S.D.R. - RED ALDER ANYONE?

Terence F. Layton and W. Ramsay Smith
University of Washington
College of Forest Resources
Seattle, WA

R. R. Maeglin
U.S. Forest Products Laboratory
Madison, WI

Introduction

The production of studs for use in construction is an important part of the United States' lumber industry. The species used have been traditionally Douglas-fir, western hemlock, lodgepole pine and the southern pines. Recent increased resource consciousness and the emergence of substantial acreages of under-utilized species has initiated the investigation of the potentials of these alternative species. Wood technologists are now looking to the country's abundant hardwoods as a possible source of construction lumber. Many low to medium density species such as yellow poplar, aspen, eastern cottonwood, sycamore and red alder have good form, small knots produce wood that nails well and has strength properties suitable for construction. However, lumber produced from these species, especially from small diameter logs, has a tendency to warp excessively when processed conventionally. For effective utilization, this warp problem must be overcome.

The development of warp in lumber can be attributed to the relief of stresses during the processing of wood. These stresses are to a large extent inherent growth stresses which are in equilibrium in a normal growing stem but are released as the stem is sawn into smaller dimensions. Additional stresses causing warp are developed due to unequal shrinkage in the drying process.

The established practice for stud production is to saw green logs into the desired dimensions prior to drying. The green dimensioned material is then placed into uniform kiln loads and dried. This method works well with old growth softwoods but not so with the smaller diameter hardwoods, which develop higher levels of warp.

In 1978, technologists at the U.S. Forest Products Laboratory reported a process for stud production which, when tested with yellow poplar and compared with the conventional process, showed a significant reduction in crook, the most critical form of warp in studs (Hallock and Bulgrin). The S-D-R process, an acronym for Saw, Dry and Rip, was developed specifically to help deal with stresses within wood. By live sawing green logs into nominal 2-inch flitches, the stresses which cause warp (particularly crook) are balanced and restrained due to the large size of the pieces and symmetry of stresses within the pieces. The green flitches are dried using a high temperature schedule (above 100°C) in place of conventional schedules. Apart from drying the wood faster, high temperature plasticizes wood allowing the stressed fibers to be relieved to a large extent. On cooling, the stress free wood sets in place. The flitches are then straight-line ripped to desired dimensions.

The encouraging results of the initial study with yellow poplar have prompted further studies on the feasibility of the process with other similar species. A study on aspen has already produced results similar to those with yellow poplar. Other species being investigated are cottonwood, paper birch and red alder. These studies on individual species are important as the various species may perform differently. Furthermore, these feasibility studies take into account such factors as available volumes, material costs and markets.

Red alder is an ideal candidate for the S-D-R process. It is plentiful in an established lumber production region but is presently under utilized. The current annual harvest is approximately 622 million board feet of which less than 60 percent is actually consumed. Over the next twenty years huge increases in available volume are expected (McGillivray, 1981). It is the purpose of this paper to discuss results of a study designed to evaluate the S-D-R process for converting red alder into studs.

Attempts at commercial stud production have been made. In fact, red alder has been accepted by the Western Wood Products Association (WWPA) and may be grade stamped under any of the "all species" grade descriptions if the minimum grade requirements are met. The abundant availability of small diameter logs, the practice of bucking logs in 8 to 10 foot lengths and the WWPA's approval make studs an ideal lumber product for alder (McGillivray, 1981).

The deformation, or warp, of lumber is a result of the relief of unequal stresses within the wood. In the production of studs the undesirable forms of warp are crook, twist and bow. These arise due to unbalanced stresses in the longitudinal direction resulting from 1) inherent growth stresses which develop during the formation of the woody tissue in trees (Panshin and de Zeeuw, 1980), and 2) stresses which occur during drying due to unequal shrinkage (Schneiwind, 1960). Seasoning stresses are not involved in the development of growth stresses but, on drying, seasoning stresses will be superimposed on the growth stresses (Jacobs, 1965).

Saw, Dry and Rip Process

In the processing of hardwoods, the problem of warp induced by growth stresses coupled with that induced during drying, has long been recognized. It is common practice in Europe to live saw hardwood logs into flitches, dry the flitches to desired moisture content and then machine to desired dimensions (Villiere, 1966).

In the S-D-R process logs are live sawn, i.e., all cuts parallel, into flitches of nominal 2 inch thickness. The flitches are slightly rough edged for compact kiln loading and dried to an average 10 percent moisture content. The dried flitches are then ripped into stud dimensions and planed (Maeglin, 1978). In an exploratory study with 54 yellow poplar logs in the 20-36 cm (8-14 in.) diameter range, using a mild drying schedule, only one stud out of 369 (of various dimensions) was rejected on the basis of warp (Hallock and Bulgrin, 1978). A later study showed that by using a high temperature drying schedule the average crook could be reduced by 30 percent over the mild schedule (Maeglin, 1978).

The S-D-R process appears to work by maintaining a balance of growth stresses in the sawed flitch. When the flitch is dried, the stresses which develop due to unequal shrinkage are again balanced and restrained within the flitch. Furthermore, when high temperature (greater than 100°C) is applied, the wood is plasticized, allowing the fibers to reorientate and relieve their stresses. The wood "hardens" when cooled and sets in a relatively unstressed condition. When the flitches are ripped, studs are straight and remain in this condition (Maeglin, 1978). The use of high temperature drying has the added advantage of significantly reducing kiln time, thus improving the viability of the process on a commercial scale.

Study Design

The design for this study was a 2^3 factorial, using 2 sawing methods, 2 drying methods and 2 sampling locations as shown in Table 1. Preliminary studies showed that the average log volume from the two sites was different and that eight logs from site 1 yielded approximately the same number of studs as five logs from site 2.

Procedures

Logs for the study were harvested in four stages, or runs, from each of the two sites. On each run, the logs were immediately transported to a sawmill where half were converted to dimensional stud material and half to 4.6 cm (nominal 2 inch) thick flitches. The sawn material was assessed for warp and thickness and then dried to a 12 percent target moisture content (ovendry basis), using either a high temperature or conventional schedule at the University of Washington. The dried pieces were again assessed for warp and thickness. Later the flitches were straight line ripped to stud dimensions at a local hardwood furniture dimension mill. All the pieces were dressed to standard lumber sizes and finally each stud was measured for warp and graded.

Drying

All drying was done in the experimental kiln at the College of Forest Resources, University of Washington. The kiln is steam heated with variable speed overhead fans and automatic venting. It was insulated to maintain the temperature required for high temperature drying. The kiln can accommodate approximately 60 studs with 10 mm stickers or a volume of 0.65 m (275 bd. ft.). Unfortunately, the length of studs was limited by the length of the kiln to 2.3 m.

Once loaded and moisture content samples prepared, the charge was restrained by a mechanical hold-down device (Figure 1). This device was designed to be used in lieu of weights because of the small kiln charges. Pressure on the charge is applied by spring loaded devices, attached between the carriage at the base of the charge and angle-iron frames on top. The frames are aligned with sticker positions. The surface area of the charge was 1.39 m^2 (15 ft^2), there were 5 sticker positions and the target pressure on the charge was 420 kg/m^2 (100 lbs/ft^2). Therefore, the springs were capable of applying 136 kg (300 lbs) of pressure at each sticker position.

Half of all the study material, both flitches and dimensioned material, was dried using a conventional schedule. A high temperature schedule (100°C) was used for the other half. The schedules used are shown in Table 2. The conventional schedule was based on Forest Products Laboratory schedule T8D3 from the Kiln Operations Manual (Rasmussen, 1961). The high temperature schedule is based on similar schedules used by the FPL to dry yellow poplar. The air velocity for the conventional schedule was 22.65 m^3/min and for the high temperature was 28.32 m^3/min. Kiln samples were used to control the schedules to an average 12% final moisture content.

Warp Measurement

The types of warp measured for each piece were crook, bow and twist. All warp measurements were taken by placing the piece on a flat surface and rotating the piece to determine the maximum deviation for each type of warp. This deviation was then measured using a depth gauge calibrated to the nearest 1 millimeter. The maximum acceptable warp limits for stud grade, according to the National Grading Rules were made more stringent to compensate for the shorter length (2.3 m). The warp criteria used is presented in Table 3.

These adjusted warp limits were determined by graphical interpolation using the warp limits for construction grade material of various lengths and rounded down to the nearest 1 mm. for 8 and 10 ft stud grade pieces. The interpolated values were rounded down to the nearest 1 mm.

Grading

All finished pieces were graded according to the national grading rules, by a qualified Western Wood Producers Association grader. Each piece was graded on the basis of all qualities other than warp. Pieces that were not acceptable as stud grade were graded Economy stud or reject.

The prime cause of degrade in studs produced from small diameter hardwoods, is the development of warp, particularly crook. Figure 2 presents the percent rejects, on the basis of warp, for each of the combined sawing and drying treatments. The numbers in each cell represent the percentage of pieces, 2x4's plus 2x3's and 2x2's, that were rejected due to excessive warp. The minimum sample size for each cell or treatment was 50 pieces. It should be noted that crook was not the sole cause of reject, many rejects exceeded only the twist limits.

The S-D-R processed pieces had, in all cases, considerably lower percent rejects than the conventionally sawed material. The least percentage of rejects was 6.3 percent obtained with the S-D-R process, using a high temperature drying schedule.

It is interesting to observe the effect of drying schedule on the conventionally sawed studs. Over 60 percent of conventionally dried studs from site 1 were rejected; this figure was almost halved by high temperature drying. Site 2 conventionally dried studs had lower percent rejects than their equivalent in site 1 but high temperature drying increased the percent rejects to over 60 percent, which was a reverse of the trend in site 1. A possible cause of this discrepancy between the sites is discussed later.

As well as being assessed for warp each individual piece was graded on the basis of qualities other than warp. Ninety-one percent of all pieces were of Stud grade or better, over 8 percent were Economy grade and less than 1 percent were rejected.

Comparison of the Effects of Treatment on Warp Development

Data for 2x4's only was used to study the effects of treatments on development of warp and degree of degrade. The effect of treatment on the percentage of 2x4's that were rejected due to warp is presented graphically in Figure 3. This chart indicates clearly that sawing, drying and source of material had definite influence, but tells nothing of how these factors influenced the type or degree of warp responsible for reject. It is apparent from the chart that the S-D-R process, using high temperature drying, is the most effective in maintaining low levels of rejects. To understand the process it is necessary to assess its influence in the different types of warp by comparison with other treatments.

Also in Figure 3 it can be seen that with conventional sawing the source of material had a confounding influence on percent rejects, indicating an interaction between site and drying. A comparison of effects of the different sawing and drying treatments on the types of warp development in 2x4's is presented in Table 4. The influence of source of material is excluded from this comparison by combining results from Sites 1 and 2. The effectiveness of the S-D-R sawing process in controlling crook development was substantial. The average crook of studs produced by S-D-R sawing (Treatments 3 and 4) was a little over 1 mm compared with 6.95 mm for conventionally sawed studs (Treatment 1). This represents an 84 percent reduction in the average crook. The drying schedule used did not appear to influence average crook.

Average twist, on the other hand, appeared to be influenced more by the drying schedule than the sawing method. Of the 355 2x4's produced in the study, 44 exceeded the allowable twist limit and exactly half of these exceeded the crook limit as well (Table 3). Ninety-three (93) exceeded the allowable crook limits and 22 of these exceeded the twist limits also. Only one S-D-R sawed stud was rejected on the basis of crook so S-D-R sawing essentially eliminated the problem of crook. Thus, in Table 4 the reduction in the percent rejects between Treatments 3 and 4 was attributed to the influence of high temperature drying in limiting the development of twist. None of the studs produced in the study exceeded the allowable bow limits however, bow development was greater in S-D-R sawn than in conventionally sawn material.

Assessment of Degree of Degrade Caused by Warp

Influence of Sawing, Drying and Site on Crook Development

The average crook for each of the treatments, along with the sample size, is presented in Table 5. The results of analysis of variance for each factor (sawing, drying, site) effect and their combined effects on crook development are presented in Table 6.

The analysis of variance shows that the sawing process used had a highly significant effect in controlling crook in studs. Note how much the F value for sawing (191.77), exceeds the minimum value for the 0.5 percent significance level (7.88).

Influence of Sawing, Drying and Site on Twist Development

The average twist for each of the factorial treatments, along with the sample size, is presented in Table 7. The results of analysis of variance for each factor (sawing, drying, site) effect and their combined effects are presented in Table 8.

Interpretation of Table 8 indicates that the most important factor in controlling twist is the drying schedule used. Use of the high temperature schedule significantly decreased the overall extent of twist development. The sawing process used did not significantly influence twist but conventionally sawn studs from the two sites reacted differently to the drying schedule, showing a trend similar to that seen with crook development.

A possible cause of this discrepancy between the sites is the difference in log sizes and form. It could be expected that a greater proportion of the site 1, conventionally processed studs, contained a mixture of normal wood, juvenile wood and/or reaction wood than the site 2 studs. It should be noted that reaction wood was not noticeable and indeed is believed to be rare in red alder (Leney, et al., 1977).

In green studs containing a mixture of normal, juvenile and/or reaction wood, the tendency to warp due to unequal shrinkage is moisture content dependent. However, when high temperature is used the wood is plasticized and inherent growth stresses are more readily relieved. Because of the nature of the growth stress gradient, the relief of these stresses tends to cause deformation in the opposite direction to deformation caused by unequal shrinkage. Thus, there is a balancing effect resulting in lesser overall deformation or warp.

In green studs that contain normal wood only, the amount of unequal shrinkage is at a minimum but the inherent growth stress gradient is still considerable. When these stresses are relieved, in high temperature drying, the deformation caused is of a higher order than that caused by unequal shrinkage. Because the tendencies to deform are not balanced, greater overall deformation results.

The same principles as above can be applied to the S-D-R sawn material. When the flitches are dried conventionally the tendency to deform is the same as in studs but the actual deformation is much less, due to the balancing of stresses across the flitch and the restraining effect of the larger piece. Although much of the stress is relieved during drying some residual stresses remain which cause deformation when the flitches are ripped to stud dimensions. However, when high temperature drying is used most of the residual stresses are relieved when the wood is plasticized. When these flitches are ripped, relatively little warp occurs.

Conclusions

1. Of all the alder 2x4's produced in the study by conventional processing methods over 53 percent contained warp in excess of the limits allowed for Stud grade. Of these, 54 percent exceeded the crook limit only, 19 percent exceeded the twist limit only and 27 percent exceeded both crook and twist limits. The bow limit was never exceeded.
2. S-D-R processing was effective in containing development of warp below the allowable limits. When combined with high temperature drying, only 6.1 percent of all S-D-R 2x4's exceeded the warp limits. In the study this 6.1% rejects represented 6 studs, of which one exceeded the crook limit only and 5 exceeded the twist limit only.
3. Live sawing alone essentially eliminated the problem of crook but was not as effective in controlling twist. The use of high temperature drying in combination with S-D-R sawing significantly reduced the development of twist.
4. Based on qualities other than warp, ninety-one (91) percent of all studs produced met the Stud grade, over eight percent were graded Economy and less than one percent were Reject.
5. To produce the same volume of finished studs, S-D-R flitches required 24 percent more kiln space than dimensioned pieces.
6. By using the high temperature schedule, drying time was reduced by 65 percent over the conventional schedule.

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Table 1. Study Design, 2^3 Factorial.

	DRYING							
	Site 1				Site 2			
	Convent.[1]		Hi Temp.[2]		Convent.		Hi Temp.	
SAWING								
Conventional	8	8	8	8	5	5	5	5
S-D-R	8	8	8	8	5	5	5	5

[1]Conventional dry schedule.

[2]High temperature drying schedule.

Table 2. Kiln Schedules for Nominal 2-Inch Thick Red Alder.

Conventional Schedule

Moisture Content (%)	Dry Bulb Temperature (°C)	Wet Bulb Depression (°C)	Wet Bulb Temperature (°C)	Time, Hours (Approx.)
+50	54.4	2.8	51.6	40
50	54.4	3.8	50.6	10
40	54.4	6.1	48.3	10
35	54.4	10.5	43.9	10
30	60	19.4	40.6	10
25	65.6	27.8	37.8	10
-25	71.1	27.8	43.3	10

Equalized at 71.1°C dry bulb temperature and 63.9°C wet bulb temperature for 24 hours.

High Temperature Schedule

Dry Bulb Temperature (°C)	Wet Bulb Temperature (°C)	Time (hrs.)
115.6	87.8	18

Equalized at 93.3°C dry bulb temperature and 87.2°C wet bulb temperature for 24 hours.

Table 3. Adjusted Warp Limits to Compensate for Shorter Length Studs.

	2 x 4	2 x 3	2 x 2
Crook (mm)	5	5	18
Bow (mm)	18	18	18
Twist (mm)	8	8	4

Table 4. Comparison of Effects of Different Treatments on Development of Warp in 2x4's. Combined Results from Site 1 and 2.

	Number of pieces	Avg. crook (mm)	Advantage on Treatment 1	Avg. bow (mm)	Advantage on Treatment 1	Avg. twist (mm)	Advantage on Treatment 1	Percent Rejected	Advantage on Treatment 1
Treatment 1 Con. Sawn[1] Con. Dried[2]	97	6.95	---	2.75	---	5.21	---	53.6	---
Treatment 2 Con. Sawn Hi Temp.[3]	98	6.54	5.9	2.33	15.3	3.54	32.1	46.9	12.5
Treatment 3 S-D-R Sawn[4] Con. Dried	83	1.14	83.6	3.73	-26.3	5.17	0.8	14.5	27.1
Treatment 4 S-D-R Sawn Hi Temp.	77	1.09	84.3	3.55	-22.5	2.79	46.4	6.1	87.9

[1]Conventionally sawn.
[2]Dried by conventional schedule.
[3]Dried by high temperature schedule.
[4]S-D-R sawn.

Table 5 Average Crook (mm), 2x4's Only

SAWING	DRYING	SITE_1		SITE_2	
		Convent.	Hi_Temp.	Convent.	Hi_Temp.
Conventional (N)		7.08 (48)	4.78 (51)	6.84 (49)	8.45 (47)
S-D-R (N)		0.91 (47)	0.45 (44)	1.44 (36)	1.94 (33)

Conventional drying schedule.
High temperature drying schedule.
Number of studs.

Table 6. Analysis of Variance (the effects of treatment factors on crook development).

Source of Variation	DF	Sum of Squares	Mean Square	F ratio value
Total	354	8309.20		
Sawing (A)	1	2788.89	2788.89	191.77***
Drying (B)	1	1.60	1.60	0.11
Site (C)	1	276.18	276.18	18.99***
Interactions				
(A x B)	1	7.84	7.84	0.54
(A x C)	1	0.67	0.67	0.05
(B x C)	1	129.34	129.34	8.89***
(A x B x C)	1	58.37	58.37	4.01
Error	347	5046.31	14.54	

* Value significant at a level of 2.5 percent probability.
** Value significant at a level of 1.0 percent probability.
*** Value significant at a level of 0.5 percent probability.

Table 7. Average Twist (mm), 2x4's Only.

	DRYING			
	Site 1		Site 2	
	Convent.[1]	Hi Temp.[2]	Convent.	Hi Temp.
SAWING				
Conventional (N)[3]	6.69 (48)	2.98 (48)	3.76 (49)	4.15 (47)
S-D-R (N)	5.70 (47)	3.05 (44)	4.47 (36)	2.46 (33)

[1]Conventional drying schedule.

[2]High temperature drying schedule.

[3]Number of studs.

Table 8. Analysis of Variance (the effects of treatment factors on twist).

Source of Variation	DF	Sum of Squares	Mean Square	F Ratio Value
Total	354	4349.70		
Sawing (A)	1	10.59	10.59	0.99
Drying (B)	1	347.17	347.17	32.17***
Site (C)	1	62.66	62.66	5.90*
Interactions				
(A x B)	1	1.90	1.90	0.18
(A x C)	1	0.52	0.52	0.05
(B x C)	1	182.71	182.71	17.21***
(A x B x C)	1	61.21	61.21	5.77*
Error	347	3682.94	10.61	

*Value significant at a level of 2.5 percent probability.

**Value significant at a level of 1.0 percent probability.

***Value significant at a level of 0.5 percent probability.

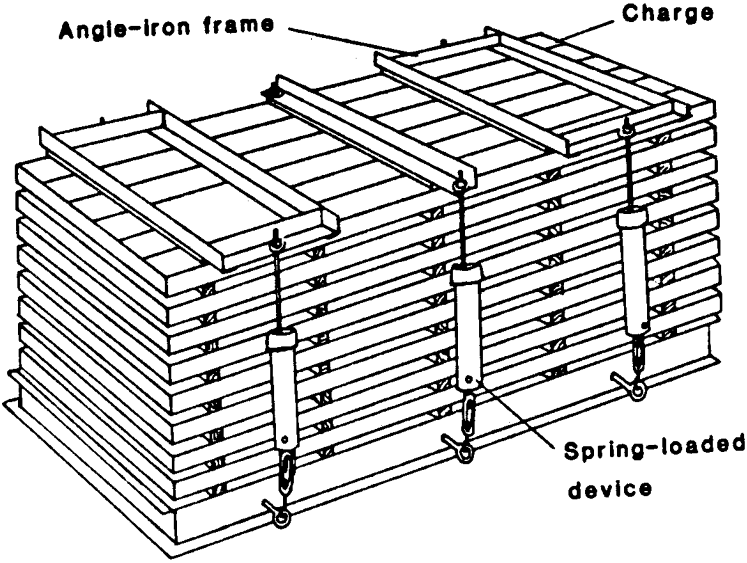

Figure 1. Mechanical hold-down device used in lieu of weights during kiln drying.

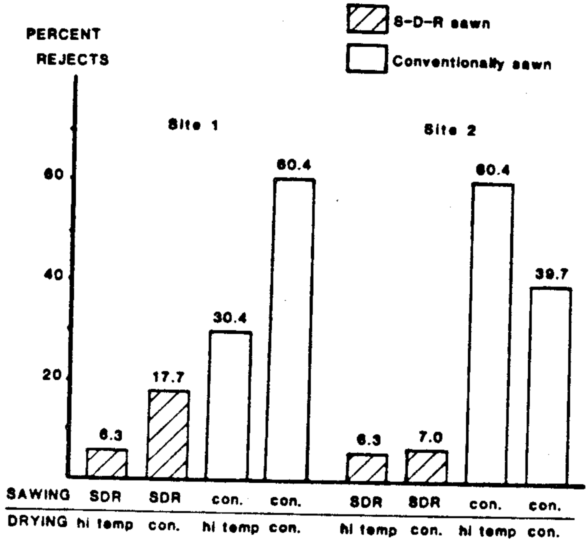

Figure 2. Percentage of studs (2x4's, 2x3's and 2x2's) rejected due to excessive warp.

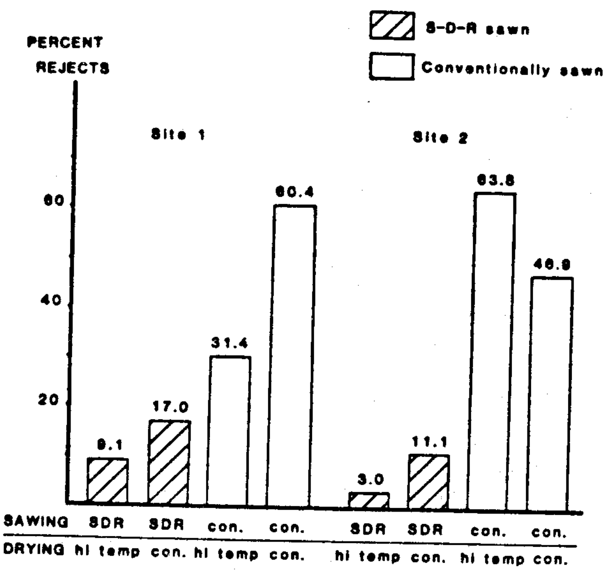

Figure 3. Percentage of 2x4 studs rejected due to excessive warp.