ABSTRACT

One hundred and ninety-two pieces of matched 2 by 6 southern yellow pine (SYP) lumber were dried in two separate charges according to an elevated-temperature (ET) and a high-temperature (HT) schedule. Wood properties including juvenile wood content, density, ring count, largest knot area, presence of pith, moisture content, and warp (crook, bow, and twist) were measured for each board. It was found that boards dried with the ET schedule had significantly higher crook than those from the HT schedule. Bow and twist from the ET schedule were also higher, but no significant difference was found between the two schedules. Crook was shown to co-vary with the largest knot area. Twist co-varied significantly with specific gravity, juvenile wood content, and number of rings per inch for the test lumber.

Southern yellow pine (SYP) has long been the principal timber species in the South. A gradual shift has occurred pertaining to the silvicultural production strategy of SYP. It is no longer grown exclusively in natural forests. In 1990, one-third of the South’s pine timberland consisted of plantations. These plantations are projected to comprise 50 percent of the total pine harvest volume by the year 2000 (2). As a result, increasing amounts of lumber are being cut each year from young, small-diameter trees. Unfortunately, this material exhibits a high propensity for warp when it is dried. Warp costs the lumber industry millions of dollars each year through downgrading and through loss of markets to alternative species and to alternative building products (1). This is obviously a serious problem that hinders its effective utilization.

SYP lumber is being dried commercially at three temperature levels: 1) conventional temperature (CT) with a maximum temperature of 180°F (82.2°C); 2) elevated temperature (ET) with a maximum temperature of 212°F (100°C); and 3) high temperature (HT) at temperatures above 212°F (11). Most newer kilns are operated at either ET or HT condition (3,13).

Several investigations have been conducted to study effects of kiln schedules on warping behavior in SYP (5-8). Hopkins et al. (5) investigated effects of CT and ET schedules on warp in drying SYP. Koch (6,7) developed several approaches to dry 2 by 4 studs in less than 24 hours at high temperatures. He concluded that HT drying at 240°F (115.6°C) under restraint significantly reduced warp in the lumber. In another study, Price and Koch (9) found that No. 2 dense 2 by 6 SYP boards dried at 240°F (115.6°C) and 270°F (132.2°C) under top load restraint had less maximum and average warp than boards dried at 180°F (82.2°C). No data have been reported to compare warp from ET and HT schedules.

The effect of wood properties such as wood specific gravity (SG), juvenile wood, and compression wood on warp is not clearly understood in structural softwood lumber. Earlier investigations, e.g., (4), showed that severe warp was often caused by one or more growth characteristics. However, recent studies suggest that little of the warp in graded softwood lumber grown in a naturally regenerated forest may be attributable to measurable growth characteristics in the lumber (1,8).

The objective of this study, therefore, was to investigate the effects of ET and HT kiln schedules on warp and to quantify the relationships of warp to wood properties including specific gravity (SG), juvenile wood content, knot area, number of rings per inch, and pith presence in plantation-grown SYP lumber.

MATERIAL AND METHOD

LOG SELECTION AND SAWING

Twenty-five 8-foot (2.44 m) logs of plantation-grown loblolly pine (Pinus taeda, L.) with an average large-end diameter of 13 inches (33 cm) were selected in a local sawmill. Wood within the 12th growth ring was painted on both...
ends of each log to identify the juvenile wood portion of the log. The logs were then sawn with a portable circular mill into predominately 2 by 6 lumber. Actual size of the lumber was 1.53 by 5.65 inch (38.9 by 143.5 mm). One hundred and ninety-two pieces of lumber were recovered. The lumber, covered with plastic film, was transported to the Louisiana Forest Products Laboratory. The boards were randomly divided into two groups for two separate charges.

MEASUREMENTS OF GREEN BOARDS AND STACKING

Each board was weighed to the nearest 0.01 pounds (0.005 kg). Board thickness and width were measured with a digital caliper at positions about 6 inches (152.4 mm) from each end. The average values of board thickness and width from the two ends and measured board length were used to calculate board volume at green. The percentage of juvenile wood was estimated from the painted marks at each end. The area of the largest knot on each board was measured. The number of rings per inch was counted from each end and presence of pith was recorded.

Lumber was stacked on a kiln cart with a 2-foot (609.6-mm) sticker space. The stack was 16 courses high with 6 boards in each course. Six iron bars with a total weight of 300 pounds (136.4 kg) were placed on the top of the stack to help restrain the lumber during drying. This yielded a loading rate of about 13 pounds per ft.*

KILN-DRYING

Matched batches of lumber were dried in a steam-heated kiln, one with an ET schedule and the other with an HT schedule (Fig. 1). The ET schedule consisted of a dry-bulb temperature ramped from 170°F (76.7°C) to 200°F (93.3°C) in 52 hours at a constant wet-bulb temperature of 150°F (65.6°C). The HT schedule included a dry-bulb temperature of 230°F (110°C) and a wet-bulb temperature of 180°F (82.2°C). It took about 12 hours for the kiln to reach 230°F (110°C). The total drying time was 30 hours with the HT schedule. During drying, fan direction was reversed every 8 hours. Air velocity through the stack was about 500 feet per minute.

MEASUREMENTS OF DRY BOARDS

Lumber was allowed to cool before unstacking. Board weight, width, and thickness were measured again. Moisture content (MC) of each board was measured at three places: 1 foot (30.5 cm) from each end and in the middle, with a resistance-type moisture meter.

Crock and bow were measured by placing the board (flatwise for crook and edgewise for bow) on an L-shaped table against two stops, 8 feet apart. Displacement of the board from a straight line (vertical edge of the table) was measured at 1-foot intervals along the length of the board with a steel ruler to an accuracy of 0.01 inch (0.254 mm). Twist was ascertained by holding three corners of the lumber down on the table surface and measuring the distance from the surface to the other corner of the piece.

DATA REDUCTION

The average of the three MC readings from each piece was calculated and used to estimate the ovendry board weight. Green MC of each piece was then calculated using the ovendry and green weights. Specific gravity was calculated using the ovendry weight and green volume for each board. The calculated SG was then converted to a value corresponding to wood volume at 12 percent MC (10).

The maximum crook and bow among the seven readings from each piece was sorted out. Statistical comparisons of the two schedules were based on a two-sample analysis procedure and included final MC, maximum crook, maximum bow, and twist. To show the effect of wood properties on warp, a multiple-correlation analysis was performed among warp (crook, bow, and twist) and wood properties (i.e., SG, juvenile wood content, ring count, and knot area).

TABLE 1. — Summary of board properties by charge.

<table>
<thead>
<tr>
<th>Kiln schedule</th>
<th>Properties</th>
<th>Elevated temperature</th>
<th>High temperature</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Green MC (%)</td>
<td>100.0 (27.3)</td>
<td>100.3 (29.1)</td>
<td>0.93976 *</td>
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<tr>
<td></td>
<td>Specific gravity</td>
<td>0.49 (0.05)</td>
<td>0.50 (0.05)</td>
<td>0.11337 *</td>
</tr>
<tr>
<td></td>
<td>Juvenile wood (%)</td>
<td>31.53 (33.19)</td>
<td>34.84 (29.79)</td>
<td>0.46945 *</td>
</tr>
<tr>
<td></td>
<td>Ring count per inch</td>
<td>4.32 (1.49)</td>
<td>4.51 (2.12)</td>
<td>0.48152 *</td>
</tr>
<tr>
<td></td>
<td>Largest knot area</td>
<td>3.99 (3.13)</td>
<td>3.82 (3.51)</td>
<td>0.72648 *</td>
</tr>
</tbody>
</table>

* Values in parentheses are standard deviations based on 96 boards. * = not significantly different at the 95 percent confidence level. Specific gravity is based on ovendry wood weight and volume at about 12 percent MC.

Figure 1. — Kiln schedules used in the study. ETS = elevated-temperature schedule; HTS = high-temperature schedule; DBT = dry-bulb temperature; WBT = wet-bulb temperature.
The test lumber. Mean green MC was not significant at the 95 percent confidence level, the pooled data from the two schedules was essentially the same. The mean ring count per inch was about 4.5 for both charges. Very few pieces had a ring count less than 2, which is considered to be fast-grown wood (1). Knots in the ET and HT charges, respectively. The results of the two-sample comparison procedure showed that the crook value from the ET charge was significantly higher than that from the HT charge at the 95 percent confidence level. The maximum crook averaged 0.253 inches (6.43 mm) for the ET charge and 0.171 inches (4.34 mm) for the HT charge. Twist averaged 0.256 inches (6.50 mm) for the ET charge and 0.244 inches (6.20 mm) for the HT charge. Both bow and twist were slightly higher from the ET charge. However, no significant difference was found in bow and twist between the two charges. These results for plantation-grown SYP lumber seemed to agree with the conclusion reached by earlier investigations (6,9) that HT drying under restraint produces lumber with higher or at least similar quality. Another advantage of HT drying is reduction in overall drying time, about 42 percent in this study compared with the ET schedule.

The fact that HT drying under restraint produces lumber with less warp may be explained by the creep and mechano-sorptive behavior of wood. It is known that wood under stress develops more creep and mechano-sorptive deformation at higher temperatures (12). In HT drying under restraint, wood is being considerably softened. Development of creep and mechano-sorptive deformation in wood under these conditions would redistribute internal drying stresses, which may help keep lumber straighter. Thus, enhancing creep and mechano-sorptive deformation, hence interrupting stress development, may be the keys to reduce warp in drying of softwood lumber.

**RESULTS AND DISCUSSION**

**LUMBER PROPERTIES**

Table 1 summarizes the properties of the test lumber. Mean green MC was about 100 percent for both charges. This value is close to the reported green MC value for southern pine lumber (10). The mean SG of the boards dried with the two schedules was essentially the same. The estimated percentage of juvenile wood content was 31.53 and 34.84 percent for the ET and HT charges, respectively. Figure 2 shows a comparison of juvenile wood distribution for the two charges. There seemed to be no particular trend in the distribution between the two charges. The mean ring count per inch was about 4.5 for both charges. Very few pieces had a ring count less than 2, which is considered to be fast-grown wood (1). Knots in some boards were fairly large with the maximum knot area up to 16 in.² (103.2 cm²). The average of the largest knot area for all boards was 3.9 in.² (25.2 cm²).

**FINAL MC AND WARP**

The average final MC for each charge was essentially the same (Table 2). The spread in the final MC was higher for the boards from the HT charge compared to the ET charge.

The maximum crook averaged 0.253 inches (6.43 mm) and 0.206 inches (5.23 mm) from the ET and HT charges, respectively. The results of the two-sample comparison procedure showed that the crook value from the ET charge was significantly higher than that from the HT charge at the 95 percent confidence level. The maximum bow averaged 0.182 inches (4.63 mm) for the ET charge and 0.171 inches (4.34 mm) for the HT charge. Twist averaged 0.256 inches (6.50 mm) for the ET charge and 0.244 inches (6.20 mm) for the HT charge. Both bow and twist were slightly higher from the ET charge. However, no significant difference was found in bow and twist between the two charges. These results for plantation-grown SYP lumber seemed to agree with the conclusion reached by earlier investigations (6,9) that HT drying under restraint produces lumber with higher or at least similar quality. Another advantage of HT drying is reduction in overall drying time, about 42 percent in this study compared with the ET schedule.

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**INFLUENCE OF WOOD PROPERTIES ON WARP**

Table 3 shows results of the multiple-correlation analysis for the effects of wood properties on warp with pooled data from the two schedules. Crook co-varied significantly with the largest knot area.
area. It was observed during tests that quite a number of boards had large spike-knots along one or both of the board edges. The knots might have caused these boards to crook significantly during drying. Bow did not correlate to any of the four properties. Twist was shown to co-vary with SG, juvenile wood content, and ring count significantly at the 95 percent confidence level. Figure 3 shows twist as a function of SG (top), juvenile wood (JW) content (middle), and ring count per inch (bottom). There was an increasing trend of twist with decreased SG, increased JW content, and reduced number of rings per inch. The distribution of out-of-kiln MC was too narrow to allow conclusions about its effect on warp. The presence of pith in some of the test boards did not show significant effects on warp development.

There was a considerable variation in crook, bow, and twist among the test lumber. Even though some significant correlations were found between crook, twist, and certain wood properties, no significant conclusion can be drawn regarding using these correlations as predictors for warp development during drying. This result supports the conclusion that the effects of most growth characteristics on warp are suppressed by such factors as drying schedule, restraint applied to lumber during drying, and sawing patterns (1). Thus, measurements on more fundamental properties such as variation of longitudinal shrinkage, strength properties, and mechano-sorptive deformation among various wood types and location of the juvenile wood within a board may shed more light on these correlations.

**Summary and Conclusions**

Plantation-grown 2 by 6 SYP lumber was dried to study effects of kiln schedules (elevated and high temperature) and certain lumber properties on warp formation. It was found that boards dried with the ET schedule had significantly higher crook than those from the HT schedule. Bow and twist from the ET schedule were also higher, but no significant difference was found between the two schedules. Crook was shown to co-vary with the largest knot area. Twist co-varied significantly with SG, juvenile wood content, and ring count for the test lumber. Results of this study should interest lumber manufacturers who dry 2 by 6 plantation SYP using ET and/or HT
schedules. A further study investigating the effect of growth ring angle with board surface, longitudinal shrinkage, stress-wave modulus, and mechanosorptive deformation on warp in SYP is underway.

LITERATURE CITED