An Investigation of Drying Technologies for Small Masson Pine Logs

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Abstract

Small-diameter Masson pine (*Pinus massoniana*) logs with a length of 800 mm and a diameter ranging from 108 to 132 mm were dried with a mild schedule in a laboratory dryer. The drying experiments were done using logs with or without bark and with or without a longitudinal cut. The reduction in moisture content over time was monitored by a resistance-type moisture meter. The results indicated that small-diameter Masson pine logs can be dried by the proposed schedule successfully. Debarking reduced drying times; however, more checks on the log surfaces were detected. Making a longitudinal cut in logs helped to increase the drying rate and reduce drying stresses.

Plantations play an important role in improving the ecoenvironment in China; with an estimated 1.5 billion m^3 of standing volume and accounting for around 12 percent of the country's total forest volume, they are important in restoring and rebuilding the total forest ecosystem (Duan et al. 2010). Of the standing forest plantations, the productive plantation area is 23.18 million hectares, with a standing volume of 1.15 billion m^3. The main plantation species are Chinese fir (*Cunninghamia lanceolata* (Lamb) Hook.), Masson pine (*Pinus massoniana*), and poplar (*Populus lasiocarpa* Oliv.), which account for approximately 60 percent of all plantation areas in the country. Plantation forest often contains a significant amount of small-diameter trees and branches. Currently, large quantities of potentially useful but largely underutilized wood materials are available for conversion into value-added wood products.

In China, small-diameter logs are useful in structural applications, such as poles and piles. Because less processing is required and less waste is generated than in timber manufacturing, poles have a greater net value per volume of harvested fiber. However, because most potential uses require dried poles, an effective drying technology for small-diameter plantation logs that optimizes utilization and improves value recovery is needed. In this study, Masson pine was used as an example to develop effective drying schedules for small-diameter logs.

In comparison to the chemical composition of mature wood, planted juvenile wood is lower in cellulose, higher in hemicelluloses, higher in alcohol-benzene soluble content, and higher in lignins (Zobel and Sprague 1998). Physically and anatomically, juvenile wood is characterized by thinner cell walls, larger lumen diameters, a higher S2 layer microfibril angle, shorter fiber length, lower specific gravity, lower transverse shrinkage, higher longitudinal shrinkage, and higher moisture content (MC). The difficulty in drying small-diameter logs is associated mainly with the large amount of shrinkage, which is due to the greater fiber angle on the S2 layers of the tracheid walls than that found in mature wood.

The value and usefulness of juvenile wood relative to mature wood is significantly affected by the differences in their chemical, anatomical, and physical properties (Bendtsen 1978). The longitudinal shrinkage of mature pine ranges from 0.1 to 0.3 percent from green to oven dry, compared with 1 to 2 percent from green to oven dry for juvenile pine (Lamb and Wengert 1987). A high amount of shrinkage in the longitudinal direction results in tensile forces that can cause the lumber to warp. Cooper et al. (2005) developed a dielectric method to detect the juvenile wood in green lumber; this allows juvenile wood to be separated from mature wood and dried using procedures designed to reduce warp and the resultant value loss.

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Because of the larger cross section of logs relative to lumber, it is not an easy task to dry logs using the conventional kiln-drying method. However, numerous studies have been conducted to develop schedules to deal with hard-to-dry species. With the aid of computer modeling, subalpine fir (*Abies lasiocarpa*) lumber containing wet pockets was dried successfully using a mild schedule (Cai and Oliveira 2008). Computer tomography imaging was used to monitor moisture transfer during the drying of 105 by 105-mm timber to minimize check formation (Lazarescu et al. 2010). An artificial neural network was developed to predict drying rates for hem-fir timbers (101 mm^2); accurate control of the drying process led to better quality timber (Wu and Avramidis 2006). To relieve drying stresses and reduce twist, a superheated steam–vacuum kiln was used to dry radiata pine (*Pinus radiate*) timber (Pang and Pearson 2004). High-quality Casuarina timber was obtained using solar drying technology (Khater et al. 2004).

In an attempt to develop cost-effective drying schedules for hard-to-dry species, such as subalpine fir, microscopic analysis was used to investigate moisture transfer between the wood cells (Zhang and Cai 2009, 2011). A conventional low-temperature drying schedule was developed for *Betula pendula* timber (Mottonen 2006). The final MC gradient (the difference in MC between the core and shell) was greater than in the vacuum-dried timber; however, the timber quality, in terms of warp, split, and check, was acceptable.

There are a number of studies on heating or steaming logs in the literature. Aydin and Colakoglu (2008) examined the effect of log presteaming on the strength of plywood panels; results varied depending on the wood species. They found that in spruce (*Picea* sp.) plywood panels, the bending strength and the modulus of elasticity values increased, but these values decreased in alder *(Alnus* sp.) plywood panels after the steaming process. Numerous studies (e.g., Steinhagen 1991, Calonego and Severo 2006) have been conducted to estimate the temperature changes and heating times in logs during the heating and steaming process.

Because it takes a long time to dry logs in kilns, Simpson and Wang (2004) used air drying for small-diameter ponderosa pine (*Pinus ponderosa*) and Douglas-fir (*Pseudotsuga menziesii*) logs and developed regression models to estimate drying times for logs 102 to 203 mm in diameter. In order to reduce surface stresses on Japanese cedar (*Cryptomeria japonica*) boxed-heart square timber during drying, Fujimoto et al. (1994) made a longitudinal groove in the 10.5 by 10.5-cm timber prior to drying. The results indicated that, although the groove increased the shrinkage in width, surface stresses were significantly reduced. As a result, fewer checks and splits were observed on the dried timber compared with the timber without grooves. More recently, Katagiri et al. (2007) used a high-temperature (120°C) treatment before drying to reduce surface checks for the boxed-heart square timber.

In an attempt to extend the utilization of small-diameter Masson pine juvenile logs, the objectives of this study were to develop schedules for the drying of small-diameter Masson pine logs, evaluate the effect of debarking on the quality of dried logs, and explore a method for reducing the drying stresses.

Materials and Methods

Sourced from Anhui Province in China, 15 Masson pine logs with diameters ranging from 10 to 14 cm and initial MC ranging from 40 to 45 percent were end sealed with epoxy resin and shipped to the laboratory. The logs were randomly separated into three groups of five logs each. Prior to drying, the logs were pretreated as follows:

1. To reduce drying stresses, warp, and checking, a 10-mm cut in the longitudinal direction was made in the logs in two of the groups (Fig. 1).
2. To explore the effect of the bark on the drying process, the logs in one group were debarked prior to drying.

Detailed information about these logs is presented in Table 1. A laboratory-made dryer with an accuracy of ±1°C and ±2 percent relative humidity was used to dry the logs, and all experiments used a preset air velocity of 0.5 m/s. The initial MC was determined by oven drying the discs (20 mm thick) that were trimmed from both ends of the logs before drying. A pin-type (resistance) moisture meter was used to monitor the reduction in MC during the drying process. Three pins with a length of log radius, ½ radius, or ⅓ radius were inserted into the logs along the radial direction (Fig. 1). Because the longitudinal cut was made from the surface to the center of the logs, the actual center point for MC measurement was approximately 10 mm away from the cut (Fig. 1). Based on previous experience, a mild drying schedule for small-diameter Masson logs was proposed (Table 2). Presteaming is an effective way to soften bark, release stresses, and increase the rate of moisture movement. The steaming time was about 12 to 15 hours. To reduce the difference in MC between the core and the shell, an equalization step was used at the end of the drying process (Table 2).

In order to examine the MC difference in the longitudinal direction of the logs after drying, three 20-mm discs were cut along the length of each log; one disc was cut at midlength, and the other two discs were cut 30 cm away from each end. To determine the MC gradient in the radial direction of the logs, one 20-mm disc was cut at the

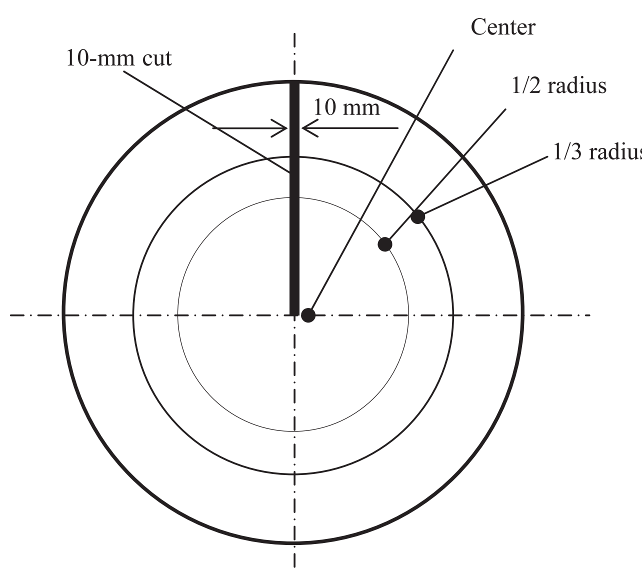

Figure 1.—Cross section of the log with a cut and three moisture content measurements.

Table 1.—Log information.

Group	Avg. diameter (cm)	Initial moisture content (%)	Log length (cm)	Description of logs
A	13.2	43.5	80	With bark and without cut
B	10.8	43.0	80	With bark and a cut
C	12.0	40.0	80	Without bark and with a cut

Table 2.—Drying schedule for small-diameter Masson pine logs.

Moisture content (%)	Dry-bulb temp (°C)	Wet-bulb temp (°C)	Time (h)
Presteaming	75	75	12–15
>40	48	46	
40–36	50	46	
35–31	50	45	
30–26	55	47	
25–21	60	47	
20–15	65	50	
<15	75	50	
Conditioning	80	75	12–15

midlength of each log. Those discs were cut into six pieces (Fig. 2). The MC values of the cut pieces were determined by the ovendry method.

Because twist is difficult to determine for logs, warp was expressed by bow only. A log was placed on a laboratory-made aluminum bench, and the highest gap between the log and the bench surface was measured using a taper gauge. To examine the difference in drying stress among the three log groups, a 20-mm-thick disc was cut at the midlength of each log, and stress samples were prepared as illustrated in Figure 3a. After 24 hours of stress release at ambient conditions, the maximum displacement d between the two stress samples was measured as shown in Figure 3b.

Results and Discussion

The MC value for each log was the average of the three measurements obtained at the center, ½ log radius, and ⅓ log radius (Fig. 1). The reduction in MC over time for each log group is illustrated in Figure 4. Because of the limitations of the resistance-type moisture meter, only MC

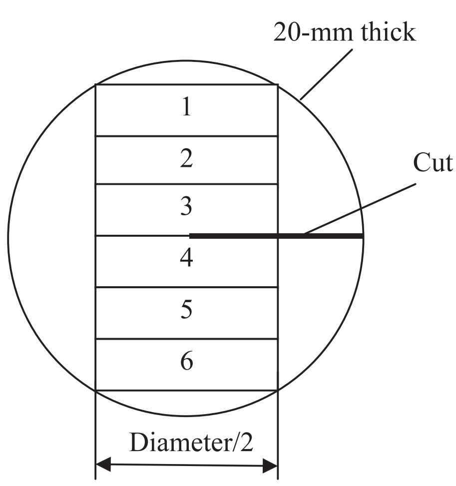

Figure 2.—Sample cuttings for determination of moisture content gradient.

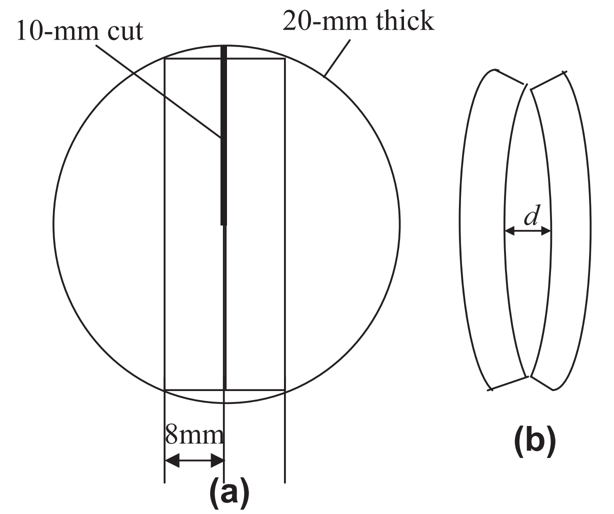

Figure 3.—Sample preparation for determination of drying stresses: (a) stress sample cutting; (b) after 24 hours of stress releasing.

values below the fiber saturation point can be obtained accurately. The initial and final MC and drying time for each group are presented in Table 3. Logs in Group C (debarked and with a cut) had the shortest drying time; it seems reasonable that moisture would move out of logs without bark more easily and that the longitudinal cut would also assist in moisture movement. Table 3 also demonstrates an MC longitudinal gradient because the center discs had higher MCs than the discs chopped 30 cm from the ends.

Figure 5 illustrates the MC changes during the drying of Group A (with bark, no cut); as expected, MC was reduced more quickly at the ⅓ log radius, followed by the ½ log radius and then by that at the center of the logs. However, below the fiber saturation point, no large difference is seen among the three curves (Fig. 5). The minor MC gradient

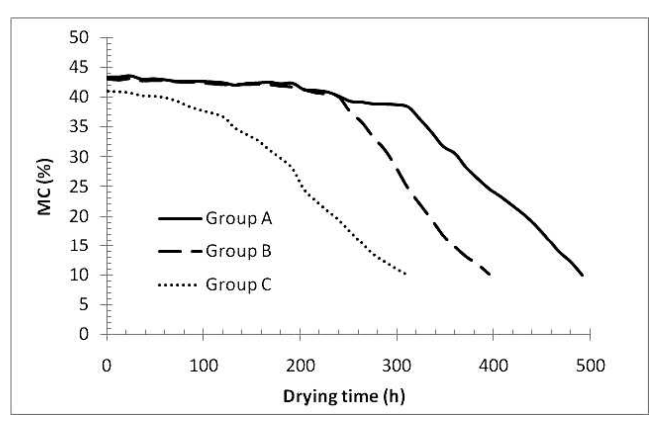

Figure 4.—Drying curves for Groups A, B, and C. MC = moisture content.

Table 3.—Initial and final moisture content (MC) and drying times.[a]

Group	Initial MC, avg. (SD) (%)	Final MC (%)				Drying time (h)
		Disc 1	Disc 2	Disc 3	Avg. (SD)	
A	43.5 (3.29)	9.8	10.2	9.8	9.9 (0.23)	492
B	43.0 (3.59)	10.1	10.6	9.9	10.2 (0.36)	396
C	40.9 (2.93)	9.8	10.1	9.9	9.9 (0.15)	312

[a] Disc 2 was cut at midlength of the log, and Discs 1 and 3 were cut 30 cm from each end.

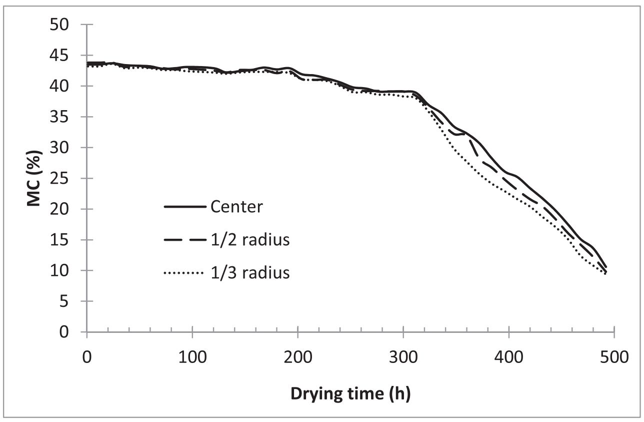

Figure 5.—Drying curves for the three locations in logs of Group A. MC = moisture content.

among the three radial locations shows that the majority of the moisture was moved out from the log ends rather than the surfaces because the bark obstructed evaporation from the log surfaces during drying.

Figure 6 demonstrates the MC changes over time at the three locations during the drying of Group B (with bark and a cut). Comparing Figures 5 and 6 shows that the longitudinal cut reduced the drying time (from 492 to 396 h). However, the impact of the cut on the MC gradient was minor because, as in Figure 5, no substantial difference is seen among the three curves in Figure 6.

Figure 7 illustrates the MC reduction over time at the three locations during the drying of Group C (debarked logs with a cut). Similar to results for Groups A and B, the center disc in Group C had the slowest MC reduction rate, and the disc at the ⅓ log radius had the fastest drying rate. Without bark to trap moisture in Group C logs, the transverse moisture transfer rate was enhanced radically, resulting in a drastic reduction in the MC at the ⅓ radius (Fig. 7).

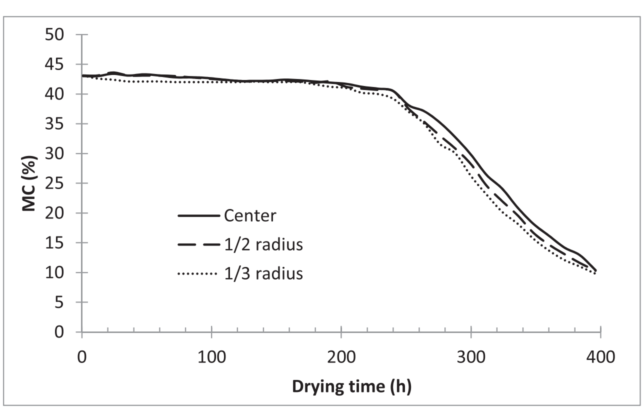

Figure 6.—Drying curves for the three locations in logs of Group B. MC = moisture content.

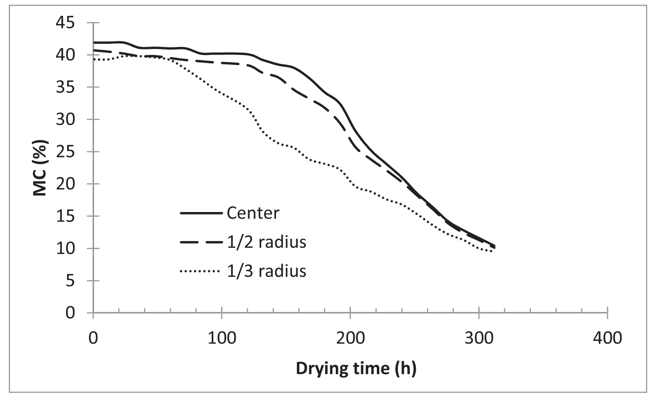

Figure 7.—Drying curves for the three locations in logs of Group C. MC = moisture content.

Figures 5, 6, and 7 illustrate that the radial MC gradient in Group C was higher than the gradients in Groups A and B. More moisture moved out of log surfaces in Group C, as a result of debarking.

Drying stress was affected by the longitudinal cut; compared with Group A, the displacements (*d* in Fig. 3b) in the stress samples in Groups B and C were reduced by approximately 50 percent (Table 4). Based on analysis of variance (ANOVA) tests, at $P = 0.05$, the null hypotheses were rejected between Group A and Groups B and C, indicating that drying stresses were significantly reduced by the cut. The null hypothesis was accepted between Groups B and C; no significant difference was found between them. Note that debarking may not affect drying stress. Our finding that the longitudinal cut helped release stresses during drying agrees with the results found in a study that examined drying Japanese cedar timber (Fujimoto et al. 1994).

Table 4 shows that there was less bow for Groups B and C compared with Group A. However, ANOVA results

Table 4.—Drying stress and bow.

Group	Displacement *d*, avg. (SD) (mm)[a]	Bow, avg. (SD) (mm)[b]
A	2.31 (0.22)	4.66 (0.46)
B	1.11 (0.18)	3.89 (0.30)
C	1.03 (0.16)	3.32 (0.45)

[a] As an indicator of drying stress, the displacement *d* is shown in Figure 3b.
[b] Gaps between the logs and the bench.

Table 5.—End and surface checks.[a]

Group	End checks			Surface checks		
	Avg. no. of checks on each log	Avg. length (mm)	Avg. width (mm)	Avg. no. of checks on each log	Avg. length (mm)	Avg. width (mm)
A	3	7.5	1.5	0	—	—
B	2	7.3	2	1	16	1
C	5	13	3	3	29	2.5

[a] The checks with a width less than 0.5 mm or a depth less than 1 cm were not taken into account.

indicated that the difference was significant only when comparing Groups A and C; no significant differences in bow were found between Groups A and B or between Groups B and C. Results indicate that debarking plus a cut may reduce the bow during drying. Because they had the shortest drying time, the log surfaces in Group C showed the most serious checking (Table 5). Compared with Group B, the number and size of checks on the surfaces of logs in Group C were doubled. Results indicate that the checks were probably increased by debarking prior to drying. The end checks were unexpectedly increased in Group C; it seems reasonable to suppose that the 10-mm cut destroyed the balance among the wood cells and that the resultant uneven shrinkages during drying caused more end checks.

Using this proposed schedule, the average final MC of the logs ranged from 9.5 to 10.5 percent, the MC difference in the longitudinal direction varied from 3 to 5 percent, and the MC difference in the radial direction (Fig. 2) was within 2.5 percent. The higher MC gradient in the longitudinal direction than that in the radial direction supports the idea that more moisture moved out from the ends than from the surfaces of the logs. The values achieved for both bow (Table 4) and checks (Table 5) fall within limits permitted for Grade No. 2 lumber based on Chinese Standard GB 6491-1999 (General Administration of Quality Supervision, Inspection and Quarantine of the People's Republic of China 1999).

Conclusions

The following conclusions were drawn from the laboratory experiments:

1. Small-diameter Masson pine logs can be dried by the proposed schedule (Table 2) successfully.
2. Debarking of logs increased the moisture transfer in the transverse direction. As a result, the drying time was shortened.
3. Drying stresses were considerably reduced by making a longitudinal cut in logs (Fig. 1) prior to drying.

Although this study was completed in a laboratory dryer with a limited number of replications, the results reveal a promising trend. Future studies will be carried out under mill conditions with a larger sample size to lead to a better understanding of the drying of small-diameter logs.

Acknowledgments

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