ALTERNATIVE METHODS FOR SAWING AND DRYING STRUCTURAL LUMBER
FROM SECOND-GROWTH LOBLOLLY PINE (PINUS TAEDA)

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and
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SUMMARY

The processing of second-growth pine is a major problem. The combination of juvenile wood, compression wood and growth stresses makes the manufacture of straight lumber difficult. Several studies at the U.S. Forest Products Laboratory have shown that it is possible to minimize the warping of second-growth loblolly pine (Pinus taeda) lumber by manufacturing techniques. Two of the most promising methods, Saw-Dry-Rip (SDR) and press drying, are reported here.

The SDR method employs live sawing (all cuts parallel), drying the wide boards (flitches), and then ripping the dried material to the desired widths for final use. This method, devised for hardwoods, has proven successful with pines. Results of studies are shown for 2.4-m stud (scantling) lengths. Yield of U.S. STUD and Select Structural grades were increased up to 20% compared to conventional processing. These grades require the lowest level of warp (crook, bow, and twist).

The press drying method uses conventional sawing combined with drying under pressure between steam-heated platens. This method dries studs to 15% moisture content in as little as 90 minutes with gains in yield of STUD grade lumber up to 25% compared to kiln drying.

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Introduction

The processing of pine for lumber, and especially for structural lumber, is generally quite easy when using large old-growth logs. There is usually little problem with warping in this type of material. However, when processing smaller, second-growth material the problems increase greatly. Items that affect processing include juvenile wood, compression wood, and growth stresses.

Juvenile wood has many characteristics that are different from mature wood, including lower density, shorter fibers, and larger fibril angles. Larger fibril angles result in greater longitudinal shrinkage, and this shrinkage causes the most difficulty in manufacturing lumber. The differential longitudinal shrinkage between juvenile wood and mature wood results in warp (crook, bow, or twist) (Fig. 1). The longitudinal shrinkage of juvenile wood may be 3 to 10 times greater than that of mature wood. Haygreen and Bowyer [2] show 6 to 9 times greater for Caribbean and loblolly pines. Generally, juvenile wood is contained in the first 5 to 20 rings from pith [1], however, in some species it may be found in a greater number of rings from pith.

Compression wood is formed as a reaction to outside stimuli, such as gravity (leaning trees), light, and wind. Because of the flexibility of young trees, the formation of compression wood occurs more readily than in older trees. Each of these external stresses may result in the formation of compression wood. Compression wood, like juvenile wood, shrinks more longitudinally than does normal wood. The differential shrinkage results in crook, bow, and twist. Commonly, compression wood shrinks 10 to 20 times more than normal wood, but the shrinkage may be as high as 60 to 70 times greater [2]. Fortunately, compression wood is not found in all logs.
Growth stresses in pine are a confusing and troublesome item. Growth stresses give trees mechanical strength to remain in an upright position. Part of the tree will be stressed in tension, another part in compression. When the tree is processed, the stresses are released in the form of strain. Tension strains result in longitudinal shrinkage and compression strains in longitudinal expansion. As with both juvenile wood and compression wood, the result is warp in the lumber being cut. However, unlike juvenile wood and compression wood, the growth stresses do not require drying to cause warp. The strains occur immediately during sawing. The greater the stresses in the tree, the greater the strains and the chance for warping.

The object of the research reported here was to reduce or eliminate the warp that normally results from these causes. The methods examined were a combination of sawing and drying technologies.

**Saw-Dry-Rip Methodology**

**Design**

The design used was a 2 by 2 factorial: two sawing and two drying methods. The sawing methods were (1) conventional centered cant sawing (Fig. 2) and (2) live sawing (Fig. 3). The drying methods, both in a steam kiln, were (1) conventional drying, not above 190°F (88°C) and (2) high-temperature drying at 240°F (116°C). Two runs of each sample combination were used to avoid data loss should the kiln malfunction (Table 1).

**Figure 2 -- Centered cant conventional sawing pattern.**

**Figure 3 -- The SDR process: small logs are live sawn into flitches; flitches are lightly edged for a compact kiln load, dried, and ripped to desired final width.**
Table 1.—Log distribution per treatment. Two by two factorial with 20 logs per treatment

<table>
<thead>
<tr>
<th>Sawing method</th>
<th>Drying method</th>
<th>Conventional</th>
<th>High temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Run 1</td>
<td>Run 2</td>
</tr>
<tr>
<td>Conventional centered cant</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>SDR live sawn</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
</tbody>
</table>

The treatments were coded as follows:
CC = Conventional Sawing, Conventional Drying
CH = Conventional Sawing, High-temperature Drying
SC = SDR-Live Sawing, Conventional Drying
SH = SDR-Live Sawing, High-temperature Drying.

Sample material was from plantation-grown trees from eastern Texas. Eighty 8-foot-long (2.4-m) loblolly pine (Pinus taeda L.) logs were divided into 8 groups of 10 logs each (Table 1). An attempt was made to distribute the diameters equally and to distribute the butt logs one per sample group.

Sawing
Conventionally sawed studs were cut using split taper sawing with a centered 4-inch (102-mm) cant (Fig. 2). The cant is located in the geometric center of the log. Side flitches were ripped to 4-inch widths while green.

SDR logs were live sawn (Fig. 3) into 1-3/4-inch-thick (45-mm) flitches using full taper sawing with a minimum 4-inch (102-mm) opening face. The flitches were lightly edged for a compact kiln load. All studs and flitches were numbered for log and piece and end trimmed before drying.

Drying
High-temperature drying was based on a schedule of approximately 20 hours at 240°F (116°C) dry-bulb temperature (DBT) and 180°F (82°C) wet-bulb temperature (WBT). Air speeds through the load were 800 feet per minute (244 m/min). Drying was followed by an equalizing period of about 20 hours at 180°F DBT/170°F WBT (82°C DBT/77°C WBT). An average moisture content of 12 ± 3% was the goal. At least three sample boards were used to monitor drying in each kiln load. All loads (both high temperature and conventional) were weighted with approximately 30 pounds per square foot (146.46 kg/m²) to minimize warp in the top layers of the piles.
The conventional kiln schedule followed FPL T13-C6 [4], starting at 170°F DBT/155°F WBT (77°C DBT/69°C WBT) and finishing at 190°F DBT/145°F WBT (88°C DBT/63°C WBT). Air speeds through the load were 400 feet per minute (122 m/min). The moisture content goal of 12 ± 3% was reached after about 93 hours. An 8-hour equalizing period followed drying, for a total time of 101 hours. The equalizing conditions were the same as for the high-temperature drying. Three sample boards were again used for monitoring each kiln load.

Sample Processing

After drying, all 2 by 4 studs were planed to American Lumber Standard (ALS) dimensions\(^1\). All SDR flitches were ripped to the ALS widths plus 1/8-inch (3.2-mm) planing allowance; e.g. 3-5/8 inches (9.2 cm), 2-5/8 inches (6.7 cm), and 1-5/8 inches (4.1 cm). Each dried flitch was ripped to obtain its maximum yield, with emphasis on 2 by 4's.

All materials in a sample group were measured for moisture content and warp after planing. Moisture content was measured using an electronic resistance moisture meter. Measurements were taken at three locations on each piece: 12 to 18 inches (30.5-45.7 cm) from each end and about in the middle.

Warp measurements (Fig. 1) were made using a flat table and calibrated wedges scribed in 1/32 inch (0.8 mm). The wedges were placed in the gap between the table and the stud at the point of greatest deflection, and warp was recorded to the nearest 1/32 inch.

Analysis

Nonparametric analysis of variance was used to evaluate the effect of treatment on average crook, bow, and twist and on the number of rejects per treatment. The basis for rejection of studs was the STUD grade warp limits of the National Grading Rule [7,8]. Any piece not meeting the STUD grade warp requirements was considered a reject.

Results and Discussion

The data distributions were almost the same for:

\[
\begin{align*}
\text{Average log diameter} & \quad \text{SDR 9.25 in. (23.5 cm), Conventional 9.33 in. (23.6 cm Conv.);} \\
\text{Log volume} & \quad \text{SDR 172 ft}^3 \quad (4.87 \text{ m}^3), \text{ Conv. 176 ft}^3 \quad (4.98 \text{ m}^3); \\
\text{Volume of studs} & \quad \text{SDR 1278.2 bd ft, Conv. 1259.3 bd ft.}
\end{align*}
\]

\(^1\) American Lumber Standard dimensions are 2 by 4 = 1.5 in. by 3.5 in.; 2 by 3 = 1.5 in. by 2.5 in.; and 2 by 2 = 1.5 in. by 1.5 in.
The average warp by treatment for 2 by 4's was

- **Crook**
- **Bow**
- **Twist**

Table 2.--Warp averages, ranges and number of rejects for loblolly pine 2 by 4's

<table>
<thead>
<tr>
<th></th>
<th>Crook (1/32 inch)</th>
<th>Bow (1/32 inch)</th>
<th>Twist (1/32 inch)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>CONVENTIONAL SAWING</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conventional drying (CC = 120)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td>7.2</td>
<td>5.2</td>
<td>2.3</td>
</tr>
<tr>
<td>Range</td>
<td>68</td>
<td>45</td>
<td>23</td>
</tr>
<tr>
<td>Rejects number</td>
<td>26</td>
<td>10</td>
<td>2</td>
</tr>
<tr>
<td>High temperature drying (CH = 109)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td>8.0</td>
<td>8.3</td>
<td>1.6</td>
</tr>
<tr>
<td>Range</td>
<td>98</td>
<td>52</td>
<td>10</td>
</tr>
<tr>
<td>Rejects number</td>
<td>27</td>
<td>16</td>
<td>0</td>
</tr>
<tr>
<td><strong>SDR LIVE SAWING</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conventional drying (SC = 101)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td>3.5</td>
<td>3.7</td>
<td>1.6</td>
</tr>
<tr>
<td>Range</td>
<td>46</td>
<td>19</td>
<td>10</td>
</tr>
<tr>
<td>Rejects number</td>
<td>9</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>High temperature drying (SH = 103)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td>2.8</td>
<td>3.1</td>
<td>1.0</td>
</tr>
<tr>
<td>Range</td>
<td>20</td>
<td>15</td>
<td>7</td>
</tr>
<tr>
<td>Rejects number</td>
<td>14</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

1 Range is from zero to value shown.
2 Based on warp requirements for STUD grade.
The analysis of variance for crook showed that there was no significant difference between treatments CC, CH, and SC or between SC and SH, but that there was a significant difference between treatment SH and the conventional sawing treatments. Crook was the only warp type that showed a significant difference between treatments.

The proportion of rejects, due to warp, by treatment were CC-22.5%; CH- 29.0%; SC-9.0%; SH-12.6%. As noted here, the high-temperature treatments for both conventional and SDR-live sawing had slightly higher reject rates. Within sawing methods (conventional or SDR-live sawing), there were no significant differences in reject rates. Significant lower rejects occurred with SDR-live sawing than with conventional sawing. Statistically, the drying method showed no differences. The SH treatment had more marginally rejected pieces which accounted for the higher reject rate. The SC treatment had slightly fewer rejects with higher average warp values. The SDR treatment rejects were all due to crook, while the conventionally sawn treatment rejects were due to crook and bow (CH) and crook, bow, and twist (CC).

For the conventionally sawed studs, CC had 22% of the pieces with excessive crook, 8% with excessive bow, and 2% with excessive twist; CH had 25% with excessive crook, 15% with excessive bow, and 0% with twist.

For the SDR-live sawn studs, SC had 9% with excessive crook, 1% with excessive bow, and 0% with twist; SH had 14% with excessive crook, 0% with bow, and 0% with twist.

The SDR process resulted in reduced warp and better grade recovery of stud material. The reduction of crook, the most important type of warp for construction, was as high as 65% between the CH and SH treatments. Between the SDR-live sawing and conventional sawing treatments, averaged over both drying treatments, the reduction was 58%. For bow, the reductions were slightly smaller; 63% between CH and SH, and 50% between sawing treatments. The reductions due to SDR in twist were very small from a practical standpoint, but proportionally about the same as the other warp types: 56% between CC and SH, and 67% between sawing treatments.

For this study, the increase in SDR-STUD grade yield was 10-20% over the conventional treatments. This increase in grade yield was principally due to the sawing, drying, and ripping sequence and not due to the type of drying used.

The use of SDR for pines resulted in poorer results than were experienced with hardwoods [3], where nearly 100% of SDR studs were in STUD grade,
Press Drying

Methodology

Design

The information presented here is part of a larger study exploring the press-drying technique. The original study design was divided into 4 parts.

1. Exploratory, to establish drying schedules.
2. Press drying presurfaced 2 by 4 studs.
   Part 2 used a 2 by 2 by 4 factorial design with two platen pressures, two cooling methods, and four log positions within the tree.
   Part 3 provided a standard to compare the press-drying treatments.
4. Press drying unsurfaced studs.

For this paper, we will only compare the presurfaced press drying (2) with the kiln drying (3).

Material from twenty-nine 36-foot-long logs (trees) was used. The trees were obtained from a loblolly pine plantation in South Carolina\(^2\). They were 28 years old with small end diameters ranging from 8 to 14 inches (20-36 cm). The trees were cut into 8-foot (2.4-m) lengths for processing; each log was identified as to position in the tree, from butt to top.

Sawing

All logs were sawn using the conventional cant sawing described in the SDR study (Fig. 2). however, only 2 by 4’s were cut from side flitches. The target thickness in this study was 1.95 inches (49.5 mm).

Drying

Two types of drying were used, press drying and conventional kiln drying. The press drying was done at platen pressures of 25 and 50 pounds per square inch (psi) (1.7575 and 3.5155 kg/cm\(^2\)). Platen temperature was 350°F (177°C). and drying time was 90 minutes. The press-drying pressures and times were determined from the exploratory part of the original study and previous work by Simpson [5,6]. In the exploratory part higher

\(^{2}\) Appreciation is extended to the Weyerhaeuser Corp. for supplying the trees and other assistance.
pressures were tested but rejected because of longer drying times and damage to the studs.

Kiln drying was done at 280°F (138°C) dry-bulb temperature with no wet-bulb control. Air velocities were 1,200 feet per minute (365.76 m/min). Time in the kiln was 10-13 hours to reach the 13% target moisture content. Each kiln load was top weighted with 50 pounds per square foot (244.1 kg/m²). One half of the kiln-dried material was equalized at 190°F dry bulb and 175°F wet bulb (88°C DB and 79°C WB) for about 8 hours. The other half was not equalized.

Cooling

Two cooling systems were used for the press-dried material. In one the material was cooled in the press, by passing cold air and then cold water through the platen while under pressure. The other cooling system removed the material from the press to cool in the open without pressure.

Sample Processing

Immediately after drying and cooling, the lumber was metered for moisture content (MC), planed to 1.5 by 3.5 inches (38 by 89 mm) and then metered again just before warp measurements were taken. Warp measurements were done as described in the section on SDR.

Results and Discussion

After surfacing the 2 by 4's, press dried at 25 and 50 psi, the wood surfaces appeared to be no different than those that were kiln dried. There was no evidence of any collapse or surface checking. The success of press drying may be, in part, because there was no heartwood in the 2 by 4's. The inclusion of heartwood may affect the press-drying process.

The average green moisture content for all materials for both kiln and press drying was about 123%. The average moisture content after press drying was 15% (range 7.5-29.5). While the kiln-dried material averaged 15.6% (range 6-31) for equalized and 16.5% (range 7-33) for unequalized.

During drying, the temperature at the center of the press-dried studs leveled out at 225°F (106°C) and 250°F (121°C), respectively, for the 25 and 50 psi treatments. The temperature differences are believed to be due to better surface contact at higher pressure. Internal temperatures were not monitored for the kiln-dried studs.

The thickness of the lumber after planing and before press drying averaged 1.819 inches (46.20 mm). After press drying, the thickness averaged 1.767 inches (44.88 mm) for 25 psi and 1.663 inches (42.24 mm) for 50 psi pressure. The thickness losses
were 3.0 and 8.5% respectively for 25 and 50 psi. The differences in the thickness loss are statistically significant, as well as of practical significance.

Warp data are found in Table 3 for both the press-dried and kiln-dried material.

Table 3.--Comparison of warp in press-dried and kiln-dried 2 by 4's

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Warp</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Crook</td>
</tr>
<tr>
<td>Press dried</td>
<td>-------1/32 inch (0.8 mm)-------</td>
</tr>
<tr>
<td>25 psi platten pressure</td>
<td>1.84</td>
</tr>
<tr>
<td>50 psi platten pressure</td>
<td>2.26</td>
</tr>
<tr>
<td>Kiln dried</td>
<td></td>
</tr>
<tr>
<td>Equalized</td>
<td>5.91</td>
</tr>
<tr>
<td>Nonequalized</td>
<td>4.10</td>
</tr>
</tbody>
</table>

For the press-dried studs, differences exist between the 25 and 50 psi treatments for crook, bow, and twist. The differences in crook and bow were not statistically significant, but the difference in twist was significant. Cooling method had no effect on the warp of the studs.

It was expected that the warp levels would be lower with higher platen pressures, but the opposite occurred. A possible explanation might be that there was a greater surface densification of the material from the 50 psi treatment--this densified and stressed wood may have been removed unequally in surfacing the studs, resulting in warp.

For the kiln-dried material, actual differences exist between the equalized and unequalized treatments for crook, bow, and twist (Table 3). Though the unequalized values are lower than the equalized, crook and bow do not differ statistically. However, like the press-dried treatments, twist is statistically different between treatments.

When comparing the press-dried stud warp with the kiln-dried stud warp, we find that only crook was statistically different. That difference was between the kiln dried-equalized material and everything else.

Log position had a small and inconsistent effect on warp, as shown in Table 4.
Table 4.--Effect of log position on crook, bow, and twist for press-dried, presurfaced studs at 25 and 50 psi pressure

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Log position</th>
<th>1 (Butt)</th>
<th>2</th>
<th>3</th>
<th>4 (Top)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Press dried</td>
<td>1/32 inch (0.8 mm)</td>
<td>1/32 inch (0.8 mm)</td>
<td>1/32 inch (0.8 mm)</td>
<td>1/32 inch (0.8 mm)</td>
<td>1/32 inch (0.8 mm)</td>
</tr>
<tr>
<td>Press dried</td>
<td>Crook</td>
<td>2.48</td>
<td>1.52</td>
<td>2.18</td>
<td>1.56</td>
</tr>
<tr>
<td>Press dried</td>
<td>Bow</td>
<td>4.76</td>
<td>3.03</td>
<td>3.24</td>
<td>3.00</td>
</tr>
<tr>
<td>Press dried</td>
<td>Twist</td>
<td>0.63</td>
<td>1.05</td>
<td>1.16</td>
<td>1.26</td>
</tr>
<tr>
<td>Kiln dried</td>
<td>Crook</td>
<td>8.24</td>
<td>3.30</td>
<td>3.14</td>
<td>3.42</td>
</tr>
<tr>
<td>Kiln dried</td>
<td>Bow</td>
<td>10.31</td>
<td>5.71</td>
<td>4.28</td>
<td>5.14</td>
</tr>
<tr>
<td>Kiln dried</td>
<td>Twist</td>
<td>1.27</td>
<td>2.11</td>
<td>3.37</td>
<td>4.04</td>
</tr>
</tbody>
</table>

While the differences between the warp of press-dried studs and kiln-dried studs are generally not statistically significant, the differences in degrade from STUD grade between them are significant. The statistical analysis of kiln-dried and press-dried material, using degrade for comparison, shows that press drying was statistically better than kiln drying for all treatments except one replicate of the unequalized kiln drying. We feel that this was of practical significance and may reflect a sample that was too small to show total statistical significance. To better see the practical aspects of the warp reduction from using press drying, a comparison of the percentage of degrade due to warp was advantageous (Table 5).

Table 5.--Comparison of the percent of studs not making STUD grade in kiln-dried and press-dried loblolly pine studs

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Crook</th>
<th>Bow</th>
<th>Twist</th>
<th>All</th>
</tr>
</thead>
<tbody>
<tr>
<td>Press dried</td>
<td>25 psi</td>
<td>3.3</td>
<td>1.3</td>
<td>0.0</td>
</tr>
<tr>
<td>Press dried</td>
<td>50 psi</td>
<td>4.6</td>
<td>2.5</td>
<td>0.4</td>
</tr>
<tr>
<td>Kiln dried</td>
<td>Equalized</td>
<td>20.6</td>
<td>11.6</td>
<td>4.7</td>
</tr>
<tr>
<td>Kiln dried</td>
<td>Unequalized</td>
<td>12.6</td>
<td>10.2</td>
<td>0.4</td>
</tr>
</tbody>
</table>
The data in Table 5 show that there is between 11.6 and 25.8% better grade recovery using press drying than using kiln drying, when all of the warp types are considered for degrade. In some pieces, more than one warp type may be involved. The "All" category is not the sum of the three individual warp types.

Conclusions

1. The two new methods (SDR and press drying) of processing loblolly pine for 8-foot-long 2 by 4 studs reduce warp and significantly improve the grade yield over the conventional processing method.

2. For SDR, high-temperature drying was not effective in reducing warp as it was with hardwoods.

3. For press drying, the drying time was reduced by a factor of about 9.5 times compared to kiln drying (1.5 hours for press drying, about 11.5 hours for kiln drying).

4. Platen pressure of 25 psi is sufficient to reduce warp.

Bibliography


