Dimensional stabilization of pine four-by-fours via restraint drying

Rubin Shmulsky*

Abstract

Four-by-four inch southern yellow pine lumber was dried, pressure treated, and kiln-dried after treatment to assess the effects of restraint drying on warp. Results showed a statistically significant reduction in average warp as crook and twist for the restraint-dried material. Lumber grade mix, based on warp criteria, was higher for the restraint-dried material following both initial kiln-drying and kiln-drying after treatment.

As part of an ongoing program aimed at improving lumber value retention through the processing chain a system of restraint drying is being developed. The pilot-scale restraint device utilizes edgewise restraint pressure to hold each course of lumber together as a rigid slab during drying. Previous related experimental research has shown significant results with respect to warp reduction, especially as crook and twist, in 2 by 4 dimension lumber both in the laboratory and at a commercial facility. A cross-sectional schematic of the restraint device is shown in **Figure 1**.

Four- by four- (4×4) inch pine lumber is widely produced and pressure treated with waterborne preservatives. Much of this lumber production is realized by processing small-diameter plantation wood through chipping canters. Virtually all of the resultant lumber contains boxed heart and a large proportion of juvenile wood. As such, its propensity for warp is high. All forms of warp can cause loss in lumber value, however the allowances for crook are often the most stringent. Because 4×4 lumber is square in section, the stringent crook rules apply to two axes, there is no stipulation for bow. Therefore it is challenging to overcome warp and maintain a high grade mix with 4×4 lumber. The cooperating mill in this study suggested that their economic loss associated with grade loss, from No. 2 & Better grade to No. 3 & Lower grade, is at least $125 ($U.S.) per thousand board feet (MBF). Thus there is a pressing financial need to maintain lumber straightness throughout drying, especially with respect to crook and twist reduction.

Objective statement

The objective of this study was to evaluate a system of restraint-drying as a means of reducing warp and improving grade in 12-foot long, 4×4 southern yellow pine (SYP) lumber.

Procedure

A cooperating southern pine mill was selected as a lumber source. The mill runs two chipping canter stations. The mill produces thick dimension and timbers, 4- by 4-inch through 12- by 12-inch size. The 4×4s are all produced from small-diameter logs. Each debarked log is processed to yield pulp chips and a single piece of lumber (thick dimension or timber) from the heart. This particular mill was selected because in addition to primary conversion, they also run a dry kiln, planer mill, and waterborne preservative pressure treating facility. This combination of operations was necessary for this study.

A total of 112 rough green 4×4s were taken from the green end of the mill to the Forest Products Laboratory (FPL) at Mississippi State University. The wood was divided into two matched packages, one for restraint drying, one for non-restrained drying. Each course contained eight pieces and each package contained seven courses. Thus each package contained 56 pieces, 896 board feet.

The edge restraint procedure employed focused on diminishing or possibly eliminating the cause and effect relationship between moisture content (MC) and warp. Edgewise restraint pressure was exerted on the lumber package such that each of the individual pieces in each course were driven tightly together into a rigid slab (**Fig. 2**). It was anticipated that this edge pressure would reduce warp, especially as crook. The restraint device was affixed to one of the two lumber packages. The device used a series of five vertically oriented bars and pneumatic cylinders as a means of applying edge pressure to the restraint lumber package. As the lumber shrinks during drying, the cylinder pistons expand and thus maintain constant pressure throughout. The five bars were evenly spaced at approximately 3-foot intervals along the 12-foot-long lumber package. Pneumatic gauge pressure on the cylinders was approximately 105 psi. This pressure level provided a maximum wood-to-steel contact pressure of approximately 52 psi, based on the restraint device parameters. This

The author is an Associate Professor, Forest Products Dept., Mississippi State Univ., MS State, MS (rshmulsky@cfr.msstate.edu).
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*Forest Products Society Member.

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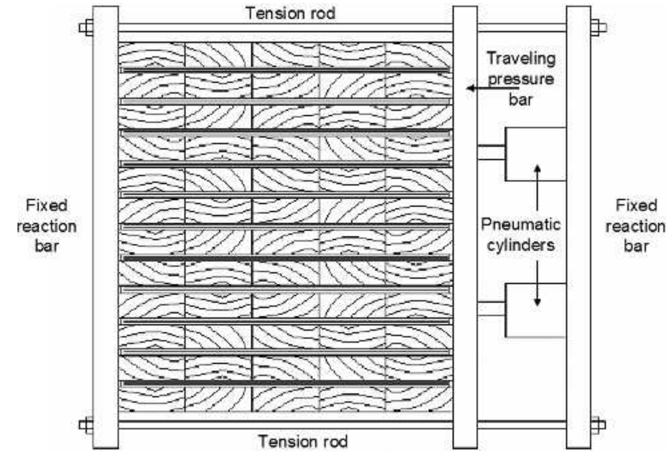

Figure 1. — Schematic of the restraint device fixed on a package of stickered lumber.

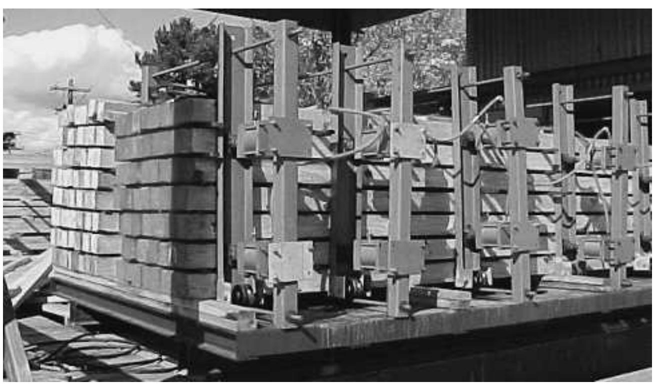

Figure 2. — Photograph of the two matched lumber packages immediately following initial kiln-drying. The depressurized restraint device is still attached to the right-hand package.

contact pressure value is under the perpendicular-to-grain 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 seven-course tall, 12-foot-long package was approximately 20,600 pounds. Each individual course, and thus each individual 4×4, received approximately 2,950 pounds of edgewise restraint force. This force level was sufficient to overcome inherent friction forces and squeeze each course of green lumber edge-to-edge into a rigid slab for drying, to hold them fast throughout drying, but not so high as to cause edge damage by crushing. The two lumber packages were then kiln-dried side-by-side at 235°F dry bulb, 175°F wet bulb for 25 hours. Airflow through the stacks was approximately 1,100 feet per minute. After 25 hours in the kiln, the restraint pressure was relieved, the tram was rolled out, and the lumber cooled. Thus the lumber was not under active restraint pressure during cool down.

To assess MC, the lumber was measured with a capacitance-type meter that was calibrated for SYP. The lumber was also measured for warp. To that end, dry pieces were measured for maximum crook and twist on a flat and true warp table. 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 via insertion of a calibrated 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. After initial kiln-drying and measurement, the lumber was returned to the mill for planing, grading, and pressure treating.

Table 1. — Average and standard deviation results for MC, crook, and twist. Within each column, T-groupings for means with the same letter are not statistically different at the α = 0.05 level.

	MC	Crook	Twist
	(%)	(in)	
KD, no restraint	10.5 (3.4)[a] A	0.336 (0.257) A	0.320 (0.302) A
KD restraint	18.2 (4.5) B	0.137 (0.141) B	0.039 (0.090) B
KDAT no restraint	14.1 (3.4) C	0.328 (0.271) A	0.026 (0.075) B
KDAT restraint	16.3 (2.4) D	0.118 (0.167) B	0.015 (0.046) B

[a]Values in parentheses are standard deviations.

Once treated with chromated copper arsenate to 0.60 pcf retention, the lumber was brought back to the FPL. The lumber was again split into two matched packages: one for restrained drying one for non-restrained drying. In this case, each package contained approximately half from the package that was initially restraint dried and half from the package that was initially kiln-dried without restraint. In this manner, following kiln-drying (KD), restraint and control lumber were evenly divided during kiln-drying after treatment (KDAT). Ultimately four treatment combinations and 3,584 board feet of lumber were evaluated.

Results

After initial KD and KDAT, the lumber was measured for MC and warp. MC results by treatment are shown in **Table 1**. Average MC values ranged from 10.5 to 18.2 percent. Analysis of variance indicated that average MC values among the four different treatment combinations were statistically different, p-value = 0.0001. The restrained package likely ended with higher MC because the individual pieces were forced tightly edge to edge, which prevents edge drying and because the restraint device partially blocked some airflow through the package. In each case, two packages were dried together, therefore it was not possible to bring these values closer together without the use of an equalization period and that was deemed commercially unfeasible.

Warp results for crook and twist are also provided (**Table 1**). With respect to crook, restraint dried lumber was straighter than non-restrained control lumber, after both initial KD and KDAT. This difference was statistically significant, p-value = 0.0001. With respect to twist, restraint-dried lumber was straighter than non-restraint control lumber after KD. This difference was statistically significant, p-value = 0.0001. There was no significant difference in twist as measured in KDAT lumber. Also, the twist noted in KDAT lumber was not significantly different that in KD restraint lumber.

Lumber was also graded as No. 1, 2, 3, or reject based on its straightness characteristics. Grade mix distributions as mea-

Table 2. — Distribution (as %) of pieces in each grade. Grading at the laboratory included only warp characteristics. Grading at the mill included all characteristics.

	No. 1	No. 2	No. 3	Reject
	------------- (%) -------------			
KD restraint (rough dry)	100	0	0	0
KDAT restraint	96.4	1.8	1.8	0
KD restraint (dressed dry, at mill)	89.3	0	10.7	0
KDAT no restraint	85.7	1.8	8.9	3.6
KD no restraint (rough dry)	60.7	19.6	16.1	3.6
KD no restraint (dressed dry, at mill)	46.4	41.1	12.5	0

sured after initial KD, after planing (as graded at the mill), and after KDAT are provided (**Table 2**).

Figure 3. — Photograph of the two matched lumber packages immediately following initial kiln-drying. With the restraint device removed, pieces in the right-hand package appear less warped.

Discussion

Cursory visual observation of the lumber immediately after drying suggested that the restraint dried materials were significantly straighter than the unrestrained controls (**Fig. 3**). This observation was supported by the lumber measurements. For the KD and KDAT lumber, the restraint system reduced average crook by approximately 59 and 64 percent, respectively. Also for the KD and KDAT, the restraint system reduced average twist by approximately 77 and 42 percent, respectively. It is acknowledged that differences in mean MC among the kiln lumber packages likely contribute to the observed differences in lumber straightness.

Previous research has shown that the restraint-dried material is highly dimensionally stable over time and thus the results detailed herein are deemed meaningful.[1]

The lumber straightness improvement directly translated into improvements in grade retention as shown in **Table 2**. This observation indicates that warp is a major causal factor with respect to grade loss in 4×4 lumber and that restraint kiln-drying from green and restraint kiln-drying after treatment are highly effective at reducing warp-associated degrade.

As an approximate measure of value increase, it was assumed that the monetary difference between No. 2 & Better grade and No. 3 & Lower grade is $125 per MBF. Immediately after KD, after planing, and following KDAT, the restraint-dried lumber yielded 14, 2, and 11 percent more No. 2 & Better grade, respectively. Additionally, when graded at the mill, the restraint-dried material yielded 89 percent No. 1 grade, whereas the unrestrained controls yielded only 46 percent No. 1 grade.

It is important to note that following drying, the lumber was cooled without any restraint pressure. The restraint pressure was released immediately after drying. This fact suggests that the restraint technology could be incorporated into a commercial operation with relative ease because the restraint pressure does not need to be maintained in the cooling and rough dry storage sheds.

Future directions for this research program include: restraint drying of 5/4 by 6-inch decking material intended for preservative treatment, restraint KDAT for the same, and further development of a commercially viable prototype restraint system.

[1] Shmulsky, R., R.W. Erickson, P.H. Steele, and D.L. Buckner. 2005. Warp reduction of SYP lumber by restrained drying. Forest Prod. J. 55(9):37-41.