SHORT, CLEAR SPECIMENS FOR ESTIMATING DRYING TIME OF SUGAR MAPLE LUMBER[1]

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(Received August 1993)

ABSTRACT

The drying times of full-length (8-ft (2.44-m)) sugar maple sapwood boards were compared to those of matched, short [11.5-in. (292-mm)] boards at eight temperature, relative humidity, and air velocity combinations. The results showed little practical difference in the drying times of the boards. We conclude that studies on drying time can be made more efficient by reducing the amount of material and the size of the drying equipment.

Keywords: Drying, kiln-drying, maple, modelling.

INTRODUCTION

The effect of material and process variables on drying time of lumber is useful information for planning purposes. When this information is incorporated into a mathematical model, the time required to dry wood under specified conditions can be estimated. In addition, sensitivity analysis can be used to estimate the consequences of variables on drying time. These methods can be used to determine if corrective action is needed in various situations. For example, does a 5 F (2.8 C) variation in dry-bulb kiln temperature merit correction? A 200-ft/min (1-m/sec) variation in air velocity? A 0.1-in. (2.5-mm) variation in lumber thickness? Knowledge about the effects of material and process variables on drying time allows us to estimate variability in final moisture content and the effect of the variables on energy consumption.

In planning experiments to determine drying time, an important decision is the size of the test specimens. Full-length lumber could be used to characterize the drying time of such lumber in laboratory experiments. However, experiments could be more efficient in terms of the amount of experimental material and the size of the test equipment if drying time of full-length lumber could be characterized using shorter specimens. The objective of this

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TABLE 1. *Specimen sizes and end-coatings used in various drying rate experiments.*

Study	Length (in.)	Length (mm)	T/E[a]	End-coating
Bramhall (1979)	36	914	24	Commercial resin
Beard et al. (1982)	11.8	300	8	Sanding sealer (3 to 4 coats)
Milota and Tschernitz (1990)	96	2,438	67,79,102	Aluminum flakes in spar varnish (2 coats)[b]
Plumb et al. (1985)	17.7	450	17	None reported
Simpson (1975)	4	102	9	Aluminum flakes in spar varnish (2 coats)
Stanish et al. (1986)	15.7	399	11	Commercial end-coating
Tschernitz and Simpson (1977)	15	381	15[c]	Asphalt mastic
Tschernitz and Simpson (1979)	44	1,118	51	Aluminum flakes in spar varnish (2 coats)
Present study (short specimens)	11.5	292	13	Aluminum flakes in spar varnish (2 coats)

[a] Ratio of transverse-grain to end-grain surface area.
[b] Both end- and edge-coated.
[c] Approximate—specimens varied.

study was to determine if short specimens dry in the same time as full-length specimens.

BACKGROUND

Several issues are related to the effect of specimen size. One issue is how well short, clear specimens represent full-length boards. Because of the natural variability of wood, the properties of a full-length board are not exactly the same as those of a short board cut from the full length. Also, full-length boards contain varying amounts of knots and grain distortion, and it is likely that such areas of the wood have a different drying rate. Because the drying rate is about ten times faster in the longitudinal direction than in the transverse direction, the wood around knots and distorted grain is expected to dry faster than the surrounding wood. In choosing short specimens to represent full-length specimens, little, if any, grain distortion or knots can be allowed because this wood will likely constitute a larger proportion of the surface area compared to a full-length board. Consequently, the wiser choice is to use short specimens with a clear surface, which can provide a standard reference. In addition, lumber grade is likely to affect how well short specimens represent full-length boards—lower grades allow more knots and grain distortion compared to higher grades.

Another issue is the effect of drying in the longitudinal direction of the specimens. Because proportionately more end-grain is exposed in short specimens compared to full-length boards, longitudinal drying is a concern. Without an effective end-coating, a short board dries faster than a full-length board. Table 1 lists specimen length, ratio of transverse-grain surface area to end-grain surface area, and end-coatings for various drying rate experiments. The two specimen lengths were 4 in. and 8 ft (25 mm to 2.4 m). With the exception of the study reported here, studies listed did not include any comparison between specimens of different lengths.

EXPERIMENTAL PROCEDURE

Ten freshly cut sugar maple (*Acer saccharum*) logs were obtained from northern Wisconsin. The logs were straight, selected for minimum knots, ranged from 65 to 93 years of age, and contained about 80% to 85% sapwood. The logs were 8½ ft (2.6 m) long, with an average diameter of about 18 in. (460 mm). Nominal 1-in. (25-mm)-thick by 8-in. (200-mm)-wide sapwood boards were flat-sawn from the logs. These boards were divided into eight groups of twelve boards each for eight experimental drying conditions.

Each board was ripped into two 4-in. (100-mm)-wide boards as shown in Fig. 1. The boards for each experimental group were wrapped in plastic and stored at 2 F (−17 C) until time of test. Several days before each

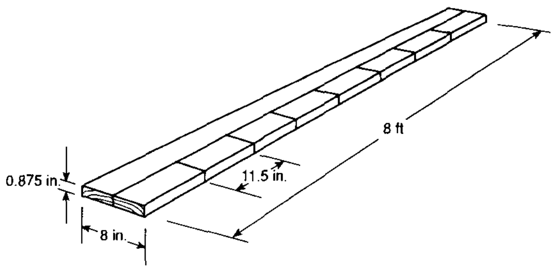

FIG. 1. Diagram showing the relationship between short and full-length boards used to determine drying time.

drying experiment, the boards were removed for thawing. All boards were surfaced on both sides to 0.875 in. (22 mm) thick. One 4-in. (100-mm)-wide board of each pair was cut into eight short 11.5-in. (290-mm) boards. (Fig. 1). Four short boards were selected, on the basis of clear wood, for matching with the full-length board in the drying experiments. The boards, short and long, were then end- and edge-coated with two coats of aluminum flakes in spar varnish; the second coat was applied within 24 h of the first.

All full-length boards and their matching short boards were dried simultaneously in specimen racks (Fig. 2). Baffling and a screen were installed in the kiln to provide a slight pressure drop to produce uniform air flow through the sticker spaces (Milota and Tschernitz 1990). The racks were constructed of two 8-ft-long wood rails separated by 4.5 in. (114 mm) using 0.75-in. (19-mm)-thick stickers. Stickers were placed at 24-in. (610-mm) intervals for full-length boards and 12-in. (300-mm) intervals for short boards. The racks made

FIG. 2. Drying racks for short and full-length boards. (M92 26-7)

TABLE 2. *Experimental drying conditions and drying times.*

Dry-bulb temperature [F (C)]	Wet-bulb temperature [F (C)]	Relative humidity (%)	Air velocity[a] [ft/min (m/sec)]	EMC[b] (%)	Drying time (h)	Clear area[c] (%)
120 (49)	89 (32)	30	545 (2.77)	5.4	168	99.47
	113 (45)	80	545 (2.77)	14.1	192	99.03
	89 (32)	30	1,090 (5.54)	5.4	168	98.78
	113 (45)	80	1,090 (5.54)	14.1	192	98.70
180 (82)	135 (57)	30	545 (2.77)	3.7	72	99.28
	171 (77)	80	545 (2.77)	11.4	144	98.45
	135 (57)	30	1,090 (5.54)	3.7	72	99.37
	171 (77)	80	1,090 (5.54)	11.4	120	99.34

[a] As measured with an Alinor model 6000-P velometer, over a four-point grid in each air space between layers. The use of trade or firm names in this publication is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.
[b] Equilibrium moisture content.
[c] Percentage of total surface area of both sides of the 12 long boards in each group free of knots and the surrounding distorted grain.

stacking and handling easier and faster, and more importantly, helped to minimize heat transfer to the edges of the boards. Thus, the dried boards were representative of a board from the interior of a package rather than from the edge.

All boards were weighed initially and then periodically during drying. A position number was assigned to each board before placing it in the rack. The racks were stacked on a kiln cart so that the entire assembly could be easily rolled from the kiln for ease in board weighing. Two full-length boards were stacked in the bottom two racks, and the third rack from the bottom held their corresponding eight short boards. This stacking pattern was repeated vertically six times until all 12 long and 48 short boards had been loaded.

The full-length boards were stacked in proximity to the corresponding short boards to minimize any effect of variability in kiln conditions on the drying rate. One full-length dummy board was placed above and below the entire stack to avoid top and bottom effects. Iron weights with a distributed load totaling 50 lb/ft^2 (2.39 kPa) were placed on top of the racks.

The racks holding the boards were withdrawn from the kiln, and the boards were removed and weighed every 2 h for four readings; the boards were then weighed again twice, at 4-h intervals. On day 2, the boards were reweighed at 8-h intervals. From day 3 to the final day of drying, the boards were weighed every 24 h. Removing the boards from the dryer, weighing them, and returning them to the dryer took approximately 12 min. The total time for a given experiment to reach a constant moisture content depended on the drying conditions used and ranged from 3 to 8 days. After each drying run, the oven-dry weight of each board was determined at 225 F (107 C) to calculate gravimetric moisture content. Table 2 shows the experimental conditions for the eight drying runs and the total time for each run. Table 2 also shows the percentage of the total surface area of the long boards that was free of knots and the distorted grain immediately surrounding them.

RESULTS

To determine whether short and full-length boards dried at the same rate, we compared board moisture contents for all experimental drying times (Table 2). Since not all boards had the same initial moisture content, the moisture contents were normalized according to the following formula:

$$E = (m - m_e)/(m_o - m_e) \qquad (1)$$

where

E = unaccomplished drying,
m = moisture content at any time (%),
m_e = equilibrium moisture content (%), and
m_o = initial moisture content (%).

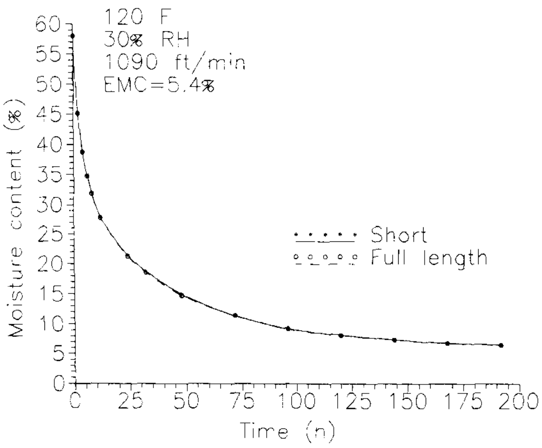

FIG. 3. Moisture content-time curve for four short boards and one full-length board dried at 120 F (49 C), 30% relative humidity, and 1,090 ft/min (5.54 m/sec) air velocity.

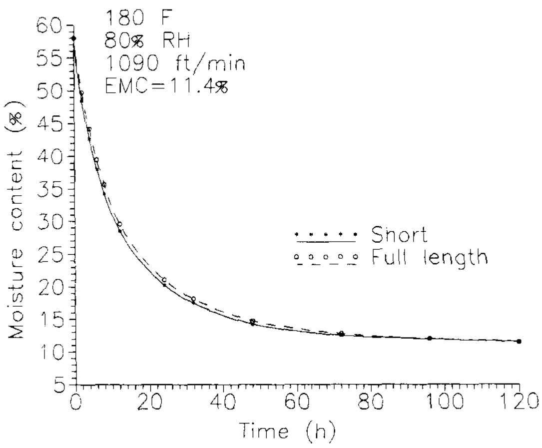

FIG. 4. Moisture content-time curve for four short boards and one full-length board dried at 180 F (82 C), 80% relative humidity, and 1,090 ft/min (5.54 m/sec) air velocity.

According to Eq. (1), all boards dry from E = 1 to E = 0, even when their initial moisture contents m_0 are different. Therefore, E values at any time can be compared directly. For easier visualization of the results, we converted the data to an actual common initial moisture content equal to the overall average initial moisture content of all specimens—58%.

Figures 3 and 4 compare moisture content as a function of time of full-length and short boards for two experimental conditions. Figure 3 shows the results with the smallest deviation and Fig. 4 the greatest deviations.

For each experimental condition, the difference in moisture content between the 12 full-length boards and the average moisture content of their four matching boards was tested for statistical significance at each experimental drying time by the Student's *t*-test (Steel and Torrie 1960). The hypothesis tested was that there is no difference between the moisture contents of the boards. Figure 5 shows statistical results for one experimental condition. At three drying times, the 95% confidence limits do not include zero. Thus, we conclude that there is a difference in moisture content at these times. For this experimental condition, there was no significant difference in moisture content at six of the nine experimental times (66.7%). At the other three experimental times, the short boards dried faster than the full-length boards.

The percentages of experimental drying times that showed no statistical difference between full-length and short board moisture contents are shown in Table 3 for all experimental conditions. The data in column 4 (4 SBs) compare the moisture content of full-length boards to the average moisture content of their four matching short boards. However, more ex-

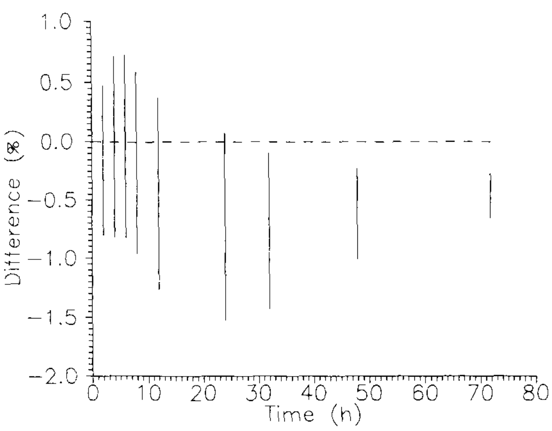

FIG. 5. Difference in moisture contents between short and full-length boards as a function of drying time at 180 F (82 C), 30% relative humidity, and 545 ft/min (2.77 m/sec) air velocity. Bars indicate 95% confidence limits.

TABLE 3. *Experimental drying times showing no significant difference in moisture content between short and full-length boards.*[a]

Drying conditions			Boards (%) showing no significant difference in moisture content per number of short boards[b,c]			
Temperature [F (C)]	Relative humidity (%)	Air velocity [ft/min (m/sec)]	4 SBs	3 SBs	2 SBs	1 SB
120 (49)	30	545 (2.77)	100	92.3	100	100
		1,090 (5.54)	100	92.9	100	100
	80	545 (2.77)	100	100	78.6	64.3
		1,090 (5.54)	100	100	100	100
180 (82)	30	545 (2.77)	66.7	77.8	77.8	100
		1,090 (5.54)	66.7	66.7	66.7	66.7
	80	545 (2.77)	36.4	54.5	27.3	54.5
		1,090 (5.54)	18.2	27.3	54.5	54.5

[a] 95% level of confidence.
[b] SB is short board.
[c] At 180 F (82 C), short boards dried faster when there was a significant difference in moisture content; at 120 F (49 C), full-length boards dried faster when there was a significant difference.

perimental efficiency would be gained if only three short boards were necessary for the comparison. Thus, one board of each set of four short boards was randomly eliminated, and the statistical analysis was redone with three short boards. These results are listed in column 5 (3 SBs). Similarly, analyses were conducted for two and one short boards (columns 6 and 7, respectively).

The data in Table 3 led to two general observations. First, one short board was apparently as good as two, three, or four short boards in characterizing the drying of a full-length board. Second, the percentage of experimental drying times that showed no significant difference in moisture content between short and full-length boards was generally smaller at 180 F (82 C) compared to 120 F (49 C). In fact, the short boards dried faster than the full-length boards at 180 F (especially at 80% relative humidity). Examination of the boards dried at 180 F showed that the aluminum paint on some boards had blistered and, in some cases, had separated from the wood, which can be attributed to a breakdown in adhesion between the paint and the wood at the higher temperature and relative humidity. This may have contributed to the observed effect at 180 F.

Even though some statistically significant differences in drying time did occur between short and full-length boards, what is the practical significance of these differences? Table 4 shows three types of comparisons that help to place the practical differences in perspective. One set of comparisons shows the absolute value of the worst individual deviation between any full-length board at any time at each experimental condition, and both one and four short boards per full-length board (Table 4, worst deviation for any board). The worst deviation for the average of four short boards was 4.2% moisture content, and for one short board 5.5%. If the deviation is based on the average of all 12 sets of boards at each experimental condition, the corresponding worst deviations were 1.6% and 2.0% (Table 4, worst deviation for 12 board average). Finally, if the average deviations are considered over all times per experimental condition, the worst deviations were 1.0% and 1.3%.

CONCLUSIONS

Based on the results of this study, we conclude that adequately end-coated, 12-in. (300-mm)-long sugar maple boards can closely simulate the drying rate behavior of 8-ft (2.4-m)-long boards. Studies to determine drying rate can be made more efficient by reducing the amount of experimental material and the size of experimental dryers.

ACKNOWLEDGMENTS

The authors thank the International Tropical Timber Organization in Yokahama, Ja-

TABLE 4. *Absolute value of moisture content deviation between matched full-length and short boards at any drying time.*

Drying conditions			Moisture content deviation (%)					
			Worst (any board)[b]		Worst (12 board avg)[c]		Average (all bds/times)[d]	
Temp [F (C)]	RH[a] (%)	Air velocity [ft/min (m/sec)]	4 SBs	1 SB	4 SBs	1 SB	4 SBs	1 SB
120 (49)	30	545 (2.77)	4.2	4.6	1.6	1.5	0.8	0.7
	30	1,090 (5.54)	2.4	3.4	1.1	1.2	0.6	0.7
	80	545 (2.77)	3.3	3.3	1.2	1.4	0.7	0.7
	80	1,090 (5.54)	2.7	4.8	1.4	1.5	0.8	0.8
180 (82)	30	545 (2.77)	3.2	5.5	1.2	1.4	0.9	1.2
	30	1,090 (5.54)	2.8	4.1	1.1	1.3	0.8	0.9
	80	545 (2.77)	2.7	4.1	1.3	1.7	0.8	1.2
	80	1,090 (5.54)	3.2	5.3	1.5	2.0	1.0	1.3

[a] Relative humidity.
[b] Worst deviation of any individual board at any drying time: deviation of any of 12 full-length boards from average of matched 4 short boards (SBs) or of 1 SB after randomly eliminating 3 SBs.
[c] Worst deviation based on average of 12 boards per experimental condition: deviation of average of 12 full-length boards from matching 48 SBs at any drying time.
[d] Average deviation based on all boards at all drying times.

pan, and the International Forest Products Program at the U.S. Department of Agriculture, Forest Service, Forest Products Laboratory, in Madison, Wisconsin, for financial and administrative support.

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