KILN-DRYING MAPLE STRUCTURAL LUMBER FROM LOG HEART CANTS

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ABSTRACT

Structural lumber products are traditionally manufactured from softwoods. However, with shrinking supplies of softwood lumber and abundant supplies of hardwood lumber, there is increasing interest in the use of hardwoods for structural applications. One factor that will be important in both the technical and economic feasibility of using hardwoods for structural lumber is drying. This study investigated the feasibility of using accelerated kiln schedules in drying maple lumber for structural uses. Traditionally, kiln schedules for maple lumber intended for appearance products were developed so that surface checking or discoloration would not develop. However, these are not degrading features in structural lumber so it is not necessary to use conservative and slow kiln schedules. In this study, maple lumber was dried in a laboratory-scale kiln in a series of incrementally more severe schedules. The result was that even the most severe, thus the most efficient, schedule caused no more structural grade loss than did the mildest schedule. This will make a positive contribution to the economics of structural applications for hardwood lumber. Using a computer simulation based on the drying time in the laboratory-scale kiln, the drying time of hard maple from 60 to 19 percent moisture content in a commercial-sized kiln was estimated to be about 4 days.

Low-grade hardwood lumber generally has low value (4). A potential higher value use for this low-grade hardwood is structural lumber (11), either for individual boards or used in trusses and I-joists. Traditional hardwood dry kiln schedules have been developed for lumber intended for appearance-type products such as furniture, cabinetry, and millwork. This means that the kiln schedules are conservative, slow, and designed to virtually eliminate even minor drying defects, such as small surface checks or discolorations from excessive kiln temperatures. In structural products, surface checking and discoloration are not considered defects. Therefore, we anticipate that kiln schedules for these end products can be more severe, faster, and more efficient than traditional hardwood schedules. Additional factors that will shorten drying time compared with traditional hardwood schedules are the higher final moisture content (MC) and wider allowable MC distribution of 15 to 19 percent in structural lumber compared with 6 to 8 percent for traditional hardwood uses. Drying from 15 to 19 percent MC to 6 to 8 percent is a significant portion of total drying time and would be eliminated in lumber for structural uses. An efficient kiln schedule would make a positive contribution to the economics of producing structural lumber products from low-grade hardwood lumber.

The main objective of this study was to begin development of a kiln schedule for standard 38- by 140-mm (nominal 2- by 6-in.; hereafter called 2 by 6's) maple lumber that is more severe, thus faster than traditional maple schedules, but still maintains the quality necessary for use in trusses, I-joists, or other structural products. Another objective was to estimate how much longer the drying times would be in a commercial-sized dry kiln compared to the laboratory-scale kiln used in this study.

BACKGROUND

The use of hardwoods for structural lumber has been studied in the past. Thompson (15,16) evaluated the technical and economic aspects of producing studs from aspen. In the 1980s the Saw-Dry-Rip (SDR) process was studied for several hardwood species and is described for yellow-poplar and aspen by Maeglin (7,8). The main purpose of the SDR process was to reduce warp, especially crook, and was found to be effective, especially when the kiln-drying was at a high temperature (113°C) (235°F). However, because SDR-produced boards are live-sawed, they are a combination of high-quality wood from the outer part of

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† Forest Products Society Member.
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Forest Prod. J. 48(6):70-76.

the log and low-quality wood from the center of the log. In a species like maple, it is not economically viable to sacrifice high-grade outer boards, which command more than $423/m^3 ($1,000/thousand board feet (MBF)) (4) by including wood in them that will drag the grade, thus value, down to less than a third of that value.

McDonald and Whipple (9) compared yields of standard 38- by 89-mm (nominal 2- by 4-in.) red oak stress-graded dimension lumber from USDA Forest Service factory- and construction-grade logs and found approximately equivalent yields between them. McDonald et al. (10) also evaluated yields of red maple, stress-graded standard 38- by 89-mm (nominal 2- by 4-in.) lumber from various factory grades of logs. High yields (73%) were obtained from factory grade F1, but only about 44 percent from F2 logs and 38 percent from F3 logs.

McDonald et al. (11) explored the potential of producing hardwood structural lumber from log heart cants, including railroad ties and pallet cants of six hardwood species. Their purpose was to look at the economic and technical aspects of producing this lumber from the low-grade inner part of logs, thus avoiding including the high-grade, high-value wood from the outer portion of logs. Hard maple maintained its grade when dried, but beech, hickory, red maple, yellow-poplar, and red oak showed an increased frequency of below-grade boards when dried.

MATERIALS AND METHODS

The general approach of this study was to compare kiln schedules of increasing severity, with the starting point being the traditional schedule for lumber intended for appearance-type products (2). The basis of comparison was drying time and warp assessed by both laboratory observations and visual grade according to the Southern Pine Inspection Bureau (SPIB) rules for structural lumber (14).

Hard maple was the focus of the study, with five kiln schedules tested. Two schedules for soft maple were also included. The seven groups of lumber, ranging from about 2.6 to 3.1 m^3 (1,100 to 1,300 BF) each, were obtained from the Upper Peninsula of Michigan. The lumber was sawed there from cants

TABLE I. – Kiln schedules, for drying hard and soft maple. TABLE 2a.– Final MC, warp, and shrinkage for hard and soft maple 2 by 6's.

Moisture content	Nominal dry-bulb temperature		Wet-bulb depression		Wet-bulb temperature		EMC	Species
(%)	(°C)	(°F)	(°C)	(°F)	(°C)	(°F)	(%)	
Schedule 1								
50+	49	120	3.9	7	45	113	14.1	Hard maple
50 to 40	49	120	5.6	10	43	110	12.1	Soft maple
40 to 35	49	120	8.3	15	41	105	9.7	
35 to 30	49	120	13.9	25	35	95	6.6	
30 to 25	54	130	22.2	40	32	90	3.8	
25 to 19	82	180	27.8	50	54	130	3.3	
Schedule 2								
50+	54	130	3.9	7	51	123	14.0	Hard maple
50 to 40	54	130	5.6	10	49	120	12.1	
40 to 35	54	130	8.3	15	46	115	9.7	
35 to 30	54	130	13.9	25	41	105	6.8	
30 to 25	60	140	22.2	40	38	100	4.1	
25 to 19	82	180	27.8	50	54	130	3.3	
Schedule 3								
50+	60	140	3.9	7	56	133	13.8	Hard maple
50 to 40	60	140	5.6	10	54	130	11.9	Soft maple
40 to 35	60	140	8.3	15	52	125	9.4	
35 to 30	60	140	13.9	25	46	115	6.9	
30 to 25	66	150	22.2	40	43	110	4.2	
25 to 19	82	180	27.8	50	54	130	3.3	
Schedule 4								
50+	66	150	3.9	7	62	143	13.7	Hard maple
50 to 40	66	150	5.6	10	60	140	11.8	
40 to 35	66	150	8.3	15	57	135	9.5	
35 to 30	66	150	13.9	25	52	125	6.9	
30 to 25	71	160	22.2	40	49	120	4.3	
25 to 19	82	180	27.8	50	54	130	3.3	
Schedule 5								
50+	71	160	3.9	7	67	153	13.4	Hard maple
50 to 40	71	160	5.6	10	66	150	11.5	
40 to 35	71	160	8.3	15	63	145	9.4	
35 to 30	71	160	13.9	25	57	135	6.8	
30 to 25	77	170	22.2	40	54	130	4.4	
25 to 19	82	180	27.8	50	54	130	3.3	

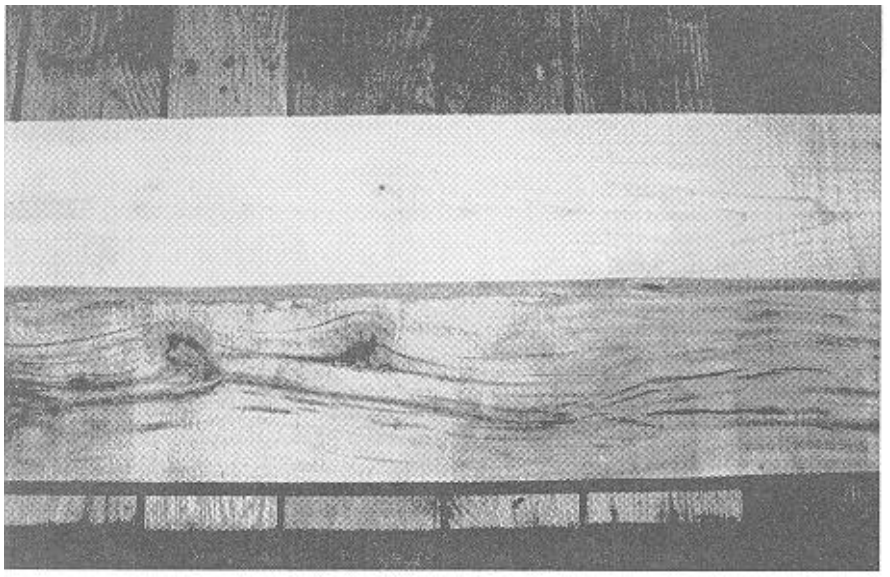

Figure 1. – Examples of extremes in surface checking: no checks (top), major surface checking (bottom).

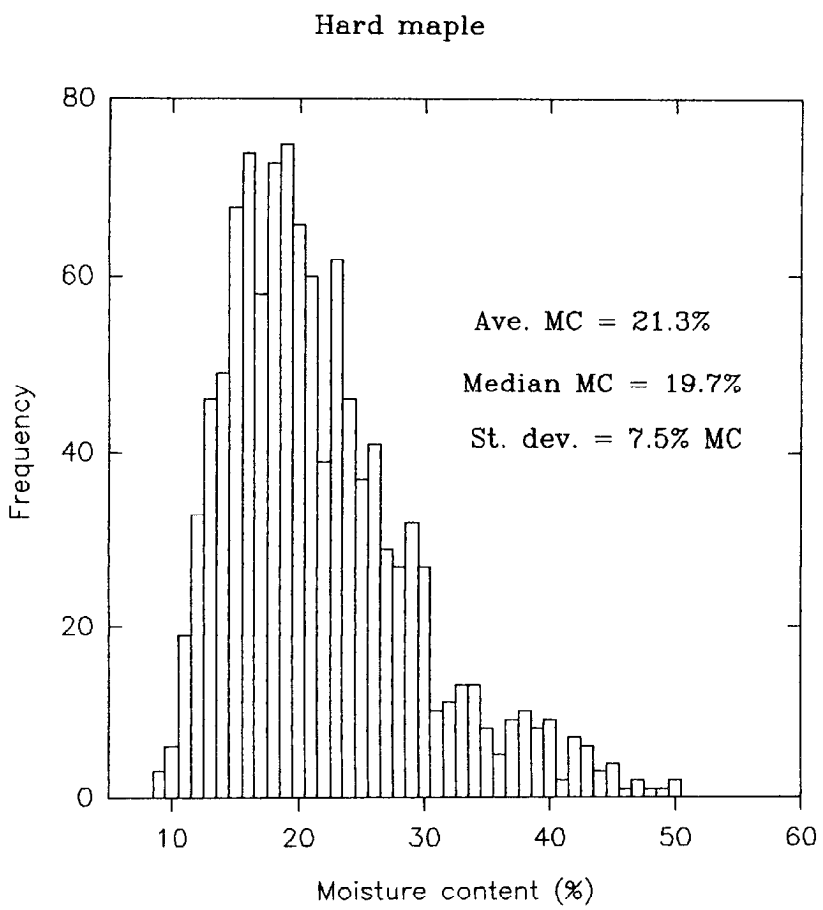

Figure 2. – Histogram of final MC after kiln-drying hard maple.

remaining after the high-grade boards were sawn from the outer parts of the logs and were 2 by 6's, 2.44 m (8 ft.) long. The hardwood lumber grades (12) were 3A, 3B, and Below Grade. The lumber was then trucked to Madison, Wis., for drying.

Because of logistics, it was not practical to randomize assignment of boards to kiln schedule. Also, because of the difficulty of holding green lumber for extended periods in the warm temperatures of spring and early summer months, we used three different Forest Products Laboratory (FPL) dry kilns in the study to complete the drying in a timely way. This introduced an additional variable in the study, i.e., the dry kiln, but that was considered the better alternative to several months of storage in warm weather while the lumber groups waited their turn in a single dry kiln.

Dry kiln schedules are given in **Table 1.** The mildest schedule was similar to the traditional maple schedules for hard and soft maple (2), starting with an initial dry-bulb temperature of 49°C (120°F). The initial dry-bulb temperature was increased by 5.6°C (10°F) in each of the more severe schedules. Air velocity was in the range of 2.54 to 3.03 m/s (500 to 600 ft./min.). Drying was monitored using eight sample boards, four on each side of the lumber stacks, by weighing them periodically. Their MC was estimated during drying from moisture sections (2) cut before drying. At the conclusion of drying, each of these sample boards was ovendried for exact calculation of the MC during drying. Stack width was 1.37 m (4.5 ft.). The stacks were top-loaded with concrete blocks to 151 kg/m^2 (31 pcf), which was equivalent to the weight of about three courses of green lumber. Air flow direction was reversed every 6 hours.

Bow, crook, twist, and cup were measured on each board after drying. During these measurements, every other board was tested for MC with a conductance-type moisture meter. Insulated electrode pins were driven to about one-quarter of the thickness of the boards to estimate the average MC. Three readings were taken along the length of each board, at mid-length, and approximately 305 mm (1 ft.) from each end.

After these measurements were completed, each board was surfaced in a four-head moulder to 38 by 140 mm (1 - 1/2 by 5-1/2 in.) thick. Following this, the lumber was graded by an SPIB quality supervisor into one of five groups according to SPIB grading rules for structural light framing lumber: Select Structural, No. 1, No. 2, or No. 3, and Economy.

Table 2a — Final moisture content, warp, and shrinkage for hard and soft maple 2 by 6's.

Code[a]	Specific gravity[b]	Initial MC	Final MC Meter	Final MC OD[c]	Bow		Crook		Twist		Cup		Shrinkage Thickness	Shrinkage Width	Kiln
		(%)	(%)	(%)	(mm)	(in.)	(mm)	(in.)	(mm)	(in.)	(mm)	(in.)	(%)	(%)	
HM120		57.1													
Mean	0.591		21.9	20.0	5.99	0.236	6.32	0.249	7.16	0.282	3.18	0.125	5.0	3.9	A
Median					5.56	0.219	4.78	0.188	6.35	0.250	3.18	0.125			
HM130		61.1													
Mean	0.601		23.6	19.4	5.69	0.224	6.25	0.246	7.16	0.282	3.07	0.121	6.9	5.4	B
Median					4.78	0.188	4.78	0.188	5.56	0.219	3.18	0.125			
HM140		62.5													
Mean	0.599		15.4	20.2	6.88	0.271	7.39	0.291	9.14	0.360	3.73	0.147	7.0	4.7	C
Median					6.35	0.250	6.35	0.250	6.35	0.250	3.96	0.156			
HM150		59.1													
Mean	0.614		21.5	20.8	3.84	0.151	5.54	0.218	7.65	0.301	3.05	0.120	5.7	4.2	B
Median					3.96	0.156	3.96	0.156	5.56	0.219	3.18	0.125			
HM160		61.8													
Mean	0.607		24.1	21.9	4.67	0.184	5.97	0.235	8.79	0.346	3.28	0.129	6.3	4.4	C
Median					3.96	0.156	5.56	0.219	7.95	0.313	3.18	0.125			
SM120		72.6													
Mean	0.518		22.4	21.4	6.43	0.253	7.06	0.278	11.8	0.465	2.41	0.095	5.0	3.5	A
Median					5.56	0.219	6.35	0.250	11.13	0.438	2.39	0.094			
SM140		67.5													
Mean	0.551		19.7	19.8	5.64	0.222	6.15	0.242	11.71	0.461	2.69	0.106	5.7	3.7	A
Median					5.56	0.219	5.56	0.219	11.13	0.438	2.39	0.094			

[a] HM is hard maple; SM is soft maple; numeric values correspond to nominal °F of dry-bulb temperature
[b] Based on ovendry weight and green volume.
[c] Average MC of eight kiln samples by ovendry method.

We were also able to collect some data on both hard and soft maple that had been dried to 15 percent in a predryer at the cooperating mill. This lumber was also graded by an SPIB quality supervisor, and the results are presented with those of this study.

RESULTS AND DISCUSSION

We divided the results into three parts: lumber quality by laboratory measurements, lumber quality according to SPIB grading rules, and drying times.

LUMBER QUALITY: LABORATORY

Even though surface checking is not a degrading factor, we note that surface checking did occur. **Figure 1** contrasts the two extremes: no surface checking in some boards and very severe surface checking in others. Surface checking was not as severe in soft maple as in hard maple.

Figure 2 is a histogram of the moisture-meter readings for hard maple after drying and points out a result that may be of some concern. Even though the majority of the MC readings are clustered around the target MC of 19 percent, there is a definite group of readings greater than 30 percent. These high readings were usually from the dark-colored heartwood near the center of the tree, which is known to be impermeable and therefore dries slowly.

Table 2a summarizes the results of the laboratory measurements. Final MC values from both the moisture meter and the eight kiln samples are given. **Table 2b** summarizes the results of the statistical analysis for significant differences between kiln schedules and species. Based on these statistical tests, only a few general patterns can be identified. Soft maple had more twist than hard maple, but less cup. HM150 (meaning, hard maple boards dried using 66°C (150°F) dry-bulb kiln schedule) and HM160 had significantly less bow than all other groups. We cannot explain this other than that these two hard maple groups probably came from a different logging run than the other three. If randomized assignment of boards to kiln run had been practical, this anomaly might have been averted.

Another observation that is difficult to explain is that HM140 had more warp than the other hard maple groups. The final MC of this group, according to the moisture meter, was 6 to 9 percent less than the other hard maple groups (although the final MC according to the eight kiln samples was comparable). We might speculate that this lower final MC caused the warp to be greater, but there is no evidence to support this theory. Regressions of all four forms of warp compared with final MC were run on all groups. Of these 28 regressions, only 3 showed a significant relationship between warp and final MC. Furthermore, the slopes of the regressions were almost equally divided between plus and minus (12 plus and 16 minus), further showing that there was no clear relationship. Thus, it is difficult to justify ascribing the

TABLE 2b. –Results of Kruskal- Wallis (3) one-way analysis of variation on ranks for nonparametric data and Dunn's (3) method for pairwise comparisons.

Bow	HM150 and HM160 < all other HM and all SM
Crook	HM150 and HM160 < HM140 and SM120
Twist	All HM < SM120
	All HM except HM160 < SM140
Cup	All HM except HM160 < HM140
	Both SM < HM120, HM130, HM160
	SM120 < HM150

greater warp to the lower final MC. There is no evidence to suggest that any differences between the three dry kilns influenced the results.

LUMBER QUALITY: GRADING

The percentage of lumber in each experimental group that lost grade because of warp or end splits is given in **Table 3.** Data from the lumber predried at the cooperating mill are also included (HMPD and SMPD). There are several patterns in these data. Twist caused more downgrade than did the other forms of warp. Downgrade from cup was almost non-existent, and downgrade from crook was also small. There is no apparent pattern for the effect of drying temperature on downgrade of hard maple from warp. However, soft maple does show a pattern of increasing bow and twist with increasing drying temperature. HM140 boards had considerably more downgrade from bow and twist than any other experimental group. This was also noted in the warp averages given in **Table 2,** and as noted in that discussion, there is no apparent explanation for this deviation.

Grade loss from end splits was quite variable and in some cases high, ranging from about 4 percent to almost 16 percent. We were not able to quantify the cause of the end splits. They may have been due to growth stresses, delay in applying end coating, log storage time and environmental conditions, or kiln schedule. We did note that many boards had end splits, sometimes severe, before kiln-drying, so it seems unlikely that the kiln schedule was a major cause of downgrade as a result of end splits. In contrast to the typical multiple and shallow end checks that are caused by end drying, the most common type of end split was a single, sometimes long, split.

Target MC was 19 percent, which is greater than the 15 percent commonly targeted for softwood structural lumber. This higher target MC means less time in the kiln, which decreases drying cost. However, it also raises a concern regarding lower modulus of elasticity (MOE) at the higher MC level, and the possible adverse effects of warp that might occur in further drying in storage or use. Compared with many softwood species (1) hard maple has a relatively high MOE and a higher ratio of green to dry MOE. Therefore, we felt that hard maple at 19 percent or above MC would perform just as well or better than most softwoods at 15 percent. The question of adverse effects of possible warp during additional drying in storage or use will be addressed in a follow-up study.

DRYING TIME

As expected, drying time did decrease with increasing initial kiln temperature **(Table 4).** Direct comparisons between the different species and initial temperature groups were not possible because of differences in board width, thickness, specific gravity, initial MC, and air velocity. In addition, using manual kiln control, it is not practical to make each schedule change at the exact MC level of the schedule steps in **Table 1.** To do so would have required weighing kiln samples at all hours of the day and night. So in almost all kiln runs, changes were made either somewhat before, but usually somewhat after, the nominal step MC. Usually the discrepancy was only 2 to 3 percent MC, but sometimes was as much as 4 to 5 percent. Similarly, it was not practical to end all kiln runs at exactly 19 percent final MC. Therefore, for a true estimate of time savings by increasing drying temperature, it was necessary to adjust the drying to a common base of identical board width, thickness, specific gravity, initial MC, all step-change MC values to those in **Table 1,** air velocity, and final MC.

A useful tool to accomplish this adjustment is available from the drying simulation developed by Hart (5,6), with addi-

TABLE 3 — Board that lost grade from warp or end splits in drying hard and soft maple 2 by 6's

Code	Number of boards	Bow	Crook	Twist	Cup	Total warp	End splits
		(%)					
HMPD[a]	792	2.3	6.9	5.2	0.3	14.7	14.4
HM120	125	5.6	0.1	4.0	0	9.7	11.2
HM130	158	3.2	0	3.2	0	6.4	7.0
HM140	148	14.9	0	14.9	0	29.8	4.7
HM150	150	2.7	0	7.3	0.7	10.7	14.0
HM160	152	2.5	1.3	5.6	0	9.4	13.1
SMPD[a]	109	0.9	0.9	5.5	0	7.3	15.6
SM120	135	1.5	0.7	9.6	0	11.8	15.6
SM140	136	5.1	0.1	11.0	0	16.2	8.8

[a] HMPD = hard maple lumber predried at the cooperating mill; SMPD = soft maple predried at the cooperating mill.

TABLE 4. — Actual initial dry-bulb temperatures, drying time, and diffusion coefficient from the drying simulation.

Code	Dry kiln	Actual dry bulb		Drying time	Diffusion coefficient"	
		(°C)	(°F)	(days)	($cm^2/s \times 10^{-6}$)	($in.^2$/day)
HM120	A	49	120	5.93	6.75	0.0904
HM130	B	56	133	5.11	6.97	0.0934
HM140	C	58	137	5.36	5.63	0.0754
HM150	B	67	153	4.31	6.52	0.0873
HM160	C	69	157	3.74	6.83	0.0915
SM120	A	49	120	8.80	4.90	0.0656
SM140	A	60	140	6.87	5.40	0.0723

tional verification by Resch et al. (13). The simulation must be tuned to fit actual drying data, but when that is done, any drying parameter can be varied to estimate its effect on drying time and MC distribution through the stack width. This tuning is done by trial-and-error selection of a diffusion coefficient that makes the simulation fit the actual drying curve of MC compared with time. In this study, the diffusion coefficients that made the simulation tit each of the seven actual drying curves were determined. Then, those diffusion coefficients were used to run the simulation for each of the seven initial temperature/species groups using a common board width, thickness, specific gravity, initial MC (60% for hard maple and 70% for soft maple), schedule change MC **(Table 1),** air velocity (2.54 m/s; 500 ft./min.), and final MC (19%).

After the kiln runs were completed, a complication was discovered. The dry-bulb temperature of two of the three kilns was found to be out of calibration. Therefore, it was necessary to adjust these temperatures when the simulations were run. The actual initial dry-bulb temperatures, drying times, and diffusion coefficients arc given in **Table 4,** and a typical comparison of the simulation compared with an actual drying curve is shown in **Figure 3.** Drying time for hard maple ranged from 5.93 days at 49°C (120°F) initial temperature to 3.74 days at 71°C (160°F). Soft maple required slightly longer drying times than hard maple, partially because of the higher initial MC.

We can further normalize the drying times to a more common basis for comparison by running the simulation using the average diffusion coefficient of all the same species groups. **Figure 4** shows the decrease in drying time from 60 to 19 percent moisture of hard maple calculated this way as drying temperature was increased. Drying time for hard maple was reduced 37 percent by increasing the initial temperature, and subsequent step temperature, from 49°C to 71°C (120°F to 160°F), and drying time for soft maple was reduced 19 percent (8.42 to 6.81 days) by increasing the initial temperature from 49°C to 60°C (120°F to 140°F).

APPLICATION TO COMMERCIAL-SIZED KILNS

The laboratory kilns used in this study were much smaller than commercial kilns: 2.84 m^3 (1,200 BF) compared with 71+ m^3 (30,000+ BF). The main problem in inferring drying times in a commercial-sized kiln from these laboratory-scale drying times is the difference in the lumber stack widths. The 1.37-m (4.5-ft.) width in this study is less than the stack width in commercial kilns, which likely is 2.44 m (8 ft.) or more. Type of kiln also enters the picture. Track-loaded kilns (common in the softwood dimension lumber industry) might have as little as 2.44 m (8 ft.) of air travel before booster steam coils are placed to reheat air that has cooled, but package-loaded kilns (common in the hardwood lumber industry) might have as much as 7.31 m (24 ft.) of unboosted air travel. The problem is that the air moving through the stack loses some of its drying capacity as it moves downstream. Water evaporating from boards decreases the temperature and increases the relative humidity of the air, thus reducing the drying rate of the next board downstream. The longer the

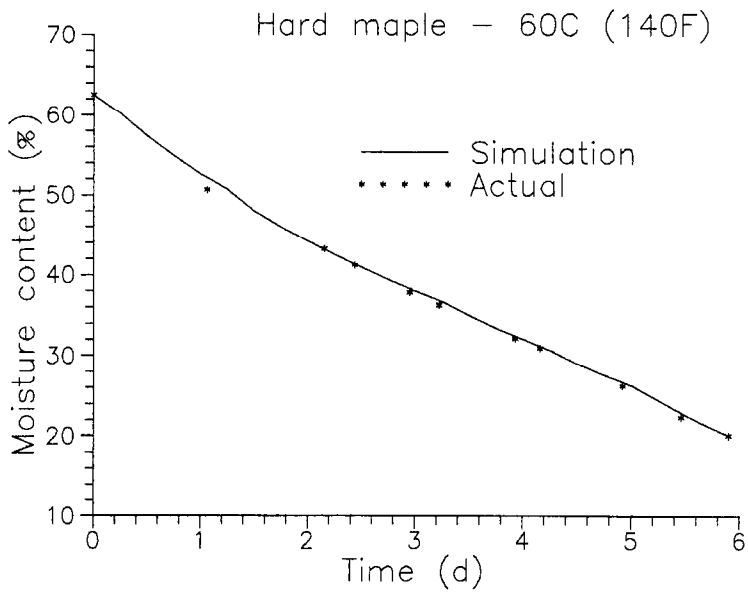

Figure 3. —Comparison of a kiln sample drying curve with a drying curve developed through simulation (5,6).

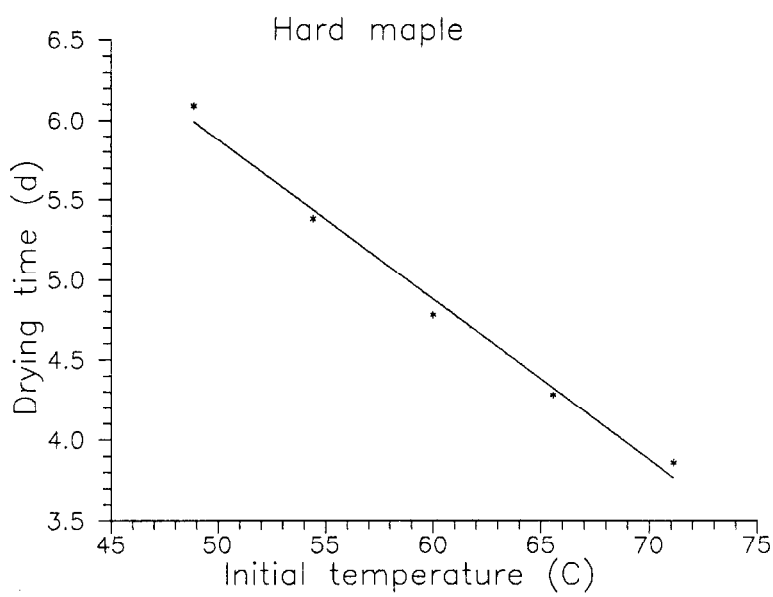

Figure 4. - Hard maple kiln-drying times normalized to common conditions as a function of initial kiln temperature.

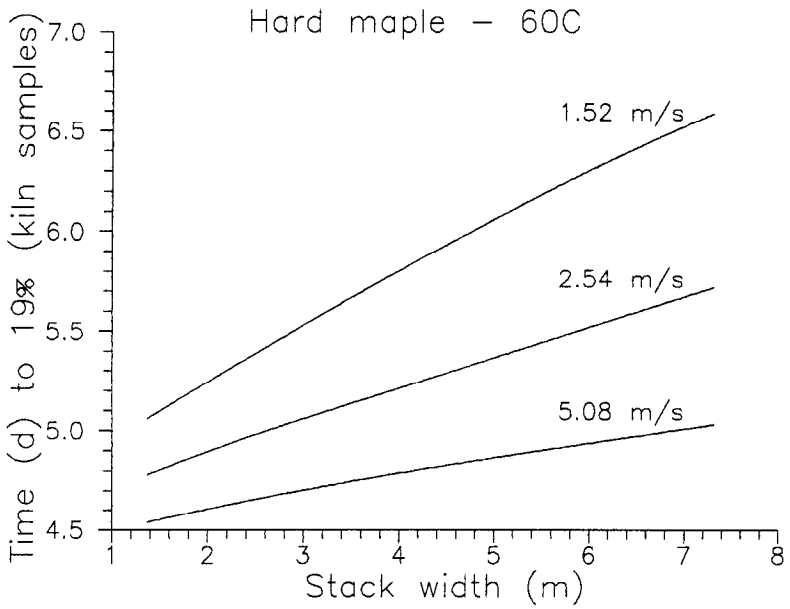

Figure 5. — Effect of lumber stack width and air velocity on hard maple drying times at an initial drying temperature of 60°C (140°F) (5).

unboosted length of air travel, the larger the effect. Thus, kiln samples on both edges of a 1.37-m- (4.5-ft.-) wide stack will usually dry faster than kiln samples on the edges of a 2.44-m- (8-ft.-) wide stack, even with fan reversal. Species and drying conditions determine the importance of the effect of stack width on drying time. The drying rate of a naturally slow-drying species being dried at mild kiln conditions would be affected less by air velocity than a fast-drying species, so stack width would be less important for the slow-drying species.

Using Hart's drying simulation (5), we can examine the effects of stack width on drying time and MC distribution through the stack and make estimates of how much the drying times observed in this study should be increased for commercial-sized kilns. **Figure 5** shows the effect of stack width on hard maple drying time at an initial drying temperature of 60°C (140°F). Schedule- controlling kiln samples are located on both edges of the lumber stack, and fan reversal is every 6 hours. The drying time in the experimental kiln with a 1.37-m- (4.5-ft.-) wide stack was 4.75 days and only increased to 4.96 days when the stack width was 2.43 m (8 ft.) wide. However, drying time increased to 5.7 days when stack width was increased to 7.31 m (24 ft.). The problem goes beyond increased drying time. The MC of boards in the center of the stack will lag further behind the kiln samples at the edges of the stack as stack width increases. Hart's simulation can offer predictions of this effect, but that analysis is beyond the scope of this study.

Conclusions and Recommendations

Hard and soft maple 2 by 6's, 2.44-m (8-h.) long, were dried by kiln schedules of varying degrees of severity in an attempt to identify a schedule that will minimize drying time while maintaining lumber quality suitable for structural uses. Results of this study give evidence to support the following observations:

· Drying temperature had no apparent effect on the magnitude of warn in hard maple or on the amount of lumber that was downgraded because of warp.

· Some evidence was found that the amount of grade loss in soft maple increased with drying temperature.

· Soft maple twisted more than hard maple.

· Hard maple cupped more than soft maple.

· Hard maple surface checked more than soft maple.

· Because drying temperature had no apparent effect on downgrade from warp in hard maple, a fast kiln schedule, starting at 71°C (160°F) dry-bulb temperature and 67°C (153°F) wet-bulb temperature, can be used.

· Using a computer kiln simulation, we can estimate the scale-up of drying time by this schedule from a laboratory-scale kiln to a commercial-sized kiln. The estimate is about 4 days drying time from 60 percent to 19 percent MC for hard maple.

One concern from the results of the study is the proportion of boards that remained at a high MC after kiln-drying. Even though no relationship was found between final MC and warp, post-kiln-drying warp could still be a concern. Additional research is planned to clarify this issue.

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