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Effects of HTLH and Kerfing Pretreatement on the Drying Characteristics of Large Square Red Pine Timber

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In this study, the effects of two different drying techniques on the properties and characteristics of large square Korean red pine timbers were examined. Wood specimens with a cross section area of 200 × 200 mm and length of 3600 mm were subjected to high temperature and low humidity (HTLH) pretreatment followed by air–drying or radio–frequency/vacuum (RF/V) drying, and the result specimens were compared. The effect of longitudinal kerfing on drying properties was also examined.

The total time of RF/V drying after HTLH pretreatment was 245 h, which led to a decrease in the initial moisture content (MC) of 83% to a final MC of 5%. RF/V drying was faster than air drying, and the difference in final MC between the internal and external layers of RF/V–dried large square timber was approximately 2%. The slopes of moisture gradients along the thickness directions were very smooth.

Our results also indicated that surface checks were effectively prevented by kerfing treatment: no surface checks were observed on kerfed and RF/V–dried timbers. Irrespective of kerfing, very few drying defects of internal checking and twisting were found on RF/V–dried timbers. Case hardening was less than 4% after drying.

Key words: HTLH, pretreatment, air drying, radio–frequency/vacuum drying, large square timber, longitudinal kerfing, drying characteristics

INTRODUCTION

Drying sawn timber is highly important because the movement of moisture and changes in moisture content (MC) can cause changes in the dimensions and physical properties of the wood. Likewise, it is important to minimize drying time to prevent defects during the drying process. Wood is commonly dried by air drying or conventional kiln drying, both of which rely on evaporating water from the wood surface. Whereas air drying utilizes natural air, kiln drying utilizes circulating air under controlled temperature and humidity conditions.

High–temperature drying has recently become widely adopted for softwood drying because of its speed and low energy cost. Indeed, drying southern pine by high–temperature drying is at least four times faster than hot air drying and requires less than half the energy (Koch, 1972). In addition, radio–frequency/vacuum (RF/V) drying is a less common method that has come into use in recent years. Importantly, RF/V drying saves time and energy compared to air drying, as well as reduces drying time and defects by increasing the internal pressure in the wood leading to rapid evaporation of moisture. Especially, RF/V is highly advantageous for drying boxed heart timber (Jung *et al.*, 2002).

Harris and Taras (1984) compared RF/V and conventional kiln drying of hardwood boards and reported the respective rates, moisture gradients, and internal stresses associated with the two drying processes. Similarly, Lee and Luo (2002) reported that RF/V has superior drying characteristics such as speed, defects, moisture distribution, and residual stress compared to conventional kiln drying.

During RF/V drying of heavy timber, dielectric heating causes a steep pressure gradient to develop from the center of the lumber towards the surface. This pressure gradient helps to quickly drive out wood moisture in both liquid and vapor form, increasing the rate of drying. Likewise, because rapid moisture transportation reduces drying stress, RF/V decreases drying defects (Harris and Taras, 1984: Kanagawa, 1989: Avramidis *et al.*, 1994: Avramidis and Liu, 1994: Lee and Luo, 2002: Li and Lee, 2004). On the other hand, Hansson and Antti (2003) studied the differences in wood strength arising from different drying methods, and reported that there is no significant difference in wood strength between conventional and microwave drying. In addition, Hansson and Antti (2006) reported that the wood hardness does not differ significantly for microwave drying between 60 and 110°C. Conversely, Oloyede and Groombridge (2003) observed a reduction in strength in wood subjected to microwave drying compared to air–circulation drying.

While RF/V drying has had some success, its use in

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the manufacturing of construction materials is presently constrained due to a lack of efficient RF/V drying technology and optimized drying schedules for heavy timbers with large cross–sections. Various methods to improve RF/V drying have been investigated, including drying pretreatments such as high temperature and low humidity (HTLH) treatment and longitudinal kerfing. With respect to HTLH pretreatment, many researchers have reported that optimized treatment conditions that incorporate HTLH pretreatment are effective at improving drying with respect to speed, final MC, defects, and achieving a smoother moisture gradient along the thickness direction of the wood (Yoshida *et al.*, 2000: Katagiri *et al.*, 2001: Oda *et al.*, 2004: Katagiri *et al.*, 2005: Lee *et al.*, 2010: Andi 2012).

The present study was conducted to clarify the effects of HTLH pretreatment upon the characteristics of subsequently air–dried and RF/V–dried large timbers. The drying characteristics evaluated in this study consisted of drying speed, moisture distribution, and drying defects. The effect of kerfing was also examined.

MATERIALS AND METHODS

Specimens

Domestic Korea red pine (Pinus densiflora S. et. Z) logs were sawn into beams 200 mm square in cross–section and 360 mm long. Twenty specimens were prepared for this study, which were evenly divided into four groups consisting of kerfed and non–kerfed (control) groups that were each subjected to either air drying or RF/V drying. Specimens were kerfed by cutting with a circular saw parallel to the grain. The kerf width was 3 mm in each specimen, and the depth was approximately 60 mm. All specimens were subjected to HTLH pretreatment before drying.

HTLH pretreatment

HTLH pretreatment was conducted using a high–temperature dryer (SKD–50HP; Shinshiba; volume capacity 14 m^3; Figure 1). Table 1 lists the conditions for HTLH pretreatment used in this study. Specimens were stacked in the upper part of chamber, and the remaining space inside the chamber was filled with dummy timbers. A top plate was compressively loaded on top of the stack to prevent twisting of pillars.

Air drying

After HTLH pretreatment, kerfed and control specimens were air dried for seven months, during which time the average temperature, relative humidity, and wind velocity were 19.8°C, 66.5%, and 2.2 m/s, respectively.

Fig. 1. Stacking arrangement for HTLH pretreatment.

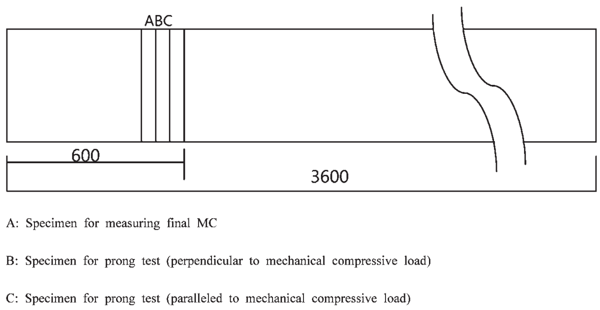


Fig. 2. Diagram of the MC section preparation for measuring moisture gradients and case hardening.

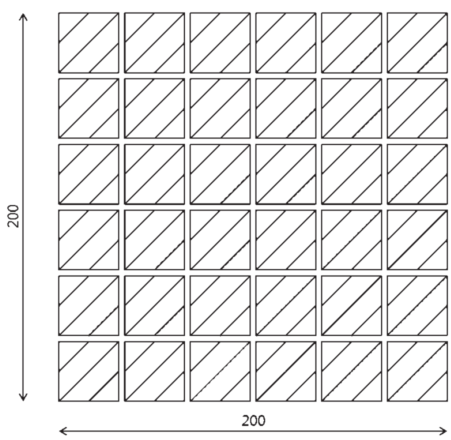


Fig. 3. Diagram of the MC section preparation for estimating the final MC distribution.

Table 1. Conditions and times for each stage of HTLH pretreatment

Stage	DBT (°C)	WBD (°C)	EMC (%)	Pretreating time
Presteaming	95	0	–	12
HTLH Pretreatment	120	27	3.3	64
Cooling	OFF	OFF	–	25
Total time				101

Table 2. Vacuum drying temperature schedule

Drying time (hour)	0~24	24~48	48~72	72~96	96~120	120~
Temperature (°C)	40	42	44	46	48	52

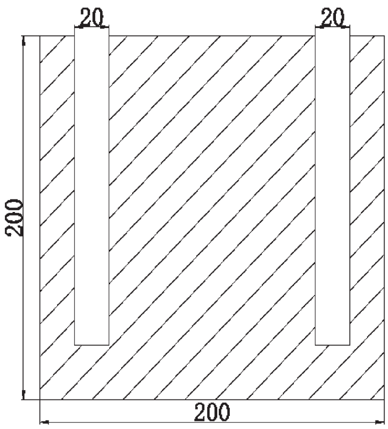


Fig. 4. Diagram of the case hardening section preparation after drying tests.

RF/V drying

The rectangular RF/V dryer used in this study was 600 cm long, 120 cm wide, and 67 cm deep. The RF/V dryer consisted of an upper cover made of soft and a radio–frequency oscillator with a maximum output of 25 kW and an operating frequency fixed at approximately 13 MHz. During operation, the oscillator was cycled on for 8 min and then off for 2 min. Specimens were stacked in the chamber and covered with a flexible rubber sheet, and were compressively loaded with a pressure of 10,000 kgf/m^2 during drying. Table 2 lists the RF/V drying conditions used in this study.

Drying characteristics

Several drying characteristics were evaluated in this study, namely drying curves, surface checking, twisting, extension of kerfing width, final MC distribution, case hardening, and internal checking. MCs and drying rates were measured for each specimen, and oven–dry weights were calculated based on the final MC of specimens. All moistures values were calculated in units of grams. MC measurements were obtained by first stopping the dryer and waiting for an appropriate amount of time before taking the measurement. The weights of specimens undergoing air drying were measured once per week until they became constant, whereas the weights of RF/V drying specimens were measured at 24 h intervals. After drying, the total length and number of surface checks present on the four surfaces of all specimens were estimated along with the maximum twist.

The kerf widening rate was calculated using equation (1) based on the specimen's kerf width before and after drying.

$$\text{kerf widening rate [\%]} = (W_a - W_b)/W_b \times 100\% \quad \text{—(1)}$$

W_a: kerf width after drying [mm]

W_b: kerf width before drying [mm]

The distributions of specimen MCs at the end of drying were estimated as indicated in Figure 2. Sample specimens were cut as shown in position A of Figure 2 and in Figure 3, and the final MCs were analyzed. Case hardening both parallel and perpendicular to the direction of the grain was investigated as shown in Figure 4. In addition, the total length and the number of internal checks present on the cross section were calculated for each specimen after drying.

RESULTS AND DISCUSSION

Drying rate and final MC

It is very difficult to dry large timbers because of the slow rate of moisture transportation in the radial and tangential directions. Figure 5 shows a graph of the MC of air–dried specimens as a function of drying time.

After HTLH pretreatment, MC was reduced from the green MC level to an MC under 18% (Figures 5 and 6). The initial MCs of kerfed and control specimens were approximately 70% and 57%, respectively. Likewise, the kerfed and control specimens were dried to about 16% and 18%, respectively, following 4 d of HTLH pretreatment. As such, the drying rates of kerfed and control specimens were 13%/day and 9%/day, respectively, after HTLH pretreatment. Air drying decreased the average MC by only up to 3%. After 4 days of HTLH pretreatment and 154 days of air drying, the MCs of kerfed and control specimens reached 14% and 15%, respectively. Thus, the air–dried wood samples would require additional drying to be useful for construction.

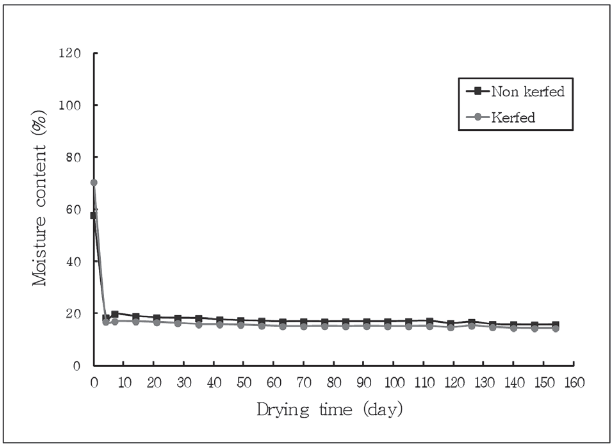


Fig. 5. MC versus air drying time.

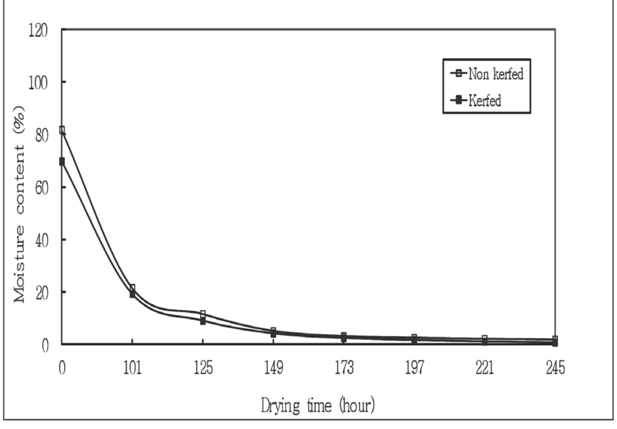
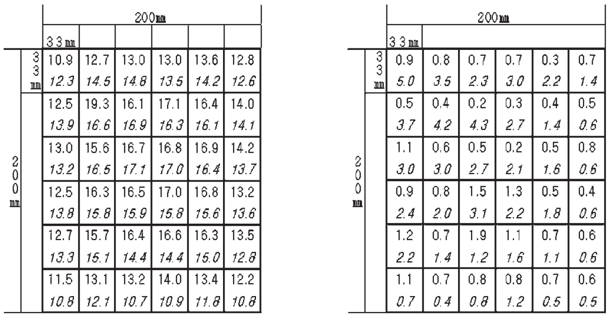


Fig. 6. MC versus RF/V drying time.



(a) (b)

Fig. 7. MC distributions at individual positions inside specimens after air and RF/V drying (italicized text: kerfed; normal text: control).

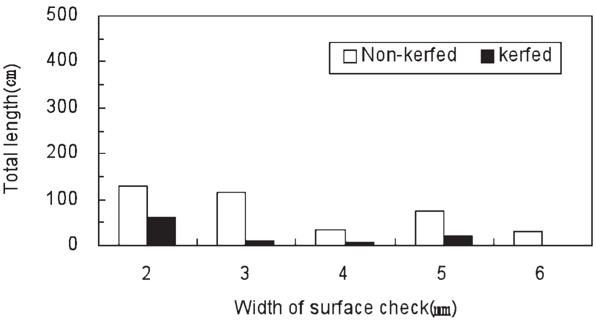


Fig. 8. Total lengths of surface checks for air–dried specimens.

A typical drying curve of a specimen subjected to HTLH pretreatment and RF/V drying is shown in Figure 6. The initial MCs of the kerfed and control specimens were 81% and 69%, and the kerfed and control specimens were dried to about 19% and 21%, respectively, following 4 d of HTLH pretreatment. Following 245 hours of RF/V drying, the MC of the control and kerfed specimens were both less than 5%. The highest drying rates obtained after 24 h of RF/V drying time were 0.388%/h and 0.369%/h for the kerfed and control specimens, respectively.

The MC distributions in the transverse directions inside individual specimens after air and RF/V drying are shown in Figure 7. For specimens subjected to air drying, the average moisture contents of the inner layer, intermediate layer, and outer layer of the control and kerfed specimens 600 mm from the end surface were 16.8%, 15.0, 14.3%, 16.5%, 15.5%, and 14.0%, respectively. On the other hand, the average moisture contents of the inner layer, intermediate layer, and outer layer of control and kerfed specimens subjected to RF/V drying were 0.9%, 0.8, 0.7%, 2.5%, 2.2%, and 1.9%, respectively, for the same location 600 mm from end surface. The moisture gradient with respect to thickness direction was smooth, and there were no significant differences between kerfed and control specimens. However, the moisture contents of the inner and outer layers of RF/V dried specimens were significantly less than those of air dried specimens. Indeed, the final moisture content of RF/V dried specimens was less than that of the air dried specimens by more than 10%. In addition, the MCs of all RF/V–dried sections were well below 3%, regardless of both the distance from the end surface and presence of kerfing. Thus, the differences in drying rates between the kerfed and control specimens were attributed to differences in the initial MC rather than the effect of kerfing.

Drying defects

Generally speaking, severe surface checking is prone to occur during the drying of large timbers due stress between the wood surface where moisture is evaporating and the inner layer of wood where it is wet. Indeed, long drying times and severe drying defects are associated with numerous problems such as increased costs of construction for wooden buildings; poor external appearance; and degraded strength, insulation, and durability.

In the present study, drying defects such as surface checking, twisting, kerf widening, case hardening, and internal checking were measured. With HTLH pretreatment was found to be effective in preventing surface checking during subsequent high–temperature vacuum drying. Comparisons of the extent of surface checking for kerfed and control specimens subjected to drying by air or RF/V are shown in Figures 8 and 9, respectively. The average width of surface checks for kerfed and air–dried specimens was less than 5 mm, whereas that for kerfed and RF/V–dried specimens was less than 3 mm. In con-

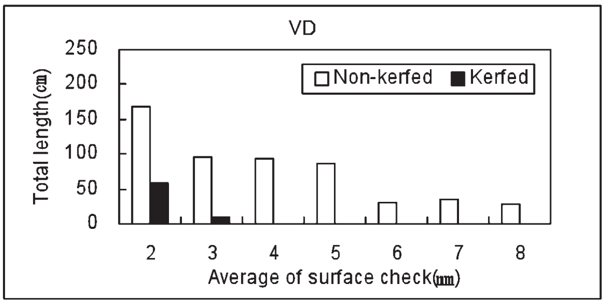


Fig. 9. Total lengths of surface checks for RF/V–dried specimens.

Table 3. Twist measurements after drying for each specimen type

Drying Method	Kerfing	Ration of twisting (mm/m)		
		Minimum	Average	Maximum
Air	control	2	3	4
	kerfed	5	6	6
RF/V	control	5	6	6
	kerfed	4	7	10

Table 4. Extension ratios of kerfing widths for air–dried and RF/D–dried specimens

Drying Method	Extension ration of kerfing width (%)
Air	200.5
RF/V	325.5

Table 5. Case hardenings ratios for air–dried and RF/V–dried specimens (%)

Drying method		Kerfing	Distance from the end of specimen (mm)					
			600		1200		1800	
			∥	⊤	∥	⊤	∥	⊤
HTLH	Air	control	0.08	0.39	–2.43	–2.53	–0.59	–9.10
		kerfed	–0.79	0.15	1.72	0.73	–1.78	0.39
	RF/V	control	0.10	0.37	0.61	3.53	1.46	1.02
		kerfed	0.52	3.05	–1.95	2.62	–2.57	–0.68

∥ , Parallel to pressure; ⊤, Perpendicular to pressure

Table 6. Internal check ratios for air-dried and RF/V-dried specimens(%)

Drying method		Kerfing	Distance from the end of specimen (mm)					
			600		1200		1800	
			TN	TL	TN	TL	TN	TL
HTLH	Air	control	0	0	0	0	0	0
		kerfed	0	0	0	0	0	0
	RF/V	control	0	0	0	0	0	0
		kerfed	0	0	0	0	0	0

TN, Total number of the occurred surface checks; TL, Total length of the occurred surface checks

trast, the width of surface checks for control RF/V–dried specimens was as high 8 mm. Based on this observation, it was concluded that kerfing reduces the width of surface checks.

Table 3 shows the extent of twisting after drying for all specimens. Twisting ranged from 2 to 5 mm/m for air–dried specimens and 5 to 10 mm/m for RF/V–dried specimens. Thus, RF/V appeared to cause more twisting than air drying. In contrast, kerfing had no significant effect on twisting between the two drying methods.

Table 4 lists the ratio of kerf widening measured after drying. Kerf widening of RF/V–dried specimens was greater than that of air–dried specimens. This difference was attributed to the fact that the MC of RF/D–dried specimens reached a lower final level than that of air–dried specimens, thereby leading to more severe drying deformation.

Table 5 shows the specimen case hardening ratios measured after air and RF/V drying. HTLH pretreatment was found to prevent case hardening of specimens regardless of kerfing. Lastly, Table 6 lists the presence of internal checks between groups. Significant differences in internal checking of dried specimens were observed. Based on these results, it was concluded that HTLH treatment was able to effectively prevent internal checking.

CONCLUSIONS

Differences in the effects of air and RF/V drying upon the drying characteristics of domestic red pine large square timbers were studied, including differences in drying rate, final MC, and drying defects. The effects of HTLH and kerfing pretreatment upon drying characteristics were also investigated. The results of this study are summarized as follows.

RF/V drying was faster than air drying and led to a lower average final MC in dried specimens. Kerfing pretreatment effectively prevented surface and internal checking, as well as twisting. Kerfing pretreatment also reduced the moisture gradient in the thickness direction when followed by RF/V drying.

Drying rates differed significantly depending on the drying method. The average time of RF/V drying from green to 3% MC was 245 h, while that for 4 days of HLH from green to 20% was 154. Based on these results, large square timbers subjected to HTLH–pretreatment and RF/V–drying are suitable for use in external structural applications. In addition, HTLH pretreatment is effective at preventing surface checking for both air drying and RF/V drying.

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