Bending strength of press-dried plantation loblolly pine

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Abstract

The bending strength and stiffness properties of plantation loblolly pine clear wood specimens press-dried at 350°F for 90 minutes were compared to those of specimens kiln-dried at 240°F for 18 hours. Specific gravity (SG), modulus of rupture, and modulus of elasticity increased 7.0, 12.9, and 19.0 percent, respectively, in lumber press-dried at 25 psi; and 10.3, 14.7, and 24.0 percent, respectively, in lumber press-dried at 50 psi. However, gamma radiation density gradient tests showed no significant difference in SG through the thickness of the press-dried lumber or between press-dried and air-dried lumber, probably because of the large variation in SG between early-wood and latewood.

Wood from fast-grown plantation trees is characterized as having more longitudinal shrinkage, lower specific gravity (SG), and lower strength properties than naturally grown trees (2). In a recent study (11), press-drying significantly reduced the warp of plantation loblolly pine lumber compared to kiln-drying and also reduced the drying time of2 by 4 lumber to less than 2 hours. Because wood is exposed to high temperature during press-drying, the effect of press-drying on the strength of wood is of concern. The study reported here was designed to investigate the effect of temperature and pressure employed in press-drying on bending strength and stiffness properties of clear wood cut from loblolly pine lumber that had been press-dried.

We expected that the high temperature applied at high moisture contents (MC) during press-drying might reduce the bending properties of the wood because of thermal degradation. On the other hand, the pressure applied during press-drying might increase the density of the wood, resulting in an increase in bending properties. MacLean (7) investigated the effect of hot-pressing on wood strength properties of Douglas-fir, Sitka spruce, yellow birch, yellow-poplar, and white oak at 250°F to 350°F for 0.5 to 32 hours at a pressure of 25 psi. The specimens used for hot-pressing and strength tests were about 0.15 to 0.17 inches thick, 2.0 to 2.1 inches wide, and 12.5 to 13 inches long. The results showed that bending strength properties tend to be reduced as temperature and time increase. However, the percentage of strength loss was often small, and in some cases, the modulus of elasticity (MOE) and modulus of rupture (MOR) values were even somewhat higher than those of the control specimens because of densification (caused by pressure) and collapse (caused by drying). Koch (5) showed that press-drying at 300°F and 83 psi did not significantly affect the MOR and MOE of beams made of thick southern pine veneer. However, significant densification accompanied by significantly increased thickness shrinkage was observed. An investigation of nine hardwood species (4) indicated that toughness, hardness, and abrasion resistance of 3/8-inch-thick boards press-dried at 345°F and 50 psi were essentially equal to the strength values of matched kiln-dried specimens if the press-dried specimens did not have severe honeycomb and surface checking.

Material and methods

Preparation for drying

Freshly sawn, 8-foot-long, nominal 2- by 4-inch flat-sawn lumber was obtained from a 35-year-old loblolly pine plantation in Arkansas. Each 2 by 4 was cut into three 32-inch-long boards, then surfaced to 1.60 inch thick. The dimensions of boards for press-drying were 1.60 by 3.75 by 32 inches. The boards were numbered in order of cut and were end-coated twice with heavily pigmented aluminum paint to reduce end drying and checking. Boards

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were randomly assigned to 10 different drying groups of 9 boards each. Five groups were randomly assigned to each press-drying condition - 25 or 50 psi pressure at 350°F platen temperature for 90 minutes. According to previous experience (10,11), boards dry from green MC to about 15 percent final MC at each of these press-drying conditions. Press-drying was done in a single-opening, 3- by 3-foot press.

Thirty-two pieces of the 8-foot-long 2 by 4 lumber were randomly selected and kiln-dried from green MC to about 15 percent final MC at a dry-bulb temperature of 240°F for 18 hours. Kiln-dried boards were used as controls to be compared with press-dried boards for bending strength properties.

Preparation for bending tests

After drying, both press-dried and kiln-dried boards were placed in a conditioning room (80°F, 65% relative humidity (RH)) for about 1 month to equilibrate to approximately 12 percent MC. Specimens for bending tests were cut from press-dried and kiln-dried boards and were free from pith, knots, and checks.

We expected the boards might be densified during press-drying and also that a density gradient might occur - that is, more densification near the surfaces in contact with the platens than at the center of the boards. Because we did not know the extent or nature of the densification, we decided that we would not change the densification response by thickness surfacing. Thus, the specimens were machined not to thickness but to width (1.50 in.), and they were cut to 23 inches long. Bending-test specimens from kiln-dried boards were machined to 1.50 inches thick and 1.50 inches wide, and cut to 23 inches long.

All specimens were conditioned at a dry-bulb temperature of 80°F and 65 percent RH for another month before the bending tests. Static bending-test procedures followed the guidelines of ASTM Standard D 143-72 (1). Specimens from press-dried boards were placed and loaded as shown in Figure 1, so that the force was applied perpendicular to the surfaces that were in contact with the platens during press-drying. The bending force was applied perpendicular to the growth rings of both press- and kiln-dried specimens. Speed of testing was 0.03 in./min. and the loading span was 22 inches. MC and SG of each specimen were determined after failure.

SG profile testing

To evaluate the density profile created by press-drying, a gamma radiation density gradient instrument was used to measure SG distribution through the thickness of both press- and kiln-dried boards. Specimens (1.50 by 2.0 by 3.8 in.) for comparative study were cut as shown in Figure 2 to eliminate the variation between boards. Laufenberg (6) showed that the measurement error of this method is less than 1 percent for reconstituted wood products.

Results and discussion

The results of the SG and bending tests are shown in Table 1. More than one bending specimen was taken from some boards; thus, Table 1 shows more than 45 replicates per group. Compared with kiln-drying, SG increased 7.0 percent for the specimens press-dried at 25 psi and 10.3 percent for the specimens press-dried at 50 psi. The MOR increased 12.9 percent at 25 psi and 14.7 percent at 50 psi, and MOE increased 19.0 percent at 25 psi and 24.0 percent at 50 psi. In all cases, the increase in SG, MOR, and MOE that resulted from press-drying was statistically significant at the 95 percent confidence level. However, the difference in response between specimens dried at 25 and 50 psi was not statistically significant.

Load-carrying capacity and stiffness in bending can be calculated by the following formulas:

$$\text{Load-carrying capacity} = \text{MOR}\ \frac{\text{width} \times \text{depth}^2}{6}$$

$$\text{Stiffness} = \text{MOE}\ \frac{\text{width} \times \text{depth}^3}{12}$$

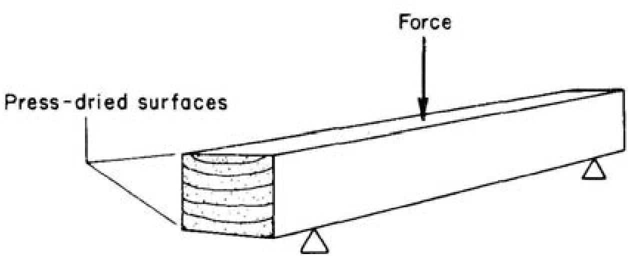

Figure 1. - Test for bending strength with force perpendicular to press-dried surfaces of specimen.

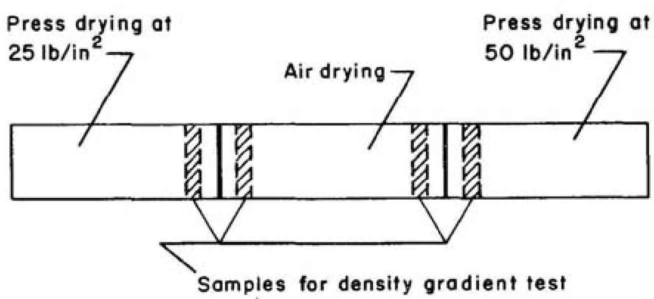

Figure 2. - Method of cutting density gradient samples for the comparative test.

TABLE 1. — *Bending strength properties of kiln-dried and press-dried loblolly pine lumber.*

Drying treatment	No. of specimens	MC Mean	MC SD[a]	SG Mean	SG SD	MOR Mean	MOR SD	MOE Mean	MOE SD
		(%)				(psi)		(×10³ psi)	
Kiln-drying	50	11.6	0.685	0.400	0.0339	9,180	1,250	1,130	222
Press-drying 25 psi	51	11.0	0.892	0.428	0.0297	10,360	1,580	1,340	224
Press-drying 50 psi	53	11.5	0.651	0.441	0.0384	10,530	1,730	1,400	252

[a] SD = standard deviation.

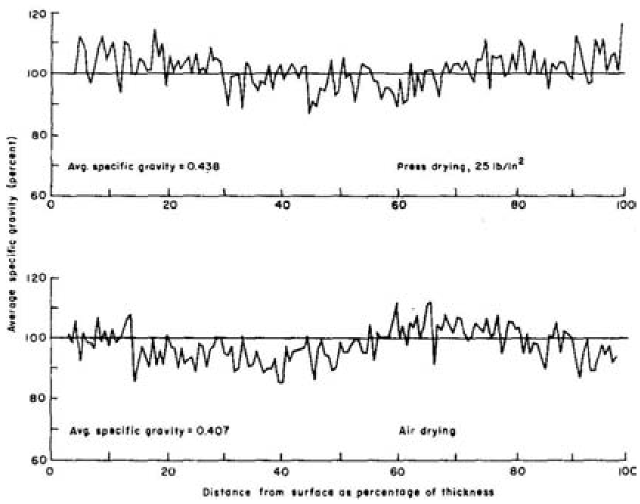

Figure 3. — SG profiles of air-dried specimens and specimens press-dried at 350°F and 25 psi.

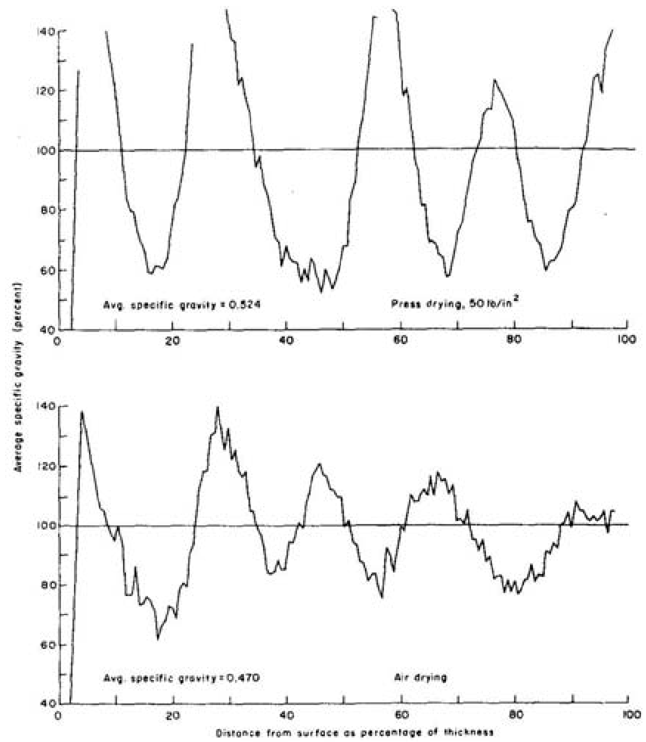

Figure 4. — SG profiles of air-dried specimens and specimens press-dried at 350°F and 50 psi.

If we assume that the cross-sectional dimensions of both press- and kiln-dried boards will be the same in use, then MOR and MOE can be used to compare bending performance of press- and kiln-dried boards. In this case, the excessive thickness loss caused by platen pressure is absorbed in the green dimension; that is, we pay a penalty by requiring a larger green thickness for press-dried boards than for kiln-dried boards so that they will be the same dimension in final use. Previous research showed that thickness loss during press-drying at 25 to 50 psi ranges from about 3 to 12 percent (11). Other studies that more fully define thickness loss and how it depends on process variables are in progress. However, we could also approach end use by taking advantage of the increased bending properties to allow use of smaller sizes. In this case, we do not sacrifice the excessive thickness loss caused by platen pressure. Comparisons between press- and kiln-dried boards must now be made with the load-carrying capacity and stiffness equations rather than with MOR and MOE because of size differences.

Two mechanisms could be operating to change the bending properties of press-dried wood - an increase because of densification and a decrease because of thermal degradation.

Increase in strength caused by densification

Wood is easily compressed under pressure at high temperature, especially when the MC is also high. MacLean (7) observed that the maximum increase in SG of specimens pressed at 250°F and 25 psi was about 4 percent for Douglas-fir, 3 percent for Sitka spruce, 8 percent for yellow birch, and 11 percent for white oak - all measured at approximately 12 percent MC. Specimens soaked in water before heating had a large increase in SG compared with specimens that had an MC of 28 to 30 percent when heated, indicating that high MC increases the densification of wood in press-drying. The higher value of bending strength properties of wood usually occurred when the values of SG were the highest. This increase in SG probably occurred because more shrinkage or collapse took place during drying.

The study by Harless et al. (3) on modeling the density profile of particleboard showed a steeper density gradient with increasing platen temperature. Strickler's investigation (12) on properties of Douglas-fir flakeboard indicated that higher initial pressure results in higher surface density and correspondingly lower center density. Press cycles, MC, and moisture distribution in the mat all affected how density was distributed throughout the thickness. For bending strength, a higher surface density of board is important. The MOR appeared to be closely correlated with the density of a layer at a depth of about 0.1 inch beneath the surface (12).

Therefore, we expected that hot-press-drying might create a U-type curve of density distribution—higher density at the two surfaces that gradually decreases toward the center. Typical results of the density profile tests through the specimen thickness are shown in Figures 3 and 4. The SG distribution was not significantly different between the surface and center of the press-dried specimens. The greater difference in density between earlywood and latewood in loblolly pine probably confounded the difference of density distribution created by press-drying, even though significant differences in overall SG did occur between kiln-dried and press-dried specimens. Note that the large saw-tooth pattern in Figure 4 shows an extreme earlywood-latewood effect.

Decrease in strength caused by high temperature

The combination of high drying temperature and high wood MC is known to affect the mechanical properties of wood. MacLean's study (7) showed that for Douglas-fir, Sitka spruce, and yellow birch, more than 2 to 4 hours of heating in a hot press at 350°F was enough to reduce bending strength. However, in some cases, bending strength increased early in the heating period, probably because of the effects of densification and because the brevity of the test period prevented thermal degradation. In our study, because the loblolly pine boards were heated in the hot-press at 350°F for only 90 minutes, thermal degradation could not occur in this brief period or the effect of densification would be greater than that of any thermal degradation. Even though platen temperature was 350°F, internal board temperatures were lower. Figure 5 shows internal temperatures in loblolly pine during press-drying. These temperatures were measured in a previous study (11); they show that internal temperature did not exceed 250°F when platen temperature was 350°F. Figure 6 shows that thermal degradation did not occur in the press-dried boards.

Pearson and Gilmore (8) found the following relationship between MOR/MOE and SG of loblolly pine (both mature and juvenile wood):

$$\text{MOR } (10^3 \text{ psi}) = 40.7\text{SG} - 4.8$$
$$\text{MOE } (10^6 \text{ psi}) = 7.81\text{SG} - 1.67$$

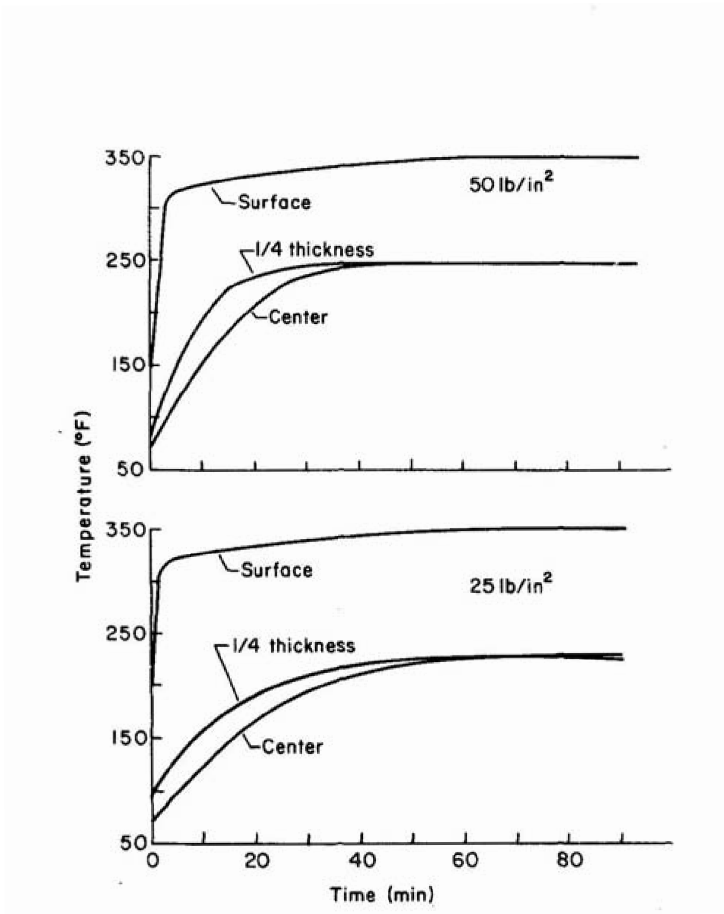

Figure 5. - Surface, center, and 1/4-thickness temperatures of loblolly pine 2 by 4 specimens during pressdrying (1 1).

Figure 6 shows the ratio of MOR or MOE at an SG of 0.40 to MOR or MOE at an increased SG caused by press-drying. The plots of the experimental data of our study and predictions from the results of Pearson and Gilmore (8) are both shown. Note that the ratios of the experimental data of our study are always above the ratios predicted by the Pearson and Gilmore relationships, which is evidence that the wood may not be thermally degraded during the thermal-pressure process that increases the SG.

Price and Koch (9) examined the effect of kiln time and temperature on the mechanical properties of southern pine lumber. At 240°F, the evidence indicates that MOR and MOE were not significantly reduced by kiln times of up to 24 hours. Compared to the MOR of boards dried

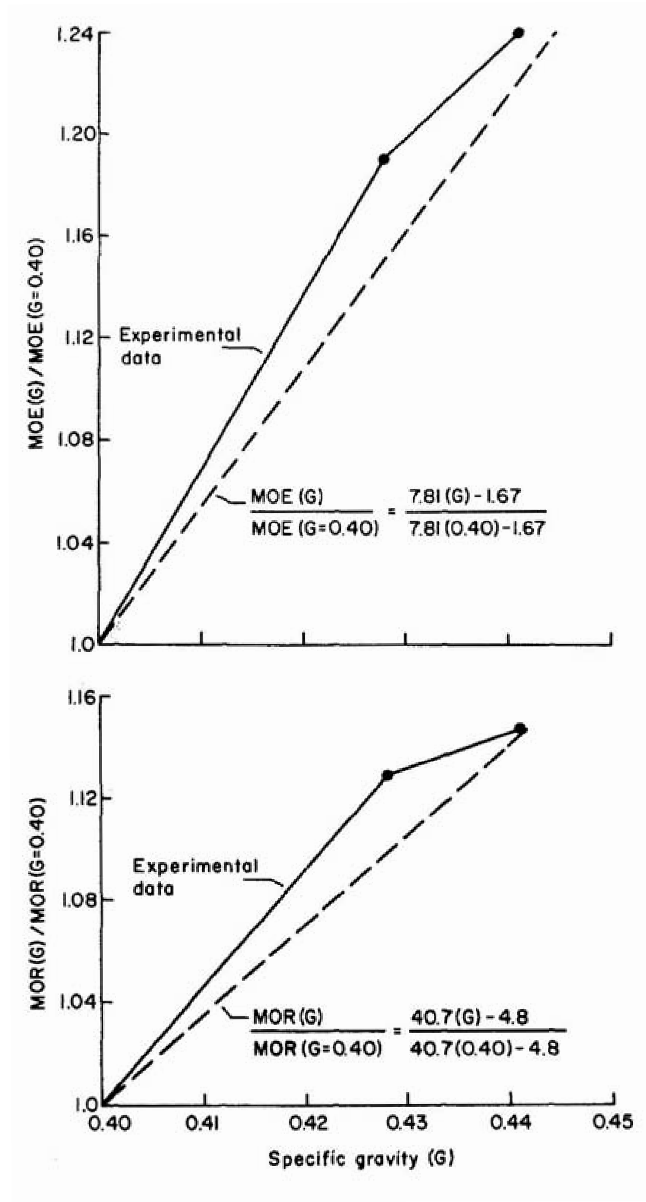

Figure 6. — Ratio of MOR or MOE at an SG of 0.40 to MOR or MOE at SGs increased by press-drying. Dashed line based on results of Pearson and Gilmore (8).

at 180°F for 120 hours, the MOR of boards dried at 240°F for 36 hours decreased about 3.5 percent, although this difference was not significant at the 95 percent confidence level. However, MOR of boards dried at 240°F for 120 hours decreased about 22.2 percent, which was statistically significant. In the Price and Koch study, a typical commercial schedule of 240°F and a drying time of 18 hours were used as the control treatment, so the bending strength values of kiln-dried boards were not expected to be reduced by kiln-drying.

Concluding remarks

To investigate the effect of hot-press-drying on the bending strength and stiffness properties of plantation loblolly pine lumber, small clear specimens (1.5 by 1.5 by 32 in.) were cut from press-dried and kiln-dried lumber and tested for SG and bending strength and stiffness. The 2 by 4 lumber was dried in three different ways: 1) press-dried at 25 psi and 350°F for 90 minutes; 2) press-dried at 50 psi and 350°F for 90 minutes; and 3) kiln-dried at 240°F for 18 hours. Statistically significant increases in SG, MOR, and MOE were found for press-dried specimens compared to kiln-dried specimens, but SG, MOR, and MOE did not differ significantly between specimens press-dried at 25 and 50 psi. Compared to kiln-dried specimens, SG, MOR, and MOE of specimens press-dried at 25 psi increased 7.0, 12.9, and 19.0 percent, respectively, and SG, MOR, and MOE of specimens press-dried at 50 psi increased 10.3, 14.7, and 24.0 percent, respectively.

The thickness density profile of both press- and kiln-dried boards was measured by a gamma radiation density gradient instrument. However, the results failed to reveal any significant SG gradient through the thickness of boards, probably because of the confounding effect of the density difference between earlywood and latewood.

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