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

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ABSTRACT

Small specimens cut from 1.79-inch-thick southern pine dried from green condition for 6 hours at a dry-bulb temperature of 300 F suffered no diminution in the mechanical properties determined, when compared to matched wood dried for 5 days at 180 F. Properties were as follows:

	Dried 5 days at 180 F	Dried 6 hours at 300 F
Modulus of elasticity (psi)	1,580,000	1,740,000
Modulus of rupture (psi)	12,980	15,390
Proportional limit (psi)	5,210	5,800
Toughness (inch pounds)	234	252
Face hardness (pounds)	822	888
End hardness (pounds)	941	1,129

Moisture content of the 300-degree wood at test (about 9%) averaged nearly two percentage points less than that of the 180-degree wood after equilibration.

Keywords: *Pinus taeda*, *Pinus palustris*, southern pine, high temperature drying, kiln schedules, modulus of elasticity, modulus of rupture, toughness, hardness, moisture content.

INTRODUCTION

During the past decade the southern pine industry has adopted technology for kiln-drying dimension lumber at temperatures above the boiling point of water. Does exposure to such temperatures diminish the mechanical properties of southern pine?

Previous research (Koch 1971) has indicated that when dried 21 hours at 240 F (160 F wet-bulb temperature) with cross-circulation air velocity of 1,000 fpm, 2 by 4's cut from southern pine veneer cores and small logs suffered no significant (0.05 level) reductions in modulus of elasticity (MOE), modulus of rupture (MOR), or proportional limit (PL) when tested in 8-foot lengths in edgewise bending. Neither was diminution of toughness observed in small clear specimens cut from the 2 by 4's dried at 240 F compared with matched wood dried at temperatures not exceeding 180 F. Contributors to this literature are not unanimous on effects of short exposure to high temperatures, however; Thompson and Stevens (1976) have summarized results of their experiments, which in some instances showed diminution of mechanical properties.

Recently, a tunnel kiln was proposed (Koch and Wellford 1977) for drying 1.75-inch-thick lumber in about 8 hours at 270 F dry-bulb temperature followed by 3 hours for conditioning and 1 hour for cooling. Reported in the same article was 6-hour drying at 300 F.

TABLE 1. *Kiln schedules evaluated for effects on some mechanical properties of 2 by 4's*

Treatment	Dry-bulb temperature °F	Wet-bulb temperature °F	Air velocity ft/min	Time in kiln Hours	Ending Moisture Content Ave. %	Stnd. Dev. %	Range %
180°F uniform for 5 days	180	160	~300	120	10.6	1.0	9.3-13.4
300°F uniform for 6 hours	Ambient to 300[a]	Ambient to 190[b]	1,600	2			
	300	190	1,300	2			
	300	190	1,000	2			
	300-200	190-170	1,000	1			
	200-163	170-155	1,000	1.5			
	163	155	1,000	1.5			
			Total	10	6.0	1.4	3.6-13.6
300°F falling to 243°F over 6 hours	Ambient to 300[c]	Ambient to 180[b]	1,800	2			
	270	180	1,800	2			
	243	170	1,800	2			
	243-185	165	1,000	1			
	185-160	165-153	1,000	1.5			
	160	153	1,000	1.5			
			Total	10	14.7	3.1	8.5-23.9

[a] 100 minutes expended in reaching the 300°F set point.

[b] 150 minutes expended in reaching the wet-bulb set point.

[c] 80 minutes expended in reaching the 300°F set point.

The objective of the work here reported was acquisition of preliminary information on strength diminution, if any, caused by 6-hour exposure of 1.79-inch-thick green southern pine to temperatures up to 300 F. We compared such lumber with matched lumber dried 5 days at 180 F, a kiln schedule typically used before widespread application of high-temperature kilns to dry southern pine.

PROCEDURE

Source of wood

Ten rough green No. 2 and better 2- by 8-inch, 16-foot-long southern pine (probably *Pinus taeda* L. and *P. palustris* Mill) planks were procured from a central Louisiana sawmill and were surfaced on one side only to an average thickness of 1.79 inches (standard deviation 0.02 inch; range 1.73 to 1.86 inches). The 2 by 8's were then crosscut to yield 63 pieces 2 feet long that were entirely clear, clear in the central length, or had sound knots of less than 1-inch diameter (no spike knots were permitted). Seventeen pieces were culled. The sixty-three 8-inch-wide pieces accepted were then center-ripped into 126 pieces averaging 4.04 inches in width (standard deviation 0.08 inch; range 3.80 to 4.24 inches). Each piece as it came from ripsaw was sequentially dealt into one of three piles to yield three groups of 42 pieces closely matched in group-average specific gravity (measured on the basis of green volume and oven-dry weight). Details of knot structure and slope of grain were not recorded since wood with knots or sloped grain was fairly and randomly distributed among treatments. The pieces were stored under water (stain inhibitor added) for 1 to 7 days before kiln-drying. Immediately before drying, the pieces were end-coated with a roofing compound of high-temperature asphalt mixed with asbestos fibers, weighed, and measured for width and thickness. Green moisture content averaged 97.4% with standard deviation of 26 percentage points and range from 43 to 164%.

Drying

To make the comparison, three kiln loads were dried on different schedules. Each load consisted of 42 end-coated boards measuring 2 feet long. Each charge measured 5 feet wide and was comprised of

TABLE 2. *Comparison of flatwise bending properties of 1.5- by 1.79-inch specimens cut from southern pine 2 by 4's dried for 120 h (5 days) at 180 F or for 6 hours at temperatures reaching 300 F*[a]

Property	5 days at 180°F	6 hours 300° 243°F	6 hours at 300°F
Modulus of elasticity (psi)			
Average	1,580,000	1,660,000	1,740,000
Standard deviation	351,000	256,000	311,000
Range	810,000-2,450,000	1,200,000-2,160,000	810,000-2,230,000
Proportional limit (psi)			
Average	5,210	5,640	5,800
Standard deviation	1,452	1,431	1,862
Range	2,940-8,150	2,730-9,490	2,970-10,010
Modulus of rupture (psi)			
Average	12,980	13,960	15,390[b]
Standard deviation	2,851	1,635	2,261
Range	6,250-17,460	10,940-18,500	11,000-21,290
Moisture content at test (%)			
Average	11.2	11.8	9.3[b]
Standard deviation	0.37	0.58	0.58
Range	10.7-11.9	9.6-12.6	8.2-10.7
Specific gravity[c]			
Average	0.544	0.545	0.544
Standard Deviation	0.04	0.03	0.03
Range	0.49-0.63	0.50-0.63	0.45-0.61

[a] Each average value shown represents data from 35 2-by-4's.

[b] Modulus of rupture and moisture content of specimens from 2-by-4's dried 6 hours at 300°F were significantly different (0.01 level) than values for the other two schedules.

[c] Basis of ovendry weight and volume at test.

three courses each holding 14 pieces. Above and below the lumber being dried were 1½-inch-thick layers of water-soaked plywood (to simulate additional courses of lumber).

The three kiln schedules (Table 1) could be briefly described as follows:

180 F uniform for 5 days

300 F uniform for 6 hours

300 F falling to 243 F over 6 hours.

Each of these schedules will dry green southern pine 2 by 4's to an average of less than 15% moisture content if cross-circulation air velocities are as specified in Table 1. Lumber dried at high temperature was stacked on 1¼-inch-square sticks; that dried at 180 F was stacked on ¾-inch-thick sticks.

Ending moisture contents on removal of 2 by 4's from the kiln averaged 6.0% for the wood dried at 300 F and 10.6% for that dried at 180 F; the variable temperature schedule yielded 14.7% moisture content (Table 1).

Specimen preparation

On removal from the kiln, pieces were immediately weighed. Each piece was then center-ripped to yield two boards about 1.7 inches thick by 2 inches wide. One was for bending tests, and the matching board was crosscut to yield a toughness-specimen blank plus two ¾-inch wafers (taken 4 to 6 inches from either end of the 2-foot end-coated board) that were weighed, oven-dried, and weighed again for moisture content determination.

The resulting 126 bending-specimen blanks and 126 toughness-specimen blanks were conditioned (71 F dry-bulb temperature and about 10 F wet-bulb depression) from 16 March to 15 April 1976. They were then sized and returned to the equilibration chamber.[1] Bending specimens were 24

[1] During specimen preparation, it was noted that exterior surfaces of wood dried at 300 F were toasted brown in color. This color penetrated to depths up to 1/16-inch. At 1/8-inch depth, all trace of brown discoloration was absent.

TABLE 3. *Properties of hardness specimens*

Property	5 days at 180°F	6 hours at 300° → 243°F	6 hours at 300°F
Face hardness, pounds			
Average[a]	822	873	888
Standard deviation	133	132	124
Range	640- 1,135	665 - 1,175	640 - 1,190
End hardness, pounds			
Average[a]	941	1,055	1,129[b]
Standard deviation	164	118	137
Range	707 - 1,360	815 - 1,360	912 - 1,360
Moisture content, %			
Average	10.7	11.4	8.9[b]
Standard deviation	0.60	0.68	0.47
Range	8.1 - 11.6	9.0 - 12.4	8.2 - 10.2
Specific gravity[c]			
Average	0.544	0.545	0.554
Standard deviation	0.04	0.03	0.03
Range	0.49 - 0.63	0.50 - 0.63	0.45 - 0.61

[a] Each average value was determined from two measurements, i.e., two sides or both ends, on 35 specimens.

[b] Significantly different (0.01 level) from the other two values.

[c] Basis of ovendry weight and volume at test.

inches long and were planed to 1.5 inches thick and 1.75 inches wide; they contained some defects as explained earlier. Toughness specimens were clear and were sized to 0.79 inches (2 cm) square by 11.02 inches (28 cm) in length. Finally, beginning 13 May 1976 (weight changes had slowed to near cessation), all specimens were evaluated over a 1-week period for mechanical properties.

Strength evaluation

Of the original 42 bending specimens from each kiln charge, seven were rejected because of excessive knot size or grain deviation revealed during specimen preparation. As a result, data for only 35 specimens from each charge were compared. After measurement of weight, width, thickness, and length, the bending specimens were loaded flatwise with centerpoint loading over a 21-inch span and evaluated for MOE, PL, and MOR. Speed of loading followed ASTM D 198-74, Static Tests of Timber of Structural Size.

Moisture content was determined from a pair of 1-inch cross-sectional slices taken from the broken specimen immediately after test. Stress at PL and MOR were calculated from the standard flexure formula. MOE was computed from the simple deflection formula, which ignores the effect of shear stress on deflection.

From each broken bending specimen, a hardness specimen was taken and evaluated on both ends and two faces according to ASTM Standard D 143-52 paragraphs 83 to 87 (except that pieces measured 1.5 by 1.75 inches in cross section and were of variable length depending on clear wood availability). Specimen moisture content was determined immediately after test.

After measurement of weight, thickness, width, and length, toughness specimens (42 from each charge) were evaluated according to ASTM Standard D 143-52 paragraph 74. Moisture content of each specimen was determined from a portion removed immediately after each test.

RESULTS AND DISCUSSION

Specific gravity and moisture content

Moisture content of the bending specimens at test was significantly (0.05 level) lower in wood dried 6 hours at 300 F (average 9.3%) than in wood dried at lower temperatures (average 11.5%). Specific gravity did not vary significantly. The ap-

TABLE 4. *Properties of toughness specimens*[a]

Property	5 days at 180°F	6 hours at 300° → 243°F	6 hours at 300°F
Toughness, inch-pounds			
Average	234.3	223.2	252.2
Standard deviation	63.7	53.1	83.2
Range	131.4 - 376.0	114.4 - 414.6	120.1 - 441.0
Specific gravity[b]			
Average	0.543	0.543	0.549
Standard deviation	0.048	0.055	0.051
Range	0.43 - 0.64	0.45 - 0.69	0.43 - 0.65
Moisture content, %			
Average	10.7	10.6	9.3[c]
Standard deviation	0.42	0.81	0.40
Range	9.9 - 11.4	8.7 - 11.7	8.3 - 10.3

[a]Each average value was based on 42 specimens.

[b]Basis of ovendry weight and volume at test.

[c]Significantly different from other two values (0.01 level).

parently slightly higher specific gravity of wood dried for 6 hours at 300 F (0.01 difference based on volume at test and ovendry weight) is probably due to slight densification from additional shrinkage attributable to the 2.2 percentage points difference in moisture content (Table 2), which in turn is traceable to reduced hygroscopicity of wood dried 6 hours at 300 F. This comment on specific gravity and moisture content is also applicable to the hardness specimens (Table 3) and to the toughness specimens (Table 4).

Because of the close matching of green-volume specific gravity, and the suspected reduced hygroscopicity of wood dried 6 hours at 300 F, covariance analysis of mechanical properties with specific gravity and moisture content was not attempted. Significant differences indicated in Tables 2, 3 and 4 are the result of one-way analyses of variance based on kiln schedule only.

Bending properties

Since bending specimens were taken from lumber of various specific gravities (0.45 to 0.63) and were cut in such a manner that some contained small knots, they varied considerably in strength. By analysis of variance, neither MOE or PL varied significantly by drying schedule. MOR of wood dried 6 hours at 300 F was significantly greater (0.01 level) than that of wood dried by the other two schedules (Table 2). A larger scale test would perhaps not show this significant difference in MOR. In any event, the lumber dried for 5 days at 180 F had lowest average values for MOE, PL, and MOR.

The higher strength of the 300-degree wood was probably due partially to its lower moisture content at time of test and slightly higher specific gravity. The classical correction for wood moisture content is about 4% increase per 1% decrease in moisture content for MOR and 2% for MOE. On this basis, one would expect the average MOR for the 300-degree wood (average 9.3% MC at test) to be about 8% greater than that of the 180-degree wood (average 11.2% at test), whereas the difference was actually 19%. By the same rationale, MOE of the 300-degree wood should have been about 4% higher than that of the 180-degree wood, whereas the difference was actually 10%.

Hardness

Face hardness values averaged 861 pounds with no significant difference among drying schedules. End hardness of wood dried 6 hours at 300 F was significantly (0.01 level) greater (1,129 pounds) than that for the other two drying schedules (average 998 pounds); the difference amounted to 13% and is in part attribut-

able to the lower moisture content of the 300-degree wood (Table 3).

Toughness

Toughness did not differ significantly by drying treatment (average 236.6 inch pounds). Wood dried 5 days at 180 F had the lowest average value, and 6-hour, 300-degree wood had the highest average (Table 4).

CONCLUSION

From this limited experiment it would appear that small specimens cut from 1.79-inch-thick southern pine dried from green condition for 6 hours at a dry-bulb temperature of 300 F, with wet-bulb temperature of about 190 F, do not have lower PL, MOR, MOE, toughness, or hardness than matched wood dried for 5 days at 180 F dry-bulb temperature with wet-bulb temperature constant at 160 F.

A more extensive experiment is in progress to establish a time-temperature relationship with mechanical properties of 8-foot-long density-matched No. 2 southern pine 2 by 6's dried at high temperature and evaluated in edgewise bending. Compression and shear strengths will also be evaluated in this larger experiment.

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