Manufacture of quality yellow-poplar studs using the saw-dry-rip (S-D-R) concept

Robert R. Maeglin
R. Sidney Boone

Abstract

Hardwood studs are not generally marketed in the United States because of manufacturing difficulties, especially excessive warp due to longitudinal growth stresses. This paper describes a new, economically viable system for manufacturing studs from low- and mediumdensity hardwoods that produces high-quality, STUD grade material from yellow-poplar. The system, called S-D-R (Saw-Dry-Rip), involves live-sawing small logs into 7/4 flitches, drying the flitches, and then ripping them into stud blanks for final planing. The S-D-R system reduces or eliminates the stresses responsible for excessive warping.

The study compares four sawing and drying treatments by evaluating warp (crook, bow, and twist) based on the National Grading Rule-STUD grade warp limits. The best treatment, S-D-R live-sawn, high-temperature dried, had 100 percent of the studs acceptable and showed an 81 percent reduction in average crook compared to the conventionally sawed and dried treatment.

Hypotheses for the success of the system are discussed as well as means for incorporating the process into a mill.

Because of the high cost of transportation and the demand on the softwood resource, the use of hardwoods for structural lumber in the near future is not only desirable but imperative.

Eighty percent of the new housing and light-frame construction is east of the Rocky Mountains, yet for 1977 to 1979 an average of 67 percent of the U.S. softwood lumber production was western in origin (24). The western softwoods are under great stress to meet eastern demands, and moving the resource across the country is expensive both in dollars and energy.

Our nation's hardwoods are in a position to relieve these pressures on the softwood resource. Ninety-one percent of the hardwood volume is found east of the Rockies, right where the lumber need is. This resource is also in surplus and growing much faster in volume than the western timber resource (28).

Why then aren't we using the hardwoods for structural lumber to meet the construction demands?

The answer is manufacturing economics. Because of excessive warp problems with sawn hardwood lumber of stud and joist sizes, the industry hasn't been able to economically produce this type of structural lumber. Mills sawing aspen studs in Canada, Minnesota, and Wisconsin have failed or have switched to softwoods. Koch and. Rousis (13) of West Virginia University reported 60 percent loss due to excessive warp in conventionally manufactured yellow-poplar studs. Funck (5) reported a loss of 45 percent due to warp in conventionally manufactured cottonwood studs.

The objective of this research is to demonstrate that the S-D-R concept is suitable for manufacturing straight structural lumber (studs) from a medium-density species, yellow-poplar (*Liriodendron tulipifera* L.). The S-D-R concept combines the attributes of sawing geometry and drying techniques to solve the problem of warp in hardwood studs.

The warp problem in hardwoods is primarily due to longitudinal growth stresses in trees and logs. As the tree grows, tension stresses develop in the newly formed

The authors are, respectively, Project Leader and Research Forest Products Technologist, USDA Forest Serv. Forest Prod. Lab., P.O. Box 5130, Madison, WI 53705. The Laboratory is maintained at Madison, Wis., in cooperation with the Univ. of Wisconsin. The authors would like to recognize the following persons and organizations for their contributions of time and materials to this research effort: William Barnes, Madison, Wis.; Monte Harold and Lynn Jackson, Tennessee Valley Authonty Norris, Tenn.; George P. Ramsey and Art Ordell, Taylor Ramsey Corp., Lynchburg, Va.; James Schroeder, Southeastern Forest Expt. Sta., USDA Forest Serv., Asheville, N. C.; and Clay Smith, Northeastern Forest Expt. Sta., USDA Forest Serv., Parsons, W. Va. This paper was received for publication in May 1982
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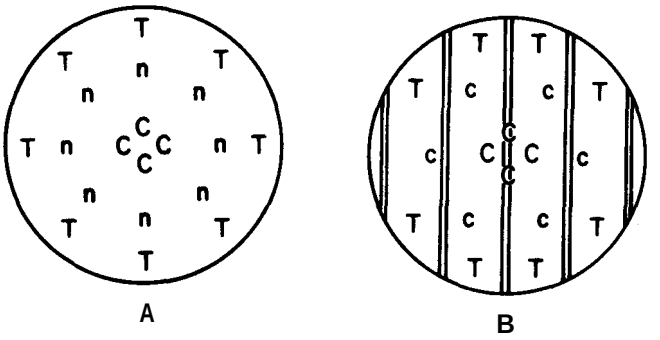

Figure 1. - A. Stress distribution in hardwood logs varies from a highly tensile zone (T) at the periphery, through a neutral zone (n), to a highly compressive zone (C) in the inner core. B. Live-sawing balances stresses (c) across the wide faces of flitches.

xylem. With the formation of subsequent rings, the area of tension stress expands and induces compression stress in the center of the tree (4) (Fig. 1A). The result of longitudinal growth stress development is a continuum of changing stress levels radially across the stem. When the stress differentials are very high (thousands of pounds per square inch are possible), lumber sawn to dimension from the log will warp immediately as it is sawed.

Considerable attention has been given to the manufacture of both hardwood and softwood studs in trying to find ways to manufacture straight, stable lumber. Thompson (26, 27), for example, worked extensively with aspen studs. He found the best approach was to saw four flat-grained studs from the periphery of each log, depending on growth ring geometry, to give quality. Hallock (8, 9, 10), working with smalldiameter softwoods, also used growth ring geometry to achieve straightness in studs. Hallock's best results came from using the improved FPL Scragg method.

Koch, in using southern pine boltwood and veneer cores to make studs (14-18), employed both sawing and drying techniques to get straighter studs. Koch (14-16) found that his best sawing technique was to cut stud blanks oversized in width and thickness. He (17, 18) also used high-temperature drying, top weighting, and serrated kiln sticks to achieve straightness in studs.

Despite these developments, the basic problem still remains of how to economically reduce the effects of longitudinal growth stress in structural lumber sawn from hardwoods. We believe SD-R is one answer to the problem.

Methods and materials

S-D-R concept

S-D-R stands for Saw, Dry, and Rip. Logs are live-sawn into 7/4 flitches. The flitches are lightly edged for a compact kiln load and dried to about 12 percent moisture content (MC). After drying, the flitches are ripped into studs that are planed for use.

By contrast, conventional practice for manufacturing studs calls for sawing studs directly from a log, drying the studs, and finally dressing them for use.

The S-D-R concept for stress relief is based on four principles or theories:

1) Live-sawing tends to balance stresses across the wide faces of the flitches (Fig. 1B). The balance of stress within a flitch helps to restrain the piece from warping in the edgewise (crook) direction. Because most logs are neither round nor concentric in ring formation, the balancing of stresses is not perfect.

2) The extra width of the flitches compensates for natural imbalances by restraining any tendency to warp in the edgewise direction.

3) The drying stresses in the final stages of drying compensate in part for the longitudinal growth stresses (19).

4) Lignin plasticization at high temperatures (generally considered to be above 212°F, 100°C) relieves stress. Because lignin is a thermoplastic adhesive, we believed that stresses could be removed if the lumber was dried at high temperature; that as the lignin plasticized, the stressed fibers would slip into an unstressed state, bond on cooling, and remain in that condition. On further examination, we found that lignin reaches peak plasticization over a range of temperatures, depending on MC (7). This indicates that lignin may reharden without cooling. Figure 2 shows the curve of lignin plasticization for temperature over MC.

If kiln-drying at 235°F, the lignin should become plastic as soon as the wood reaches 194°F, at or about 37 percent MC. As the wood dries below 37 percent MC, but before it reaches 235°F, the lignin should reharden, i.e., the MC is reduced below the point of peak plasticization and rehardens (Fig. 2).

As the data are examined, our research results will substantiate these hypotheses.

Design

The study design was a 2 by 2 by 4 factorial using two sawing methods, two drying methods, and four sampling locations. To avoid sample loss, in the event of a kiln malfunction during drying, two replications of each of the four treatment combinations were used (Table 1). Treatment combinations were: 1) conventionally sawn-conventionally dried (CC), 2) conventionally sawn-high-temperature dried (CH), 3) S-D-R live-sawn-conventionally dried (SC), and 4) S-D-R live-sawn-high-temperature dried (SH).

Sample size (number of logs) for the study was determined statistically using preliminary data developed by Hallock and Bulgrin (11). By selecting a sample size of 20 logs per cell, the probability of detecting a 5 percent difference in stud acceptance (studs meeting STUD grade warp limits) is slightly greater than 95 percent.

Log collection and segregation

Small, woods-run trees were selected from four locations in the central and southern Appalachian region. The locations were in northwest North Carolina, east-central Tennessee, southwest Virginia, and northern West Virginia. At each location, 18 to 26 trees, 8 to 12 inches in diameter at breast height (DBH), were selected to provide 90 logs. Trees were selected to get equal numbers in each diameter class. All logs were cut 8

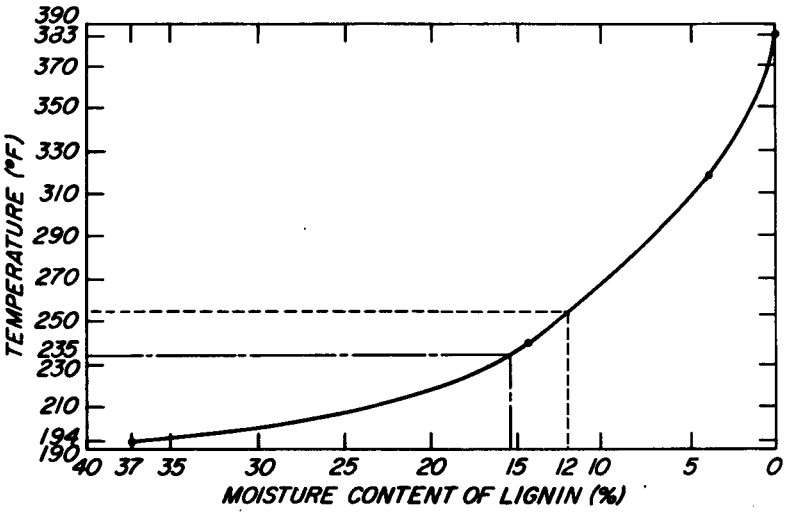

Figure 2. - Relationship of moisture content and temperature to peak (maximum) lignin plasticization (7).
———— - ———— = temperature used in yellow-poplar high-temperature drying and the moisture content at peak plasticization.
- - - - - - - - - - - =desired moisture content

feet long plus trim and numbered consecutively from butt to top within a tree. A minimum top diameter of 4.5 inches inside bark (DIB) was used.

At the FPL, logs from each area were sorted by 1-inch-diameter classes. Nine replications of 10 logs each were drawn from each location shipment, distributing the replications as to butt and upper logs and diameter as much as possible. The nine replications were two each for the four treatment combinations and one for a factory lumber sample (Table 1).

Sawing

The conventionally sawn studs were cut with a 4-inch cant located in the geometric center of the log. The cants were produced by split-taper sawing. When possible, 7/4 flitches were sawn green from the sides of the logs, adjacent to the cants. The cants and flitches were immediately resawn into studs for drying. Flitches were ripped into 2 by 4's, 2 by 3's, and 2 by 2's for maximum utilization.

S-D-R 7/4 flitches were cut by live-sawing (through and through on one plane). Logs were sawn using full-taper sawing (parallel to one of the outside faces of the log) with at least a 4-inch opening face. The flitches were edged green to about 1/2 inch wider than acceptable wane limits. This edging was done to reduce the material to be dried and to make a compact kiln load.

The 4/4 factory lumber was cut for a comparison of dollar value and volume yields for studs and factory lumber (23).

Drying

The conventional drying treatment for SC and CC 7/4 stud stock and for 4/4 factory lumber was FPL-schedule T11-D4 (20), drying to 12 ± 3 percent MC for studs (an average equilibrium moisture content (EMC) for studs in use), and 8 ± 2 percent for factory lumber. A top load weighting of 25 pounds per square foot was used.

Prior to beginning this study, a suitable high-temperature drying schedule (3) was developed for the high-temperature drying treatments SH and CH. The schedule was based on time and temperature: 28 hours at 235°F dry bulb, 190°F wet bulb, followed by 48 hours at an EMC of 10 percent, 200°F dry bulb, 188°F wet bulb. A top load weighting of 25 pounds per square foot was used.

TABLE 1. - *2 by 2 by 4 factorial study design for studying yellow-poplar studs.*

Location No.	Drying method	Sawing method: Conventional	Flitch (S-D-R)	Supplemental shop lumber
1[a]	Conventional	X[b]	X	X
	High temperature	X	X	
2	Conventional	X	X	X
	High temperature	X	X	
3	Conventional	X	X	X
	High temperature	X	X	
4	Conventional	X	X	X
	High temperature	X	X	

[a]1 - North Carolina, 2 - Tennessee, 3 - Virginia, 4 - West Virginia.
[b]X = 10 logs.

Ripping and planing

After sawing and drying, conventionally sawn studs were planed from target size to standard dressed sizes as specified in PS-20-70 of the American Lumber Standards (29). The same dimensions apply to finished S-D-R studs.

After live-sawing and drying, S-D-R flitches were ripped into 2 by 4's, 2 by 3's, and 2 by 2's, maximizing yield. Flitches were measured before ripping to determine the best yielding combination of piece sizes (2 by 4, 2 by 3, 2 by 2). After ripping, the studs were planed to standard sizes.

Measuring warp

Once planed, all studs were measured for warp. Three forms of warp were evaluated: crook, bow, and twist. Crook is the deviation edgewise from a straight line drawn from end to end of a piece. Bow is the deviation flatwise from a straight line drawn from end to end of a piece. Twist is a deviation flatwise or flatwise and

TABLE 2. - *Warp average, range,[a] and number of rejects by treatment and area. Initial measurement after machining. All stud sizes combined (2 by 2, 2 by 3, 2 by 4).*

Treatment		Conventionally sawn						S-D-R live-sawn					
		Conventionally dried			High-temperature dried			Conventionally dried			High-temperature dried		
Area	Warp	Avg. (1/32 in.)	Range (1/32 in.)	No. of rejects[c]	Avg. (1/32 in.)	Range (1/32 in.)	No. of rejects[c]	Avg. (1/32 in.)	Range (1/32 in.)	No. of rejects[c]	Avg. (1/32 in.)	Range (1/32 in.)	No. of rejects[c]
North Carolina	Crook	5.1	19	18	3.4	15	9	1.9	12	2	0.9	6	0
	Bow	8.4	35	3	5.9	34	2	5.7	15	0	6.6	22	0
	Twist	1.0	9	0	.4	5	0	.6	5	0	.8	4	0
Tennessee	Crook	3.7	21	10	3.0	16	5	1.2	8	0	.6	5	0
	Bow	6.6	18	0	3.2	18	0	4.5	20	0	3.2	14	0
	Twist	1.1	7	0	.6	6	0	.8	7	0	.6	5	0
Virginia	Crook	4.8	20	13	4.3	20	11	2.9	13	5	.8	6	0
	Bow	8.6	26	2	5.9	27	1	8.7	29	4	4.4	16	0
	Twist	2.5	22	2	1.8	17	1	1.1	6	0	.8	8	0
West Virginia	Crook	4.4	21	15	3.8	15	9	1.6	7	0	1.0	5	0
	Bow	7.0	24	0	4.6	30	1	5.1	16	0	4.8	19	0
	Twist	2.5	14	1	1.3	7	0	1.2	6	0	.8	9	0
Combined areas[b]	Crook	4.5	21	56	3.6	20	34	1.9	13	7	.8	6	0
	Bow	7.7	35	5	4.9	34	4	6.0	29	4	4.8	22	0
	Twist	1.8	22	3	1.0	17	1	.9	7	0	.7	9	0

[a]Range is from zero to value shown.
[b]Total number of samples per treatment: conventionally sawn: conventionally dried—356, high-temperature dried—372; S-D-R live-sawn: conventionally dried—403, high-temperature dried—417.
[c]Based on warp requirements for STUD grade.

edgewise, in the form of a curl or spiral so that the four comers of any face are not in the same plane. Each piece was measured to the nearest 1/32 inch for the three types of warp.

Acceptance of studs was determined using the National Grading Rule for dimension lumber, STUD grade. Only warp was considered, not wane, knots, etc. Those pieces not meeting STUD grade would be considered ECONOMY grade or lower and were rejected. Limits of warp for the 8-foot STUD grade are: 2 by 4 and 2 by 3—crook1/4 inch, bow 3/4 inch, and twist 3/8 inch; and 2 by 2—crook3/4 inch, bow 3/4 inch, and twist 3/16 inch.

After the initial warp measurement the studs were stored in an open-sided shed for 30 days or more and then remeasured .to determine stability and storage quality.

Moisture content

Moisture content of all lumber was measured using an electrical resistance moisture meter with an insulated two-pin electrode. The pins were driven to a 1/2-inch depth at three positions on each stud, at least a foot from each end and at the center of the piece to give a conservative estimate of MC.

Strength evaluation

As a separate study, an evaluation was conducted on the effects of high-temperature drying on stud strength (6).

Economic evaluation

Also as a separate study, data from the S-D-R research were incorporated into an economic analysis (12).

Results and discussion

Warp data are presented for all stud sizes combined (2 by 2,2 by 3, and 2 by 4) in Table 2 and for 2 by 4 studs only in Table 3.

Because of the study design it is possible to evaluate the effects of drying and sawing on stud quality in a stepwise manner. Tables 2 and 3 show a progressive improvement in stud quality based on average crook. Crook is the most important warp type because it determines whether a stud wall will be flat or bowed. Average crook varies from a high of over 4/32 inch for the combined areas in the CC-control treatment (conventionally sawn-conventionally dried) to less than 1/32 inch for the combined area data in the SH treatment (S-D-R live-sawn-high-temperature dried). Intermediate values are shown for the other two treatments.

The data in Table 2, for combined stud sizes, show that CH treatment (conventionally sawn-high-temperature dried) reduces crook about 20 percent over the CC control. The SC treatment (S-D-R live-sawn-conventionally dried) resulted in an almost 60 percent reduction in crook, and using SH reduced crook over 80 percent. The data in Table 3, for 2 by 4's only, show that average crook was reduced 20 percent by CH treatment,

TABLE 3. - *Warp average, range,[a] and number of rejects by treatment and area. Initial measurement after machining, for 2 by 4 studs only.*

Treatment		Conventionally sawn						S-D-R live-sawn					
		Conventionally dried			High-temperature dried			Conventionally dried			High-temperature dried		
Area	Warp	Avg. (1/32 in.)	Range (1/32 in.)	No. of re-jects[c]	Avg. (1/32 in.)	Range (1/32 in.)	No. of re-jects[c]	Avg. (1/32 in.)	Range (1/32 in.)	No. of re-jects[c]	Avg. (1/32 in.)	Range (1/32 in.)	No. of re-jects[c]
North Carolina	Crook	4.7	19	13	3.3	14	6	1.2	6	0	0.8	4	0
	Bow	8.0	35	3	4.5	16	0	5.2	15	0	6.5	16	0
	Twist	1.1	9	0	.6	5	0	.9	5	0	.9	4	0
Tennessee	Crook	4.0	21	10	2.8	11	2	.6	4	0	.4	5	0
	Bow	6.3	16	0	2.9	18	0	4.5	14	0	3.4	11	0
	Twist	1.1	7	0	.6	6	0	1.3	7	0	1.0	5	0
Virginia	Crook	4.2	20	9	4.1	17	8	2.4	9	1	.5	3	0
	Bow	7.4	22	0	5.2	16	0	8.7	29	3	4.1	12	0
	Twist	2.4	22	1	1.8	17	1	1.3	6	0	1.2	8	0
West Virginia	Crook	5.1	21	13	4.0	15	6	1.1	5	0	.7	5	0
	Bow	6.1	21	0	4.6	13	0	5.2	16	0	4.6	19	0
	Twist	2.4	14	1	1.1	6	0	1.7	6	0	1.0	9	0
Combined areas[b]	Crook	4.5	21	45	3.6	17	22	1.5	9	1	.6	5	0
	Bow	7.0	35	3	4.3	18	0	6.2	29	3	4.6	19	0
	Twist	1.8	22	2	1.2	17	1	1.3	7	0	1.0	9	0

[a]Range is from zero to value shown.
[b]Total number of samples per treatment: conventionally sawn: conventionally dried—261, high-temperature dried—257; S-D-R live-sawn: conventionally dried—201, high-temperature dried—216.
[c]Based on warp requirements for STUD grade.

67 percent by SC treatment, and 81 percent by SH treatment.

The effect of the treatments on bow, for all areas combined, it not as dramatic as for crook (Table 2). For combined stud sizes, average bow was reduced 22 percent by SC treatment, 36 percent by CH, and 38 percent by SH. For 2 by 4's only, the reductions in average bow were SC 12 percent, SH 34 percent, and CH 38 percent. The fact that the conventionally dried studs have more bow than the high-temperature-dried studs indicates stress was removed due to high temperatures and lignin plasticization.

The effect of the treatments on average twist shows that, for all areas and stud sizes combined (Table 2), a trend of improvement is evident: CH 42 percent, SC 47 percent, and SH 58 percent. For the 2 by 4-only data, the improvements were SC 27 percent, CH 29 percent, and SH 42 percent. The lower improvement reflects the extra width of the 2 by 4 studs, compared to 2 by 3 and 2 by 2 studs, which results in higher values of twist for the same degree of twisting. The data also show the lowering effect of high-temperature drying on average twist.

Figure 3 shows comparative differences in the percentage of reject pieces by treatments for combined geographic areas, stud sizes, and warp. Once again the progressive improvement due to treatment can be noted: zero percent rejects for SH, 3 percent for SC, 10.5 percent for CH, and 18 percent for CC. For 2 by 4's only, the rate of rejects is zero percent for SH, 2 percent for SC, 9 percent for CH, and 19 percent for CC.

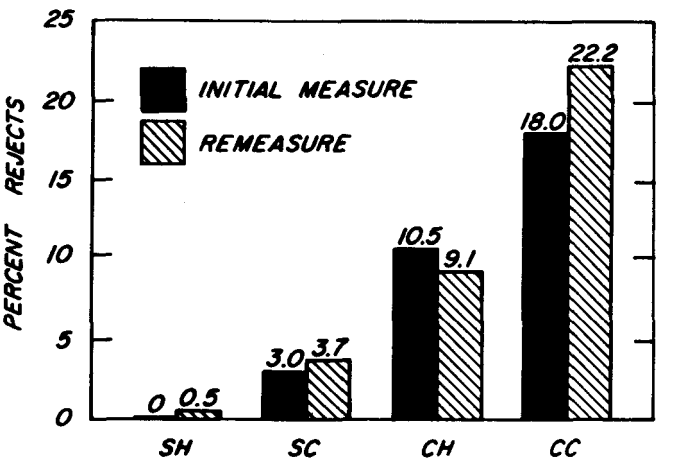

Figure 3. - Percent of rejects per treatment, approximately 400 pieces per treatment.

Analysis of variance

Table 4 shows results of an analysis of variance for area, treatment, and log position in the tree. We have already shown that practical differences in quality exist due to treatment and Table 4 shows these differences are highly significant. The table shows that the effects of area on warp are highly significant, too, but that these effects are neither as great nor as consistent as those of treatment.

Table 5 shows the Duncan's Multiple Range Test of area and treatment differences. For crook, there are no statistical differences between Virginia and North Carolina or between North Carolina and West Virginia; all other combinations are statistically different. For bow, only Virginia and North Carolina are not significantly different. For twist, no statistical differences exist between Virginia and West Virginia or between Tennessee and North Carolina; all other combinations are significantly different. Because of these inconsistencies between warp types, the differences between areas are not deemed very important.

TABLE 4. - *Analysis of variance of warp for area, treatment, and log position in tree. All stud sizes combined.*

Source	DF[a]	Crook	Bow	Twist
		F value and significance		
Area	3	9.65**	26.13**	24.17**
Treatment	3	133.81**	32.13**	24.46**
Log position	10	3.42**	1.62[ns]	3.55**
Area × treat.	9	1.42[ns]	4.18**	3.32**
Area × logpos.	22	1.70*	1.55*	1.16[ns]
Treat. × logpos.	24	1.47[ns]	.90[ns]	1.49[ns]

** - Highly significant P = 0.01.
* - Significant P = 0.05.
[ns] - Not significant.
[a]Degrees of freedom.

TABLE 5. - *Duncan's Multiple Range Test for combined stud sizes by area and treatment.*

Area and treatment	Crook (mean)	Bow (mean)	Twist (mean)
Area			
VA[b]	3.1	6.9	1.5
NC	2.7	6.6	1.4
WV	2.6	5.4	.8
TN	2.0	4.3	.6
Treatment			
CC[c]	4.5	7.7	1.8
CH	3.6	6.0	1.0
SC	1.9	4.9	1.0
SH	.8	4.8	.7

[a]Vertical lines indicate no significant difference.
[b]NC - North Carolina, TN - Tennessee, VA - Virginia, WV - West Virginia.
[c]CC - conventionally sawn, conventionally dried; CH - conventionally sawn, high-temperature dried; SC - S-D-R live-sawn, conventionally dried; SH - S-D-R live-sawn, high-temperature dried.

Log position in tree

The position of a log in a tree relative to the quality of studs in softwoods is important. Hallock (8, 9, 10) and Blake and Voorhies (2) show that butt logs can contribute greatly to the warp in softwood studs.

The analysis of variance for log position (Table 4) shows highly significant differences for crook and twist but no significant difference for bow. In Table 6 log positions are ranked by decreasing warp. The table shows no sequential trends of log position with warp. However, looking at the butt log (log position 1), crook is affected. Log position 10 has a higher average crook but is only represented by 15 pieces, whereas the butt log is represented by 350 pieces. Thirteen of the 15 pieces for log position 10 are from North Carolina where log position 1 had the highest crook of all log positions. Only 1 percent of the pieces are higher in crook than the average for butt logs while 76 percent are lower in average crook. For bow, 19 percent of the studs from upper logs averaged higher than the butt log average and 58 percent lower; for twist, 53 percent of the studs from upper logs had higher average warp than the butt log average and 26 percent lower.

When the combined stud size data are separated by area or treatment, no sequential trends are revealed by log position. But the effect of butt log on crook is still strong, the effect on bow is moderate, and the effect on twist is reversed, as was shown for the combined data, i.e. butt logs have less average twist.

When the number of reject studs is evaluated, butt logs predominate in rejects. When the data are separated by treatment, rejects from butt logs are 34 percent for CH, 43 percent for SC, and 44 percent for CC. For SH there were no rejects.

These findings on the effect of butt logs agree with those of Hallock for pines (8, 9, 10) that show butt logs are higher in crook, moderate in bow, and lower in twist.

The use of the SH treatment effectively removes the butt log effect in the manufacture of yellow-poplar studs.

TABLE 6. - *Ranking of average warp values from high to low by log position for combined areas, treatments, and stud sizes.*

Crook			Bow			Twist		
Log position[a]	Avg. (1/32 in.)	No. of logs at each position	Log position	Avg. (1/32 in.)	No. of logs at each position	Log position	Avg. (1/32 in.)	No. of logs at each position
10	3.6	15	11	11.0	1	3	1.7	232
1	3.4	350	8	6.9	46	9	1.5	21
6	3.0	133	10	6.7	15	4	1.3	209
3	2.5	232	3	6.3	232	10	1.1	15
8	2.4	46	1	6.0	350	6	1.0	133
2	2.3	269	4	5.9	209	5	1.0	208
5	2.2	208	5	5.8	208	1	.9	350
4	2.2	209	9	5.8	21	2	.9	269
9	2.1	21	6	5.7	133	7	.8	65
7	1.8	65	2	5.2	269	8	.7	46
11	.0	1	7	4.4	65	11	.0	1

[a]Position of log in the tree: 1 = butt log, 2 = second log above ground, 3 = third log above ground, etc.

TABLE 7. - *Warp average, range,[a] and number of rejects by treatment and area. Remeasurement after 30 or more days storage. All stud sizes combined (2 by 2, 2 by 3, 2 by 4).*

Treatment		Conventionally sawn						S-D-R live-sawn					
		Conventionally dried			High-temperature dried			Conventionally dried			High-temperature dried		
Area	Warp	Avg. (1/32 in.)	Range (1/32 in.)	No. of rejects[c]	Avg. (1/32 in.)	Range (1/32 in.)	No. of rejects[c]	Avg. (1/32 in.)	Range (1/32 in.)	No. of rejects[c]	Avg. (1/32 in.)	Range (1/32 in.)	No. of rejects[c]
North Carolina	Crook	5.6	18	22	3.7	15	10	2.5	10	3	1.5	7	0
	Bow	9.7	34	4	6.1	30	2	6.2	25	1	7.2	22	0
	Twist	1.2	8	0	.3	4	0	.9	5	0	.5	5	0
Tennessee	Crook	4.3	22	15	3.4	16	7	2.1	10	2	1.2	6	0
	Bow	5.8	24	0	4.2	12	0	5.6	19	0	3.8	18	0
	Twist	.8	5	0	.5	5	0	.9	12	0	.5	4	0
Virginia	Crook	5.0	19	13	4.6	18	13	3.8	15	8	1.4	12	2
	Bow	8.2	25	1	7.0	29	1	8.0	29	1	5.7	15	0
	Twist	2.2	16	1	1.3	13	1	1.2	7	0	1.0	9	0
West Virginia	Crook	4.9	19	16	3.8	13	6	1.8	7	0	1.2	7	0
	Bow	7.4	25	1	5.0	24	0	5.5	15	0	3.9	24	0
	Twist	1.8	13	1	1.1	7	0	1.0	5	0	.6	7	0
Combined areas[b]	Crook	5.0	22	66	3.9	18	36	2.6	15	13	1.3	12	2
	Bow	7.8	34	6	5.6	30	3	6.3	29	2	5.2	24	0
	Twist	1.6	16	2	.8	13	1	1.0	12	0	.7	9	0

[a]Range is from zero to value shown.
[b]Total number of samples per treatment: conventionally sawn: conventionally dried—356, high-temperature dried—372; S-D-R live-sawn: conventionally dried—403, high-temperature dried—417.
[c]Based on warp requirements for STUD grade.

Storage of studs

To evaluate the stability of the studs, individual treatment batches were solid stacked, steel strapped, and stored in an open-sided shed for 30 to 60 days and remeasured. The results of storage and remeasure are found in Table 7 and Figure 3.

Individual stud warp varied in response to storage. Some pieces increased in warp while others decreased. A comparison of data from Tables 2 and 7 indicates that crook increased in all treatments for all areas combined. Even with the increase in crook for SH, the average value is still 73 percent less than CC, 66 percent less than CH, and 48 percent less than SC. The SC treatment is 49 percent less than CC and 34 percent less than CH.

All treatment averages increased in bow after storage. Though the high-temperature treatments increased more in bow, their averages were still lower than the conventionally dried treatments: CH was 28 percent lower than CC and SH was 18 percent lower than SC.

Unlike crook and bow, which increased with storage, overall average twist decreased in the CC and CH treatments and stayed the same in the SH treatment.

On an area basis for the SC treatment, twist decreased after storage only in West Virginia material but enough to offset most of the small increases in material from the other states.

Moisture content

The goal of the drying schedules was to achieve 12 ± 3 percent average MC for the studs. Because kiln loads were mixed studs and flitches, the smaller sized studs dried to about 2 percent lower MC than the flitches. Treatment averages for combined areas were CC = 9.2 percent, CH = 9.2 percent, SC = 11.8 percent, and SH = 11.6 percent MC.

It would appear that a relationship exists between average MC and the degree of warp because the conventionally sawn studs were drier and had more warp. However, further analyses showed that the treatment and not the MC caused the difference in warp. Regression analyses show very low correlations of warp with MC. For initial crook, correlations (r) were as follows: CC = 0.08, CH = 0.18, SC = 0.18, and SH = 0.23. Similar or lower correlations were found for bow and twist. At best these regressions account for only 5 percent of the variation in crook, which is not of practical importance.

Regressions of MC on warp, after storage, show increased correlation values but they still only account for a maximum of 11 percent of the warp variation—that for crook. Correlations for remeasured crook were: CC = 0.10, CH = 0.25, SC = 0.33, and SH = 0.26. As before, bow and twist correlations were similar to or lower than those for crook.

Unlike results shown by Arganbright et al. (1) and Blake and Voorhies (2) for ponderosa pine, the correlations of MC and crook for yellow-poplar were positive (higher MC, higher crook). The correlations for bow and twist were negative (lower MC, higher warp), as were those for ponderosa pine. The negative correlations for bow and twist were very low, accounting for a maximum of 2 percent of the warp on initial measurement and a maximum of 3 percent of the warp on remeasurement.

Yield comparisons

One of the major questions for a new technique such as S-D-R is will it yield as much lumber as conventional practice? In this study, 6960 board feet (BF) of lumber were cut. Between the S-D-R live-sawing and the conventional cant sawing techniques, the difference in yield was only 30 BF: S-D-R=3495 BF, and conventional = 3465 BF. A greater difference existed in the distribution of stud sizes between sawing techniques than in volume. For S-D-R there were 417 2 by 4's, 190 2 by 3's, and 213 2 by 2's. Conventional sawing yielded 518 2 by 4's, 118 2 by 3's, and 92 2 by 2's.

If, when using S-D-R, the number of 2 by 4's was maximized, flitches that could yield a 2 by 3-2 by 2 combination would be cut into 2 by 4's instead. The volume yield would decrease by about 1.8 percent. In this study 478 flitches were sawn, of which 110 had 2 by 3-2 by 2 combinations in them. By eliminating the 2 by 3's and 2 by 2's and instead cutting 2 by 4's, the yield would be 3404 BF or 98.2 percent of the conventional yield. The dollar value yield would increase, however, because of the higher value of 2 by 4's.

The input log volume to the study was 2030 BF Scribner Dec C scale for S-D-R and 2025 BF for conventional. Because of the small average log size (7.3 in. small end diameter), the overrun was quite high—72.2 percent for S-D-R, 70.2 percent for conventional. The lumber recovery factor (LRF)[1] was 8.5 for both sawing systems. More information on yield is given by Maeglin et al. (23).

Strength comparisons

Another question concerning the S-D-R process is what effect does high-temperature drying have on the mechanical properties of the wood?

To answer that question Gerhards (6) has analyzed the bending strength of 809 2 by 4 studs from this study. The analysis showed that high-temperature-dried studs were not significantly lower in strength than conventionally dried studs. Pieces containing pith were lower in strength than those without pith. Gerhards cautions that because 84 percent of the pieces evaluated were of Select Structural grade, the result may apply only to studs meeting the highest visual standards. While his warning should be heeded, the use of small trees with small knots will help to minimize the occurrence of lower grade lumber.

Economics of the process

A third question pertaining to the S-D-R concept is will it be economically feasible? The answer is yes, according to Harpole et al. (12). They state that "using lumber prices and wood raw material costs for the southern pine regions, analysis indicated that an average return to sales would be about 40 percent for manufacture of S-D-R studs, or about 48 percent for manufacture of 2 by 4 Random-Length lumber of 15 percent Utility and 85 percent Standard and better grades." The above estimate was based on 1979 and early 1980 market conditions.

[1]LRF =board foot lumber yield per cubic foot of log input.

Manufacturing alternatives

Ideally a mill established with S-D-R stud manufacture in mind would include the most current equipment and the best material flow for the process. Such a mill has been designed by Ed Williston Associates, Inc.[2] to produce 25 million BF of studs per year on a two-shift basis. While the Williston design is specific to S-D-R, many existing mills could be adapted to cut S-D-R studs from hardwoods using present equipment and plant design.

Sawing.—Anumber of different headrig types can be used to create live-sawn flitches: single-cut band or circular saws, double-cut band, circular saw canters or chipper canters, or multiple-cut scraggs or frame saws. Cants can be resawn into already edged flitches for drying using scraggs, bands, frame saws, etc. as long as the pith is centered. If cants are sawn, eccentric logs should be oriented to be cut parallel to a line drawn through the pith, dissecting both the long and short radii. The cants would then be resawn perpendicular to the canting cuts.

Drying.—Though the S-D-R conventionally dried studs are not as high in quality as the S-D-R high-temperature-dried studs, they are considerably better than conventionally sawn studs. It may be feasible for some operations to use conventional dry kilns to dry flitches for S-D-R studs. A kiln capable of 200°F temperatures may produce better results than found for the 180°F maximum conventional schedule used for the study. Airdrying of flitches may also be suitable, however, no tests were conducted using air-drying.

Ripping.—A number of different configurations of edgers are available for ripping flitches. The ideal rip would be an automated unit controlled by a laser width scanner, but an operator-controlled 2-, 3-, or 4-saw edger with laser or shadow lines can also work.

Conclusions

The data show that for yellow-poplar:

1) Each treatment (CH, SC, SH) results in reduced warp compared to the control (CC) treatment.

2) Live-sawing, whether with conventional or high-temperature drying, produces straighter studs than conventional cant sawing.

3) High-temperature drying produces straighter studs than conventional drying.

4) The effect of butt log on crook is substantial for conventionally sawn material but is nearly eliminated by S-D-R treatments.

5) Storage of studs for 30 days or more resulted in minor increases in warp and rejects for the S-D-R material but notable increases for the CC treated studs. The CH treated studs improved in quality but still had much greater warp than SC and SH treated studs.

6) The volume yield for live and conventionally sawn material was the same. Both methods had a lumber recovery factor (LRF) of 8.5.

From correlated reports and data, the following inferences have been drawn:

[2]Engineering Economy Report on Saw-Dry-Rip Stud Mill for Processing Yellow-Poplar Hardwood for USDA, Forest Serv., Forest Prod. Lab., Madison, Wis.; Oct. 1979.

1) The use of high-temperature drying does not practically or significantly reduce strength in yellow-poplar studs.

2) The S-D-R concept is economically viable.

3) Many alternative machine combinations may be used to manufacture S-D-R studs—all necessary machines are commercially available.

4) Other studies (21, 22) and three industrial trials indicate that S-D-R is viable for other low- and medium-density species.

The advantages of using S-D-R for manufacturing studs from yellow-poplar and other hardwoods include:

a) Using the surplus hardwood resource.

b) Allowing for better management of the hardwood resource through thinnings.

c) Relieving pressure on the softwood resource.

d) Providing energy and cost savings by minimizing transportation distances to point of utilization.

e) Providing quality studs for the consumer.

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