Effect of press-drying on static bending properties of plantation-grown No. 2 loblolly pine lumber

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Abstract

The purpose of this study was to determine the effects of two press-drying treatments on the static bending properties of plantation-grown, No. 2 grade, 2 by 4 loblolly pine lumber. Specimens were divided into groups containing primarily juvenile wood or primarily mature wood. The groups were subjected to three drying method-temperature/pressure combinations: (1) kiln-drying at 116 °C (240 °F), (2) press-drying at 172 or 345 kPa (25 or 50 psi), and (3) press-drying at 177 or 210 °C (350 or 410 °F). Modulus of rupture (MOR), modulus of elasticity (MOE), work to maximum load (WML), and specific gravity (SG) were determined. The results showed no change in SG in relationship to press-dry treatment and no practical differences in both MOE and MOR between press-dried and kiln-dried specimens. The only significant change was a decrease in work to maximum load with press-drying at 345 kPa and 210 °C (50 psi and 410 °F), which was detectable only in the higher quality pieces. The results suggest that loblolly pine properties are far more affected by the presence of juvenile wood and the inherent defects associated with the No. 2 grade than by press-dry treatment. Further work is needed to determine the influence of press-drying on the SG of full-size lumber. We expect that any effects will be most noticeable in higher quality pieces.

Compared to high-temperature kiln-drying, press-drying is an effective way to reduce warp and grade loss from warp in plantation-grown loblolly pine lumber (Simpson et al. 1992). Fast-grown plantation trees contain a high percentage of juvenile wood. The lumber from such trees therefore tends to have lower specific gravity (SG), lower elastic and strength properties, and higher longitudinal shrinkage. Press-drying may minimize warp in fast-grown plantation lumber. In addition, press-drying may increase elastic and strength properties by increasing lumber density and controlling temperature degrade.

The purpose of our study was to determine the effects of press-drying on the elastic and strength properties of plantation-grown, No. 2 grade, 2 by 4 loblolly pine lumber.[1]

Background

Press-drying is a process in which two heated platens are used to remove moisture from a board. The pressure applied is usually 172 to 517 kPa (25 to 75 psi), and the drying temperature generally ranges from 121 to 232 °C (250 to 450 °F) (Hittemeier et al. 1968). The combination of heat and pressure not only serves to dry the wood faster than conventional kiln-drying methods on a piece-by-piece basis but can also alter engineering properties.

The two mechanisms that could change the bending properties of lumber are an increase in density and thermal degradation (Hittemeier et al. 1968, Tang and Simpson 1989). For small, clear specimens, an increase in density normally

[1] 2 by 4 refers to nominal 2- by 4-in (38- by 89-mm) lumber.

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Forest Prod. J. 57(11):70-73.

corresponds to an increase in bending properties, whereas thermal degradation results in a decrease in bending properties. Studies show that the balance between the two mechanisms may he tipped one way or the other depending on the species and the condition of the wood before drying (McLean 1955, Chen 1978, Tang and Simpson 1989).

For example, refractory hardwoods such as white oak, post oak, and hickory cannot he dried too aggressively because they are prone to checking, collapse, and honeycomb (Chen 1978). Since moisture cannot move quickly out of refractory hardwoods, severe moisture gradients occur, resulting in drying stresses. Alternatively, woods that are more permeable allow moisture to escape and are not as prone to checking, collapse, and honeycomb (Simpson et al. 1988). It has also been demonstrated that some woods densify more when press-dried from a saturated state as opposed to being dried from 28 percent to 30 percent MC (McLean 1955, Tang and Simpson 1989).

Milota and others (1995) found mature wood to be more permeable than juvenile wood in plantation loblolly pine. However, Tang and Simpson (1989) showed that because of its overall high permeability, plantation loblolly pine responds positively to press-drying. In the Tang and Simpson work, the 2 by 4 loblolly pine was dried in three ways: (1) press-dried at 172 kPa and 177 °C (25 psi and 350 °F) for 90 minutes, (2) press-dried at 345 kPa and 177 °C (50 psi and 350 °F) for 90 minutes, and 3) kiln-dried at 116 °C (240 °F) for 18 hours Small, clear specimens were cut from the dried lumber and tested according to ASTM Standard D 143–72 (ASTM 1974). For specimens press-dried at 172 kPa (25 psi), SG increased 7.0 percent, modulus of rupture (MOR) increased 12.8 percent, and modulus of elasticity (MOE) increased 18.6 percent compared to those properties of kiln-dried samples; for specimens press-dried at 345 kPa (50 psi), SG increascd 10.3 percent, MOR 14.7 percent, and MOE 23.9 percent. The differences in response for press-drying at 172 and 345 kPa (25 and 50 psi) were not statistically significant.

Experimental

Test material and specimen preparation

A total of 120 loblolly pine trees were harvested from a 25-year-old plantation in North Carolina. Two logs were sawn from each tree, resulting in a total of 600 pieces of 2.4-m-(8-ft-) long, 2 by 4 lumber. The lumber was visually graded by an inspector of the southern pine Inspection Bureau according to the National Grading Rule (SPIB 1977).

The logs were first sawn into a diametrical plank from which adjacent pieces of 2 by 4 lumber were sawn (**Fig. 1**). Pieces sawn from the left of the pith (looking toward the top of the log) were labeled 1 L, 2 L, and 3 L from pith to bark; similarly, pieces sawn from the right of the pith were labeled 1R, 2R, and 3R from pith to bark. If the cants were large enough, additional lumber was cut (**Fig. 1**, pieces 2 A, 3 A, 2 B, 3 B). Most logs were not large enough to yield additional lumber.

This sawing pattern resulted in two groups of lumber primarily consisting of juvenile wood (groups 1 L and 1R); the remaining groups primarily consisted of mature wood. Specimens were labeled by tree number, position of log in the tree (top or butt), and position of piece in the plank (e.g., 1 L). Ring counts were not taken.

Testing

Full-length MOE was measured nondestructively by transverse vibration before drying to achieve even MOE

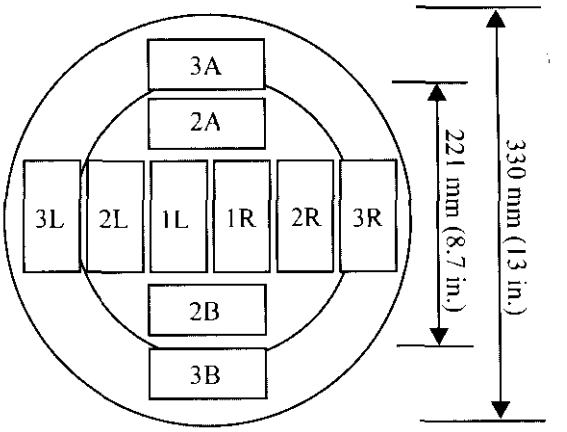

Figure 1. — Sawing pattern used to produce inner boards (1 L and 1R) and outer boards (all other designations).

Table 1. — Allocation of groups to treatments.

Board type[a]	Group	Platen pressure	Platen temperature
		(kPa (psi))	(°C (°F))
Outer	1	345 (50)	177 (350)
	2	([b])	kiln-dry
	3	172 (25)	177(350)
	4	345 (50)	210 (410)
	5	172 (25)	210 (410)
Inner	6	345 (50)	210 (410)
	7	172 (25)	210 (410)
	8	172 (25)	177 (350)
	9	([b])	kiln-dry
	10	345 (50)	177 (350)

[a]Outer, boards sawn from region away from the pith; inner, boards sawn from region closer to pith.
[b]Kiln temperatures: 116 °C (240 °F) dry-bulb, 82 °C (180 °F) wet-bulb.

distribution among treatment groups. The 600 pieces of lumber were divided into 10 treatment groups of 60 pieces each. The groups were labeled serially 1 through 10. Groups 1 through 5 comprised pieces from the outer regions of the plank, which contained primarily mature wood. Groups 6 through 10 were taken from the inner regions, which contained primarily juvenile wood.

Each group was further subdivided into 5 replicates of 12 pieces each. The boards in each replicate were selected to have as similar a distribution of MOE as possible, which meant that the groups did not have an equal number of specimens from top and butt logs.

The groups were randomly allocated to treatments, as shown in **Table 1.** The control groups (groups 2 and 9) were subjected to kiln-drying at 116 °C (240 °F) dry-bulb temperature. All other groups were subjected to press-drying treatment at two combinations of platen pressure and temperature: 172 or 345 kPa (25 or 50 psi) and 177 or 210 °C (350 or 410 °F). Specimens were press-dried for 195 minutes at 177 °C (350 °F) and 155 minutes at 210 °C (410 °F) (SD of 26 and 15 minutes, respectively) to 15 percent MC (Simpson et al. 1992). Specimens were then block stacked and stored indoors without temperature or humidity control until time of testing.

Static bending testing was conducted in accordance with standard procedures (ASTM 1992). Specimens were subjected to third-point loading over a span of 1.5 m (5 ft) (17:1

Table 2. — Strength properties of inner and outer boards.[a]

			Strength property at various percentiles									
			MOE			MOR			WML			
Group	Pressure	Temp.	fifth	50th	95th	fifth	50th	95th	fifth	50th	95th	SG
	kPa (psi)	°C (°F)	(GPa (10^6 psi))			(MPa (10^3 in^2))			(kJ/m^3 (in-lbf/in^3))			
Outer boards												
1	345 (50)	177 (350)	4.41 (0.64)	8.69 (1.26)	12.5 (1.82)	14.5 (2.10)	32.0 (4.64)	74.9 (10.86)	6.41 (0.93)	17.7 (2.56)	79.3 (11.50)	0.50 (12.2)
2	Kiln-dry	116 (240)	4.69 (0.68)	8.27 (1.20)	13.4 (1.94)	15.9 (2.30)	30.8 (4.46)	68.7 (9.96)	4.34 (0.63)	18.4 (2.67)	72.6 (10.53)	0.51 (9.6)
3	172 (25)	177 (350)	4.34 (0.63)	7.93 (1.15)	12.1 (1.76)	17.4 (2.52)	31.6 (4.59)	61.6 (8.93)	7.72 (1.12)	22.3 (3.23)	64.3 (9.33)	0.50 (10.0)
4	345 (50)	210 (410)	4.69 (0.68)	8.48 (1.23)	13.0 (1.88)	17.6 (2.55)	29.9 (4.33)	62.4 (9.05)	4.83 (0.70)	18.1 (2.62)	43.6 (6.33)	0.51 (8.4)
5	172 (25)	210 (410)	4.62 (0.67)	8.83 (1.28)	12.7 (1.84)	17.7 (2.56)	29.2 (4.23)	76.8 (11.14)	4.41 (0.64)	14.6 (2.12)	72.7 (10.54)	0.50 (9.3)
Average			4.55 (0.66)	8.41 (1.22)	12.8 (1.85)	16.6 (2.41)	30.7 (4.45)	68.9 (9.99)	5.52 (0.80)	18.2 (2.64)	66.5 (9.64)	0.50 (9.9)
Inner boards												
6	345 (50)	210 (410)	3.72 (0.54)	6.27 (0.91)	10.5 (1.52)	15.1 (2.19)	25.6 (3.72)	43.4 (6.30)	4.83 (0.70)	11.3 (1.64)	23.2 (3.36)	0.46 (7.9)
7	172 (25)	210 (410)	3.31 (0.48)	6.07 (0.88)	10.2 (1.48)	19.0 (2.75)	29.2 (4.23)	46.7 (6.78)	5.38 (0.78)	17.5 (2.54)	41.4 (6.01)	0.45 (8.9)
8	172 (25)	177 (350)	3.59 (0.52)	6.34 (0.92)	9.58 (1.39)	16.8 (2.44)	28.1 (4.08)	48.7 (7.06)	6.07 (0.88)	14.1 (2.04)	43.4 (6.30)	0.45 (10.3)
9	Kiln-dry	116 (240)	3.72 (0.54)	6.00 (0.87)	9.65 (1.40)	17.0 (2.46)	27.9 (4.04)	43.3 (6.28)	6.34 (0.92)	15.2 (2.21)	45.3 (6.57)	0.46 (14.3)
10	345 (50)	177 (350)	3.72 (0.54)	6.27 (0.91)	0.93 (1.44)	15.7 (2.28)	27.8 (4.03)	44.5 (6.45)	5.24 (0.76)	14.3 (2.07)	42.7 (6.19)	0.46 (10.6)
Average			3.59 (0.52)	6.21 (0.90)	9.93 (1.44)	16.7 (2.42)	27.7 (4.02)	45.3 (6.57)	5.58 (0.81)	14.5 (2.10)	39.2 (5.69)	0.46 (10.4)

[a]Results of static bending tests. Because mean values were not fully descriptive of the results, the fifth and 95th percentile values are included. Groups 1 to 5 primarily contained mature wood; groups 6 to 10 primarily contained juvenile wood. Values are averages. Values in parentheses are COV (%).

span:depth ratio). The worst apparent defect was placed in the tension zone. The ultimate load was recorded.

After failure, samples were obtained from an intact area as close to the failure zone as possible. SG and MC were determined from these samples. Before analysis, the data were corrected to 12 percent MC using the quadratic surface model (Green and Evans 1992). MC was adjusted to 12 percent because this value was closest to the average actual MC of the specimens.

Results and discussion

Table 2 shows the average results of all measurements for each test group. Any differences between repetitions within each group were deemed insignificant.

In general, there were no practical differences between the median values of both elastic and strength properties of any mature wood groups (groups 1 to 5) or juvenile wood groups (groups 6 to 10) (**Figs. 2** to **4**). However, practical differences were apparent between juvenile and mature wood groups in some instances. For example, a noticeable difference in MOE occurred at the fifth percentile, and noticeable differences in both MOE and MOR occurred above the 50th percentile.

Modulus of elasticity

As **Figure 2** shows, the press-drying treatments in this study neither significantly raised nor lowered MOE. The relationship ofkiln-dry treatment to MOE varied with different percentile levels, sometimes appearing lower or higher than the relationship of the press-drying treatments to MOE. This variation may have been the result of the unequal number of top-of-log and butt specimens within each repetition, which may have skewed some data distributions and consequently skewed the comparison of the percentile values. Overall. the primary difference in the data set occurred not in the comparison of drying treatments hut in the comparison ofjuvenile and mature wood groups.

Modulus of rupture

Modulus of rupture was not significantly affected by the treatments. Up to the 40th percentile level, there was no practical difference between any groups (**Fig. 3**). Similar to the

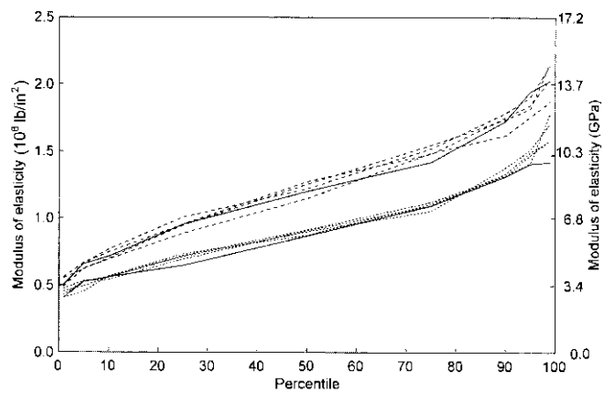

Figure 2. — Modulus of elasticity of all treatment groups by percentile. Solid lines indicate kiln-dried specimens. Dashed lines represent press-dried specimen groups 1, 3, 4, and 5, and dotted lines represent press-dried groups 6, 7, 8, and 10. Groups with higher MOE values consisted primarily of mature wood.

data for MOE, the MOR data may have been slightly skewed because of the unequal proportions of top and butt specimens in each repetition. Therefore, though it appears that the upper percentile of the mature groups showed a specific relationship to the kiln-dry treatment, there was really no relationship since the higher two groups were opposite in both temperature and pressure treatment.

Though the differences between treatments were not significant, the differences between juvenile and mature groups were significant. These groups began to diverge between the 40th and 50th percentiles and became significantly different with increase in wood quality.

Work to maximum load

Work to maximum load (WML) ofthe higher quality specimens was affected by the treatments. Below the 40th percentile, there was no practical difference between any groups

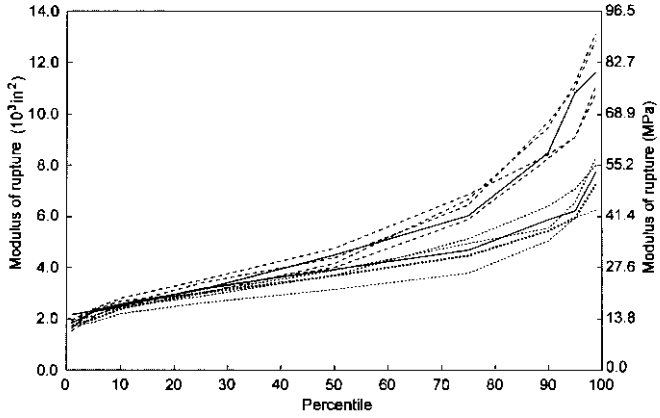

Figure 3. — Modulus of rupture of all treatment groups by percentile. Groups with higher MOR values consisted primarily of mature wood. See legend to Figure 2 for designation of treatment groups.

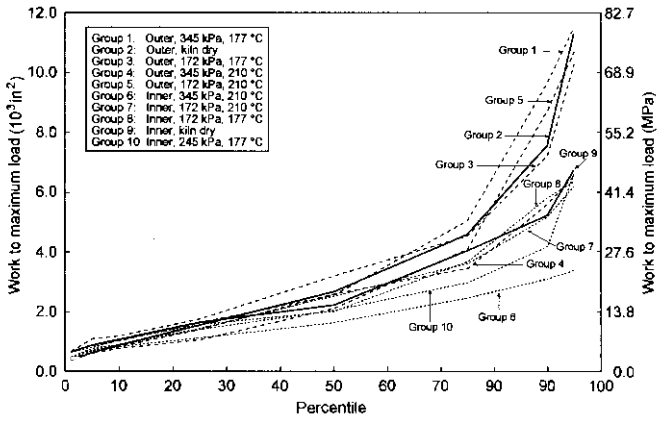

Figure 4. — Work to maximum load of all treatment groups by percentile. See legend to Figure 2 for designation of treatment groups.

(**Fig. 4**). Similar to MOE and MOR, the WML data may have been slightly skewed because of the unequal proportions of top and butt specimens in each repetition. Nevertheless, it appears that for both the mature and juvenile groups, the press-dry treatment of 344 kPa and 232 °C (50 psi and 410 °F) significantly lowered the WML of the higher quality specimens (>70th percentile).

Specific gravity

The results for SG between the kiln-dried and press-dried groups are given in **Table 2.** As expected, the SG values for the outer boards were considerably higher than those for the juvenile wood inner boards, with average values of 0.504 and 0.456, respectively. Mean SG of the kiln-dried lumber was 0.488, with a COV of 12.7 percent. Mean SG of the press-dried lumber for all groups was 0.478, with a COV of 10.8 percent. Groups subjected to the 172-kPa (25-lb/in^2) treatment were not detectably different from groups subjected to the 345-kPa (50-lb/in^2) treatment, regardless of whether they consisted of inner or outer material.

Conclusions

This study demonstrates that press-drying does not necessarily improve the stiffness and strength properties of plantation-grown, No. 2 grade, 2 by 4 loblolly pine lumber. The SG of the specimens was not significantly increased by the press-drying process used. Although press-drying did not improve properties, neither did it result in substantial degradation. MOE and MOR were generally unaffected by the press-drying treatments when compared with that of the kiln-dried specimens. However, a marked decrease in WML occurred in the upper percentile of specimens subjected to the 345-kPa, 210 °C (50-lb/in^2, 410 °F) press-drying treatment.

Factors such as the presence of juvenile wood and inherent defects outweighed the influence of the treatments. Inherent defects such as knots and slope-of-grain were more prevalent in the lower quality pieces, represented by the lower percentile values. The higher quality specimens were most affected by either the presence of juvenile wood or the treatment. Therefore, if an increase in SG could be obtained, we expect that the effects would occur in the higher quality specimens and would be unnoticeable at the lower percentiles.

Allowable properties for MOR and MOE were unaffected by the treatments. The allowable property for MOR is dependent on the fifth percentile. Since there was clearly no significant difference in treatment at this level, there is no need for adjustment due to treatment. MOE is dependent on the 50th percentile. At this level, our results show a very significant difference in MOE resulting from the presence of juvenile wood. However, the effects of juvenile wood on allowable properties were not within the scope of this study.

The results reported here are not limited to the pressures and temperatures tested. Further study is warranted on the effects of an increase in SG on the properties of plantation-grown, full-size structural lumber.

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