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Saw-Dry-Rip Improves Quality of Random-Length Yellow-Poplar 2 by 4's

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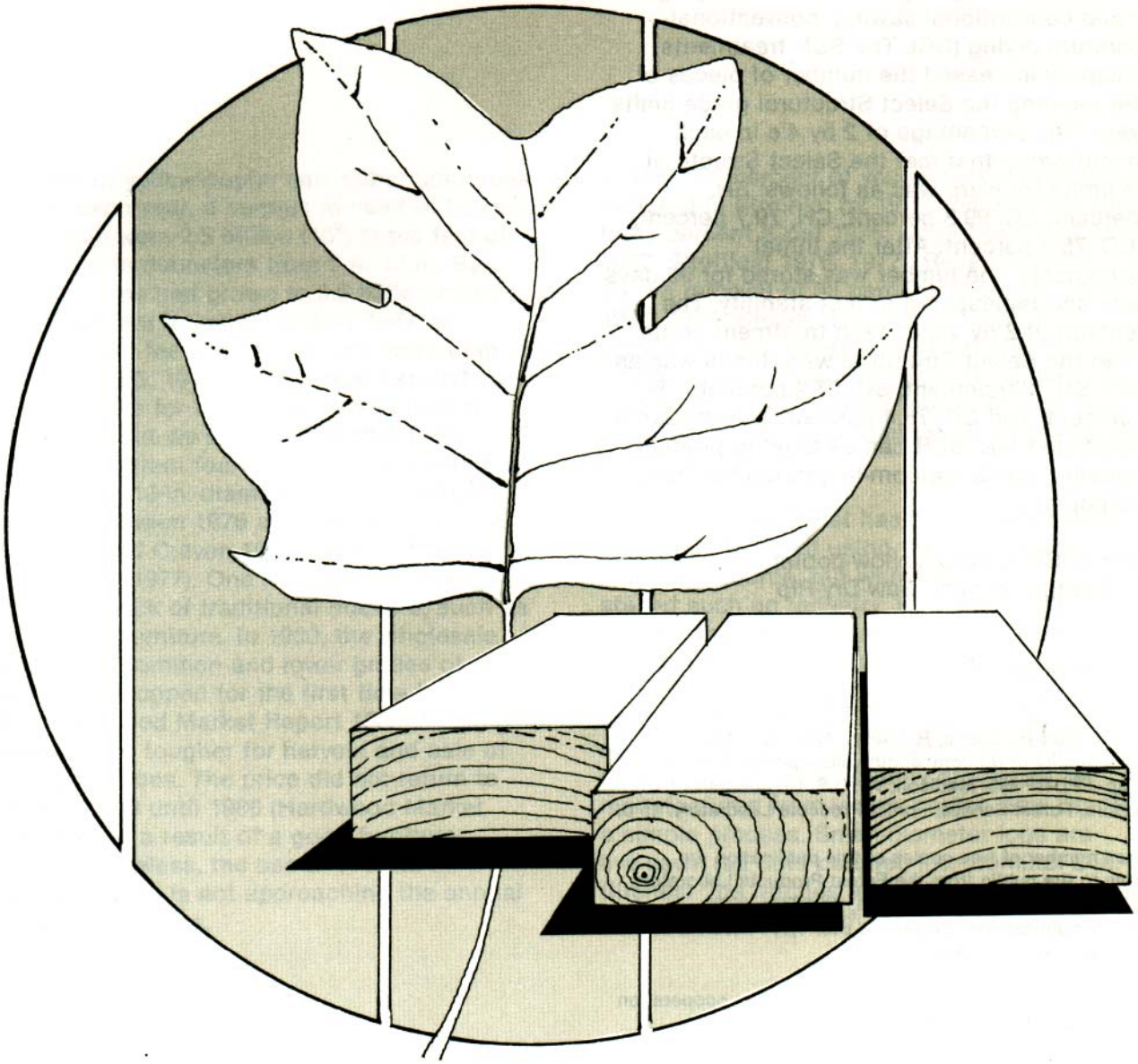

Abstract

Past attempts to manufacture studs and other structural lumber from small-diameter yellow-poplar have resulted in excessive rejects because of warp. Although the Saw-Dry-Rip (SDR) process has been shown to produce straight, high-quality lumber from stud-length small-diameter wood, this process has not been used for random-length lumber. In our study, small 16-ft yellow-poplar logs of 8- to 14-in. diameter were processed by conventional methods and by SDR. Four treatments combining different sawing and drying methods were used in the research: SDR, high-temperature drying (SH); SDR, conventional-temperature drying (SC); conventional sawing, high-temperature drying (CH); and conventional sawing, conventional-temperature drying (CC). The SDR treatments significantly increased the number of pieces of lumber meeting the Select Structural grade limits for warp. The percentage of 2 by 4's in each treatment group that met the Select Structural grade limits for warp was as follows: SH, 100 percent; SC, 99.3 percent; CH, 79.7 percent; and CC, 75.4 percent. After the initial measurements, the lumber was stored for 90 days or more and remeasured to test stability. The percentage of 2 by 4's in each treatment group that met the Select Structural warp limits was as follows: SH, 100 percent; SC, 97.2 percent; CH, 77.6 percent; and CC, 78.4 percent. This research demonstrated that SDR can be used to produce high-quality, stable random-length lumber from yellow-poplar.

Keywords: SDR, warp, yellow-poplar, random-length lumber, Saw-Dry-Rip

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Introduction

The volume of yellow-poplar sawtimber continues to expand each year, a surplus in need of harvest. In 1963, there were 2.5 billion (10^9) cubic feet of yellow-poplar in diameters from 7 to 13 in. By 1970, the volume had grown to 3.6 billion cubic feet (a 44 percent increase) and by 1977, to 5.5 billion cubic feet, or 119 percent more than in 1963 (USDA 1965, 1973, 1982). Recent statistics are not available for the whole distribution of yellow-poplar, but we can assume that it has followed the pattern found in Virginia, where the volume of 7- to 13-in.-diameter trees increased 7.3 percent between 1976 and 1985 (Brown 1985, 1986; Brown and Craven 1985; Cost 1976; Sheffield 1976, 1977). One reason for this surplus growth is the lack of traditional markets, such as core stock for furniture. In 1980, the wholesale price of No. 2 Common and lower grades of yellow-poplar dropped for the first time in over 3 years (Hardwood Market Report 1980), making the market even tougher for harvest and sale of these surplus trees. The price did not return to the level of 1979 until 1986 (Hardwood Market Report 1986) as a result of a good furniture market. Nevertheless, the use of 7- to 13-in. yellow-poplar logs is not approaching the annual growth of the species.

In 1966, 69 percent of yellow-poplar growth was removed in Virginia; by 1976, removal had dropped to 43 percent (Cost 1976; Knight and McClure 1967; Sheffield 1976, 1977). Recent reports have shown removal of 52 percent of growth (Brown 1985, 1986; Brown and Craven 1985). These growth-removal figures are for all diameters of yellow-poplar. Only 1985 data are available for 7- to 13-in. trees; removal levels for these small trees are much lower than those for the larger diameter trees.

The structural market has historically been a potential means of using the small-diameter surplus resource, but warp degrade has forestalled such an industry. Koch and Rousis (1977) showed that studs could not be economically produced from yellow-poplar using conventional manufacturing techniques. STUD grade recovery was only 34 to 40 percent. However, early and continued research on Saw-Dry-Rip (SDR) has shown that improved quality studs can be manufactured from yellow-poplar. Saw-Dry-Rip is a simple process. Small-diameter logs are live-sawn (all cuts parallel) into nominal 2-in.-thick flitches. The flitches are dried and then ripped to the desired final width.

The initial research on the SDR process was done on yellow-poplar. The earliest studies, by Hallock and Bulgrin (1978a,b), used yellow-poplar from southern Illinois. Subsequent studies by Boone and Maeglin (1980), Maeglin (1978), Maeglin and Boone (1983), and Maeglin et al. (1981) used yellow-poplar from North Carolina, West Virginia, Tennessee, and Indiana. All these studies used 8-ft-long stud material. Research at Virginia Polytechnic Institute and State University in the areas of drying and grading showed the SDR process to be viable for stud manufacture (Denig et al. 1984, Weik et al. 1984). In addition, North Carolina State University has developed specific information on production (Allison et al. 1987) and the engineering and construction properties of yellow-poplar structural lumber, including span tables (North Carolina State University 1983, 1985), and has produced a video tape on the use of yellow-poplar in house construction.[1]

In 1981, Harpole et al. released an economic analysis of SDR showing its validity for a medium-sized stud mill, and they also indicated that the addition of random-length 2 by 4's to the product mix would make the process much more viable. Random-length 2 by 4's generally bring a premium of $5 to $100 over cut-to-length STUD, grade lumber. Table 1 shows the premiums for western spruce-pine-fir random-length 2 by 4's, graded Standard and Better, compared to STUD grade lumber for November 1985 through October 1986 (Random Lengths 1985-86).

The figures in table 1 indicate a dollar advantage in adding random length to the product mix. But questions remain. (1) Will longer lumber be straight enough to meet the grade rules? (2) Will SDR produce yields of random-length lumber equal to the yields produced by conventional processing? Our study was conducted to answer these questions.

Table 1—Wholesale prices of western spruce-pine-fir, Standard and Better grade, from November 1985 to October 1986

Value	Wholesale price ($/MBF)[a]					
	STUD[b] grade	Random-length 2 by 4's				
		8ft	10ft	12ft	14ft	16ft
Average	155	153	178	155	156	196
High	191	191	220	190	190	231
Low	135	132	153	132	132	161

[a]Dollars per thousand board feet.

[b]Precision end trimmed (Random Lengths 1985-86).

[1]"Yellow-Poplar as a Building Material," available from School of Forest Resources, Agricultural Extension Services, Box 8003, North Carolina State University, Raleigh, NC 27695-8003.

Materials and Methods

The study was designed to evaluate the SDR process for manufacturing random-length 2 by 4's up to 16 ft in length. Warp and yield of SDR-processed lumber are compared to that of conventionally processed lumber.

The four treatment combinations were as follows: SDR, high-temperature drying (SH); SDR, conventional-temperature drying (SC); conventional sawing, high-temperature drying (CH); and conventional sawing, conventional-temperature drying (CC).

The statistical design of the study was a 2 by 2 factorial, comparing conventional sawing and live sawing and conventional-temperature drying and high-temperature drying. Twenty logs were used for each sawing and drying combination. There were two replicates of 10 logs for each drying schedule to provide data should a kiln malfunction during drying.

The principal criterion for evaluation was warp. The standards for warp were the National Grading Rules for Light Structural Framing and Light Framing (Northern Hardwood and Pine 1978, U.S. Department of Commerce 1970). Warp limits for all grades of random-length structural lumber are found in table 2, and limits for yellow-poplar random-length lumber by treatment and other data on lumber variables are given in table 3.

Material Selection

Eighty woods-run logs were selected from the Hoosier National Forest in Indiana. These logs were taken from trees 8 to 12 in. at breast height diameter. A minimum top diameter of 5 in. (inside bark) was used. The logs were cut to 16 ft plus trim. Nine of the 80 logs were under 16 ft long by less than a foot.

At the Forest Products Laboratory (FPL) the logs were sorted into 8 replications of 10 logs each, balancing the replications in average small-end log diameter, total average volume, and butt and upper logs.

Table P-Warp limits for random-length lumber by grade and length

Grade of lumber and degree of warp[a,b]	Lumber length (ft)	Warp (1132 in.) at various lumber widths							
		Crook			Bow			Twist	
		2 in.	3 in.	4 in.	2 in.	3 in.	4 in.	2 in.	3 and 4 in.
Construction, Select Structural, and No. 1 (112 Medium)	8	8	8	8	24	24	24	6	12
	10	22	16	12	66	48	36	8	14
	12	24	18	16	72	54	48	9	18
	14	32	24	20	96	72	60	10	20
	16	40	30	24	120	90	72	12	24
Standard and No. 2 (Light)	8	12	12	12	36	36	36	8	16
	10	24	20	16	72	60	48	10	20
	12	32	24	22	96	72	66	12	24
	14	40	32	28	120	96	84	14	28
	16	52	40	32	156	120	96	16	32
Utility and No. 3 (Medium)	8	16	16	16	48	48	48	12	24
	10	44	32	24	132	96	72	16	28
	12	48	36	32	144	108	96	18	36
	14	64	48	40	192	144	120	20	40
	16	80	60	48	240	180	144	24	48

[a]All material not making one of these grades is classified as Economy.

[b]Terms in parentheses refer to the level of warp allowed for the lumber grades as shown in the grading handbook (Northern Hardwood and Pine 1978).

Table 3—Log size and volume, lumber yield recovery, and lumber moisture content by treatment for yellow-poplar random-length lumber

Lumber variable	Average data for various treatments[a]			
	SH	SC	CH	CC
Small-end log diameter (in)	10.9	10.8	10.9	11.0
Log volume[b] (ft^3)	202.4	200.4	200.9	200.4
Scribner decimal C volume (fbm)	1,345	1,345	1,300	1,320
Gross lumber volume (fbm)	1,493	1,555	1,319	1,564
Net lumber volume[c] (fbm)	1,493	1,544	1,095	1,238
Lumber recovery factor[d]	7.4	7.8	6.6	7.8
Overrun[e] percent	11.0	15.6	1.5	18.5
Moisture content (percent), initial	8.3	8.5	8.6	8.9
Moisture content (percent), remeasure	7.6	7.6	7.4	8.0

[a]SH is SDR, high-temperature drying; SC is SDR, conventional-temperature drying; CH is conventional sawing, high-temperature drying; CC is conventional sawing, conventional-temperature drying.

[b]Product of small-end area and length.

[c]Acceptable graded pieces.

[d]Ratio of gross lumber volume to cubic foot volume.

[e]Ratio of gross lumber volume to Scribner log volume.

Sawing

The conventionally sawn 2 by 4's were cut using the centered cant method (a 4-in. cant is located in the geometric center of the log). The cants were produced by split-taper sawing. Nominal 2-in. (7/4) flitches were sawn from the sides of the logs, adjacent to the cants, where possible. The cants and flitches were then ripped green for drying. The cants were ripped into 2 by 4's. The flitches were ripped into 2 by 2's, 2 by 3's, and 2 by 4's to maximize recovery, with emphasis on producing 2 by 4's.

For the SDR treatments, live sawing (all cuts parallel) was used to produce 7/4 flitches. The logs were sawn using full-taper sawing (parallel to one outside face of the log) and an opening face of at least 4 in. The flitches were edged green to 1/2 in. wider than the acceptable wane limits and the presumed final edging line. Rough edging of the flitches reduces the amount of excess wood for drying and makes the kiln load more compact.

Drying

Lumber or flitches for each kiln charge were stacked on 3/4-in. stickers spaced 2 ft apart, forming a pile 4 ft wide and about 3 ft high. All loads were top weighted with 25 lb/ft^2 to minimize warp in the top courses.

The 7/4 lumber was conventionally dried according to FPL Schedule T11-D4 (Rasmussen 1961), starting at 150 °F dry bulb (DB) and 143 °F wet bulb (WB) temperatures, with airspeeds of 400 ft/min and with a target of 12 ± 3 percent moisture content. Three sample boards were used to monitor drying in each kiln load.

The high-temperature drying schedule was developed by modifying the schedule used for 8-ft studs (Boone and Maeglin 1980). The schedule was 22 h at 235 °F DB and 180 °F WB, followed by an equalizing period of 17 h at 180 °F DB and 172 °F WB, providing an equilibrium moisture content of 10 percent. Airspeeds in the kiln were 800 to 900 ft/min. Target moisture content was 12 ± 3 percent.

All materials in a treatment were measured for moisture content and warp after planing. Moisture content was measured using an electronic resistance moisture meter. The probes were driven into each piece to a depth of 3/8 in. Measurements were taken at three locations on each piece: 12 to 18 in. from each end and about in the middle. All knots and general defects were avoided when measuring moisture content.

Ripping and Planing

All conventionally sawn lumber was immediately cut to target size. After drying, the lumber was planed to standard dressed dimensions as specified in PS-20-70 of the American Lumber Standards (U.S. Department of Commerce 1970). The same dimensions applied to the finished SDR lumber.

After live sawing and drying, SDR flitches were ripped into 2 by 4's, 2 by 3's, and 2 by 2's, maximizing yield but concentrating on 2 by 4's. Flitches were measured before ripping to determine the best yielding combination of piece sizes. After ripping, the pieces were planed to standard sizes.

Measurement of Warp

Measurements of crook, bow, and twist were done on an 18-ft-long table, using tapered metal gauges calibrated in 1/32 in. Because of the length of the pieces, measurements were made so that the weight of the 2 by 4's did not alter the amount of warp. To do this, the deflection from straightness was measured from the vertical back of the table. The metal gauges were inserted to the point of refusal between the 2 by 4's and the back of the table at the point of greatest deflection, measuring to the nearest 1/32 in. Crook, bow, and twist were measured (fig. 1). Crook is the deviation edgewise from a straight line drawn from end to end of the piece, bow the deviation flatwise from a straight line drawn from end to end of the piece, and twist a deviation flatwise or flatwise and edgewise, in the form of a curl or spiral, so that the four corners of any face are not in the same plane. Pieces were rejected if they did not meet the warp limits of the National Grading Rule Select Structural grade. Only warp was considered, not wane, knots, and other defects. The limits for warp can be found in any softwood grading rules book, such as Northern Hardwood and Pine (1978).

After the initial warp measurement, the lumber was stored in an open-sided shed for at least 90 days and then moved to heated storage for 4 to 6 weeks, awaiting remeasurement for moisture content and warp. Methods for remeasurement were the same as those used initially.

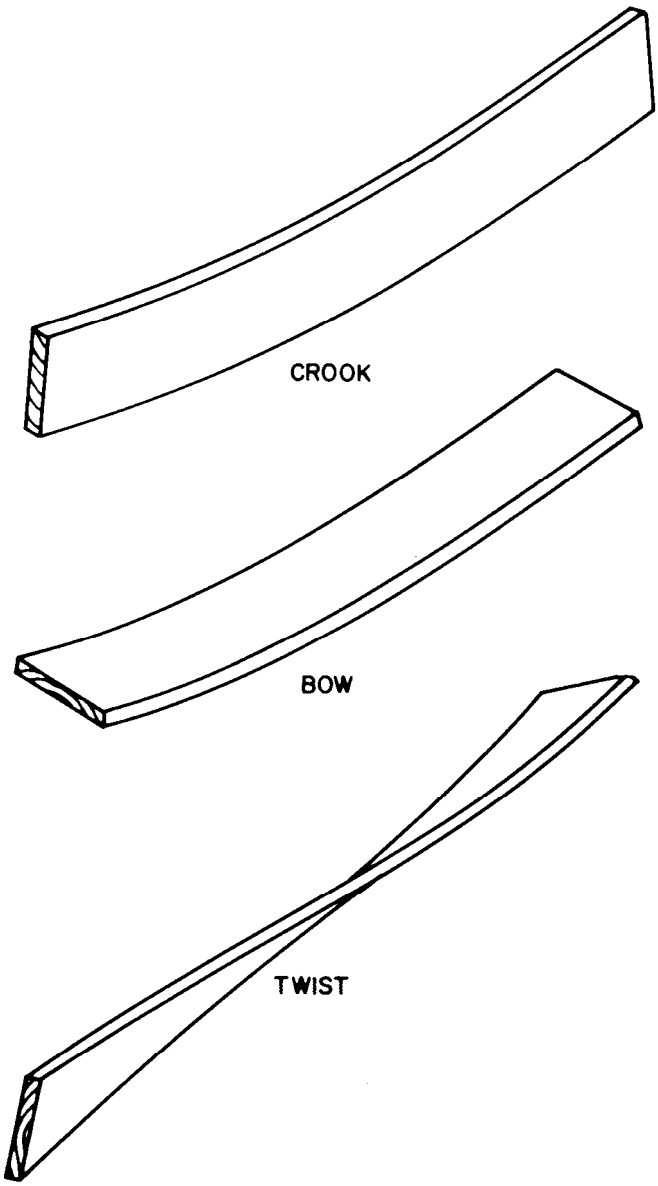

Figure 1—Three types of warp studied. (ML84 5549)

Results and Discussion

The study was designed to have balance in log diameter and total log volume. The average log diameter was 10.9 ± 0.1 in. for all treatments, and total log volume was between 200.4 and 202.4 ft^3 (table 3).

Initial Measurement of Lumber

Immediately after manufacture of the lumber, warp was measured and analyzed to determine treatment effects. The effects of treatment before storage are discussed here.

Average moisture content of lumber in each treatment group (8.3 to 8.9 percent) was lower than the target of 12 ± 3 percent but is very close to the values expected when lumber is placed in the walls of a heated or air-conditioned building (table 3).

In this study, as in the earlier stud-length study of yellow-poplar (Maeglin and Boone 1983), SH treatment gave the best overall results, followed by SC, CH, and CC. The results were evaluated by the number of rejects and the total amount of warp (tables 4 to 8).

Table 4—Warp average, maximum, and standard deviation (SD) for SH-treated[a] lumber at initial measurement[b]

Lumber		Crook (1/32 in.)			Bow (1/32 in.)			Twist (1/32 in.)		
Size (in.)	Length (ft)	Average	Maximum	SD	Average	Maximum	SD	Average	Maximum	SD
2 by 2	7	1.0	1	3.2141	4.0	4	—	0	0	—
	8	2.3	6	3.2141	6.7	13	5.6862	1.3	4	2.3094
	10	5.5	7	2.1213	8.0	11	4.2426	0	0	—
	12	1.7	2	0.5774	4.7	8	3.0551	0.3	1	0.5773
	14	6.5	13	4.5092	16.2	22	5.6789	0.5	1	0.5773
	16	1.0	1	—	16.0	16	—	8.0	8	—
2 by 3	6	0.5	1	0.7071	3.0	4	1.4142	0	0	—
	7	0.5	1	0.7071	5.5	7	2.1213	1.0	2	1.4142
	8	1.5	3	1.2910	3.5	7	2.6458	0.8	3	1.5000
	10	1.0	1	—	1.0	1	—	0	0	—
	12	1.5	4	1.73212	4.8	8	3.7749	0.2	1	0.5000
	14	6.8	12	3.8622	8.5	14	3.6968	2.0	3	0.8165
	16	8.0	12	4.8990	10.5	22	8.8887	2.8	4	1.8929
2 by 4	6	1.7	3	1.5275	2.0	3	1.7321	0.3	1	0.5773
	7	0	0	—	7.0	7	—	1.0	1	—
	8	1.0	5	1.4610	4.0	15	3.7659	1.4	4	1.4058
	10	2.0	3	1.0000	4.2	6	2.4900	1.4	4	1.6733
	12	3.7	12	4.4979	5.7	12	3.1460	1.2	3	1.0681
	14	4.2	20	4.3558	9.5	32	6.9255	2.1	11	2.4000
	16	5.0	16	3.9032	12.2	40	9.6843	2.5	10	2.6628

[a]SH is SDR, high-temperature drying.

[b]SH-treated lumber had no rejects at initial measurement.

Table 5—Warp average, maximum, and standard deviation (SD) and number of rejects[a] for SC-treated[b] lumber at initial measurement

Lumber		Crook (1132 in.)				Bow (1/32 in.)[c]			Twist (1132 in.)			
Size (in.)	Length (ft)	Average	Maximum	SD	Rejects (No.)	Average	Maximum	SD	Average	Maximum	SD	Rejects (No.)
2 by 2	6	2.5	4	2.1213		3.0	4	1.4142	0.5	1	0.7071	
	8	1.5	2	1.0000		4.5	14	3.6968	2.2	5	2.2173	
	10	3.0	3	—		14.0	14	—	3.0	3	—	
	12	2.8	5	2.2174		7.2	10	3.5940	2.5	10	5.000	1
	14	6.2	10	3.4928		10.2	15	4.6043	3.0	13	5.6568	1
	16	3.7	7	1.8619		7.2	15	4.4008	0.8	1	0.4082	
2 by 3	7	2.0	2	—		2.0	2	—	0	0	—	
	8	0.7	1	0.5774		4.7	5	0.5774	1.0	3	1.7320	
	12	2.6	4	1.5166		7.0	10	2.9155	1.4	2	0.5477	
	14	4.0	4	—		7.0	7	—	1.0	1	—	
	16	9.9	14	3.7961		6.4	9	1.4079	1.5	6	2.1380	
2 by 4	6	0.5	1	0.7071		1.5	2	0.7071	1.5	2	0.7071	
	7	1.0	1	—		2.5	3	0.7071	2.0	3	1.4142	
	8	1.1	6	1.9821		3.9	9	2.7911	2.4	10	2.4181	
	10	3.0	8	2.5166		4.6	11	3.9521	2.1	8	3.1320	
	12	2.9	6	1.8141		6.5	17	4.4354	1.5	7	2.3393	
	14	5.9	20	5.9299		5.7	12	3.6520	2.6	8	2.1675	
	16	6.5	25	6.0970	1	8.5	44	7.0255	3.5	17	3.8546	

[a]No column entery indicates no rejects.

[b]SC is SDR, conventional-temperature drying.

[c]No rejects.

Table 6—Warp average, maximum, and standard deviation (SD) and number of rejects[a] for CH-treated[b] lumber at initial measurement

Lumber		Crook (1/32 in.)				Bow (1/32 in.)				Twist (1/32 in.)			
Size (in.)	Length (ft)	Average	Maximum	SD	Rejects (No.)	Average	Maximum	SD	Rejects (No.)	Average	Maximum	SD	Rejects (No.)
2 by 2	10	1.0	1	—		3.0	3	—		0	0	—	
2 by 3	6	1.5	2	0.7071		1.5	2	0.7071		0.5	1	0.7071	
	7	8.0	15	0.8995	1	4.0	5	1.4142		8.0	11	4.2426	
	8	5.6	14	5.0409	2	6.9	24	7.6240	1	3.8	19	6.2962	1
	10	4.7	8	3.0551		5.7	8	2.0817		1.0	2	1.0000	
	12	2.5	3	0.7071		18.0	33	21.2132		4.5	8	4.9497	
	14	23.0	24	1.4142		5.5	6	0.7071		4.5	5	0.7071	
	16	22.0	45	17.6328	1	12.0	25	8.9069		3.8	8	3.4034	
2 by 4	6	6.0	6	—		10.0	10	—		0	0	—	
	7	2.5	4	2.1213		3.5	6	3.5355		6.5	7	0.7071	
	8	7.5	19	5.0706	16	4.9	16	3.6628		2.4	11	2.9220	
	10	7.1	25	5.6506	1	7.4	19	4.9527		1.8	5	1.9397	
	12	9.1	36	10.6599	2	8.1	18	5.3014		2.6	11	3.2564	
	14	15.2	40	9.1078	8	9.2	27	6.7899		3.4	13	3.4604	
	16	11.8	40	7.9815	2	13.6	57	10.9016	1	4.1	20	4.8229	

[a]No column entry indicates no rejects.

[b]CH is conventional sawing, high-temperature drying.

Table 7—Warp average, maximum, and standard deviation (SD) and number of rejects[a] for CC-treated[b] lumber at initial measurement

Lumber		Crook (1/32 in.)				Bow (1/32 in.)				Twist (1/32 in.)			
Size (in.)	Length (ft)	Average	Maximum	SD	Rejects (No.)	Average	Maximum	SD	Rejects (No.)	Average	Maximum	SD	Rejects (No.)
2 by 2	6	0	0	—		0	0	—		0	0	—	
	16	4.0	4	—		4.0	4	—		1.0	1	—	
2 by 3	6	1.7	3	1.5275		2.7	6	3.0551		7.3	10	2.0551	
	7	2.0	2	—		0	0	—		1.0	1	—	
	8	1.3	2	0.5774		4.0	6	3.4641		4.7	10	4.6188	
	10	4.0	4	—		7.0	7	—		0	0	—	
	12	4.3	9	4.5092		3.3	4	1.1547		1.0	3	1.7320	
	14	2.4	4	2.1213		22.5	42	27.5772		1.5	2	0.7071	
	16	13.0	19	8.4853		7.5	13	7.7782		1.5	3	2.1213	
2 by 4	6	1.7	3	1.5275		4.0	4	—		2.3	6	3.2145	
	7	7.0	7	—		1.0	1	—		2.0	2	—	
	8	9.6	26	7.0116	13	5.2	14	3.6219		3.1	9	2.4774	
	10	9.7	23	7.8140	7	9.8	28	7.2619	1	4.8	23	6.0445	1
	12	8.7	24	6.8730	3	8.7	26	7.5730		4.5	13	3.8334	
	14	11.0	29	7.8214	5	8.5	25	6.4114	41	3.9	15	3.7308	
	16	15.9	47	11.2657	13	9.5	55	9.1823	1	5.6	31	6.3129	2

[a]No column entry indicates no rejects.

[b]CC is conventional sawing, conventional-temperature drying.

Table 8—Distribution of rejects by treatment[a] at initial measurement and remeasurement after storage

Treatment	Number of rejects[b]	
	Initial measurement	Remeasurement
SH	0 (0)	1 (0)
SC	3 (0.7)	7 (2.8)
CH	35 (20.3)	39 (22.4)
CC	41 (24.6)	42 (21.6)

[a]See table 3 footnote for treatment definitions.

[b]Failure to meet Select Structural grade warp limits. Values in parentheses are the percentage of total number of pieces.

The results of this study are not as easily interpreted as those for previous studies because of the mixture of sizes. Average warp must be evaluated by each width and length because warp limits change with width and length (table 2). As indicated in tables 4 to 7, warp decreased with the change from conventional-temperature drying to high-temperature drying and conventional sawing to SDR (least warp in SH-treated lumber and most in CC). For instance, for 16-ft 2 by 4's, crook averaged about 16/32 in. for CC treatment, about 12/32 in. for CH, 6.5/32 in. for SC, and 5/32 in. for SH. Similar but not as consistent trends were found for the 2 by 3 and 2 by 2 lumber. The trends were not as strong for bow and twist as for crook.

Percentage of Maximum Allowable Warp

To establish a more common ground for evaluating treatment effects, the 2 by 4 warp averages in tables 4 to 7 were converted to percentage of maximum allowable warp.

$$\text{Percent MAW} = (AW/MAW) \times 100$$

where

MAW is maximum allowable warp
AW is average warp per treatment

Values of the percent MAW were summed for each treatment and are compared in table 9. This method of examining the results shows that SDR treatments were better than conventional treatments in terms of not only fewer rejects but also less actual warp.

Table O-Maximum allowable warp by treatment at initial measurement and remeasurement after storage

Type of warp and time of measurement	Percentage of maximum allowable warp by treatment[a]			
	CC	CH	SC	SH
Crook				
Initial measurement	75	67	23	19
Remeasurement	76	70	28	21
Bow				
Initial measurement	28	28	19	22
Remeasurement	29	27	29	20
Twist				
Initial measurement	26	16	14	10
Remeasurement	24	19	17	12

[a]See table 3 footnote for treatment definitions.

Analyses of Variance

Analyses of variance for combined sizes were made using Chi-square tests (SAS Institute 1985). There were significant differences between the SDR and conventional treatments for crook (ρ = 0.0001) but not for bow or twist. There were no significant differences between CC and CH treatments nor between SC and SH treatments. These tests show a significant effect for sawing method but not for drying method for the combined sizes, even though the material dried at a high temperature had lower average warp and less rejects.

Tukey's studentized range test was used to test treatment effect within 2 by 4 lumber of different lengths (SAS Institute 1985) (Table 10). For crook, the 8-, 14-, and 16-ft lengths showed significantly lower warp for SDR compared to conventional

Table 10—Tukey's studentized range test for effect of treatment on warp of 2 by 4's of various lengths

Type of warp	Lumber length (ft)	Treatment effect[a,b]			
Crook	8	CC	CH	SH	SC
	10	CC	CH	SC	SH
	12	CC	CH	SC	SH
	14	CH	CC	SC	SH
	16	CC	CH	SC	SH
Bow	8	CC	CH	SC	SH
	10	CC	CH	SC	SH
	12	CH	CC	SC	SH
	14	SH	CH	CC	SC
	16	CH	SH	CC	SC
Twist	8	CC	SC	CH	SH
	10	CC	CH	SC	SH
	12	CC	CH	SH	SC
	14	CC	CH	SC	SH
	16	CC	CH	SC	SH

[a]See table 3 footnote for treatment definitions.

[b]Underscores indicate which treatment effects were not significantly different.

treatments, but the 10- and 12-ft lengths showed a significant difference only between CC and SH treatments. For bow, the 8- to 14-ft lengths showed no differences; however, in the 16-ft length, the CH treatment resulted in statistically more bow than the other treatments. For twist, the 8-, 10-, and 14-ft lengths showed no differences; in the 12-ft length, CC resulted in significantly more twist than the other treatments; and in the 16-ft length, CC resulted in significantly more twist than SH.

Lumber Grade Distribution

The percentage of rejected specimens and average warp values describe the effectiveness of treatment in a broad manner, but random-length lumber has more grade options than studs. The grade structure of random-length lumber, based on warp and as reflected in table 2, permits three warp levels and eight grades plus the Economy category. The treatments had a noticeable effect on the distribution of acceptable lumber within the various grades; SDR treatments produced 24 to 25 percent more grade No. 1 lumber than CC and 19 to 20 percent more than CH.

Structural lumber is often purchased as grade No. 2 and Better. In this category the SDR treatments still excelled, with 100 percent of the 2 by 4 stock making the grade compared to 88 to 91 percent of conventionally treated material (table 11).

Table 11—Distribution of 2 by 4's meeting various grades by treatment at initial measurement and remeasurement after storage

Grade[a] and time of measurement	Percentage of pieces by treatment[b]			
	CC	CH	SC	SH
No. 1				
Initial measurement	75	80	99	100
Remeasurement	77	77	97	99
No. 2				
Initial measurement	13	11	1	0
Remeasurement	10	12	3	1
No. 3				
Initial measurement	8	6	0	0
Remeasurement	7	8	0	0
Economy				
Initial measurement	4	3	0	0
Remeasurement	6	3	0	0

[a]Grade combinations based on warp include the following: No. 1—Select Structural, STUD, and Construction; No. 2—Standard; No. 3—Utility.

[b]See table 3 footnote for treatment definitions.

Remeasurement of Lumber After Storage

Lumber does not usually go directly from a mill to a structure. The material usually stays in the mill, wholesale, and retail yards for extended periods. Fluctuations in weather conditions can have a major effect on the stability of the lumber while it is in storage. To evaluate the effect of storage, we stored all stock in an open-sided shed exposed to ambient air conditions. The lumber was stored for at least 90 days from July through November, a period that included humid and dry air as well as hot and cold temperatures. The lumber was solid piled and strapped with metal bands. It was remeasured for warp after the storage period. The low moisture content of the lumber at the time of remeasurement reflects 4 to 6 weeks of heated storage while awaiting remeasurement. Moisture content was undoubtedly higher at the end of the open-shed storage period.

In keeping with the initial evaluation, SDR treatments were proven to be more effective than the conventional treatments after the period of open-shed storage and heated storage. Evaluation by the total amount of warp (tables 12 to 15) shows the same trend noted at initial measurement: warp decreased with the change from conventional-temperature drying to high-temperature drying and conventional sawing to SDR (least warp in SH-treated lumber and most in CC). For instance, crook of 16-ft 2 by 4's averaged 15/32 in. for CC treatment, about 12/32 in. for CH, 9/32 in. for SC, and 6/32 in. for SH. The average crook for the SDR treatments increased slightly (from 6.5 to 9/32 in. for SC and from 5 to 6/32 in. for SH). Crook averages for conventional treatments stayed the same or decreased slightly (CH-treated lumber remained at 12/32 in., and CC-treated lumber decreased from 16/32 to 15/32 in.).

Percentage of Maximum Allowable Warp

Following the same technique used for the initial evaluation, the 2 by 4 warp averages in tables 12 to 15 were converted to percentage of maximum allowable warp. The results for 2 by 4's by treatment are shown in table 9. The trend of decreasing warp from CC to SH was still apparent after storage, but the differences between treatments were slightly smaller at remeasurement than at the initial measurement. The SDR treatments still excelled in warp reduction.

Analyses of Variance

Analyses of variance were again run using chi-square tests (SAS Institute 1985). The tests showed that SDR-treated lumber had significantly lower crook than conventionally treated lumber after storage (ρ = 0.0001). There were no significant differences for bow or twist, and no significant differences were found between CC and CH treatments. The SH treatment, however, resulted in significantly lower crook than SC (ρ = 0.05). There was no significant difference in bow or twist for both SDR treatments.

These analyses show that drying method did not affect warp of conventionally sawn lumber after storage but did affect warp of SDR-processed lumber. The reduction of warp resulting from SDR was statistically significant even after extended storage of the lumber.

Lumber Grade Distribution

After storage, treatments continued to have a noticeable effect on the distribution of acceptable lumber within various grades. The SDR treatments still resulted in 20 to 22 percent more grade No. 1 lumber than CC or CH. In the grade No. 2 and Better category, SDR treatments continued to excel, with 100 percent of the 2 by 4 stock making the grade compared to 87 to 89 percent of conventionally treated lumber (table 11).

Table 12—Warp average, maximum, and standard deviation (SD) for SH-treated[a] lumber after storage

Lumber		Crook (1/32 in.)[b]			Bow (1/32 in.)[b]			Twist (1/32 in.)[c]		
Size (in.)	Length (ft)	Average	Maximum	SD	Average	Maximum	SD	Average	Maximum	SD
2 by 2	7	1.0	1	—	6.0	6	—	0	0	—
	8	1.0	3	1.7321	6.3	7	1.1547	2.0	6	3.4641
	10	3.5	5	2.1213	6.5	11	6.3640	0	0	—
	12	4.0	10	5.2915	10.0	14	6.9282	0.3	1	0.5774
	14	10.0	25	10.8628	16.0	33	12.1929	1.8	5	2.3629
	16	3.0	3	—	7.0	7	—	15.0	15	—
2 by 3	6	0	0	—	3.5	7	4.9497	0	0	—
	7	1.5	2	0.7071	5.5	7	2.1213	1.0	2	1.4142
	8	1.2	2	0.5000	3.8	6	2.6300	2.5	5.0	1.7320
	10	4.0	4	—	2.0	2	—	0	0	—
	12	3.0	6	2.4495	5.2	10	3.3040	0	0	—
	14	4.5	8	2.6458	11.0	19	6.7823	1.5	3	1.0000
	16	5.8	11	4.5735	14.8	36	14.4539	1.8	4	1.7078
2 by 4	6	1.3	2	1.1547	2.0	4	2.0000	0	0	—
	7	2.0	2	—	6.0	6	—	0	0	—
	8	1.2	3	0.9367	3.6	10.0	2.6562	1.6	4	1.4650
	10	2.8	8	3.1145	4.2	6	1.6432	1.6	7	3.0496
	12	3.4	13	3.4044	4.8	16	3.8045	1.5	4	1.4500
	14	4.0	13	2.8281	8.5	22	5.0585	2.4	13	2.6036
	16	6.2	16	4.1434	11.9	34	8.7062	3.7	19	3.9602

[a]SH is SDR, high-temperature drying.

[b]No rejects.

[c]One reject (16-ft 2 by 2 lumber).

Table 13—Warp average, maximum, and standard deviation (SD) and number of rejects[a] for SC-treated[b] lumber after storage

Lumber		Crook (1/32 in.)				Bow (1/32 in.)				Twist (1/32 in.)			
Size (in.)	Length (ft)	Average	Maximum	SD	Rejects (No.)	Average	Maximum	SD	Rejects (No.)	Average	Maximum	SD	Rejects (No.)
2 by 2	6	1.5	2	0.7071		6.5	11	6.3640		0	0	—	
	8	0.5	1	0.5774		6.2	21	9.8446	1	1.8	3	1.5000	
	10	5.0	5	—		28.0	28	—		1.0	1	—	
	12	2.8	5	1.7078		13.0	24	8.6023		3.8	15	7.5000	1
	14	6.0	12	4.2426		8.6	13	3.5071		2.0	9	3.9370	
	16	4.8	13	4.9565		15.7	30	8.6872		0.7	3	1.2111	
2 by 3	7	0	0	—		3.0	3	—		0	0	—	
	8	1.3	3	1.5275		7.7	9	1.5275		1.3	3	1.5275	
	12	3.8	7	3.1145		11.0	15	3.8730		1.2	2	0.8367	
	14	3.0	3	—		10.0	10	—		0	0	—	
	16	11.6	17	4.6579		8.9	15	4.8237		2.2	8	2.9641	
2 by 4	6	1.0	2	1.4142		2.5	3	0.7071		1.5	2	0.7071	
	7	0.5	1	0.7071		3.0	5	2.8284		1.0	1	—	
	8	2.0	8	2.3875		6.1	16	4.5638		2.6	15	3.5139	1
	10	3.0	9	2.8284		9.0	21	7.3937		2.3	8	3.3523	
	12	3.4	9	2.8026		9.3	22	5.4971		2.8	12	4.5126	
	14	6.5	25	6.8176	2	6.3	16	4.0356		2.6	9	2.2806	
	16	9.2	25	6.8353	2	11.0	44	8.5655		4.0	20	4.3525	

[a]No column entry indicates no rejects.

[b]SC is SDR, conventional-temperature drying.

Table 14—Warp average, maximum, and standard deviation (SD) and number of rejects[a] for CH-treated[b] lumber after storage

Lumber		Crook (1/32 in.)				Bow (1/32 in.)				Twist (1/32 in.)			
Size (in.)	Length (ft)	Average	Maximum	SD	Rejects (No.)	Average	Maximum	SD	Rejects (No.)	Average	Maximum	SD	Rejects (No.)
2 by 2	10	8.0	8	—		14.0	14	—		2.0	2	—	
2 by 3	6	2.0	3	1.4142		2.0	2	—		1.5	2	0.7071	
	7	9.0	17	11.31137	1	4.0	5	1.4142		4.5	6	2.1213	
	8	7.0	23	7.0305	2	6.1	10	2.4165		4.2	18	5.9221	
	10	5.7	7	1.5275		5.7	9	2.8868		1.0	3	1.7320	
	12	4.0	6	2.8284		19.5	34	20.5061		3.0	5	2.8284	
	14	19.0	20	1.4142		7.5	8	0.7071		5.5	6	0.7071	
	16	17.2	36	12.6062	1	14.2	31	11.3541		4.8	12	5.1881	
2 by 4	6	10.0	10	—	1	6.0	6	—		0	0	—	
	7	4.0	6	2.8284		5.0	9	5.6569		9.5	11	2.1213	
	8	7.8	19	5.1112	15	4.8	15	3.7427		3.0	13	3.7938	1
	10	8.1	36	8.4021	2	6.8	13	3.0659		1.6	8	2.2173	
	12	8.8	29	8.7127	3	8.0	16	3.5810		2.9	15	3.8940	
	14	15.7	39	9.8026	10	9.6	30	7.7548		4.4	16	4.3243	
	16	12.0	49	9/1784	2	12.8	56	10.3536	1	4.6	18	4.8297	

[a]No column entry indicates no rejects.

[b]CH is conventional sawing, high-temperature drying.

Table 15—Warp average, maximum, and standard deviation (SD) and number of rejects[a] for CC-treated[b] lumber after storage

Lumber		Crook (1/32 in.)				Bow (1/32 in.)				Twist (1/32 in.)			
Size (in.)	Length (ft)	Average	Maximum	SD	Rejects (No.)	Average	Maximum	SD	Rejects (No.)	Average	Maximum	SD	Rejects (No.)
2 by 2	7	0	0	—		3.0	3	—		0	0	—	
	16	6.0	6	—		10.0	10	—		1.0	1	—	
2 by 3	6	0.7	2	1.1547		3.3	5	2.0817		3.3	5	2.0817	
	7	1.0	1	—		3.0	3	—		1.0	1	—	
	8	2.0	3	1.0000		3.7	8	3.7859		3.0	7	3.4641	
	10	5.0	5	—		13.0	13	—		0	0	—	
	12	3.0	5	2.6458		10.3	13	3.7859		0.7	2	1.1547	
	14	3.5	5	2.1213		23.5	34	14.8492		1.0	2	1.4142	
	16	10.5	18	10.6066		7.5	13	7.7782		1.5	3	2.1213	
2 by 4	6	4.3	6	1.5275		3.7	5	1.1547		1.7	4	2.0817	
	7	7.0	7	—		7.0	7	—		2.0	2	—	
	8	10.5	30	7.6980	13	6.3	18	4.9721	1	3.4	12	3.2570	
	10	9.5	28	7.2457	5	7.4	25	5.8934	1	3.3	16	4.1981	1
	12	8.1	24	6.7287	3	8.8	25	6.1783		4.1	14	3.5950	
	14	11.2	35	8.4357	6	7.8	26	6.5708		4.1	17	3.9585	
	16	15.4	56	12.5835	9	13.6	76	14.2810	2	6.0	29	6.4006	1

[a]No column entry indicates no rejects.

[b]CC is conventional sawing, conventional-temperature drying.

Concluding Remarks

This study compared the results of manufacturing random-length 2 by 2, 2 by 3, and 2 by 4 structural lumber by conventional and SDR methods. Both conventional and high-temperature kiln drying were used in the processing. The results show that SDR resulted in a significant reduction of crook. Bow and twist were also reduced by using SDR but not as consistently or as much as crook. The SDR treatments also resulted in a significant increase in pieces meeting the Select Structural grade limits for warp. For 2 by 4 lumber, 100 percent of SH-treated material met the Select Structural warp limits, SC 99.3 percent, CH 79.7 percent, and CC 75.4 percent. After 90 days of storage in an open-sided shed, 19 to 22 percent more SDR-treated lumber compared to conventionally treated lumber met Select Structural warp limits.

Given the surplus of small yellow-poplar, the SDR process provides an opportunity for mills to develop a new structural resource while making a high-quality product.

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