EFFECTS OF ELEVATED AND HIGH-TEMPERATURE SCHEDULES ON WARP IN SOUTHERN YELLOW PINE LUMBER

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Abstract

One hundred and ninety-two pieces of matched 2x6 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.

Introduction

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% 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 prevents its effective utilization.

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

Several investigations have been conducted to study effects of kiln schedules on warping behavior in SYP (5,6,7,8). Hopkins et al. (5) investigated effects of CT and ET schedules on warp in drying SYP. Koch (6,7) developed several approaches to dry 2x4 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

2x6 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 has 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 Methods

Log Selection and Sawing

Twenty five 8-ft (2.44 m) logs of plantation-grown loblolly pine (*Pinus taeda, L.*) with an average 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 2x6 lumber. Actual size of the lumber was 1.53x5.65-inch (38.9x143.5-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 (0.00455 kg). Board thickness and width were measured with a digital caliper from one end. 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 Kgs) were placed on the top of the stack to help restrain the lumber during drying.

Kiln Drying

Matched batches of lumber were dried in a steam-heated kiln, one with an ET schedule and the other with a HT schedule (Figure1). 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 web 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 hrs with the HT schedule. During drying, fan direction was reversed every 8 hrs.

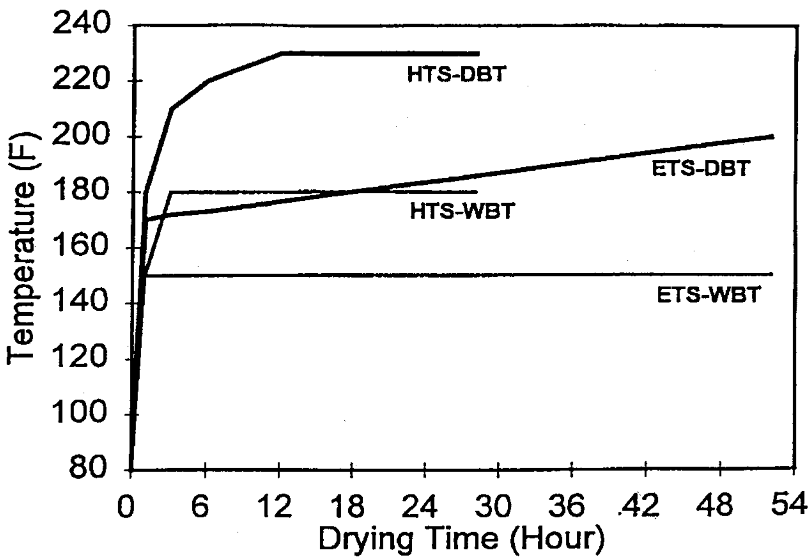

FIGURE 1. Kiln schedules used in the study. ETS: elevated temperature schedule; HTS: high-temperature schedule; DBT: dry bulb temperature; WBT: wet bulb temperature.

Measurements of Dry Boards

Lumber was allowed to cool before unstacking. Board weight, width, and thickness were measured. 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.

Crook and bow were measured by placing the board (flatwise for crook and edgewise for bow) on a L-shape 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 oven dry board weight. Green MC of each piece was then calculated using the oven-dry and green weights. Specific gravity was calculated using the oven-dry weight and green volume for each board. The calculated SG was then converted to a value corresponding to wood volume at 12% MC (10).

The maximum crook and bow among the seven readings from each piece was sorted out. Statistical comparisons were made on final MC, maximum crook, maximum bow, and twist from the two schedules. To show 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).

Results and Discussion

Lumber Properties

Table 1 summarizes the properties of the test lumber. Mean green MC was about 100% for both charges. This value is close to reported green MC value for southern pine lumber (10). The mean SG of the boards dried with the HT schedule was about 0.01 higher than that of the boards dried with the ET schedule, but no significant difference was found between the two groups. The estimated percentage of juvenile wood content was 31.53% and 34.84% 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 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 cm^2). The average of the largest knot area for all boards was 3.9 in^2 (24.5 cm^2).

TABLE 1. Summary of board properties by charge.

Properties	Kiln schedule		p-value
	Elevated Temperature	High Temperature	
Green MC (%)	100.0 (27.3) [a]	100.3 (29.1)	0.93976 (NSD) [b]
Specific Gravity [c]	0.49 (0.05)	0.50 (0.05)	0.11337 (NSD)
Juvenile Wood (%)	31.53 (33.19)	34.84 (29.79)	0.46945 (NSD)
Ring Count Per Inch	4.32 (1.49)	4.51(2.12)	0.48152 (NSD)
Largest Knot Area (In^2)	3.99 (3.13)	3.82 (3.51)	0.72648 (NSD)

[a] Values in parentheses are standard deviations based on ninety-six boards.
[b] NSD - not significantly different at 95% confidence level.
[c] Specific gravity is based on oven-dry wood weight and volume at 12% MC.

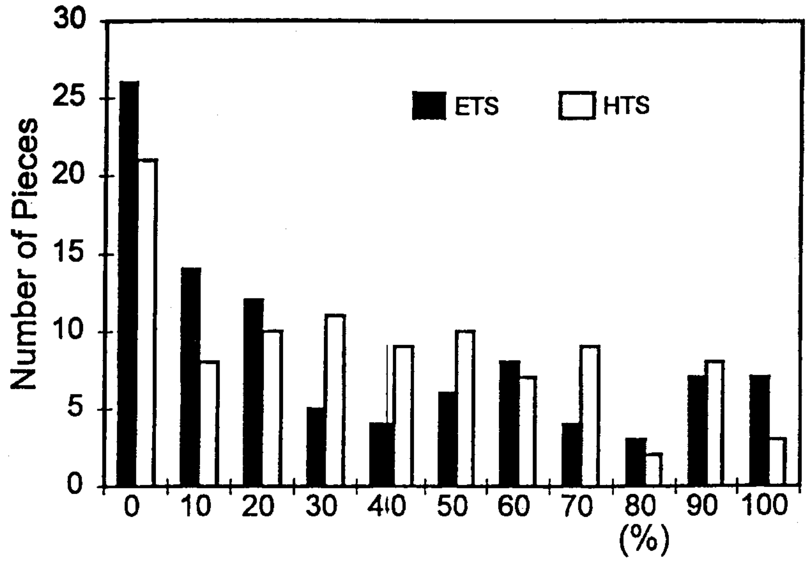

FIGURE 2. Distribution of juvenile wood content in the test lumber dried with elevated temperature schedule (ETS) and high-temperature schedule (HTS).

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 that of the ET charge.

TABLE 2. Summary of final MC and mean values of crook, bow, and twist for the test lumber.

	Kiln schedule		
Properties	Elevated Temperature	High Temperature	p-value
Final MC (%)	12.7 (1.6) [a]	12.3 (2.3)	0.61292 (NSD) [b]
Crook (Inch)	0.253 (0.145)	0.206 (0.159)	0.03676 (SD) [c]
Bow (Inch)	0.182 (0.092)	0.171 (0.117)	0.48427 (NSD)
Twist (Inch)	0.256 (0.225)	0.244 (0.184)	0.68908 (NSD)

[a] Values in parentheses are standard deviations based on ninety-six boards.
[b] NSD - not significantly different at 95% confidence level.
[c] SD - significantly different at 95% confidence level.

The maximum crook averaged 0.253 inches (6.43 mm) and 0.206 inches (5.23 mm) from the ET and HT charges, respectively. Statistical comparisons showed that the crook value from the ET charge was significantly higher than that from the HT charge at 95% 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 seem 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 45% in this study compared to the ET schedule. This will greatly increase overall kiln capacity for a given facility.

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 reducing warp in drying of softwood lumber.

Influence of Wood Properties on Warp

Table 3 shows results of 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. 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% confidence level. Figure 3 shows twist as a function of SG (Fig. 3a), juvenile wood (JW) content (Fig. 3b), and ring count per inch (Fig. 3c). 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 conclusion about its effect on warp.

TABLE 3. Results of multiple correlation analysis for the effects of wood properties on warp with the pooled data from two schedules. Data shown in the table is p-value.

Warp	Specific Gravity	Juvenile Wood	Ring Count	Knot Area
Crook	0.1979 (NS [a])	0.3795 (NS)	0.1729 (NS)	0.0085 (S)
Bow	0.1608 (NS)	0.4664 (NS)	0.8136 (NS)	0.1704 (NS)
Twist	0.0006 (S [b])	0.0000 (S)	0.0037 (S)	0.2821 (NS)

[a] NS - not significant at 95% confidence level.
[b] S - significant at 95% confidence level.

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 the use of 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 Maccan-sorptive deformation among various wood types may shed more light on these correlations.

Summary and Conclusions

Plantation-grown 2x6 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 2x6 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 Maccan-sorptive deformation on warp in SYP is underway.

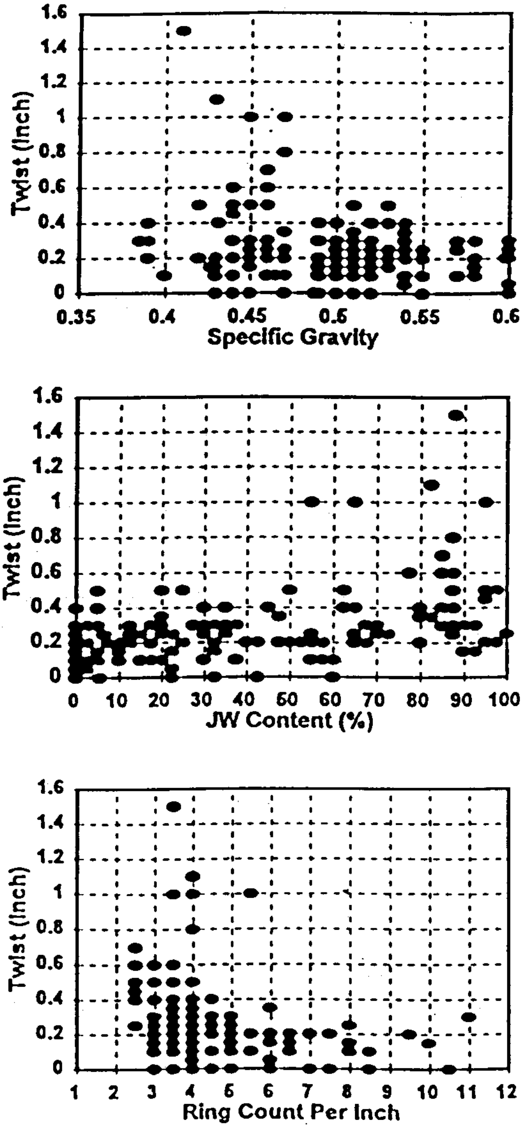

FIGURE 3. Twist as a function of wood growth properties. a) specific gravity, b) juvenile wood (JW) content, and c) ring count.

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