Warp reduction of SYP lumber by restrained drying

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Abstract

Warp in dimension lumber is a significant cause for loss in grade and value. Among dimension lumber, the 2- by 4-inch size is typically the most susceptible to warp for a variety of reasons. Among the various sizes of southern yellow pine (SYP) dimension lumber, 2 by 4 is produced in the greatest volume. Two-by-four material sawn from young trees, thinnings, and stem tops contains a significant proportion of juvenile wood and is particularly notorious for warp. At the planer mill, warped 2 by 4's represent a significant loss in value. In-service replacement of warped 2 by 4's as wall studs or truss members is costly. In this research, a drying restraint system was evaluated as a means of warp reduction in 8- and 16-foot-long SYP lumber. Both restrained and control boards were dried to approximately 9 percent moisture content, representative of final in-service conditions. The lumber was then measured for crook, bow, and twist. Results showed a significant improvement in higher grade recovery for the restrained material. As a means of assessing long-term dimensional stability, the 16-foot-long restrained package was remeasured for warp after both 1 and 9 months of warehouse storage.

Because a large proportion of 2- by 4-inch lumber is currently sawn from young small-diameter trees, problems associated with wood quality are significant. High percentages of juvenile wood in these young stems reduce grade retention. Juvenile wood is particularly known for its ability to induce crook and other forms of warp (Bowyer et al. 2003). The immediate result is noted at the planer mill where the affected lumber is downgraded from No. 2 and better grade to No. 3 and reject. Because this lumber is from young small-diameter trees, knots are generally not of sufficient size or frequency to cause downgrade below No. 2 grade. If dried free of warp, it is estimated that southern yellow pine (SYP) 2 by 4's could be produced with approximately 90 percent as No. 2 and better, with degrade occurring from knots and wane. On average however, SYP 2 by 4's are produced at only 73 percent No. 2 and better. The remaining 27 percent is No. 3 and lower. For this lumber, warp is a highly important predictor of value. Grade retention improvements are achievable through control of warp frequency and severity.

The economic value loss for the lumber downgrade is significant, on the order of 50 to 150 U.S. dollars per thousand board feet (MBF). Based on this and previous studies related hereto, we estimate that 7 percent of the total SYP 2 by 4 production could be upgraded from No. 3 and lower via restrained drying. At an average increase of \$100/MBF and a total annual SYP 2 by 4 production of approximately 5.1 billion BF (SFPA 2002), this represents an added value of \$35 million annually. For a commonly sized small log mill (125 million BF per annum) that produces primarily 2 by 4 stock, this 7 percent increase in grade recovery translates to \$900,000 per annum.

In many instances, warp develops in dressed lumber that is stored at the planer mill for weeks or months. Storage regularly occurs when lumber prices decline and inventories accumulate. During storage, the lumber continues to moisture

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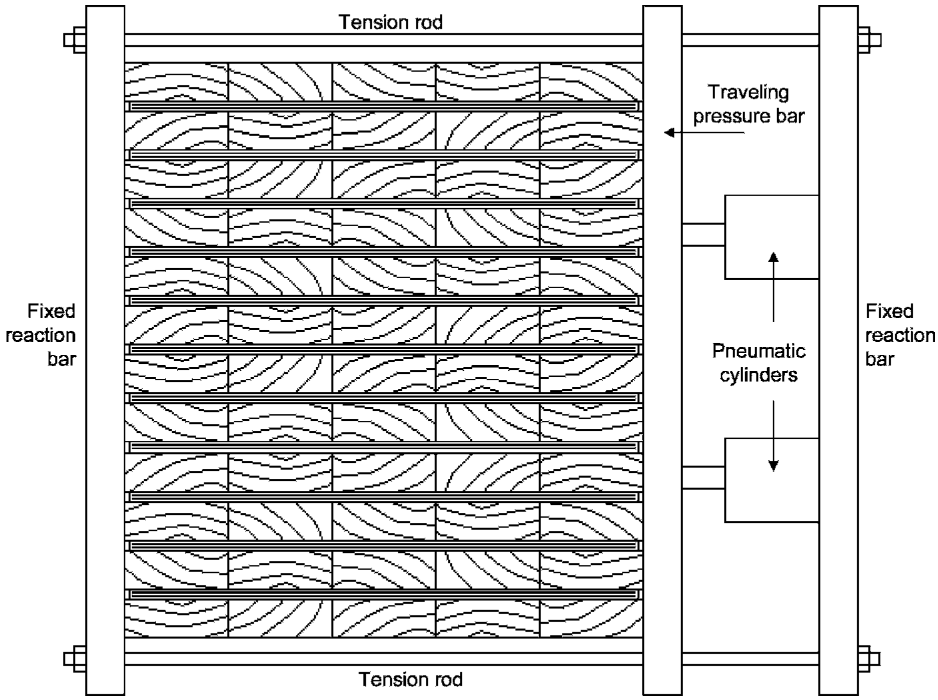

Figure 1. — Sectional schematic of one restraint device clamp.

equilibrate and associated stresses build. Lumber that is regraded after storage often does not meet its previous grade designations because of warp. In other cases, the warp develops after lumber has been shipped due to moisture content (MC) changes at distribution centers, lumberyards, or after installation. When warp develops after shipment, the lumber may be rejected, or sold at a discount. When warp develops in-service, costly claims to fix bowed drywall, cracked plaster, nail-pops, and warped siding can result. Warped lumber is not well tolerated in engineered truss manufacturing where straight and true members are critical for set-up, production, and ultimate performance. In the literature, Hoadley (1980) and Koch (1972) recommend a final kiln-dried wood MC range of 7.5 to 10 percent in order to establish dimensional stability for framing lumber. Producers are understandably reluctant to kiln-dry to this level, mainly due to increased incidence of warp.

The edge restraint procedure employed herein focused on diminishing or possibly eliminating the cause and effect relationship between MC and warp that is common in lumber cut from young small-diameter trees. The system utilizes pneumatically actuated air cylinders and vertically oriented steel bars to clamp and maintain restraint pressure throughout drying (**Fig. 1**). For the 8-foot-long lumber, restraint clamps were located at approximately 4-foot intervals; three clamps were used, one at each end and one at midlength. For the 16-foot-long lumber, restraint clamps were located at approximately 3.2-foot intervals along the lumber length; six sets of restraint bars were used. Air cylinders were charged with air pressure that ranged from 90 to 100 psi. This pressure was sufficient to drive the lumber in each course tightly together, into a rigid slab. This pressure was maintained throughout drying. As the width of the lumber courses decreased due to wood shrinkage, mechanical restraint pressure remained constant.

Another edgewise restrained drying technique by Koch (1971) has been investigated. In that case however, crook restraint during drying was limited because boards were dried in fixed-width channels and under spring tension. There, as boards shrank, the warp restraint became less effective because the tension in the springs was lost and the fixed-width channel no longer tightly held the shrunken board(s). Top load restraint has shown some efficacy in commercial mills, especially those that manufacture warp-prone lumber. The lack of crook restraint, difficulty in handling, and general bulkiness of the top loads limit the applicability of this technology.

The drying schedules employed herein were developed to closely simulate commercial kiln-drying and to produce a final average MC to which the boards would equalize in service. In contemporary commercial mill situations, the final MC values are higher, averaging about 15 percent. In that case, further unrestricted drying usually occurs after lumber shipment and is fertile ground for warp. SYP was selected because it represents the most economically important commercial softwood lumber group in the United States. Most SYP 2 by 4's are manufactured from young, small-diameter trees, thus these have a strong propensity to warp during drying. Also, among structural SYP lumber production (boards, dimension, and timbers) sizes, 2 by 4 is produced in the greatest volume. In 1998, approximately 31 percent of SYP lumber was milled as 2 by 4's.

Objective statement

The objective of this study was to evaluate a system of pneumatically actuated restraint-drying as a means of reducing warp in 8- and 16-foot-long SYP 2 by 4 lumber.

Procedure

Lumber was obtained as rough green 2 by 4's from McDavid, FL. The contributing sawmill produces a predominance of 2 by 4 lumber from small-diameter logs; averaging 5 to 6 inches in diameter. It was expected that the natural warp potential for the lumber was high. For both lengths, 8- and 16-foot, lumber was divided into matched packages: one for control and one for restraint drying.

For the 8-foot-long lumber, 200 pieces were obtained. The control package contained 96 pieces and the restrained package contained 90 pieces, the remaining 14 were culled. For control drying, lumber was stacked on 0.75 inch-thick stickers, spaced 2 feet apart. Boards were stacked tightly edge-to-edge. For restraint drying, one lumber package was outfitted with the restraint device. Restraint clamps were located at each end and in the middle at midlength and 0.625-inch-thick stickers were located at 2-foot intervals.

For the 16-foot length, 230 pieces of rough green 2 by 4 lumber were obtained. Each package, control and restraint, contained 112 pieces for a total of 224. The remaining 6 pieces were culled. Both lumber packages were stacked on 0.75-

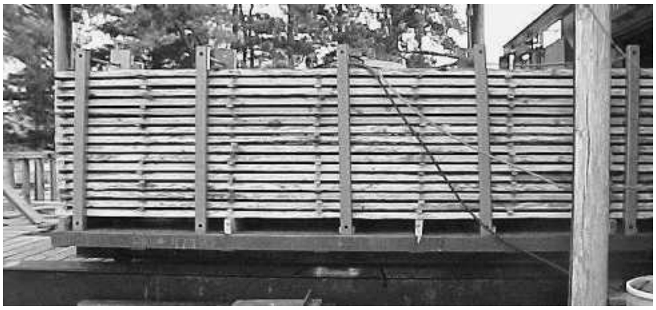

Figure 2. — Photograph of the restrained lumber package. The package is 16 feet long and 16 courses tall. The six vertically oriented steel restraint bars are spaced approximately 3.2 feet apart along the lumber length. The two airlines that actuate the pneumatic cylinders are draped across the package.

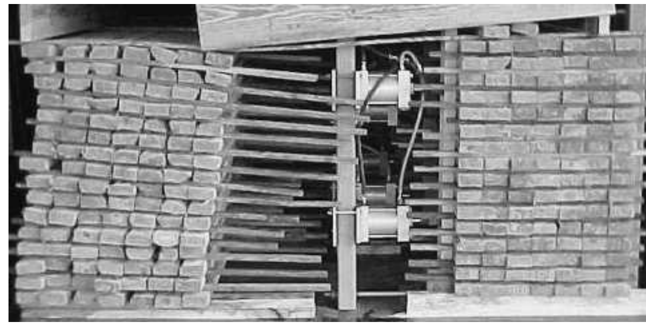

Figure 3. — Photograph of the dry nonrestrained control (left) and restrained (right) lumber packages immediately after drying. The pneumatic cylinders and vertical steel bars are visible and the courses of restrained lumber are well ordered. The control package has perceptible lean, caused by excessive and erratic twist. Individual control boards appear much more distorted.

inch-thick stickers, spaced 2 feet apart. Each lumber package was 7 boards wide by 16 courses tall. Thus, each of the matched packages contained 1,194 BF stacked tightly edge-to-edge. For the restraint drying, the lumber was outfitted with the restraint device. Restraint clamps were located at each end and at 3.2-foot intervals along the lumber length (**Figs. 2** and **3**).

At 90 psi airline gauge pressure, the maximum wood-to-steel contact pressure was approximately 40 psi. This contact pressure value is well under the crushing strength for SYP lumber, thus no compression damage was developed along the edges of the boards that were in direct contact with the device. The total compressive force applied to the 15-course-tall, 8-foot-long package was approximately 10,500 pounds. As such, each individual lumber course in this package received approximately 700 pounds of edgewise restraint force. The total compressive force applied to the 16-course-tall, 16-foot-long package was approximately 21,000 pounds. As such, each individual lumber course in this package received approximately 1300 pounds of edgewise restraint pressure. These levels of pressure were sufficient to overcome the inherent friction forces and squeeze each course of green lumber tightly together as a slab, to overcome warp forces during drying, yet not so high as to cause edge damage by crushing.

For the 8-foot-long lumber, two charges were dried, each in the same kiln at: 230°F dry bulb and 140°F wet bulb. Then the charges were equalized at 190°F dry bulb and 170°F wet bulb. Air velocity through the kiln packages was approximately 600 feet per minute. Because of this relatively slow air velocity, drying time was somewhat longer than that typical of industry. Drying from green took approximately 22 hours. Equalization was run for approximately 20 hours. It is not believed that the lower air velocity and longer drying time had any impact on warp except as the warp relates to final MC. Upon completion of drying, the lumber was cooled for 24 hours and then each piece was measured for MC and warp.

For the 16-foot-long lumber, the two lumber packages were loaded side by side on an 8-foot-wide kiln tram. The two matched packages were then dried together. Kiln conditions were set for 240°F (exiting air) dry-bulb temperature and 160°F wet-bulb temperature. The maximum temperature drop across the load (TDAL) was 40°F, thus the maximum entering air temperature was approximately 280°F. Airflow through the lumber was approximately 1,500 feet per minute. The kiln heat was shut off when the TDAL reached 3°F. The total drying time was 14 hours. The lumber was then cooled in the kiln for 5 hours with the heat off, the vents open, the door ajar, and the fans on 25 percent velocity (approximately 350 ft/min through the stacks). Immediately following this 5-hour cooldown period, restraint pressure was released and the lumber was measured. After measurement, the 16-foot-long lumber was repacked unrestrained and placed in a dry storage non-temperature/humidity controlled warehouse. The warehouse was open at one side and thus the lumber was subject to fluctuations in outdoor temperature and humidity. After 1 and 9 months of storage, the lumber that was dried under restraint was remeasured for warp and MC. These measurements were performed to assess the long-term stability of the said lumber when placed in a non-controlled atmosphere in an unrestrained condition.

Table 1. — Final MC percent mean, variation, and 95th percentile.

	Avg.	SD[a]	95th
		(%)	
Restrained, 8-foot	8.4	2.0	11.7
Control, 8-foot	8.7	2.9	13.5
Restrained, 16-foot (immediately after drying)	9.3	2.4	13.3
Restrained, 16-foot (after one month)	9.2	2.0	12.5
Restrained, 16-foot (after nine months)	8.7	2.3	12.5
Control, 16-foot	7.9	1.0	9.6

[a]SD = standard deviation.

Moisture assessment

Because Hoadley (1980) and Koch (1972) recommend a final kiln-dried wood MC range of 7.5 to 10 percent in order to establish dimensional stability for framing lumber, this MC range was targeted. Producers are understandably reluctant to kiln-dry to this level because it causes more warp at the mill, but this MC range is reasonable as an equilibrium target, especially for interior partition framing, and floor and roof trusses. Upon completion of drying, the MC of each board was measured with a capacitance-type moisture meter that was calibrated for SYP.

Warp assessment

Immediately after removal from the kiln, each 2 by 4 was measured for crook, twist, and bow to the nearest 0.025 inch in the rough-dry condition. In practice, it is often difficult to precisely separate the three forms of warp (crook, bow, twist) in a given board. Care was taken to be as fair and consistent as possible in the measurement technique from board to board. The following procedure was used for warp measurement:

1. Each piece was positioned on a warp table to examine the extent of each warp type.
2. If the amount of warp appeared so small that a meaningful determination seemed implausible, a judgment of "no warp" was assigned.
3. When a measurement was judged to be required it was made to the nearest 0.025 inch via insertion of an inclined plane wedge. With the wedge inserted to the point of mild refusal, the reading was read off the calibrated vertical face of the wedge.

Results and discussion

MC results are summarized in **Table 1**. Average MC values were within the target range of 7.5 to 10 percent. These final MC values are generally lower than those called for in the grading rules; however, they are consistent with long-term equalization.

Warp results as mean, median, and standard deviation, by type, for the 8- and 16-foot-long lumber are given in **Tables 2** and **3**, respectively. These tables reveal that for the 8-foot-long lumber, the device was effective at significantly reducing warp as crook. For the 16-foot-long lumber, the device was effective at significantly reducing warp as crook, bow, and twist.

Warp in the restrained lumber directly from the kiln was statistically compared to that after 1 and 9 months of storage by using paired t-tests. For the 1-month storage period, no significant impact on average crook was detected; p-value was 0.45. Average bow increased by 0.08 inch, from 0.24 to 0.32 inch. Average twist increased by 0.09 inch, from 0.14 to 0.23 inch. Both differences were of little practical significance, but both were statistically significant. The p-values for the change in bow and the change in twist after 1 month were 0.00 and 0.00, respectively. For the 9-month storage period, no statistically significant impact on average crook or twist was detected; p-values were 0.97 and 0.13, respectively. Average bow decreased from 0.30 to 0.05 inch. This difference was highly significant; p-value was 0.00.

No statistically significant change in MC was measured in the lumber after 1 month of storage. A random sample of 40 boards showed starting and final MC values of 9.25 and 9.22 percent, respectively. A paired t-test on these board's MC values produced a significance level (p-value) of 0.925. Another sample of boards was measured for MC after 9 months of storage. With these boards, the initial and final MC averages were 9.37 and 8.71 percent, respectively. A paired t-test of the difference in these boards' MC values produced a significance level of 0.049. This result shows a 0.7 percent drop in MC that occurred over the 9-month storage period was statistically significant. These

Table 2. — Mean, median, and variation of warp by type for the 8-foot-long lumber. All values are in inches. The values in parentheses are t-test results (p-values) for restraint versus control, 0.05 level considered statistically significant.

		Restrained	Control
		(in)	
Crook	Mean	0.069	0.122 (0.05)
	Median	0	0
	SD	0.151	0.212
Bow	Mean	0.318	0.331 (0.80)
	Median	0.250	0.281
	SD	0.332	0.341
Twist	Mean	0.227	0.261 (0.40)
	Median	0.156	0.250
	SD	0.289	0.266

Table 3. — Mean, median, and variation of warp by type for the 16-foot-long lumber. Values in parentheses are t-test results (p-values) for restraint (directly from kiln) versus control, 0.05 level considered statistically significant.

		Restrained (directly from kiln)	Restrained (after one month)	Restrained (after nine months)	Control (directly from kiln)
			(in)		
Crook	Mean	0.33	0.31	0.29	0.61 (0.00)
	Median	0.25	0.25	0.31	0.40
	SD[a]	0.26	0.28	0.29	0.58
Bow	Mean	0.24	0.32	0.05	0.78 (0.00)
	Median	0.14	0.25	0.00	0.67
	SD	0.35	0.37	0.10	0.69
Twist	Mean	0.14	0.23	0.14	0.51 (0.00)
	Median	0.00	0.14	0.00	0.48
	SD	0.21	0.29	0.23	0.40

[a]SD = standard deviation.

Table 4. — Percent of lumber in each grade.

Length	Grade	Restrained (directly from kiln)	Restrained (after one month)	Restrained (after nine months)	Control (directly from kiln)
			(%)		
8-foot	No. 1	62.2	NA[a]	NA	50.0
	No. 2	13.3	NA	NA	27.1
	No. 3	13.3	NA	NA	12.5
	Reject	11.1	NA	NA	10.4
16-foot	No. 1	93.8	94.5	93.7	69.6
	No. 2	3.6	1.8	3.2	16.1
	No. 3	2.7	3.6	3.2	8.9
	Reject	0.9	0.0	0	5.4

[a]NA = not applicable.

Figure 4. — Photograph of nonrestrained control (left) and restrained (right) lumber packages shortly after removal from the kiln and the restraint device.

results suggest that the final MC of the lumber was close to what would be encountered in use.

Next, the boards were graded, based on warp, as No.1, No. 2, No. 3, or reject. **Table 4** illustrates the lumber grade distributions for the control and restrained packages. For the 8-foot length, the restraint treatment increased No. 1 grade from 50.0 to 62.2 percent. For the 16-foot length, the restraint treatment increased No. 1 grade from 69.6 to 93.8 percent vs. control. No. 2 and better increased from 85.7 to 97.4 percent. This high proportion of No. 2 and better remained after 1 and 9 months of storage. In those cases, the percentages of No. 2 and better were 96.3 and 96.9, respectively. No compression wood in damaging form was detected.

These results indicate that the restraint system is highly effective at reducing crook, bow, and twist in kiln-dried lumber, especially for longer lumber lengths (**Fig. 4**). It is entirely possible to dry SYP 2 by 4 lumber to MC values consistent with interior equilibrium MC conditions. These results along with the results that indicate little change in warp after uncontrolled storage indicate that lumber dried under restraint will remain stable and straight in service. It is estimated that value increases on the order of $10 per MBF are possible for lumber dried in the restraint device, even after long-term uncontrolled lumber storage.

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