Kiln Time and Temperature Affect Shrinkage, Warp, and Mechanical Properties of Southern Pine Lumber

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Abstract

Four hundred and eighty No. 2 Dense southern pine 2 by 6's, 95 inches long, were kiln-dried in 4-foot-wide loads with a 3,000-pound top load restraint. The kiln-drying regimes consisted of dry-bulb temperatures of 180°, 240°, and 270°F with wet-bulb temperature of 160°F and kiln times of 120 hours at 180°F; 36 and 120 hours at 240°F; and 9, 36, and 120 hours at 270°F. After kiln-drying and a 1-year conditioning period, boards were loaded to failure in edgewise bending. From undamaged sections, small clear specimens were removed for evaluation of several properties. MC of loads on emergence from the kiln ranged from 0.2 to 11.9 percent. After 1 year of conditioning, boards dried at high temperature for a prescribed number of hours had lower EMC than boards dried an equal time at low temperature. Shrinkage was least in wood dried at 270°F for 9 hours. Boards dried at 240°F and 270°F and equilibrated had less average crook, bow, and twist, and less maximum crook and bow than boards dried for 120 hours at 180°F. Boards dried by schedules approximating commercial practice (180°F for 120 hr., 240°F for 36 hr., and 270°F for 9 hr.) did not differ significantly in MOR, proportional limit, MOE, compression strength parallel to the grain, shear strength parallel to the grain, hardness, and toughness. Regression relationships of MOR to MOE were also similar for the three drying treatments. Boards dried 120 hours at 240°F or 270°F had reduced MOR and toughness; also, the regression relationships of MOR to MOE were different from those observed for wood dried on the shorter schedules.

THE EFFECTS OF KILN TEMPERATURES hotter than 212°F on strength of lumber dried have interested many. Two replicated experiments (3, 6) have shown that 24-hour exposure to a dry-bulb temperature of 240°F may not significantly reduce stiffness or bending strength of southern pine 2 by 4's and 2 by 6's. Data on higher temperatures are limited to one small-scale experiment (4), which indicated no loss in modulus of rupture (MOR) or modulus of elasticity (MOE) in small bending specimens cut from southern pine 2 by 4's dried 6 hours at 300°F.

The objective of our experiment was to produce curves that depict the relationship between kiln temperature and lumber strength, as a function of time in kiln.

Materials and Methods

Treatments in the experiment were: 1) dry-bulb temperatures in the kiln of 180°, 240°, and 270°F, with wet-bulb temperature of 160°F; 2) kiln times of 120 hours (5 days) at 180°F, 36 and 120 hours at 240°F, and 9, 36, and 120 hours at 270°F. Green lumber thickness and width were 1.75 inches by 5.88 inches. Each kiln load was 40 boards, 95 inches long; two separate kiln loads were dried under each combination of conditions. Load width was 4 feet with each course comprised of eight boards. The five-course loads were top-loaded during drying with 8 inches of concrete applied as a pair of slabs 24 inches wide over the length of the load (for a total of about 3,000 lb.) Stickers separating courses were spaced about 2 feet apart; those for the 180° and 240°F loads were 0.75 inch thick and 1.5 inches wide, while those for loads dried at 270°F measured 1.25 inches square. Circulated air velocity during drying varied with kiln temperature (180°F — 300 ft./min., 240°F — 1,000 ft./min., 270°F — 1,600 ft./min.).

A total of 700 No. 2 Dense southern pine boards, obtained from a sawmill in central Louisiana, were cut 97 inches long and planed to a uniform thickness (1.75 in.) and width (5.88 in.). Grade of the planed boards was authenticated by a representative of the Southern Pine Inspection Bureau. From a pair of 1-inch wafers removed from board ends, the specific gravity (SG) of each board was determined. To decrease the SG variability of test specimens, 140 boards in the upper and lower range of SG were discarded.

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Five hundred and sixty boards were selected; i.e., 14 kiln loads — 12 for test and 2 as spares in the event of kiln malfunction. These boards had an average SG (based on ovendry weight and green volume) of 0.49 with a range from 0.40 to 0.58. Green moisture content (MC) just before drying, calculated from initial board weight and board weights and MC at test, averaged 111 percent and the range was 37 to 176 percent of dry weight. All MCs in the study were obtained by the ovendry method.

Boards were randomly assigned to the 14 loads of 40 boards each, and stored under water containing a fungicide. Kiln schedules were run in random order. Just before drying, boards were weighed and measured for length, width, and thickness at third points. Crook, bow, and twist of the green boards were also recorded. The electrically heated kiln was preheated before each load was charged, and kerosene-fueled burners were used to get charges up to set-point temperatures quickly — about 1 hour to 180°F, 2 hours to 240°F, and 4 hours to 270°F.

For the longer kiln times, the warmup was ignored and total kiln times were exactly 36 and 120 hours. The loads dried at 270°F for 9 hours actually underwent 4 hours of warmup and 7 hours at 270°F. We assumed that 4 hours of warmup will equal 2 hours at 270°F.

Immediately after drying, boards were weighed, measured for length, width, and thickness, and for crook, bow, and twist. To allow "in use" MC equilibration differences to affect our test results, all boards were stacked on sticks in an air-conditioned laboratory and allowed to equilibrate for 1 year at about 70°F and 50 percent relative humidity (RH) (an EMC of about 9.1%). At the conclusion of equilibration, boards were again weighed and dimensions and warp were measured. They were then surfaced on one side to 1.58 inch thickness, and surfaced on the other side to a final target thickness of 1.50 inches. From each edge, 0.10 inch of wood was planed. Dimensions and warp of these planed boards were immediately measured, and the boards were weighed. Dry, planed boards averaged 1.48 inches thick and 5.43 inches wide.

The boards were loaded to failure in edgewise bending over a 91-inch span with dual-load heads spaced 14 inches apart (symmetric about midspan) according to ASTM Standard D 198-74 (1). This loading arrangement yielded the maximum ratio of shear span-to-beam depth possible with available equipment. Also, for loading, the maximum defect was placed on the tension side of the board.

After failure, MC was determined and small clear specimens were removed from undamaged parts of each board for determination of each of the properties described in Table 1. Test procedures followed the guidelines of ASTM Standard D 143-72 (2). The small bending specimen was tested with center-point loading over a 21-inch span. MC and SG of each test specimen were determined after observation of the property.

TABLE 1. — *Sizes of small, clear specimens cut from larger tested-to-failure boards and used to determine five mechanical properties.*

Property	Specimen size (In.)
End and face hardness	1.5 by 1.5 by 6
Toughness	0.79 by 0.79 by 11
Shear (2 planes)	2 by 1.5 by 2.5
Compression parallel to grain	1.5 by 2 by 8
Bending	1.5 by 1.5 by 24

TABLE 2. — *Average MCs, immediately after kiln-drying and at time of test, of boards dried under different kiln conditions.*

Kiln conditions	Avg. MC	
	On emergence from kiln	At test
	% of dry weight	
180°, 120 hr.	11.9	9.2
240°, 36 hr.	2.8	7.4
240°, 120 hr.	2.3	7.1
270°, 9 hr.	8.5	8.4
270°, 36 hr.	.2	7.2
270°, 120 hr.	1.1	6.3

This paper reports property averages for boards and small specimens. Another manuscript in preparation by Dell and Price will analyze distribution of property values.

Results and Discussion

Full-Length Boards

Moisture content. — MCs on emergence of boards from the kiln, based on total board weight and MC obtained after failure, varied with treatment; on emergence from the kiln and after 1 year of conditioning, boards dried equal time had lower equilibrium moisture content (EMC) if they were dried at higher kiln temperatures (Table 2).

All the values at test were significantly different (0.05 level) based on Duncan's multiple range test except for two cases: boards dried at 240°F for 120 hours compared with boards dried at 270°F for 36 hours, and boards dried for 36 hours at 270°F and 240°F. It is evident that prolonged exposure of southern pine lumber to 240° or 270°F reduces its EMC at 50 percent RH by 1 to 3 percent compared with lumber dried at 180° for 120 hours. EMCs as function of kiln temperature and kiln time throughout a range of RHs were also slightly altered (Fig. 1) (5).

Shrinkage. — After conditioning for a year, board thickness shrinkage from green dimension did not differ significantly with treatment; however width shrinkage did. The least width shrinkage (3.0%) was observed in boards dried at 270°F for 9 hours. The general results for shrinkage are given in Table 3.

Warp. — Of commercial interest is the warp (Table 4) in lumber dried 120 hours at 180°F, 36 hours at 240°F, and 9 hours at 270°F, and then conditioned 1 year. Although the difference was not significant statistically, the sample boards dried at 240° (7.4% MC after conditioning) and 270°F (8.4% MC) had less average warp, smaller standard deviation in warp, and less maximum crook and bow than boards dried at 180°F (9.2% MC).

Bending properties. — Proportional limit stress of boards dried at 180°F for 120 hours (5,087 psi) differed significantly from proportional limit of boards dried at 240°F and 270°F extended over 120 hours (4,504 and 3,779 psi). Boards dried at 240°F for 36 hours (4,906 psi), at 270°F for 9 hours (4,906 psi), or at 270°F for 36 hours

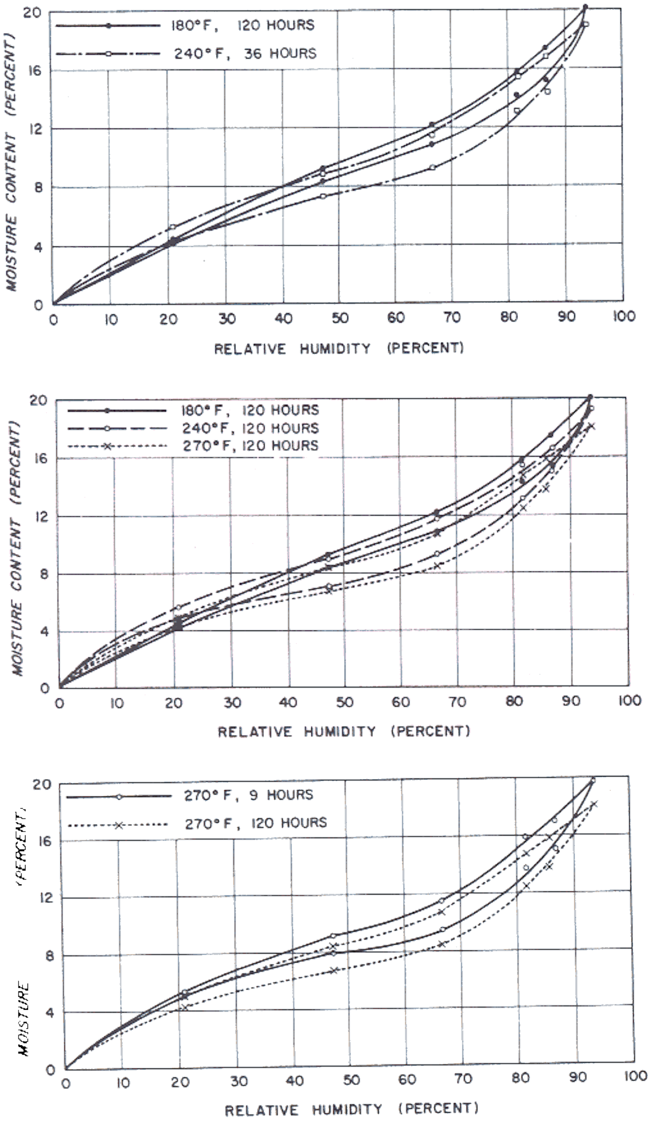

Figure 1. — Sorption isotherms for water vapor at 67°F by southern pine dried on different kiln schedules.

TABLE 3. — *Average amounts of shrinkage after drying under different kiln conditions and conditioning for 1 year at 9.1 percent EMC.*

Kiln conditions	Shrinkage: Thickness		Volumetric
	----------%----------		
180°, 120 hr.	4.3	3.5	7.8
240°, 36 hr.	4.5	3.5	8.0
240°, 120 hr.	4.7	3.7	8.4
270°, 9 hr.	4.0	3.0	7.0
270°, 36 hr.	4.4	3.7	8.0
270°, 120 hr.	5.1	4.0	9.0

(4,712 psi) did not differ significantly in proportional limit from those dried at 180°F for 120 hours (Table 5).

MOR of boards dried at 180°F for 120 hours (7,853 psi) differed significantly from MOR of boards dried at 270°F for 36 hours (6,506 psi), at 240°F for 120 hours (6,109 psi), and at 270°F for 120 hours (5,100 psi). The three treatments approximating commercial practice or proposed practice, i.e., 180°F for 120 hours, 240°F for 36 hours (7,582 psi), and 270°F for 9 hours (7,278 psi), differed by less than 8 percent. However, the values did not differ significantly (Table 5). The trend of the curves relating MOR to time and kiln temperature (Figs. 2 and 3) indicates that drying at 270°F must be done with caution, and kiln time should not exceed 9 hours at this temperature. At 240°F the evidence indicates that MOR is not significantly reduced by kiln times of up to 24 hours.

TABLE 4. — *Warp in No. 2 Dense southern pine boards that were 1.75 inches thick, 5.88 inches wide, and 95 inches long, related to kiln-drying conditions and stage in manufacture*

Kiln conditions	Green	Emergence from kiln	Conditioned 1 yr.	Planed and at test
	----------In.----------			
	CROOK			
180°F, 120 hr.	0.11 (0.05)[*] *0.32*	0.17 (0.15) *0.98*	0.21 (0.25) *1.77*	0.21 (0.25) *1.80*
240°, 36 hr.	0.11 (0.07) *0.31*	0.22 (0.17) *0.92*	0.20 (0.14) *0.77*	0.20 (0.14) *0.77*
240°, 120 hr.	0.13 (0.08) *0.41*	0.24 (0.19) *1.38*	0.22 (0.15) *0.94*	0.19 (0.14) *0.92*
270°, 9 hr.	0.11 (0.07) *0.31*	0.15 (0.09) *0.60*	0.16 (0.08) *0.50*	0.17 (0.09) *0.51*
270°, 36 hr.	0.10 (0.07) *0.32*	0.20 (0.14) *0.89*	0.18 (0.11) *0.65*	0.18 (0.13) *0.80*
270°, 120 hr.	0.11 (0.06) *0.29*	0.23 (0.16) *1.02*	0.20 (0.14) *0.85*	0.20 (0.15) *0.89*
	TWIST			
180°, 120 hr.	0.04(0.02) *0.11*	0.16 (0.11) *0.68*	0.24 (0.18) *0.76*	0.19 (0.15) *0.69*
240°, 36 hr.	0.04 (0.03) *0.17*	0.18 (0.15) *0.63*	0.15 (0.12) *0.56*	0.11 (0.10) *0.54*
240°, 120 hr.	0.05 (0.03) *0.23*	0.20 (0.15) *0.71*	0.17 (0.11) *0.49*	0.13 (0.10) *0.52*
270°, 9 hr.	0.04 (0.02) *0.16*	0.16 (0.14) *0.73*	0.15 (0.13) *0.77*	0.13 (0.13) *0.66*
270°, 36 hr.	0.04 (0.04) *0.30*	0.14 (0.11) *0.56*	0.11 (0.07) *0.35*	0.08 (0.06) *0.33*
270°, 120 hr.	0.05 (0.02) *0.11*	0.17 (0.13) *0.54*	0.14 (0.12) *0.70*	0.10 (0.09) *0.38*
	BOW			
180°, 120 hr.	0.09 (0.04) *0.16*	0.20 (0.11) *0.87*	0.23 (0.15) *1.18*	0.19 (0.25) *2.13*
240°, 36 hr.	0.10 (0.07) *0.41*	0.19 (0.10) *0.58*	0.16 (0.06) *0.32*	0.14 (0.09) *0.61*
240°, 120 hr.	0.10 (0.06) *0.38*	0.27 (0.11) *0.59*	0.18 (0.08) *0.43*	0.17 (0.12) *0.69*
270°, 9 hr.	0.10 (0.07) *0.37*	0.21 (0.12) *0.68*	0.16 (0.07) *0.41*	0.14 (0.09) *0.51*
270°, 36 hr.	0.10 (0.07) *0.36*	0.23 (0.12) *0.83*	0.15 (0.05) *0.30*	0.12 (0.07) *0.32*
270°, 120 hr.	0.12 (0.09) *0.64*	0.25 (0.16) *1.12*	0.17 (0.08) *0.58*	0.14 (0.07) *0.33*

[*]The first value in each tabulation is an average for two kiln loads; following in parentheses is standard deviation in warp; listed below in italics is the maximum warp value observed in any of the 80 boards comprising the two kiln loads.

TABLE 5. — *Properties of 1.5 inch by 5.5 inch No. 2 Dense southern pine boards static tested in edgewise bending over a 91-inch span, related to drying treatment.*

Kiln conditions	MC at test	Density: Based on ovendry weight and green volume	Density: Based on ovendry weight and volume at test	Proportional limit stress	MOR	MOE
	%	pcf	pcf	psi	psi	psi
180°, 120 hr.	9.2^{c*}	30.0^{a}	32.7^{a}	5,087^{b}	7,853^{c}	1,801,480^{a}
240°, 36 hr.	7.4^{c}	30.6^{a}	33.5^{a}	4,906^{bc}	7,582^{c}	1,960,395^{a}
240°, 120 hr.	7.1^{b}	29.2^{a}	32.0^{a}	4,504^{c}	6,109^{b}	1,862,893^{a}
270°, 9 hr.	8.4^{d}	30.3^{a}	32.8^{a}	4,906^{bc}	7,278^{c}	1,860,845^{a}
270°, 36 hr.	7.2^{bc}	29.8^{a}	32.4^{a}	4,712^{bc}	6,506^{b}	1,837,408^{a}
270°, 120 hr.	6.3^{a}	29.1^{a}	32.2^{a}	3,779^{a}	5,100^{a}	1,818,683^{a}

*Within a column, values marked with the same letter are not significantly different (0.05 level) based on Duncan's multiple range test.

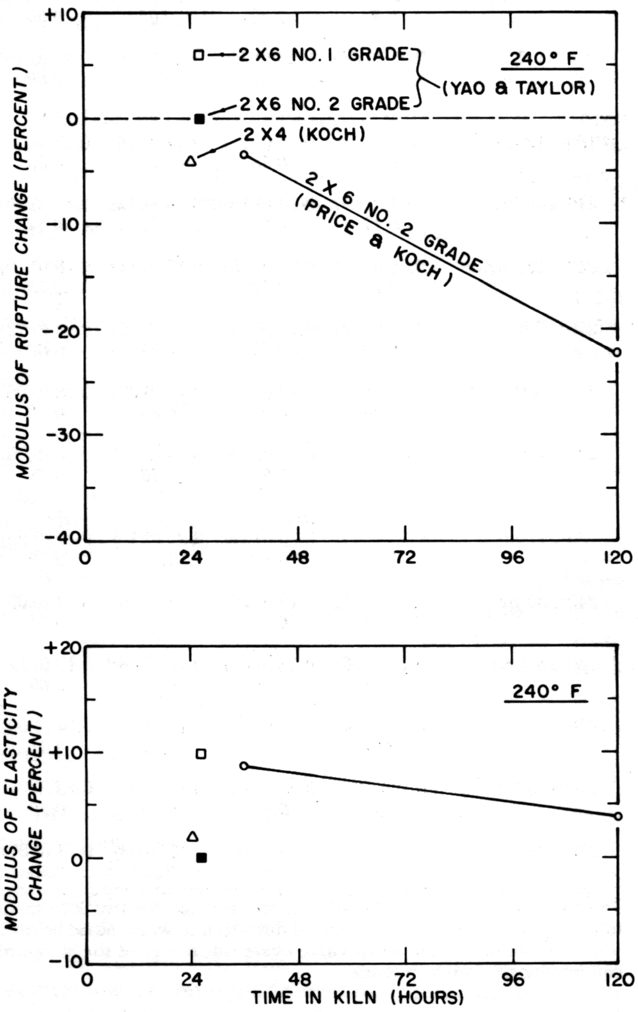

Figure 2. — Solid line graphs change in MOR and MOE in 8/4 southern pine after 36 and 120 hours at 240° F dry-bulb and 160° F wet-bulb temperature. Filled and hollow squares are data points from Yao and Taylor (6). Triangular points from (3). Reference values from lumber dried 120 hours at 180°.

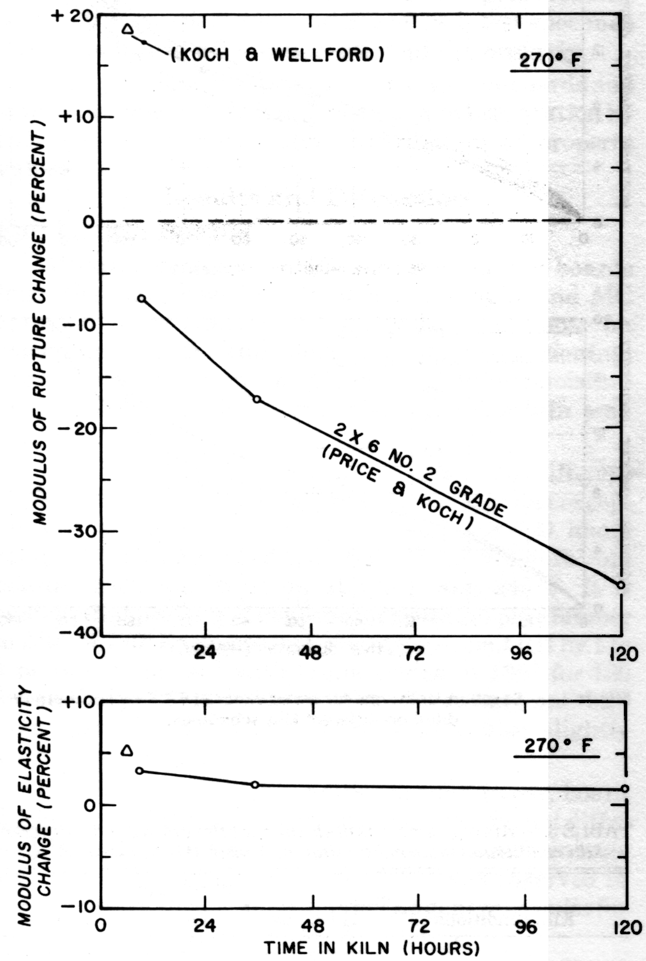

Figure 3. — Solid line graphs change in MOR and MOE in 8/4 southern pine after 9, 36, and 120 hours at 270°F dry-bulb and 160°F wet-bulb temperature. Triangular point from Koch and Wellford (4). Reference values from lumber dried 120 hours at 180°F.

Average MOE of the boards tested in edgewise bending did not differ significantly by treatment (Table 5). The overall average for the 480 boards was 1,857,000 psi. Average values of MOE for lumber dried at 240°F and 270°F were actually slightly greater, a maximum of

TABLE 6. — *Regression statistics for predicting MOR based on measurement in edgewise bending of MOE for No. 2 Dense southern pine boards 1.5 inches thick by 5.5 inches wide.*

Kiln conditions	Equation (psi)	S_e	R^2
180°F, 120 hr.	MOR = –1,179 + .005014(MOE)	2,515	0.33
240°F, 36 hr.	MOR = – 728 + .004239(MOE)	2,891	.24
270°F, 9 hr.	MOR = +1,115 +.003312(MOE)	2,569	.21

TABLE 7. — *Hardness and bending property averages of 1.5 inch southern pine taken from larger boards related to drying treatments.*

Kiln conditions	MCs at test		Density**	Hardness		Proportional limit	MOR	MOE
	Hardness	Bending		Surface***	End			
	%			lb.		psi		
180°, 120 hr.	10.5^{c}*	9.4^{c}	32.8^{a}	838^{a}	983^{a}	7,079^{a}	14,528^{bc}	1,722,000^{a}
240°, 36 hr.	8.4^{c}	7.5^{c}	33.8^{a}	873^{a}	1,143^{a}	8,083^{a}	15,424^{c}	1,835,000^{a}
240°, 120 hr.	7.6^{b}	6.9^{b}	32.7^{a}	844^{a}	1,090^{a}	7,681^{a}	13,833^{b}	1,778,600^{a}
270°, 9 hr.	9.4^{d}	8.3^{d}	32.8^{a}	873^{a}	1,038^{a}	7,144^{a}	14,187^{bc}	1,717,800^{a}
270°, 36 hr.	7.8^{b}	7.0^{b}	33.0^{a}	843^{a}	1,143^{a}	8,111^{a}	14,333^{bc}	1,802,700^{a}
270°, 120 hr.	6.8^{a}	6.0^{a}	32.7^{a}	752^{a}	1,015^{a}	7,336^{a}	11,271^{a}	1,743,000^{a}

*Within a column, values marked with the same letter are not significantly different (0.05 level), based on Duncan's multiple range test.
**Based on ovendry weight and volume at test of bending specimen.
***Average of two side and two edge measurements per specimen.

9 percent, than those for lumber dried at 180°F for 120 hours (Figs. 2 and 3).

Some systems of nondestructive testing of lumber are based on measuring MOE to predict MOR. It is evident from Figures 2 and 3 that long kiln times at 240°F or 270°F alter this relationship. When kiln times are shortened to those in industrial use (21 to 24 hr. at 240°F), or projected for industrial use (a few hours at 270°F), the relationship appears not to be statistically altered in slope or level (Table 6).

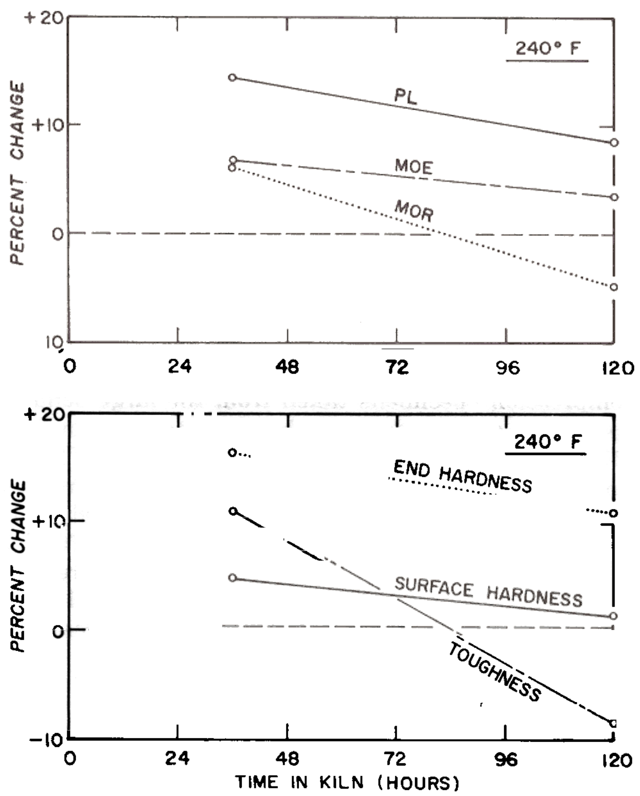

Figure 4. — (Top) Change in proportional limit, MOE, and MOR in specimens from boards dried 36 and 120 hours at 240° F. (Bottom) Change in end hardness, surface hardness, and toughness in similar specimens. Each point is an average of 80 specimens. Reference values from lumber dried 120 hours at 180° F.

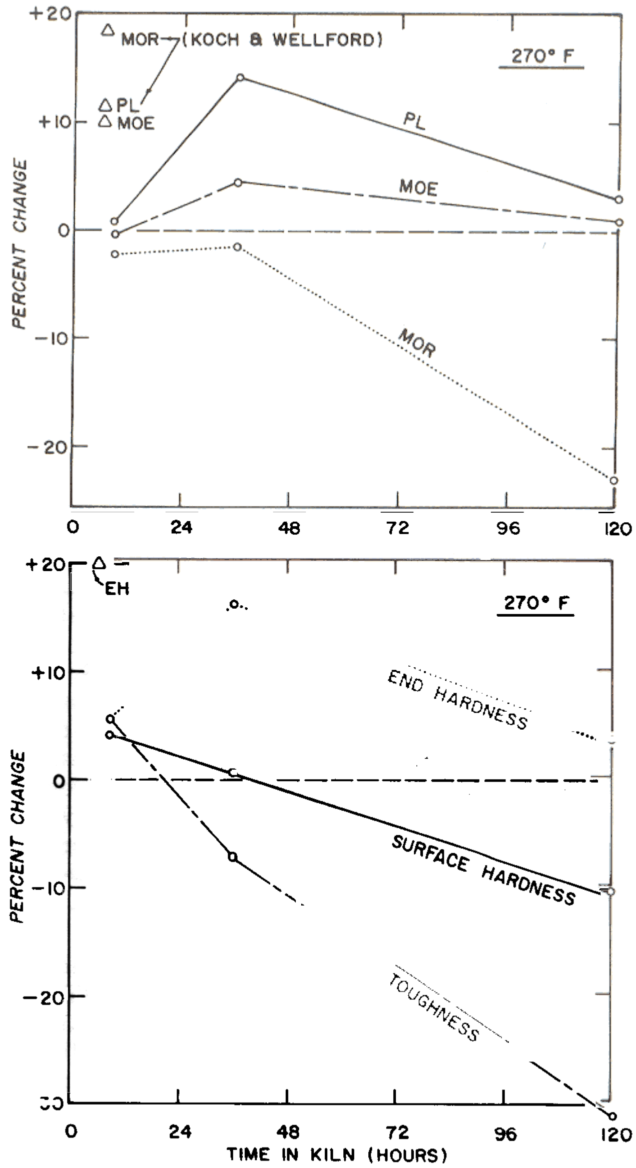

Figure 5. — (Top) Change in proportional limit, MOE, and MOR in specimens from boards dried for 9, 36, and 120 hours at 270° F. (Bottom) Change in end hardness, surface hardness, and toughness of small specimens. Each circular data point is an average of 80 specimens. Reference values from lumber dried 120 hours at 180° F. Triangular points from Koch and Wellford (4) for 35 specimens from southern pine 2 by 4's dried 6 hours at 300° F.

TABLE 8. — *Shear and toughness properties of specimens taken from large boards, related to drying treatment.*

Kiln conditions	Shear specimen		Toughness specimen		
	MC	Strength	Density**	MC	Toughness
	%	psi	pcf	%	In.lb.
180°, 120 hr.	8.9[c]*	1,093[ab]	32.4[a]	9.7[c]	262.9[bc]
240°, 36 hr.	6.8[c]	1,111[ab]	33.7[a]	7.5[c]	291.9[d]
240°, 120 hr.	6.2[b]	1,031[ac]	32.3[a]	6.9[b]	239.5[b]
270°, 9 hr.	7.9[d]	1,193[b]	33.0[a]	8.7[d]	277.5[cd]
270°, 36 hr.	6.5[b]	1,027[ac]	32.9[a]	7.2[bc]	244.5[b]
270°, 120 hr.	5.4[a]	933[c]	32.1[a]	6.1[a]	181.5[a]

*Within a column, values marked with the same letter are not significantly different (0.05 level) based on Duncan's multiple range test.
**Based on ovendry weight and volume at test.

TABLE 9. — *Compression parallel to the grain of specimens taken from large boards, related to drying treatment.*

Kiln conditions	MC	Density**	Compression strength	MOE
	%	pcf	psi	psi
180°F, 120 hr.	11.2[e]*	32.0[a]	6,878[a]	1,827,000[a]
240°F, 36 hr.	9.5[cd]	32.6[a]	7,495[b]	1,811,000[a]
240°F, 120 hr.	8.7[a]	31.8[a]	7,432[b]	1,872,000[a]
270°F, 9 hr.	10.1[d]	31.9[a]	7,168[ab]	1,802,000[a]
270°F, 36 hr.	9.0[bc]	32.2[a]	7,590[b]	1,793,000[a]
270°F, 120 hr.	8.1[ab]	31.9[a]	7,569[b]	1,839,000[a]

*Within a column, values marked with the same letter are not significantly different (0.05 level), based on Duncan's multiple range test.
**Based on ovendry weight and volume at test.

Small Specimens

General. — Specimens for hardness tests were cut from undamaged ends of the small bending specimens. Density measured on the bending specimens was therefore considered applicable to the wood on which hardness was measured and averaged 33.0 pounds per cubic foot based on ovendry weight and MC at test. Hardness was measured some days after evaluation of bending properties, and average wood MC increased from 7.5 to 8.4 percent during the interim. Since all specimens were stored in the same environment, this increase was not considered to be induced by the drying treatments. In both the bending and hardness MC evaluations, MC at test decreased with an increase in kiln temperature and time. Each kiln schedule yielded wood that equilibrated at a significantly different MC, except that specimens dried 120 hours at 240°F were not different in MC from those dried 36 hours at 270°F (Table 7).

Bending properties. — Proportional limit and MOE did not differ significantly with kiln schedule (Table 7, Figs. 4 and 5). Values averaged 7,572 and 1,766,520 psi, respectively. Nor did average MOR differ significantly among the three schedules of industrial interest: 180°F for 120 hours, 240°F for 36 hours, or 270°F for 9 hours. Only at 270°F, with kiln time extended to 120 hours, was MOR significantly diminished from that of wood dried at 180°F.

Hardness. — Neither end hardness nor surface hardness varied significantly with kiln schedule. Averages were 837 and 1,069 pounds, respectively (Table 7, Figs. 4 and 5).

Toughness. — Density of toughness specimens averaged 32.7 pounds per cubic foot (based on ovendry weight and volume at test) and did not vary significantly with kiln schedule. As with other specimens, MC at test decreased with an increase in kiln temperature and time. Average MC at test was 7.7 percent (Table 8).

Toughness did not differ greatly among the three schedules of commercial interest (see Bending Properties). The value for 240°F (36 hr.) was judged to be significantly different from the other two. Only at 270°F, with kiln time extended to 120 hours, was toughness significantly diminished from the toughness of wood dried at 180°F (Table 8, Figs. 4 and 5).

Shear parallel to the grain. — Shear specimens were taken from the small bending specimens and did not differ in density with kiln schedule; the average was 33.0 pounds per cubic foot based on ovendry weight and volume at test. When tested, the shear specimens averaged 7.0 percent MC. MC generally decreased with an increase in kiln temperature and time. Only those specimens cut from wood dried at 240°F for 120 hours and 270°F for 36 hours did not differ significantly in MC at test (Table 8).

Shear strength did not differ significantly among the three schedules of commercial interest (see Bending Properties) (Table 8). Only at 270°F, with kiln time extended to 120 hours, was shear strength significantly diminished (to 933 psi) from that of wood dried at 180°F.

Compression parallel to grain. — Density of compression specimens taken from the large bending specimens did not differ with kiln schedule; however, MC was reduced with kiln time (Table 9). The 180°F, 120-hour treatment yielded the minimum compression strength mean value, but it was not judged to be significantly different from the means for the 270°F, 9-hour treatment. The results indicated that by increasing the temperature and time from the conventional 180°F drying schedule, compressive strength was increased or unaffected while MOE was unaltered.

Summary

Three of the kiln schedules studied should interest lumber manufacturers who dry No. 2 Dense southern pine 2 by 6's:

180°F for 120 hours with air velocity of 300 fpm passing through courses spaced with 3/4-inch-thick sticks

TABLE 10. — *Average mechanical property values of small specimens taken from broken 2 by 6's dried under different kiln conditions.*

Property	180°F 120 hr.	240°F 36 hr.	270°F 9 hr.
MOE, thousand psi	1,722	1,835	1,718
Proportional limit, thousand psi	7.1	8.1	7.1
MOR, thousand psi	14.5	15.4	14.2
Compression parallel, thousand psi	6.9	7.5	7.2
Shear strength parallel, psi	1,093	1,111	1,193
End hardness, lb.	983	1,143	1,038
Side hardness, lb.	838	873	873
Toughness, in.-lb.	263	292	278

240°F for 36 hours with air velocity of 1,000 fpm passing through courses spaced with 3/4-inch-thick sticks

270°F for 9 hours with air velocity of 1,600 fpm passing through courses spaced with 1-1/4-inch-thick sticks

In all schedules the wet-bulb temperature was held at 160°F, and the 4-foot-wide, 8-foot-long kiln stacks carried a top load of 3,000 pounds of concrete.

These schedules dried the green wood (111% average starting MC), which measured 1.75 inches thick and 5.88 inches wide, to 11.9, 2.8, and 8.5 percent MCs, respectively. After a year of equilibration the lumber attained 9.2, 7.4, and 8.4 percent MCs, respectively. At these MCs, shrinkage was least (4.0% in thickness and 3.0% in width) in the 2 by 6's dried for 9 hours at 270°F. Although the differences were not statistically significant, boards dried at 240°F and 270°F, and equilibrated, had less average crook, bow, and twist, less standard deviation in crook, bow, and twist, and less maximum crook and bow than boards dried at 180°F.

When surfaced boards were tested full size (1.5 by about 5.5 in.) in 94-inch lengths to destruction in edgewise bending, averaged MOE, proportional limit, and MOR did not differ significantly. In comparing these treatments, the straight-line regression relationship between MOR and MOE was unaltered in slope or level by drying treatments.

Small bending, shear, hardness, compression, and toughness specimens were excised from the broken 2 by 6's; average values for their mechanical properties were not reduced by the 240°F and 270°F schedules (Table 10). Matched loads of lumber (replicated) were also dried at 240°F for 120 hours and at 270°F for 36 hours and 120 hours. The 120-hour schedules reduced MOR and toughness, and altered MOR:MOE regression relationships.

Literature Cited

1. AMERICAN SOCIETY FOR TESTING AND MATERIALS. 1974. Standard methods of static tests of timbers in structural sizes. ASTM D 198-74. Philadelphia, Pa.
2. ________. 1974. Standard methods of testing small clear specimens of timber. ASTM D 143-72. Philadelphia, Pa.
3. KOCH, P. 1971. Process for straightening and drying southern pine 2 by 4's in 24 hours. Forest Prod. J. 27(5):39-47.
4. ________ and W. L. WELLFORD, Jr. 1977. Some mechanical properties of small specimens cut from 1.79-inch-thick southern pine dried for 6 hours at 300°F or for 5 days at 180°F — a comparison. Wood and Fiber 8(4):235-240.
5. SUCHSLAND, O. 1980. Determination of sorption isotherms in minidessicators. Wood Sci. 12(4):214-217.
6. YAO, J., and F. TAYLOR. 1979. Effect of high-temperature drying on the strength of southern pine dimension lumber. Forest Prod. J. 29(8):49-51.