Change of Color and Wettability of Heat-treated Hard Maple Lumber

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In order to investigate change of wood color and wettability of hard maple after heated at the temperature of 165℃, 180℃ and 195℃, L*a*b* was measured using a color–difference meter, the anti–absorption efficiency, anti–swelling efficiency and anti–volume efficiency of specimens were calculated in this study. The results of this study were as followings: Chrominance was lowest (17.5) for 165℃ and highest (43.5) for 195℃ treated specimen. As heat temperature was increasing, the whiteness index and yellowness index of the surface layer of treated specimens were reduced but redness index was increased while the whiteness index of the inner layer of specimens presented higher value, however, the yellowness index and redness index presented lower value compared to surface layer of specimens.

Anti–absorption efficiency and anti–swelling efficiency of treated specimens were significantly increased as heat temperature being increasing. Anti–absorption efficiency was high when specimens were subjects to high temperature and low relative humidity and that was low when specimens were subjects to low temperature and high relative humidity.

Key words: Heat treatment, Color change, Anti–Absorption Efficiency, Anti–Swelling Efficiency, Anti–Volume Efficiency

INTRODUCTION

Hard maple was widely used as high quality wood products such as gym floor, stairs, bowling pins, Piano action etc. because of its brilliant wood color and hard texture, however, when it was applied to high quality interior, coloring was necessary. Artificial coloring with stain was not only eco–friendly and unnatural. Recently technology of eco–friendly and natural concentrate by heating treatment was developed (Chen *et al.*, 2012; Matsuo *et al.*, 2016). Heating treatment was not only concentrate wood color but also increase the dimensional stability and weather resistance (Borrega and Kaerenlampi, 2010; Korkut *et al.*, 2010; Poncsak *et al.*, 2011). The wood color was changed into more uniform from surface to inside wood after heat treatment than before heat treatment.

The effect of heat treatment on the color and wettability of the maple lumbers was investigated in this study.

MATERIALS AND METHODS

Specimen Preparation

8 pieces of kiln dried hard maple (*Acer saccharum*) lumbers with the dimension of 28 mm in thickness, 145 mm in width and 800 mm in length were prepared for four treatments. The moisture contents of specimens were 9.5–11.0%, measured with portable dielectric constant–type moisture meter (HM530, KETT).

Heating treatment

The treatment had been conducted in a kiln that had the stack space of 700 mm in width and 600 mm in height and 800 mm in length. The thickness of stacker was 20 mm. The air velocity was 4m/s. The schedule for heat treatment was shown in Figure 1. During drying stage, the time to rise temperature was 1 hour from start to 100℃, at which remained 10 hours. During heat treatment, the temperature had been risen for 10 hours until reaching target temperature and remaining it 3 hours, then cooled dawn which needed 10 hours. The control specimens had dried at 100℃ for 2 days.
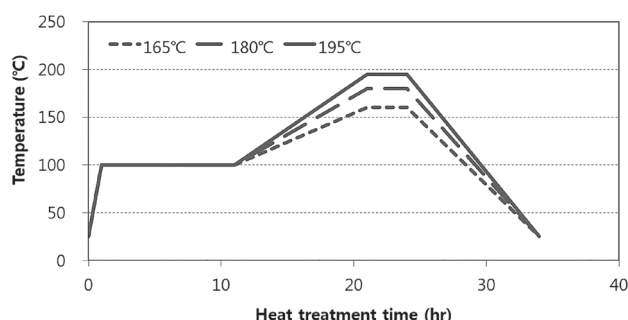

Fig. 1. Three different schedules for heat treatment.

Measuring wood color

CIE L*a*b* were measured using a color–difference meter (Hunter Lab Mini Scan XE Plus). A source of light was Xenon flash lamp in the wavelength range of 400~700 nm. At three positions on each surface of specimens before and after the specimens were planned to 22.5 mm of thickness, the wood color was measured. Average values measured from six positions were used

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as chrominance (ΔE*), ΔE* was calculated by the equation [1].

$$\Delta E^* = \sqrt{(L_2^* - L_1^*)^2 + (a_2^* - a_1^*)^2 + (b_2^* - b_1^*)^2}$$ ....[1]

Here, ΔE* was chrominance, L* was whiteness index, a* was redness index, b* was yellowness index

Specimens to measure moisture content

After measuring wood color, eight pieces of samples, six pieces for sorption test and two pieces for water absorption test, were cut at the central part of the specimens with length of 800 mm.

Water absorption test

The weights and dimensions of specimens were measured before and after being impregnated in distilled water for five days, and then Anti–Absorption Efficiency (Eab) and Anti–Swelling Efficiency (Esw) were calculated from the equation [2], [3] and [4].

$$E_{ab} = \alpha_c - \alpha_h$$

$$\alpha = \frac{W_f - W_{od}}{W_{od}} \times 100\%$$ ....[2]

Here, E_{ab} = anti–absorption efficiency (%), α_c = weight percent gain of control specimen (%), α_h = weight percent gain of treated specimen (%), W_{od} = oven–dry weight (g), W_f = weight after impregnation (g)

$$E_{sw-l} = \beta_c - \beta_h$$

$$\beta = \frac{L_f - L_{od}}{L_{od}} \times 100\%$$ ....[3]

Here, E_{sw-l} = anti–swelling efficiency (%), β_c = length growth rate of control specimen (%), β_h = length growth rate of treated specimen (%), L_{od} = oven–dry length (cm), L_f = catcher's length (cm)

$$E_{sw-v} = \chi_c - \chi_h$$

$$\chi = \frac{V_f - V_{od}}{V_{od}} \times 100\%$$ ....[4]

Here, E_{sw-v} = anti–volume efficiency (%), γ_c = volume growth rate of control specimen (%), γ_h = volume growth rate of treated specimen (%), V_{od} = oven–dry volume (cm³), V_f = catcher's volume (cm³)

Saturated salt solution experiment

Different kinds of saturated salt solution were made in six desiccators. Relative humidity inside desiccator was different according to the different saturated salt solution as shown in Table 1. After six specimens were put in different desiccator, the cover of desiccator was closed and the edge of cover was sealed with vaseline. After the balance of specimens was reached, the weight of specimens was measured, and specimens were oven dried and weighted.

Table 1. Relative humidities (RHs) of saturated salt solutions used for this experiment (Hoadley, 2000)

Saturated salt solution	RH (%) at 20˚C
$CaCl_2 \cdot 2H_2O$	32.0
NaBr	58.0
$(NH_4)_2SO_4$	80.5
$ZnSO_4 \cdot 7H_2O$	90.0
$NaSO_4$	95.0
H_2O	100.0

Equilibrium Moisture Content (EMC) of specimen was calculated from equation [5].

$$EMC = \frac{W_{eq} - W_{od}}{W_{od}} \times 100\%$$ ....[5]

Here, EMC = equilibrium moisture content (%), W_{eq} = weight after absorption (g), W_{od} = oven dry weight (g) E_{ad} was calculated from equation [6].

$$\Delta E_{ad} = \frac{EMC_{cn} - EMC_{ht}}{EMC_{cn}} \times 100\% \times 100\%$$ ....[6]

Here, E_{ad} = anti–adsorption efficiency (%), EMC_{cn} = EMC of control specimen (%), EMC_{ht} = EMC of treated specimen (%)

RESULTS AND DISCUSSION

Oven–dry density

The oven–dry densities of specimens are shown in Table 2. The oven–dry densities of treated specimens were 0.693 g/cm³, 0.691 g/cm³, and 0.690 g/cm³, showed a trend of the density being reduced as the temperature being increased. It was found that there was a highly significant difference between treated and control specimens but there was not significant difference between treated specimens.

Table 2. Comparison between the oven–dry densities of heat–treated and control specimens

Specimen	Oven–dry density (g/cm³)	
	Average	Standard deviation
Con	0.712	0.002
165˚C	0.693	0.004
180˚C	0.691	0.007
195˚C	0.690	0.006

Comparison of wood color between surface and inner layer

The wood color of treated and control specimens before being planned is presented as shown in Table 2. The wood color of treated specimens was deeper than that of control specimens, and deeper as the temperature of heat being increased. The results of wood color measured before and after the specimens were planned
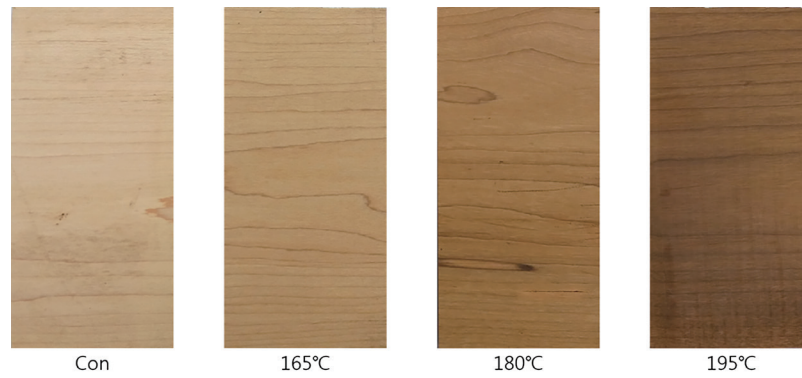
Con   165°C   180°C   195°C

Fig. 2. Photos of heat–treated at three different temperatures and control specimens.

are displayed in Figure 3. As heat temperature was increasing, the whiteness index and yellowness index of treated specimens were reduced but the redness index was increased. Whiteness index of inner layer of the inner layer of specimens presented higher value than that of the surface layer while the yellowness index and redness index presented lower value compared to surface layer of specimens. The difference in chrominance before and after the specimens were planned was biggest for control specimens, this could be accounted for less thermal degradation of control specimen under the temperature of 103°C than that of treated specimens under the temperature of 165°C

Chrominance

Chrominance (ΔE^*) of other specimens except control specimen was calculated from equation [1] by the standard of wood color of control specimen because change of wood color of which was least (Figure 4). Chrominance was lowest (17.5) for 165°C treated specimen, highest (43.5) for 195°C treated specimen. Chrominance of specimens presented significant differences compared to that of inner layer of control specimen. There was no large difference between surface layer and inner layer of treated specimens, and the difference become smaller as heat temperature being increasing.

Anti–absorption efficiency

Absorption graph of specimens is shown in Figure 5. The moisture contents of all specimens were sharply increased until six hours after impregnation, and become gentle. The absorption rate was highest for control specimens, and lower as heat temperature being increasing. After 15 hours of impregnation, Eab was 0% for 165°C treated specimen, 6.9% for 180°C treated specimen and 21.7% for 195°C treated specimen, which indicated that anti–absorption efficiency was significantly increased as heat temperature being increasing.

Anti– swelling efficiency

E_{sw-1} and E_{sw-v} are shown in Figure 6. E_{sw-1} was larger in width than in thickness. E_{sw-1} and E_{sw-v} were increased as heat temperature being increasing. E_{sw-v} was very low
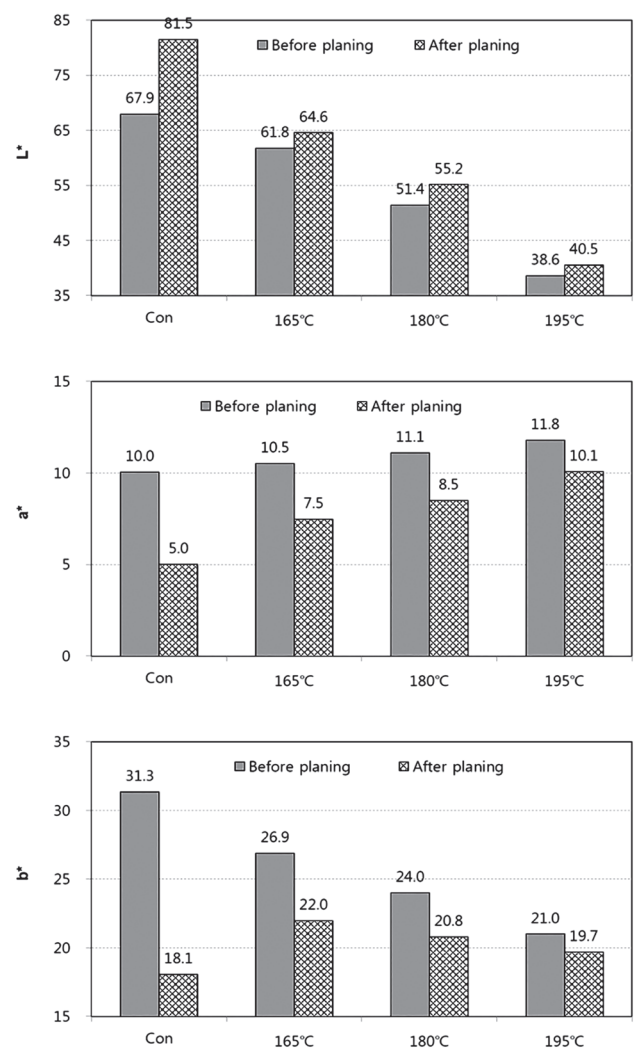

Fig. 3. Color indexes measured before and after planning of control and heat– treated specimens.

(0.9%) for 165°C treated specimen while E_{sw-v} was high (6.6%) for 19°C treated specimen.

Sorption isotherm curve and anti–absorption efficiency
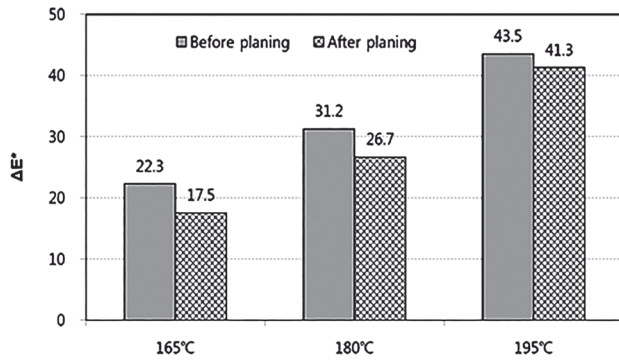
Sorption isotherm curve obtained from saturated

Fig. 4. Color differences (ΔE*) before and after planning of heat–treated specimens compared to the color of the control specimen.
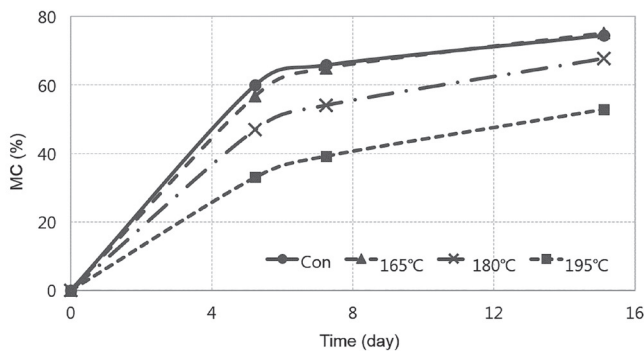

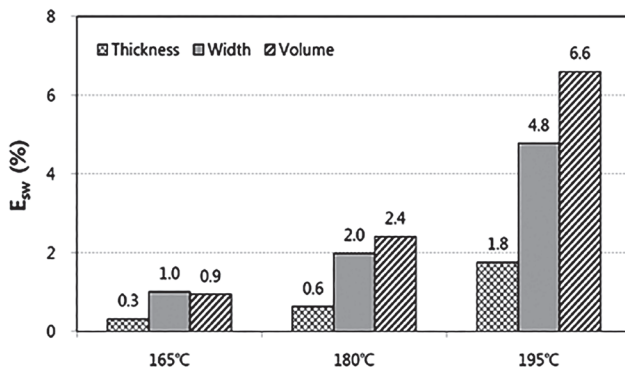**Fig. 5.** Moisture content curves of specimens soaked in water.

Fig. 6. Anti– swelling efficiencies of heat– treated specimens.

Fig. 7. Sorption isotherm curves of the specimens heat– treated at 165, 180°C and 195°C, compared with the control.

Table 3. Anti– Adsorption Efficiency (E_{ad}) of heat– treated specimens at various RH

RH(%)	Temperature of heat treatment		
	165°C	180°C	195°C
32.0	18.9	31.1	46.8
58.0	17.8	25.5	44.1
80.5	10.5	18.2	36.2
90.0	10.6	17.0	35.6
95.0	13.8	20.2	35.5
100.0	7.5	17.6	29.0

salt solution experiment is shown in Figure 7. The curve of control specimen was at position of highest while that of treated specimens was at lower position, which indicates that EMC was lower as heat temperature of treated specimens being increased. E_{ad} is shown in Table 3. Anti–absorption efficiency was increasing as heat temperature of treated specimens being increased under same relative humidity, which means that adsorption points was reduced as heat temperature of treated specimens being increased. Meanwhile, there was a trend of E_{ad} being reduced when relative humidity was increased. E_{ad} of 195°C treated specimens was highest as being 46.8% under the lowest relative humidity of 32.0% while that of 165°C treated specimens was lowest as being
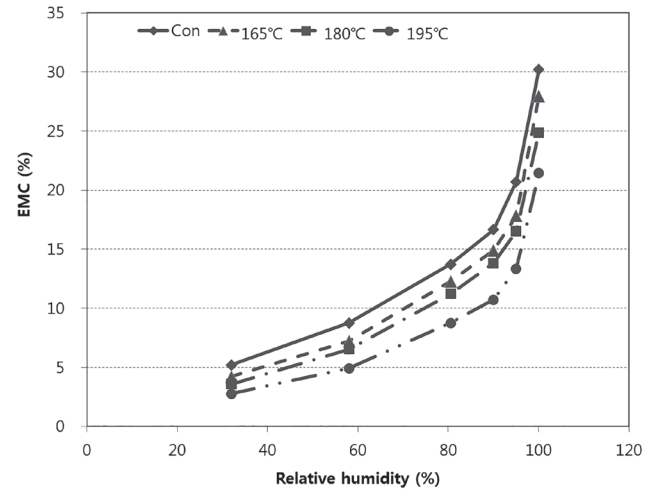
7.5% under the highest relative humidity of 100%. It was noted that anti–absorption efficiency was high when specimens were subjects to high temperature and low relative humidity and that was low when specimens were subjects to low temperature and high relative humidity.

CONCLUSIONS

In order to investigate change of wood color and wettability of Canadian hard maple after high temperature heated treatment, L*a*b* was measured using a color–difference meter, Anti–absorption efficiency, anti–swelling efficiency and anti–volume efficiency of specimens were calculated. The results of this study were as followings:

1. Chrominance was lowest (17.5) for 165°C treated specimen and highest (43.5) for 195°C treated specimen, presented significant differences compared to that of inner layer of control specimen. As heat temperature was increasing, the whiteness index and yellowness index of the surface layer of treated specimens were reduced but redness index was increased while the whiteness index of the inner layer of specimens presented higher value, however, the yellowness index and redness index presented lower value

compared to surface layer of specimens.

2. Anti–absorption efficiency and anti–swelling efficiency of treated specimens were significantly increased as heat temperature being increasing

3. Anti–absorption efficiency was high when specimens were subjects to high temperature and low relative humidity and that was low when specimens were subjects to low temperature and high relative humidity.

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