The Change in Permeability of Larch Boxed-Heart Timber During Drying After High Temperature and Low Humidity Treatment

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Abstract

Japanese larch (*Larix kaempferi*) boxed-heart timbers with the dimension of 100 × 100 × 1,000 mm were dried after being steamed at 100°C and 0°C wet-bulb depression for 5 hours, and then dried at 120°C and 30°C wet-bulb depression for 8, 12, and 16 hours, respectively. The radial permeability of the surface layers of the timbers during drying was measured to discover the moisture movement mechanism in the transverse direction. The radial permeability in the surface layers of pretreated timbers decreased and tended to decrease as pretreating time increased. The decreased permeability can be attributed to the reduced distance between microfibrils inside the surface layers of pretreated timbers attributable to the pretreatment. This reduced distance decreases the moving rates of the bound water and water vapor from the inner part to surface layers of pretreated timbers during drying. Therefore, the average drying rate of pretreated timbers was decreased.

High temperature and low humidity (HT–LH) treatment has been usually implemented prior to commercial kiln-drying of coniferous boxed-heart timbers in structural applications over 1 decade in Korea and 2 decades in Japan because it effectively controls surface checks on the timber (Yoshida et al. 2000; Katagiri et al. 2005, 2007; Lee et al. 2010; Ai et al. 2017). However, there have been some problems in the real production process. First was uneven final *M* (moisture content) distribution. It was often found that there were >25 percent of final *M*s in the core of boxed-heart timbers although average final *M* of the timbers reached <12 percent, especially for a large cross-section of boxed-heart timbers. The second problem was that the drying period of HT–LH-treated boxed-heart timbers was delayed by unknown causes. Hermawan et al. (2012) found that the drying time of sugi boxed-heart timbers (220 mm in diameter) pretreated at a temperature of 135°C for 10 hours was longer than that of the timbers pretreated for 3 hours and 7 hours. Moreover, they attributed this trend to the free water at the inner part (about 100% *M*) of the timbers could not be moved to the surface layer by capillarity tension force because of the lack of free water at the outer part (about 7% *M*). Whereas, they did not consider two other types of moistures (i.e., the bound water within cell walls and the water vapor in lumens) as accounting for the trend. Although Kang et al. (2020) also reported that drying rate of HT–LH-treated larch boxed-heart timbers was slower than that of control timbers and tended to decrease as pretreating time increased, they did not give an explanation for the trend. Hence, until now no complete explanation has been found for the trend.

Permeability was a measure of the ease with which a fluid flows through wood under the influence of a pressure gradient, and thus it was considered as an indicator of drying

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rate (Zhang et al. 2008, Jang et al. 2019). Lihra et al. (2000) measured the permeability of balsam fir and used the permeability as an indicator to predict the drying rates. In our previous study (Kang et al. 2020), the drying rate of the surface layers of the timbers was not measured because it was difficult to accurately measure the *M* of the surface layers by the weight-measuring method during drying. Thus, it is necessary to evaluate drying rate of the surface layers by measuring permeability in order to accurately compare drying behavior of the surface layers of different groups (pretreated and control) of timbers during drying. In view of the above considerations, subsequent research introduced permeability to evaluate the drying rate of moisture through the transverse moisture pathways in the surface layers of the timbers to explain the cause of the trend in this study.

The transverse moving mechanism of moisture is not only related to the uneven final *M* distribution and delayed drying period of HT–LH-pretreated boxed-heart timbers, but also to some quality problems that occurred during hot pressing plant fiber boards and wood-reconstituted panels, etc. Thus, it is meaningful to explore the moisture transverse moving mechanism during larch boxed-heart timbers drying after HT–LH treatment in this study.

Materials and Procedures

The boxed-heart timbers with the dimension of 100 × 100 × 1,650 mm were sawn from green Japanese larch (*Larix kaempferi* G.) logs with an average diameter of 150 mm. Then 20-mm-thick cross-sections were cut at distance of 300 mm from each end of the timbers, were oven-dried, and then green *M* of each timber was calculated. The ends of the specimens (dimension of 100 × 100 × 1,000 mm) were coated with waterproof paint. The average green *M* of specimens was 38.10 ± 0.25 percent while the average final *M* of specimens was 12.95 ± 0.79 percent. Next, 60 specimens (20 pieces for each HT–LH treatment) were steamed at 100°C dry-bulb temperature and 0°C wet-bulb depression for 5 hours. Then they were dried at 120°C dry-bulb temperature and 30°C wet-bulb depression for 8, 12, and 16 hours in a forced-air drier (SKD-90HPT, Shinshiba, Asahikawa, Japan), respectively. Twenty pieces of control (untreated) specimens were stacked in the same drier and dried together with HT–LH-pretreated specimens using pretreatment and drying conditions (Table 1). Eight pieces of the specimens with high initial *M* selected from each treatment and control specimens were weighed at intervals of 24 hours to measure *M*s during drying (Table 2).

Table 1.—Pretreatment and drying conditions.[a]

Drying stage	Moisture content range (%)	Dry-bulb temperature (°C)	Web-bulb depressions (°C)	Treatment time (h)
Steaming		100	0	5
HT–LH		120	30	8, 12, 16
1	>40	45	3	48
2	40–30	45	4	72
3	30–25	50	6	144
4	25–20	55	8	72
5	20–15	60	10	48
6	<15	60	14	120

[a] HT–LH = high temperature and low humidity treatment.

Forty specimens were pulled out of the drier during each drying stage (initial, middle, and last stage of drying), respectively, and 100-mm-long check-free sections were cut off at a distance of 200 mm from an end of each specimen (Fig. 1b). Then 5-mm-thick surface layers (100 mm long, 100 mm wide) were cut off parallel to a surface of 100-mm-long sections (Fig. 1c). And then the rounded specimens with a diameter of 60 mm were sawn off from 5-mm-thick surface layers by a hole saw (Cai and Oliveira 2007, Zhang et al. 2008, Ai et al. 2017 [Fig. 1D]). The number of 5-mm-thick rounded specimens for each drying stage was 40 pieces (10 pieces for each treatment and control). Therefore, the total number of rounded specimens was 120 pieces (Table 2). The average *M* of rounded specimens was 24.6 ± 0.45 percent for initial, 14.9 ± 0.61 percent for middle and 10.5 ± 0.21 percent for the last drying stage. The radial permeability of rounded specimens was measured by a Capillary Flow Porometer (CFP-1200AEX, Porous Materials Inc., Ithaca, USA) under the gaseous pressure of 1 bar after the lateral surfaces of specimens were coated with quick adhesive (Zhang et al. 2008).

Results and Discussion

The result of measured radial permeability of the surface layers of control and HT–LH-treated specimens is showed in Figure 2. Statistical analysis of the radial permeability using the SAS software indicated that there was significant differences in radial permeability among different group of specimens (HT–LH treated for 8 h, for 12 h, for 16 h, and control; $P < 0.0001$) and among different drying stages ($P < 0.0001$). As seen in Figure 2, the radial permeability inside the surfaces of HT–LH-treated specimens during each drying stage was lower than that of control specimens and tended to decrease as pretreating time increased. This trend is in agreement with the drying rate found in a previous study (Kang et al. 2020). This tendency implies that the moisture transverse pathways in the surface layers of HT–LH-treated specimens become smaller and/or fewer compared with control specimens, and that they increase as pretreating time increases.

The moisture diffusivity in the surface layers of presteamed specimens is increased during presteaming (Cong et al. 1999). Increased moisture diffusivity favors increased moisture evaporation because of the redistribution and partial removal of extractives from wood, some extractive being dissolved, and certain hydrolysable components being degraded during presteaming (Cong et al. 1999).

The high temperature and low humidity also accelerates the drying rate of the surface layer during HT–LH treating. These result in larger tensile stresses in the surface layers of HT–LH-treated specimens compared with control specimens. As HT–LH treating proceeds, the larger tensile stresses is reversed to larger compressive stresses (Erickson 1989). The larger compressive stresses and considerably decreased *M*s induce larger compressive creep, which means that additional displacement and fixation occur between microfibrils inside the surface layers in the transversal direction of the specimen. After the displacement, the distance between microfibrils is reduced because transverse shrinkage is increased under larger compressive stresses in the same application direction of shrinkage and compressive stresses. This

Table 2. Information about specimens[a].

To measure	Treatment	Dimension (mm)	Quantity	*M*
M during drying and end of drying	HT–LH 8 h	100 × 100 × 1,000	20	
	HT–LH 12 h		20	
	HT–LH 16 h		20	
	Control		20	
M during drying	HT–LH 8 h	100 × 100 × 1,000	2	
	HT–LH 12 h		2	
	HT–LH 16 h		2	
	Control		2	
permeability	HT–LH 8 h	Diameter 60 × 5	3 × 10	24.6% at initial;
	HT–LH 12 h		3 × 10	14.9% at middle;
	HT–LH 16 h		3 × 10	14.9% at middle;
	Control		3 × 10	10.5% at end

[a] *M* = moisture content; HT–LH = high temperature and low humidity treatment.

suggests that the moisture transverse pathways in the surface layers of HT–LH-treated specimens are smaller or/and fewer. Consequently, permeability of the surface layers of HT–LH-treated specimens was decreased compared with control specimens during the whole drying period (Fig. 2). As pretreating time increases, the compressive creep becomes larger; thus, the permeability of HT–LH-treated specimens is decreased the most for 16 hours, the least for 8 hours, and a medium amount for 12 hours of pretreating time.

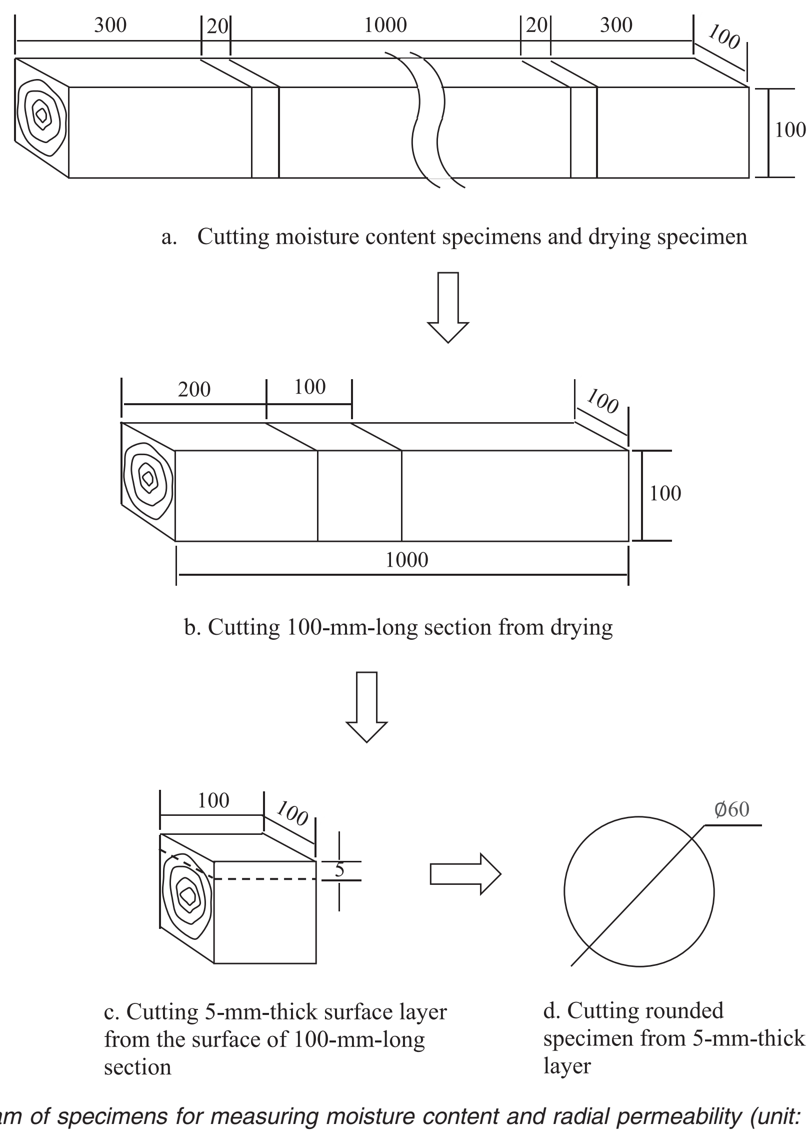

Figure 1.—Cutting diagram of specimens for measuring moisture content and radial permeability (unit: mm).

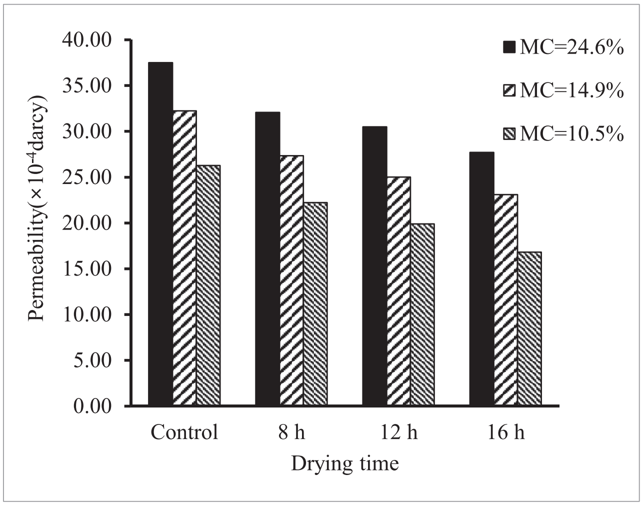

Figure 2.—Permeability of the surface layers of control and pretreated specimens.

Meanwhile, the reduced distance between microfibrils in the surface layers also decreases the moving rates of the bound water and water vapor from the inner part to surface layers of HT–LH-treated specimens. Moreover, these surface layers obstructed free water to move by capillary forces from the inner part to surface layer of specimens during HT–LH pretreatment (Hermawan et al. 2012). Thus, the average drying rate of HT–LH-treated specimens was slower than that of control specimens and tended to decrease as pretreating time increased.

For the same reason as discussed above, the surface layers, in which wood structure had been changed by HT–LH pretreatment, of the timber had a delayed drying period or incurred uneven final *M* distribution in the transverse direction of the timber. This finding is also important to understand the moisture moving mechanism in the surface layers of other materials, such as plant fiber boards or wood-reconstituted panels, during hot pressing. For example, some quality problems such as surface cracks often happened during hot pressing of medium-density fiberboard because the surface layers, in which *MS* deformation was formed, of the board hindered moisture moving from inner part to the surface layers.

Conclusion

According to the result of this study, the following conclusion can be obtained. The radial permeability in the surface layers of HT–LH-treated specimens decreased compared with that of control specimens and tended to decrease as pretreating time increased. This tendency can be caused by the reduced distance between microfibrils inside the surface layers due to HT–LH treatment. The reduced distance between microfibrils inside the surface layers of HT–LH-treated specimens decreases the moving rates of the bound water and water vapor from the inner part to surface layers of the specimens during kiln-drying. Therefore, average drying rate of HT–LH-treated timbers was decreased during whole drying period when compared with control specimens.

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