Heat treatment; Color change; Oak; Ash; Beech; Cherry; Maple

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INTRODUCTION

The color of a product is one of the main factors that influence its perceptions. The native color of wood varies between different wood species, and differences even within one trunk can be observed (sapwood *vs*. heartwood). The original color of a wooden surface changes with time because of various factors (Oltean *et al.* 2010). Thermal modification is an industrialized process to enhance the color of wood.

Wood modification can be defined as a process that improves the properties of the wood, thus producing a new material that does not present an environmental hazard any greater than unmodified wood when disposed at the end of the product life cycle (Hill 2006). Heat treatment is an extremely popular process of wood improvement nowadays. Across Europe, there is an increasing demand for heat-treated wood materials that are dark in color, similar to tropical woods. This creates a potential for other wood species to reach new markets where more exotic hardwoods are normally used (Syrjänen 2001; Militz 2002; Patzelt *et al.* 2003; Bekhta and Niemz 2003; Christmas *et al.* 2005). Another advantage of heat treatment is to give a decorative design to an otherwise less appealing wood even at lower temperatures (Németh *et al*. 2007, 2013).

In the industrial sector 230 °C is generally marked as the highest temperature for heat treatment. Processes above 200 °C have minor beneficial impact when the features of the final product and the aspects of profitability are taken into consideration. It may be noted that at 200 °C, carbon dioxide is formed in small quantities though, and at higher temperatures combustible gases such as carbon monoxide and methane are also formed during decomposition. There are no significant weight loss or gas formation processes taking place during a treatment at more moderate temperatures (100 to 200 °C), although a significant change in some of the characteristics of the wood, including the color in particular, may be observed (Németh 1998).

This process may be observed both for dry and wet wood, though in the case of dry timber only a slight color change can be initially seen (Tolvaj *et al.* 2010). Based on the analysis by Hanger *et al.* (2002), the extent of weight loss relative to the absolute dry state varies between 5 and 15% for pine species and 5 and 10% for broadleaved trees.

Several studies suggest that the largest variations in wood color are associated with the extractive content of the wood (Moya *et al*. 2012). Gierlinger *et al*. (2004) found that in several larch species, the red color (a^*) and luminosity (L^*) parameters highly correlate with the extractive content of the wood, and there is a tight connection between the yellow color and photochemistry parameters of the chemical components of the cell walls (cellulose, hemicellulose, and lignin).

Wood discoloration produced by treatment in a temperature range between 100 and 200 °C is a result of the chemical transformation of the extractives. The change in color at temperatures between 160 and 180 °C increases rapidly both in inert (Németh *et al*. 2009) and oxidative atmospheres, which can be attributed to the decomposition of the extractives that is supplemented by the effects of leaching. The steaming of most wood species also results in homogeneity (for example the black locust and cherry) (Dianiskova *et al.* 2008). The color characteristics vary depending on the wood species and the applied atmosphere as follows: the lightness of the wood significantly decreases; the color of the wood becomes less saturated and shifts to the red ranges; the saturation of the wood hardly changes; as the treatment progresses, the rate of change significantly decreases and the color of the wood approaches a limiting value that is characteristic to the species under treatment and to the treatment time. A prolonged heat treatment produces similar color-stimulus properties to those observed at higher temperatures (Németh 1998).

Bourgois *et al.* (1991) found that the decrease in lightness and the color shift produced under heat treatment (240 to 310 °C) can be mainly attributed to the decline in the amount of hemicellulose and pentose in particular (Csonkáné 2005).

Németh established in his studies (1989 a,b, 1998) that it is the change in the lightness of the wood that provides the most information on the wood material during thermal treatment, and this value is the closest to the data of subjective color assessment. Csonkáné (2005) examined black locust with a high extractive content and black poplar species with a lower extractive content, and pointed out that the color change of black locust with no extractives content that is produced as a result of heat treatment bears similarities to that of black poplar. Based on a similar analysis of quercetin and robinetin, Csonkáné also found that hardwoods can be classified into two groups on the basis of their extractive compounds that change similarly to one of these two model compounds.

The darker tonality of heat-treated wood is often attributed to the formation of colored degradation products from hemicelluloses (Sehlstedt-Persson 2003; Sundqvist 2004) and to extractives that seem to participate in the color formation of heat-treated

wood (McDonald *et al.* 1997; Sundqvist and Morén 2002). The formation of oxidation products such as quinones is also stated as the reason for color change (Tjeerdsma *et al.* 1998; Mitsui *et al.* 2001; Bekhta and Niemz 2003).

Niemz (2004) treated spruce specimens in different media, and found that they produce different changes in color under heat treatment at 200 °C. Chen *et al*. (2012) examined black locust and found that there was a greater difference in color when the samples were heated in the presence of oxygen than in the presence of nitrogen.

The heat treatment of the veneer is a simple and quick procedure because of its geometric dimensions. The veneer can easily reach the temperature of the medium, and the modification can take place quickly throughout the entire cross-section. A goal of the work was to find the lower limit of low temperature modifications where visible differences in color can be produced. This is because in industrial applications the necessary energy demand and the length of the treatment period are significant factors. These color-modifying treatments for aesthetic purposes have potential to be used for the replacement of deep-toned exotic species with hardwoods, which is not only a cost-effective method but can stimulate the economy as well.

EXPERIMENTAL

The research included testing the most popular veneer materials in Hungary such as oak (*Quercus robur* L.), ash (*Fraxinus excelsior* L.), beech (*Fagus silvatica* L.), cherry (*Prunus avium*), and maple (*Acer campestre* L.). The samples were collected from a veneer processing factory in Hungary, and had been climatised at a temperature of 20 °C and at 65% relative humidity.

The heat-treatment process was conducted in a drying oven at atmospheric pressure and in the presence of water vapor and air. The heat treatments were applied at temperatures of 80, 120, 160, and 200 °C in 12 different treatment periods (in every 5 min) by using a Memmert UFP-400 device. The veneer samples were directly placed into the oven, which had been preheated to the required temperature. The results observed included the average of the 5 repeated measurements.

The color of the wood was measured on the same side of successive veneer samples (4×48 pcs, 500×100×1 mm) by shedding from blade, on 10 pre-designated points by sample by using Konica Minolta's CM-2600-type device, which uses CIELAB color measurement system. Regarding both the temperature and the treatment time, the measurements were carried out at the pre-designated points on the veneers. The extent of a particular color change was specified based on the difference of the values in the CIELAB system (ΔL^*, Δa^*, Δb^*). The cumulative effect of such differences by calculating the value of the total color change (ΔE^*). The categorization of colors into systems is an objective method of color assessment. Instrumental color measurement is the most modern method of objective color assessment where color parameters can be expressed by numbers. CIELAB color measurements were also mentioned as a possible approach to determine the quality of heat-treated wood (Brischke *et al.* 2007).

RESULTS AND DISCUSSION

There were no significant changes in the color coordinates of samples for heat treatments within the range of 80 to 120 °C. Differences in the color coordinates must be clearly determined by differences relative to the baseline (control) color. This can be observed in the case of all color components regardless of the tree species. However, the increased change in the color coordinates measured at the last measurement points (50-55-60 min) at 120 °C suggests that there are further trends in color as a function of time in the case of certain species. It should be noted that in the case of such low-temperature treatment the only important change was the decrease in the oak's *L** (lightness factor), but the other two color factors did not change appreciably.

A spectacular change in the color-stimulus components could be clearly observed at a temperature of 160 °C. Of each of the studied species it can be said that with the shifting of coordinates *a** and *b** into the positive direction – in proportion to the increase of treatment time – the color increasingly moved towards red and yellow, while *L** decreased (wood became darker).

With respect of *a** that is a change in green-red colors, the cherry and the maple samples exhibited a significant color change among all the studied species. However, the pace of the change in color coordinates gradually slowed down from the initial intensity after *ca*. 30 min. Considering the longest treatment period (60 min), the *a** color coordinate (red content) increased by 2 to 3 times in case of oak, beech, and ash veneers, and by 5 to 6 times in case of cherry and maple as opposed to the initial state. At the temperature of 200 °C with regard to all treatment periods it was also the maple whose *a** component showed the greatest (tenfold) change in color, while in the case of cherry the respective component increased only slightly as compared to the measured values at 160 °C. The change in the red color component of ash samples accelerated over the time of the treatment and became similar to that of the cherry (6 to 7 folds). The change in the *a** component of the beech and oak specimens was similar to the modification values measured at 160 °C.

In case of the *b** (blue-yellow) axis of the spatial color coordinate system it is the maple that showed the greatest value at 160 °C, displaying a change that was 3 to 4 times greater than in the case of the other species studied during the first 5 to 10 min of the treatment period. This difference remained constant until the end of the maximum treatment period. In the case of beech, ash, cherry, and oak veneers the changes in color to yellow were on the same (from 2 to 2.5-fold) level.

At the highest treatment temperature, the change of *b** coordinates in the case of the maple specimens already reached a 5 to 6 fold value during the shortest (5 min) time interval, but a substantial and constant increase began only 30 to 35 min after the start of the heat treatment. The final value was from 11 to 12 times of the baseline. The yellow color component of the ash samples rose continuously – as at 160 °C – but at twice the rate. The values of the other investigated species did not change to a significant extent.

There were no significant differences in the change of the lightness factor (*L**) of the different species given the same temperature and treatment time. At 160 °C the *L** value of the cherry declined continuously (after 30 min of treatment), while in the case of the other species the luminosity change slowed down with time. At 200 °C this continuity could be observed for each species, but it was only the beech for which this rate decreased with the treatment time.

The difference of color-stimulus (ΔE^*) expresses the combined – visually perceptible – effects of the color change. Taking the tendencies into consideration, the calculated values at 80 °C did not show a clear relation to the treatment period. The differences between the measured values reflected the differences between the control samples regardless of the species. At 120 °C a closer functional relationship can be observed in the case of oak and beech, but the differences between the initial control samples had significant effects in this treatment. The observation that color change between 160 and 180 °C increases dramatically (Németh 1998) is correct for veneers alike, as the measured difference in color-stimulus showed a significant difference in the case of our heat-treated samples at 160 °C, and there were major differences between the respective species.

There was a close relationship between the measured values over time (Table 1). These results can also be attributed to the fact that the measurements of the color coordinates were evaluated uniformly on the outer (cylindrical) side of the veneers. According to other work (Thompson *et al.* 2005) the rate of the changes in color is significantly affected by the place and the anatomical direction of the raw material in the timber, besides the temperature and treatment time. Considering that veneers with a thickness of 1 mm dry out within a few minutes of time at these temperatures, the moisture content of the samples did not significantly affect the change in the ΔE^* factor. Weight loss due to heat treatment were varied depending on the wood species, but coincided with the range 5 to 10% as described in the literature (Hanger *et al.* 2002).

Table 1. Coefficients of Determination between the Treatment Time and ΔE^* at 160 and 200 °C

	Beech	Cherry	Ash	Oak
160 °C	0.9805	0.9901	0.9603	0.8541
200 °C	0.9383	0.9363	0.8446	0.9148

Compared to the initial state, a similar intensity of color change was observed in the case of all the investigated species at 160 °C during a treatment period of 30 to 35 min. After one hour of treatment, the cherry and the maple showed the greatest change in color, but the cherry's rate of changing became more intensive by the end of the treatment. The ash displayed the lowest rate of color change despite its bright coloration.

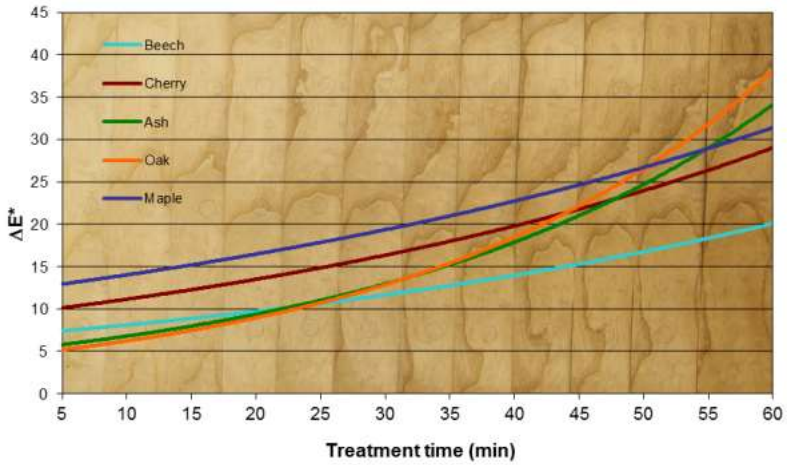

Fig. 1. Total color change at 200 °C

Similarly to the figures measured at 160 °C the change in color at 200 °C became more intensive after a treatment period of 30 to 35 min, but in this case it was the oak and the ash that showed the highest rates of change. At this temperature it was the beech that displayed the steadiest rate of change in Δ*E**, but its final value was significantly lower than those of the other species (Fig. 2).

Observing the change in the color components of oak, cherry, and maple under heat treatment at 160 (Fig. 2) and 200 °C (Fig. 3), it can be seen that these components determined the Δ*E** values in different percentages in the case of different species. Naturally, a different rate of change was observed as the treatment time was extended and the temperature was rising.

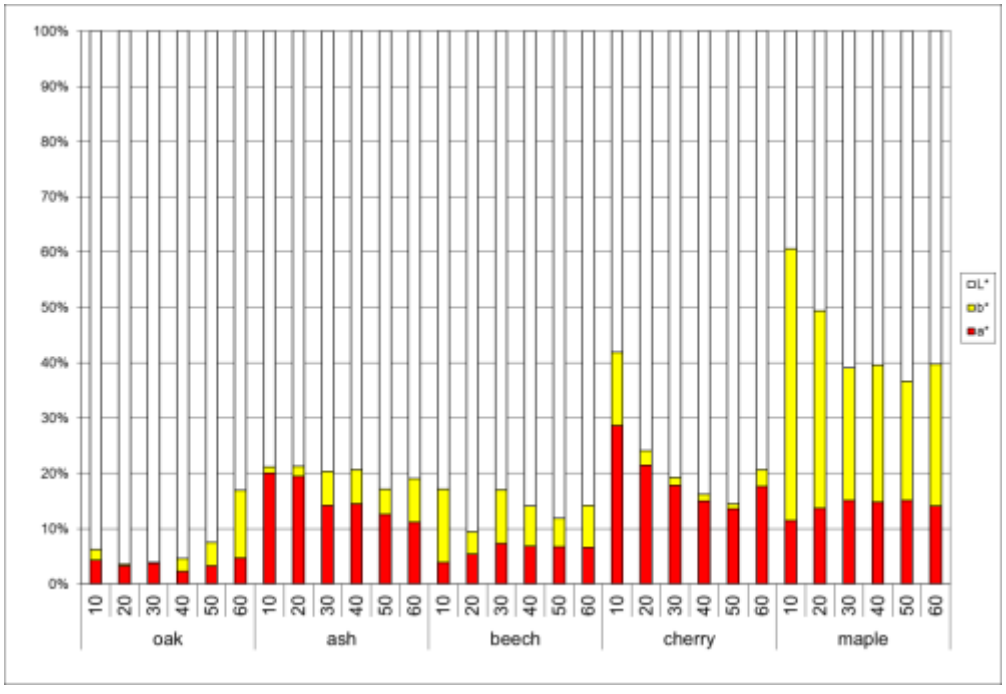

Fig. 2. The ratio of color coordinates determining Δ*E** at 160 °C

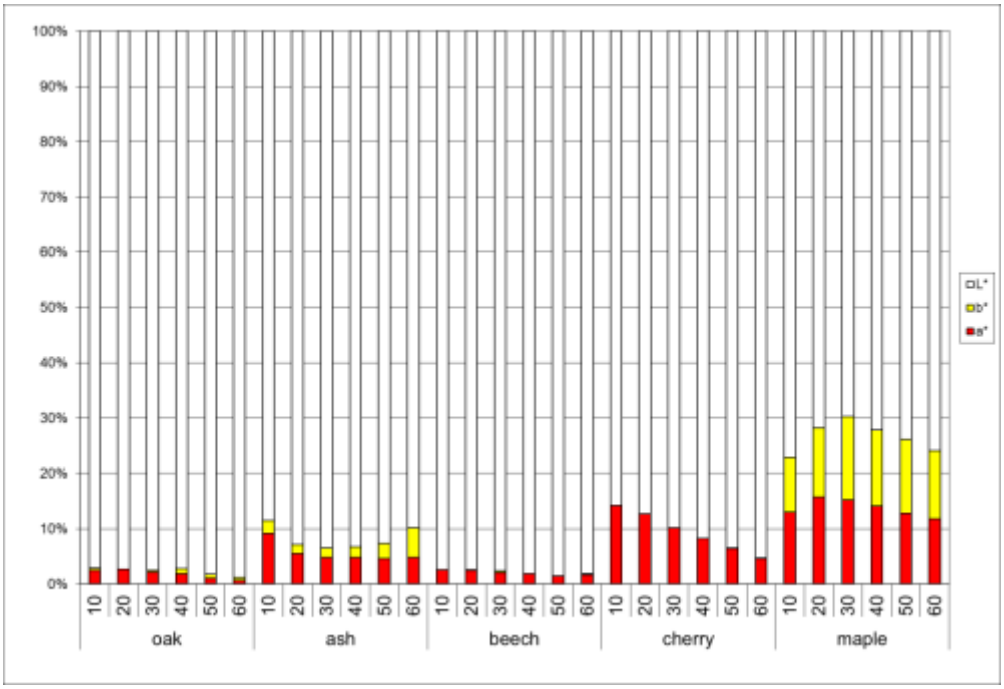

Fig. 3. The ratio of color coordinates determining Δ*E** at 200 °C

Below the treatment temperature of 160 °C the color stimulus differences were significantly affected by the changes in the yellow and red hues, while at higher temperature it primarily resulted in changes in lightness. At both treatment temperatures *a** and *b** were decreasing, while the *L** coordinate was increasing with time. These changes were varied in different species. In the case of the maple, which was treated at a temperature of 160 °C for a period of an hour–with steadily declining rate of participation – the yellow and red hues of the color stimuli constituted 40% of the difference. In the case of the cherry and the oak, this rate was only 20%. In the case of the maple, at a higher treatment temperature color change could primarily be attributed to the *a** and *b** components as opposed to the *L** value, but its importance had declined. In the case of the oak and the cherry the changes in the yellow hue at a higher temperature were completely negligible.

CONCLUSIONS

1. The heat treatment of veneer can be performed quickly and easily due to its geometrical dimensions, as the entire cross-section easily reaches the temperature of the medium in a relatively short period of time.
2. Under treatment temperatures of 120 °C, a treatment time of an hour was required before changes in color were perceptible to the eye. This minimal change could be seen in the case of oak and maple samples only, and was barely perceptible in the other species.
3. It can be generally stated that at treatment temperatures of 160 and 200 °C the difference in color stimulus was visible (3<) or large (6<) as the treatment period increased.
4. It can be stated of all the species studied that at treatment temperatures of 160 and 200 °C there was a tight relationship between the change in color stimulus and the length of the treatment time, which was supported by the high coefficients of determination values (min 0.84).
5. The extent of the difference in color stimulus at different treatment temperatures showed significant differences for the species studied. While, for example oak exhibited the lowest change in color at 160 °C, its color modification was the greatest at higher temperatures.
6. As the treatment temperature rose, the change in the color stimulus was mostly produced by the change in the lightness factor (L^*). This is followed by the change in the red (a^*) and yellow (b^*) components, with the exception of the maple. Therefore, the discoloration of the veneer was primarily produced by the darkening of the wood.

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