Effect of Pretreatments on Reducing Surface Cracks of Heat-treated Western Hemlock Roundwoods*[1]

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ABSTRACT

A large diameter roundwood is an important element of Korean traditional buildings, Hanok, and is hard to be dried without surface cracks. Four different pretreatments, such as pre-cracking, oil heating, kerfing-oil heating and PEG impregnation, were investigated for reducing the surface cracks of large-diameter roundwood specimens during heat treatment. The roundwood specimens of pre-cracking, oil heating and kerfing-oil heating showed surface cracks during pretreatment, but that of PEG impregnation did not. It was confirmed that kerfing reduced the total crack width. Among the four pretreatments and control only the PEG impregnation roundwood specimen had no crack on both outer and inner surfaces after heat treatment. The PEG impregnation specimen shrank only 1.6% in the tangential direction while the pre-cracking did 8.0%.

Keywords : Core-hollowed roundwood, pretreatment, heat treatment, oil heating, PEG impregnation, Kerfing, *Tsuga heterophylla*

1. INTRODUCTION

Korean traditional buildings, Hanok, are mostly constructed with large dimension lumbers and roundwoods. They are hardly kiln-dried without severe defects, thus usually air-dried from some months to an year. It was found that heat treatment above 160°C made the surface cracks of large diameter roundwoods closed (Kang, 2010).

A heat-treatment apparatus was recently made in Korea and was used to develop color-change technology for domestic species, such as Korean red pine, Korean pine, and Larch (Kang, 2008). It was found that the device can be used for rapid drying large dimension timbers.

Heat treatment reduces the growing stress of wood, increases the crystallinity of cellulose, decreases equilibrium moisture content, and improves the dimensional stability (Tejada *et al*., 1997). It has been reported that the crystallinity of wood heat-treated at high moisture content was increased as twice as that at oven-dry con

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Fig. 1. A lathe machine for making a large diameter roundwood.

dition (Bhuiyan *et al*., 2000).

Another method of heat treatment is oil heating. Recently, the Menz Holz process has been developed in Germany in which wood is treated at 180～220°C in refined linseed oil in a closed process vessel (Sailer *et al*, 2000). Dubey et al. (2010, 2011, 2012) have investigated the application of oil heating to radiata pine (*Pinus radiata*).

Polyethtylene glycol (PEG, HO-[CH_2CH_2O]$_n$-H) is a water-soluble non-ionic surfactant and is subject to combine with a hydroxyl group of cellulose in cell wall (Ralph, 2006). PEG has been recommended to reduce drying defects of wood (Stamm, 1959; Mitchell and Wahlgren, 1959; Mackay, 1972; Alma *et al*., 1996). Mitchell and Iverson (1961) and Ralph (2006) applied it for defect-free drying of wood carvings and a refractory species, *Eucalyptus regnans*.

In this study roundwood specimens of 250 mm diameter were pretreated with four different methods, such as pre-cracking, oil heating, kerfing-oil heating and PEG impregnation and their effects on the reduction of surface cracks during heat treatment were investigated.

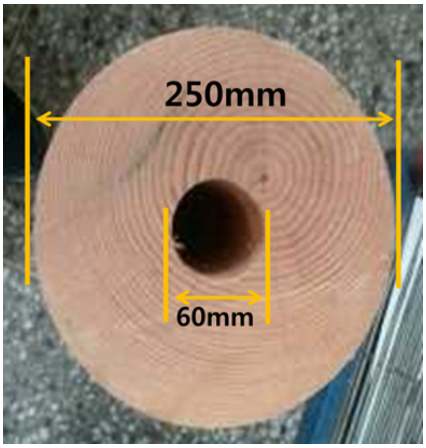

Fig. 2. A photo of western hemlock core-hollowed specimen with 250 mm diameter.

2. MATERIAL and EXPERIMENTAL PROCEDURE

2.1. Preparing a Core-hollowed Roundwood

Western hemlock (*Tsuga heterophylla*) was selected for this study. A green 2,000 mm-long log was debarked and lathed to make a 250

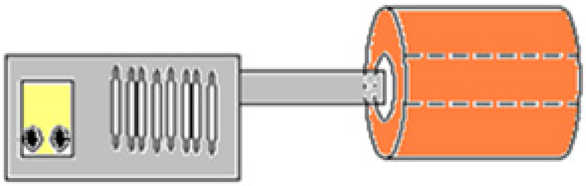

Fig. 3. A schematic diagram of an apparatus for Intentionally developing internal cracks in the roundwood specimen.

mm-diameter roundwood (Fig. 1). Its core was hollowed out with 60 mm-long drill as shown in Fig. 2. This work was conducted at a saw-mill in Incheon. A 2,000 mm-long roundwood was cut into five 300 mm-long specimens after removing a 200 mm-long piece from each end. They were used for four different pretreatment and a control roundwood specimens. Each specimen was put in a heavy-duty plastic bag to prevent from drying and was transported to Chungnam National University in Daejeon.

2.2. Pretreatments

2.2.1. Pre-cracking

It was postulated that intentionally developed internal cracks would reduce stress on surface and prevent surface checking. For this purpose hot air blew through a hole in th roundwood specimen to make cracks around a hole (Fig. 3). A heater equipped with a controller and a stain-less pipe of 55 mm diameter was used. The temperature of hot air at inlet of the specimen was set at 70°C. It conducted for 3 days. Thereafter a 30mm-long specimen was cut from the end of the roundwood specimen and was split into three layers, such as the outer surface, middle and inner surface layers. The small moisture content specimens were weighed with a precise digital balance of 0.01 g accuracy and oven- dried in a 103 ± 2°C oven. The rest of the round wood specimen was air-dried at room temperature.

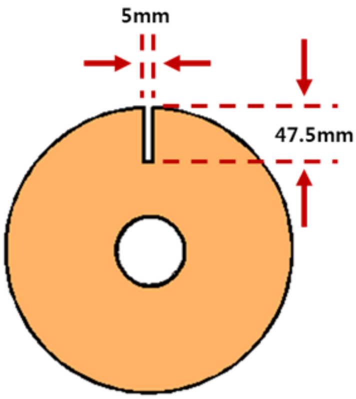

Fig. 4. A schematic diagram of the roundwood specimen with a kerf

2.2.2. Oil Heating

Heat capacity of oil is higher than air or water, thus heat transfers quickly into wood during oil heating. The purpose of this experiment is to make many tiny cracks on the inner and outer surfaces of the roundwood specimen by immediate heat transferring, which would hopefully prevent large cracking.

Commercial soybean oil was heated until 200°C in an autoclave of 60 liter and the specimen was immerged at 200°C for 5 hours. The specimen was taken out and extra oil on the

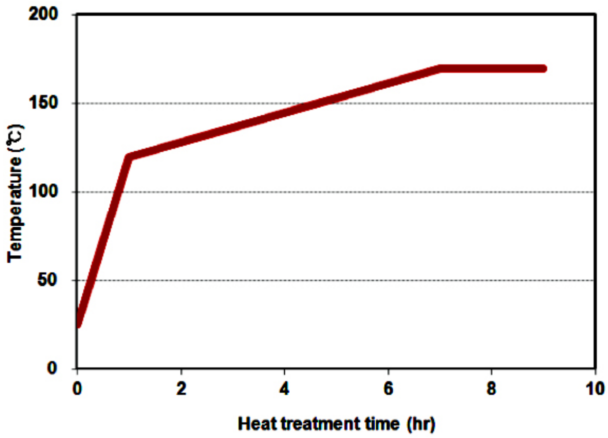

Fig. 5. A time schedule for heat treatment.

surface was wiped out. It was air-dried at room temperature.

2.2.3. Kerfing-oil Heating

Unexpectedly several large and random cracks appeared on the surfaces of oil heated specimen. Kerfing has been used to eliminate random cracking on the surface of a roundwood (Evans *et al*., 2000; Yeo *et al*. 2007). In this experiment a kerf of 5-mm width and 47.5-mm depth was made on the outer surface of the roundwood specimen (Fig. 4). The specimen with a kerf was immerged in 200°C soybean oil for 2 hours, which would be enough time for stress concentration around a kerf.

2.2.4. PEG Impregnation

Low molecular weight PEG has been used for improving dimensional stability of wood (Mackay, 1972; Alma *et al*., 1996; Ralph, 2006). Thus molecular weight 1,000 was selected for this experiment. PEG-1000, solid at room temperature, was heated in a water bath and mixed with water by 50 : 50 in weight ratio. The roundwood specimen was immerged in the solution for 15 days at room temperature.

2.3. Heat Treatment

Four pretreated and one control roundwood specimens were weighed and air-dried for 45 days at room temperature. During drying they were weighed at a certain interval. Thereafter all five specimens were heat-treated in the lab-scale dry kiln. Its capacity is 0.5 m^3 and air temperature can rise to 230°C. Air velocity between boards was 4 m/s. For heat treatment kiln temperature rose to 120°C from ambient during 1 hour and then rose to 170°C during 6 hours (Fig. 5). The duration of 170°C was 2 hours. This heating schedule was repeated twice. The specimens in the dry kiln were cooled down to room temperature between kiln runs and after heat treatment. Humidity in the dry kiln was not controlled.

2.4. Measuring Widths of Cracks

After heat-treatment the numbers of cracks on the outer surface were counted and their width were measured with a width gauge. The largest value was selected among three width measure-

Fig. 6. A photo for crack development during pre-cracking.

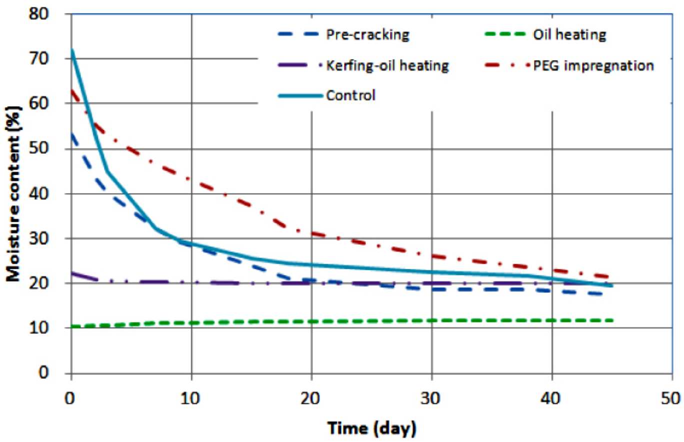

Fig. 7. Air drying curves of four pretreated and a control roundwood specimens.

ments of each crack.

3. RESULTS and DISCUSSION

3.1. Pretreatments

The average intial moisture content of the five roundwood specimens was 72%, which was calculated by oven-drying them at 103 ± 2°C after heat treatment.

The moisture contents of the outer, middle and inner layers of the pre-cracking roundwood specimen were, respectively, 21, 68, 44%. As expected the inner layer was dried most and the middle layer was little dried. No cracks were found on the outer surface, but several narrow cracks were found on the inner surface as shown in Fig. 6.

The moisture content of the oil heating roundwood specimen was 10.4% after 5 hour heating while that of the kerfing-oil heating roundwood specimen was 22.4% after 2 hour heating.

The moisture content of the PEG impreg- na- tion roundwood specimen was 62.8%, which was almost equivalent to the green moisture

Table 1. Moisture contents of the western hemlock roundwood specimens before and after heat treatment

Heat treatment	Moisture contents (%)					
	Pre-cracking	Oil-heating	Kerfing-oil heating	PEG impregnation	Control	Average deviation
Before	17.8	12.3	22.2	19.7	19.5	2.6
After	0.6	0.9	1.4	0.0	0.6	0.4

Table 2. Features of the cracks on the outer surface of western hemlock roundwood specimens after heat treatment

Pretreatments	Number of surface cracks	Width of largest surface crack (mm)	Total width of surface cracks (mm)
Pre-cracking	6	29.0	30.4
Oil heating	3	8.0	18.1
Kerfing-oil heating	5	2.5	7.4
PEG impregnation	0	0	0
Control	2	7.0	12.5

content. No cracks were found on both outer and inner surfaces.

3.2. Air Drying

Air drying curves of four pretreated and control roundwood specimens are plotted in Fig. 7. All plots except (kerfing and) oil heating specimens are curvilinear. It was no doubt that oil heating rapidly decreased the moisture contents of the specimens.

It was observed that the pre-cracking roundwood specimen had six cracks on the outer surface with the maximum crack width of 6.5 mm. Three cracks were found on the outer surface of the oil heating roundwood specimen with the maximum crack width of 7.2 mm while two small cracks were found on the outer surface of the kerfing-oil heating roundwood specimen with the maximum crack width of 1.5mm. However non of cracks were found on both outer and inner surfaces of the PEG impregnation roundwood specimen.

3.3. Heat Treatment

The average deviations of moisture contents between the pretreatments were 2.6% and 0.4% before and after heat treatment (Table 1). It was revealed that heat treatment decreased the variation of moisture content between the pretreatments.

The cracks on the outer surfaces of the heat-treated roundwood specimens were visually examined by computing their numbers, largest width and total width (Table 2). Six cracks were found on the pre-cracking roundwood specimen. The largest and total widths were 29.0 mm and 30.4 mm, respectively. It means that they were a largest and five narrow cracks.

Comparing the oil heating and kerfing-oil heating the number of cracks of the former was

Table. 3. Total tangential shrinkages of the heat-treated western hemlock roundwood specimens

Pretreatments	Pre-cracking	Oil heating	Kerfing-oil heating	PEG impregnation	Control
Total tangential shrinkage (%)	8.0	5.8	4.4	1.6	6.6

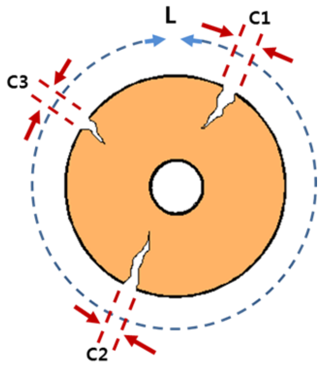

Fig. 8. A schematic diagram of the cracked roundwood specimen.

three while that of the latter was five. However the total crack width of the former was 18.1mm, almost three times larger than that of the latter. It was confirmed that kerfing helped to reduce the total crack width.

It was noticeable that non of cracks were found on both outer and inner surfaces of the PEG impregnation roundwood specimen after heat treatment. The control roundwood specimens showed as many surface cracks as the (kerfing- and) oil heatings. Thus the most cracked specimen was the pre-cracking, and followed by the oil heating, control, kerfing-oil heating and PEG impregnation.

The circumference and total crack width of the heat-treated roundwood specimens were measured as shown in Fig. 8, and compared with the green one in Fig. 9. The white bars in Fig. 9 represent the circumference of wood substance only.

The total tangential shrinkages of the heat-treated specimens were calculated using Eq[1].

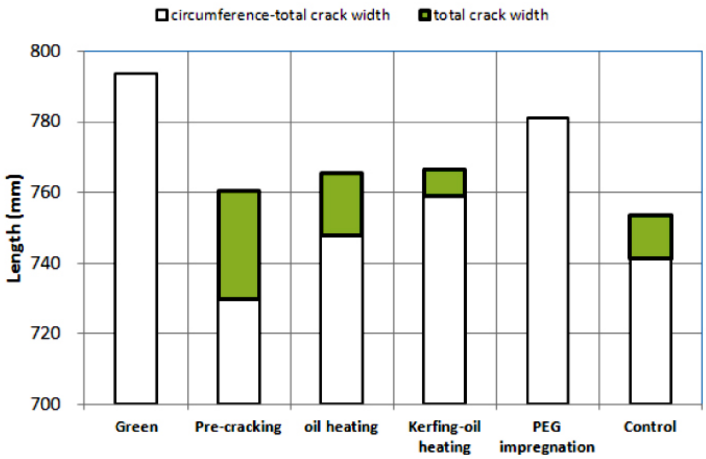

Fig. 9. Comparison of the circumferences and total crack widths of western hemlock roundwood specimens pretreated with various methods and heat-treated.

$$\alpha_t = \frac{L_0 - (L - T)}{L_0} \times 100\% \quad [1]$$

$$T = \sum_{i=1}^{n} C_i$$

where, α_t = total tangential shrinkage (%), L_0 = the circumference of a green specimen (mm), L = the circumference of the heat-treated specimen (mm), T = the total crack width of the heat-treated specimen, and C_i = the width of a crack (Fig. 9)

The pre-cracking specimen shrank most, and followed by the control, oil-heating and kerfing-oil heating. It could be explained that oil prevented the specimens from shrinking. As expected the PEG impregnation specimen shrank only 1.6%.

4. CONCLUSIONS

Four different pretreatments, such as pre-cracking, oil heating, kerfing-oil heating and PEG impregnation, were investigated for reducing the surface cracks of large-diameter roundwood specimens during heat treatment. Conclusions obtained from this study are as follows.

1. The roundwood specimens of pre-cracking, oil heating and kerfing-oil heating showed surface cracks after pretreatment, but that of PEG impregnation did not.

2. The average deviation of moisture contents between the pretreatments before heat treatment was 2.6% and it decreased to 0.4% after heat treatment, which confirmed that heat treatment decreased it.

3. It was confirmed that kerfing helped to reduce the total crack width by comparing the oil heating and kerfing-oil heating specimens.

4. No crack was found on both outer and inner surfaces of the PEG impregnation roundwood specimen after heat treatment.

5. The pre-cracking specimen shrank most, and followed by the control, oil-heating and kerfing-oil heating and PEG impregnation after heat treatment. The PEG impregnation specimen shrank only 1.6% in the tangential direc- tion.

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