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Air Circulating Oven-drying Characteristics of Hollowed Round-post for Korean Main Conifer Species.*[1]

- Part 2: For Korean red pine hollowed round-post -

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ABSTRACT

In this study the effect of heartwood-coating (HCO), vapor-dam (VD), bark-remaing (BR) and bark-remaining-coating (BRC) treatments were evaluated during air circulating oven-drying of hollowed round-post of Korean red pine. Hollowed round-post could be dried from the green condition to approximately 6% MC within 84 to 156 hours for the UC, HCO and VD specimens and it took 72 to 240 hours to about 8% MC, which is recommended as the indoor in-use MC. The temperatures in the hole of the Control (UC) and HCO specimens constantly showed a higher-leveled distribution pattern than those inside wood. The vapor pressure in the hole of the UC, HCO and BR specimens was higher than that inside wood and showed difference as highest value of about 20 mbar. The surface checks of all specimens were mild and were observed in increasing order of BRC, BR, UC, VD and HCO specimens.

Keywords : hollowed round-post, heartwood coating treatment, vapor-dam treatment · BR treatment · BRC treatment · drying rate · checking

1. INTRODUCTION

There has been growing interests in Korean traditional wooden buildings in Korea, resulting in an increasing need for posts which is one of the most necessary materials for wooden buildings. It is essential that the timbers be dried to a specific moisture content (MC) consistent with the service conditions. However, it is difficult to avoid checking and cracking during drying due to differential shrinkage stress, internal growth stress and surface stress during the drying process (Kubler, 1975; Hsu and Tang, 1984). The presence of surface checks on the post diminishes their appearance and reduces the holding power of the traditional joint. Because the MC inside the wood is higher than that outside after drying, it is difficult to inject preservatives deep into the wood also.

It was reported that a kerfing treatment can reduce the incidence of checking, particularly the number of severe checks (Ruddick and Ross,

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Table 1. Dimension, evaporating surface area, heartwood percentage and initial moisture content of Korean red pine specimens for each treatment

Treatment	D* (mm)	T** (mm)	Evaporating surface area (cm^2)				Heartwood percentage (%)	Initial MC (%)
			outer	inner	end	sum		
UC	270	30	4239	3297	452	7988	0	109
VD	270	30	4239	0	0	4239	8.49	109.4
HCO	270	30	4239		452		0	115.7
BR	300	30	0	3768	509	4277	0	123.4
BRC	300	30	0	3768	0	3768	0	115.1

* : Diameter.
** : Thickness.

Table 2. Drying schedule

Drying Times (h)	0～24	24～48	48～72	72～96	96～168	168～216	216～240
Temperature (°C)	55	60	65	70	75	80	85

1979; Evans, 2000). However, the width of the kerf modified to relieve the drying stresses increased during drying. Lee and Luo (2002) reported that a low pressure steam explosion treatment to enhance the permeability of wood was effective in accelerating the drying rates but was failed to reduce the occurrence of checking during the drying of larch pillars. Fang (2001) reported that the drying time could be reduced by radio-frequency/ vacuum (RF/V) drying some softwood poles on laboratory scale. However, RF/V drying is energy consuming and less efficient process with high start-up cost.

According to Lee (2007) excellent results were also obtained during air circulating oven-drying of Royal Paulownia green stock using a Vapor-dam treatment combined with a coating treatment. While drying the hollowed stock with the Vapor- dam treatment, the moisture evaporating from the inner surface of a solid body can be stored in the hole, and the moisture can be supplied to the inner surface the moment tension stresses begin to form on the inner surface. Coating the end surfaces and the surface of heartwood can prevent splitting, or V-shaped cracks, and reduce the drying rates of heartwood to prevent checking of heartwood.

This study evaluated the effect of heartwood-coating and Vapor-dam treatments during air circulating oven-drying of Hollowed round-posts with short length of Korean red pine (*Pinus densiflora, S.et.Z.*). Furthermore, temperature and vapor pressure distribution were also evaluated.

2. Materials and Methods

2.1. Preparation of Specimens

Two Korean red pine logs 1800 mm-long and 300 mm in diameter at the top end were obtained from a sawmill. Three specimens (untreated control (UC), heartwood-coating (HCO) treatment and Vapor-dam (VD) treatment specimens), 500 mm in length, were cut from one of the Korean red pine logs, which were processed into a round post 270 mm in diameter and two specimens. Two specimens, 500 mm in length, were cut from the other red pine log remaining

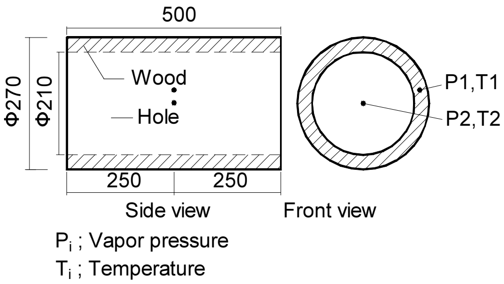

Fig. 1. Schematic diagram of the Control specimen and the locations of the fiber optic sensors on the specimen. (unit : mm).

the bark. Two 20 mm-long log cross section(L)s were cut from both ends of each specimen to measure the percentage of heartwood and the initial MC. A big hole was drilled at the center of all specimens along axial direction leaving 30 mm thick of wood.

The boundary between heartwood and sapwood of the Ls cut from both ends of specimens were clarified and scanned on graphic paper, to estimate the percentage of heartwood. The Ls were then cut into several 8 mm-thick circumferential slices to measure the radial distribution of the initial MC (Lee, 2007). Table 1 showed the percentage of heartwood and the initial MCs of the specimens for each treatment.

2.2. Pretreatment

Both ends of the vapor-dam (VD) specimen were covered with 15 folds of vinyl wrap; and a rubber band, 2 mm in thickness and 15 mm in width, was fixed around the circumferential surface to prevent the moisture evaporating from the inner surface of the specimen. The part of the heartwood on the end surface and inner surface of the heartwood-coating (HCO) specimen were brushed twice with epoxy waterproof paint. Bark was remained to prevent the moisture on the outer surface of the specimen from evaporating for both Bark-remaining (BR) and Bark-remaining-coating (BRC) specimens and the end surface were brushed twice with epoxy waterproof paint for BRC specimen.

2.3. An Air Circulating Oven-Drying

The internal dimensions of the rectangular chamber of the air circulating-oven used in this experiment were 500 mm in length, 500 mm in width and 600 mm in depth, which could be controlled with an accuracy of ±1°C and fixed air velocities of 1.5 m/s. The specimens were dried individually in each run.

The drying schedule used for this study started from an initial air temperature of 55°C which was increased by 5°C every 24 hours. After 96 hours, it was increased to 75°C and maintained at that temperature until 168 hours. The temperature was then increased to 80°C and maintained until the end of the drying test (Table 2).

2.4. Measurement of Temperature and Vapor Pressure

2.4.1. Insertion of Sensors

Fig. 1 showed a schematic diagram of the methodology for probing the temperatures and vapor pressures inside wood and in the hole of the specimen. Initially, a large hole, 13 mm in diameter from the outer surface along the radial direction was drilled in the middle of the specimen and epoxy resin was injected into the hole to approximately one of the third depth. After the epoxy resin was cured sufficiently, a small hole, 6 mm in diameter was made through the center of the epoxy resin section. A Teflon tube, 6 mm in diameter, was then inserted into the hole and the epoxy resin was injected into the large hole again. After the epoxy resin was cured satisfactorily, the entrance of the large

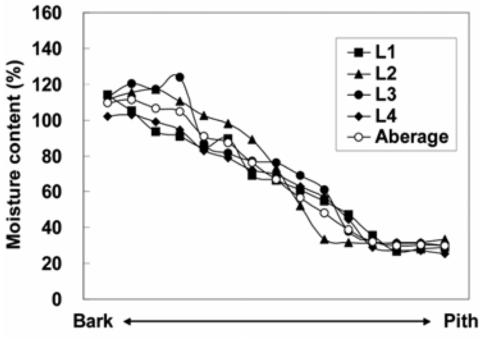

Fig. 2. Radial MC distribution of Ls for UC, HCO and VD specimens.

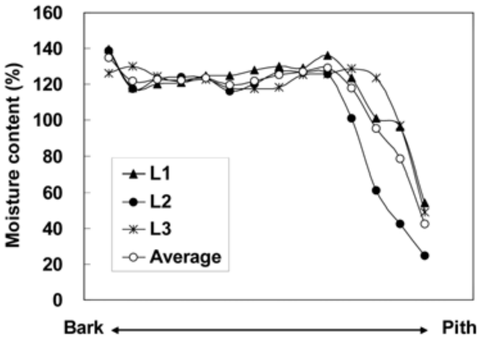

Fig. 3. Radial MC distribution of Ls for BR and BRC specimens.

hole was sealed with silicone to prevent air flowing into the specimen from the entrance of the hole, during the drying test.

2.4.2. Measurement of Temperature and Vapor Pressure

The temperatures and vapor pressures inside the specimens were measured every 5 minutes during drying test using an optical fiber signal measuring instrument (UMI, FISO Technology, Canada), with a resolution of 0.05°C. It was in a range of -40～250°C for the temperature sensor, and 0.1% at the level scale ranging from 0 ～to 68 kPa for the vapor pressure sensor. After drying, the temperature and vapor pressure distribution were analyzed.

2.5. Drying Curves and Drying Times

Each specimen was weighed every 8 hours until the 72 hours of drying time and then every 12 hours till the end of drying to determine the change in MC during the drying test. The drying time excluded the dead time required for measuring.

2.6. Checks

The total length and number of checks which occurred in both the inner and outer surfaces were estimated at the same time of measuring the weight, until the lengths of the checks were not accelerated to estimate the accumulated total length of the surface checks.

2.7. Shrinkage

The thickness and circumference shrinkage of the specimens were calculated by measuring the dimensions during drying using a digital vernier caliper and π tape with an accuracy of 0.01 mm.

3. Results and Discussion

3.1. Radial distribution of the initial MC

Figs. 2 and 3 showed the radial distribution of the initial MCs of the Ls cut from both ends of specimens.

For the Ls cut from both ends of UC, HCO and VD specimens, the MC near the pith was as low as 25.4～33.4% irrespective of the location on the post and increased rapidly towards the bark, showing a minimum value of 102.0% and a maximum value of 113.9% near the bark side. For the Ls cut from both ends of BR and BRC specimens, the MC near the pith was as

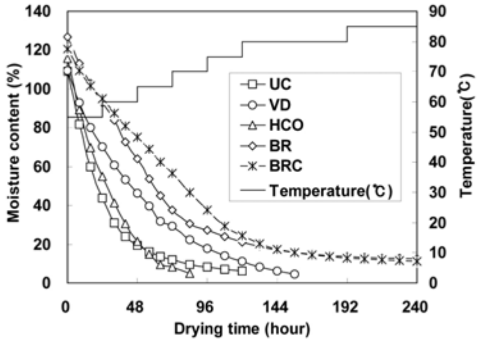

Fig. 4. Drying curve of specimens during air circulating-oven drying.

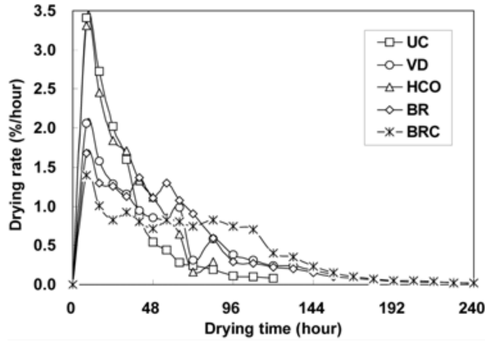

Fig. 5. Drying rates of specimens during air circulating-oven drying.

low as 24.8～54.0% irrespective of the location on the post and increased rapidly till around 1/3 thickness, then presented almost liner distribution showing an average value of 120.7%.

Lee (2002) reported that the initial MC on the identical log cross section showed a steep moisture gradient along the radial direction during drying, which could result in the production of border checks.

After drilling, the heartwoods of specimens were almost removed and the average MCs of specimens showed as 126.4% for the UC, HCO and VD specimens and 126.5% for the BR and BRC specimens, respectively. Therefore, drilling holes was expected to help decrease the moisture gradient to prevent checks.

3.2. Drying Curves and Drying Rates

Fig. 4 showed the distribution of MCs and the drying rates of the specimens during air circulating-oven drying as a function of the drying time, respectively.

It took 120, 84 and 156 hours to dry the UC, HCO and VD specimens, respectively, from the initial MC to 6% MC resulting in the possibility that hollowed round-posts can be used as the materials used in-door. The VD specimen required longer drying time than the UC and HCO specimen, which might be due to the prevention of moisture evaporation from the inner surface of the specimens. While it takes 240 hours to dry BR and BRC specimens from the initial MC to the final MC of 12.5% and 11.3% respectively.

Fig. 5 showed drying rates of specimens. The average drying rates of UC specimen for the beginning of 12 hours was 0.902% and showed much high value compared with BR specimen, which was 0.551% per hour. This may be due to the prevention of moisture loss from outer surface by the bark, because of the reduction in available evaporating surface. This also results in the increment of the distance of moisture movement.

Especially, at the beginning of the 24 hours of drying, the drying rates of UC specimens was 3.410% per hour over two times of the drying rate of BR specimen, which was 1.676%, because during the early stages of drying, the drying rate was dominated mainly by the evaporation rate from the surface of the wood. The available evaporating surface area of UC specimen was about 1.9 times as much as that of BR specimen. Hence, there were notable differences in drying rates between UC and BR specimen.

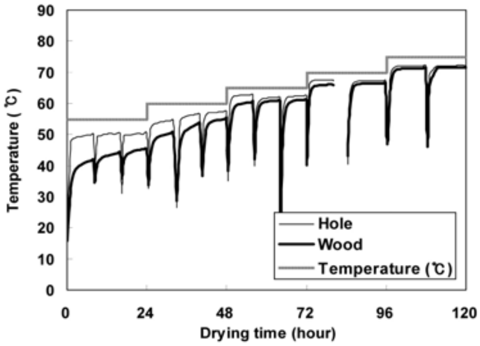

Fig. 6. Temperature distribution of UC specimen during the drying process.

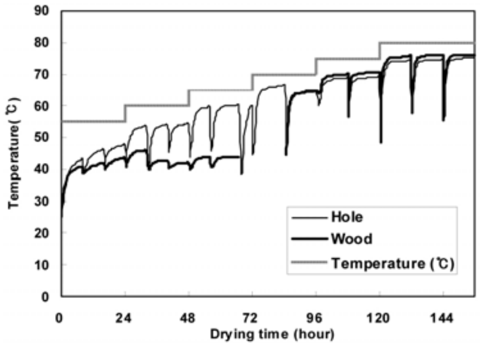

Fig. 7. Temperature distribution of VD specimen during the drying process.

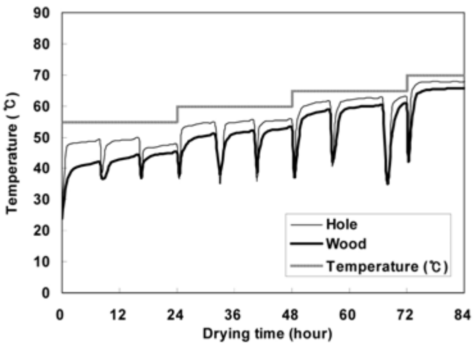

Fig. 8. Temperature distribution of HCO specimen during the drying process.

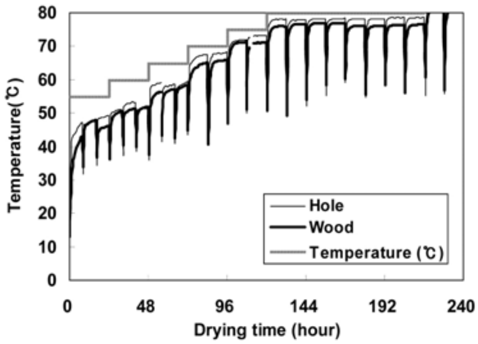

Fig. 9. Temperature distribution of BR specimen during the drying process.

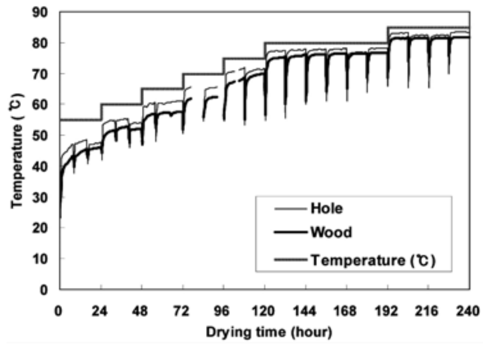

Fig. 10. Temperature distribution of BRC specimen during the drying process.

3.3. Distribution of Temperature during Air Circulating Oven-drying

Figs. 6～10 showed the temperature distribution inside the hole and wood of specimens.

The temperatures in the hole of the UC and HCO specimens constantly showed a higher distribution pattern than those inside wood. On the other hand, the temperature in the hole of the VD specimen showed lower distribution pattern and reversed from 96 hours of drying. As the drying progressed, there was little differences in temperature, between the hole and wood for UC and HCO specimens. For the BR and BRC specimens, the differences between the hole and

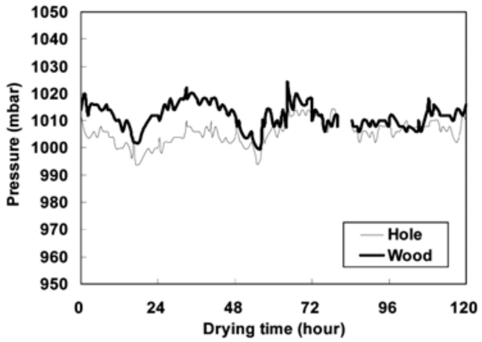

Fig. 11. Vapor pressure distribution of UC specimen during the drying process.

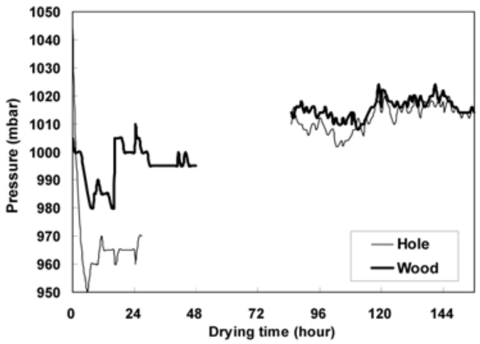

Fig. 12. Vapor pressure distribution of VD specimen during the drying process.

wood maintained relatively constant. In the case of the UC and HCO specimens, moisture evaporated vigorously from the outer surface in the early stages of drying, and the wet line moved inside the solid body. Therefore, the solid body showed no increase in temperature due to the loss of heat by latent heat.

3.4. Distribution of vapor pressure during air circulating oven-drying

Figs. 11～15 showed the vapor pressure distribution inside the hole and wood of specimens.

The vapor pressure in the hole of the UC, HCO and BR specimens was higher than that

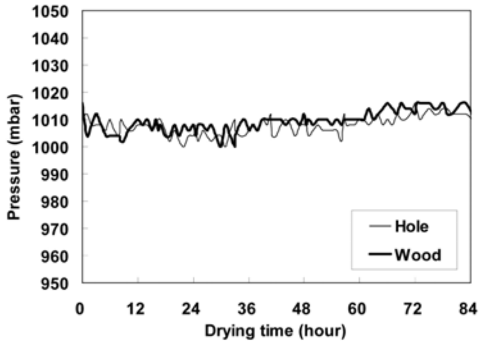

Fig. 13. Vapor pressure distribution of HCO specimen during the drying process.

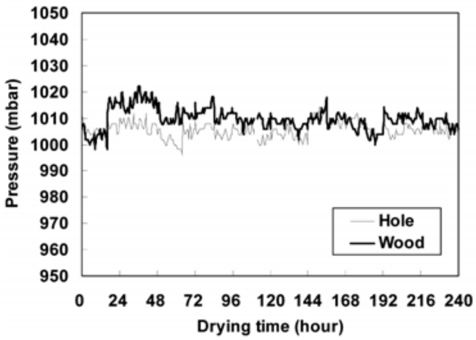

Fig. 14. Vapor pressure distribution of BR specimen during the drying process.

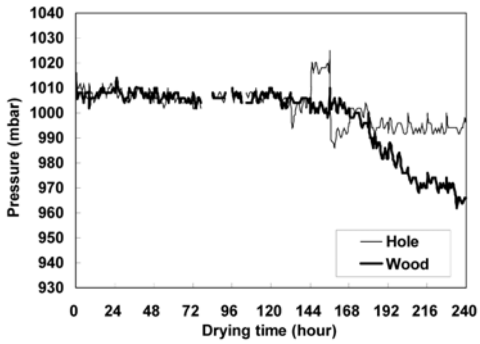

Fig. 15. Vapor pressure distribution of BRC specimen during the drying process.

inside wood and showed difference as highest value being 20 mbar.

Table 3. Anova of check length on the pretreatment for Korean red pine.

Factor	S	Φ	ν	F	F (0.05)
Check length	4	11001	2750	3.07	0.017
Error	234	209403	895		
Total	238	220404			

* : 95% confidence level.

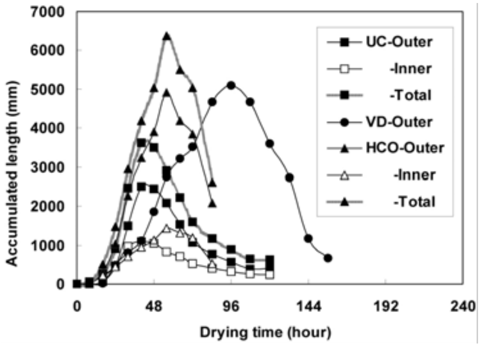

Fig. 16. Accumulated surface checks of UC, VD and HCO specimens during drying.

At the beginning of 24 hours, vapor pressure in the hole decreased sharply, showing 950 mbar at the lowest point. This may be due to the development of pressure difference between hole and oven. At the beginning of drying, the temperature in the hole was lower than that in the oven, which resulted in the difference of pressure between inside and outside the hole. This indicates that the aim of storing moisture in the hole was not effective at the beginning of the drying.

3.5. Surface Checking During Drying

In this study, one way anova analysis were used to test the significance between pretreatments. The confidence level was 95% and the individual confidence level was 99.36%. The results showed that in confidence level of 95 %, the check lengths were significant on pretreatments and were presented as an important factor to the pretreatments (Table 3).

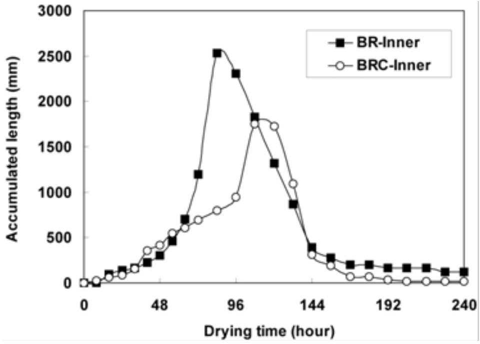

Fig. 17. Accumulated surface checks of BR and BRC specimens during drying.

Figs. 16 and 17 showed the total length of surface checks occurring on the outer and inner surfaces of specimens during drying process.

The surface checks were observed in increasing number in the following order: BRC, BR, UC, VD and HCO specimens. For BRC and BR specimens, the accumulated length of both outer and inner surface checks was 635 mm and 125 mm. This was probably because BR and BRC specimens almost consisted of sapwood, and it was expected that prevention of surface checks could be effective even if the thickness of wood was increased or the area was reduced.

The accumulated length of surface checks was presented most severely at 48 hours and 96 hours for UC and BR specimens, respectively, and then decreased sharply. This may be due to tension stress developed on the surface because of the moisture gradient reversed into compression stress, which may lead to the closure of the open checks. This will be helpful to the determination of kiln drying schedules.

3.6. Shrinkage

Table 4 and Fig. 18 showed the level of shrinkage of the circumferential and thickness

Table 4. Shrinkage after drying of UC, VD and HCO specimens.

Treatment	Shrinkage (%)		
	Cercumfrence[a]	Thickness[b]	a/b
UC	6.12	4.00	1.53
VD	4.90	3.18	1.54
HCO	4.48	3.47	1.29

of specimens during air circulating-oven drying.

The ratio of circumference and thickness shrinkage was 1.29 for HCO specimen, presenting less value comparing with UC and VD specimens. Thickness shrinkage of UC and HCO specimens were lower than circumferential shrinkage from beginning of drying until 56 and 72 hours, respectively, and then the values were reversed. This moment the surface checks developed were most severe. At the beginning of drying, circumferential shrinkage was less evaluated due to the appearance of surface checks. Then ,some closures of checks leaded to a drastic increase in of circumferential shrinkage.

4. CONCLUSIONS

This study evaluated the effect of heartwood-coating (HCO) and VD treatments during air circulating oven-drying of hollowed round-post of Korean red pine. Hollowed round-post could be dried from the green condition to approximately 6 % MC within 84 to 156 hours to dry the UC, HCO and VD specimens and it took 72 to 240 hours to about 8 % MC, which is recommended as the indoor in-use MC. The temperatures in the hole of the Control and HCO specimens constantly showed a higher distribution pattern than those inside wood. The vapor pressure in the hole of the UC, HCO and BR specimens was higher than that inside wood; and showed difference as highest value of 20 mbar. The surface checks of all specimens were mild and the average length of checks were observed in increasing order of BRC, BR, VD, HCO and UC specimens.

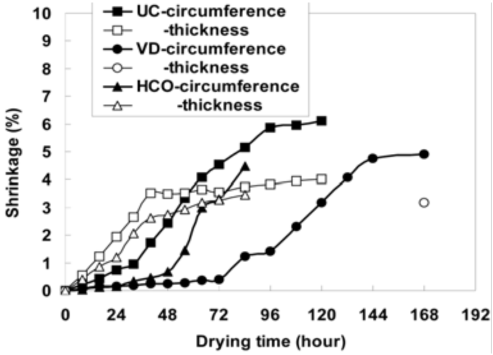

Fig. 18. Circumferential and thickness shrinkage of UC, VD and HCO specimens during air circulating oven-drying.

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