Analysis of Warp in Lumber Manufactured from Suppressed-Growth Douglas-Fir

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Introduction

The Watershed Research and Training Center (WRTC) in Hayfork, California, manufactured lumber as part of a program to develop economic opportunities in a remote, rural community with high unemployment resulting from a sawmill closure. The source of the lumber was the Hayfork watershed that contains numerous stands of densely spaced, slow-growing Douglas-fir trees that contribute to a significant fire hazard in the region. This suppressed Douglas-fir is the result of past harvesting practices and fire suppression efforts in the Trinity National Forest.

The trees were harvested with a mini-skyline harvester built by the WRTC team. The trees are mostly 80 to 90 years old with an average diameter at breast height (d.b.h.) of 6 to 8 in. Two weeks after harvest the logs were milled on a portable scragg/chipper type mill designed to produce 2-in. dimension size lumber from small logs. In order to gain maximum value from this material and to help recover the high cost of processing small stems the dimension lumber was resawn into 4/4 lumber.

The close grain and small, tight knot character of this lumber makes it an attractive material for high-value end uses such as paneling, furniture, and flooring. Unfortunately, first attempts at producing dry lumber from these small trees exhibited a significant twist problem which precluded its use in many of the higher-value products needed to make the process economically viable.

The extent of the twist problem was documented in a preliminary visit to the mill site. The samples are biased as an unknown quantity of straight boards were removed and remanufactured before the visit. Twist was measured in a total of 112 eight-ft. long boards that were dried to an average moisture content (MC) of 10.8 percent. These results were compared to the twist allowances for various lumber grades as defined by the Western Wood Products Association (WWPA). To be acceptable in most higher dimension lumber grades the amount of twist present must be less than one-half of the medium twist category (9.53 mm for 4-in. wide and 14.3 mm for 6-in. wide boards).

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For finish and lumber grades much less twist is allowed (1.59 mm for 4-in. and 2.38 mm for 6-in. wide boards). As seen in Table 1, the magnitude of twist essentially precludes the use of this material for higher-value products. Of this preliminary sample, 22 percent had more twist than allowed in the dimension lumber grading rules (Table 1), and 84 percent had more twist than allowed in the B or better select lumber grade. The twist limits in the grading rules for select lumber were used even though this material has a higher frequency of knots than would be allowed for these grades, because it is believed that any use of this material in high-value products would have to meet these criteria.

Excessive warp in lumber from small-diameter trees is a common problem that has been well documented in many young-growth trees with a high proportion of juvenile wood. The problem has not been as well studied in lumber produced from older, suppressed-growth, small-diameter trees. It was also thought that spiral grain might play a major role in the development of twist. As expected, the analysis of the preliminary data showed that warp was greatest in the boards that are from zones close to the pith (Fig. 1). The average twist in boards with the pith present in one end was 10.2 mm or 50 percent greater than the twist in boards with no presence of pith (6.0 mm) and in the boards with pith on both ends it was 9.0 mm or 35 percent greater.

Objectives

This study was undertaken to determine if warp reduction methods found to be successful with young-growth lumber are effective in reducing warp in lumber from suppressed-growth trees. The purpose of this study was to evaluate warp in suppressed-growth Douglas-fir and to determine if lumber drying techniques can influence the magnitude of warp. The objectives were:

- evaluate twist, cup, bow, and crook in suppressed-growth Douglas-fir,
- determine if warp can be reduced by drying methods, and
- analyze the relationship between warp and basic wood properties.

The study analyzed the relationship between warp and the following parameters: board width, drying rate, drying conditions, top-load restraint, and the basic wood properties of growth rate, specific gravity, MC, pith, and spiral grain.

Experimental Design

Warp differences between 8 different drying treatments were analyzed. Two levels each of drying schedule, top-load restraint (200 lb/ft.[2]), and steam conditioning before drying (pre-steam) were tested resulting in the following 8 treatments:

1. Steam-heated schedule, restraint, no pre-steam (S-R)
2. Dehumidification schedule, restraint, no pre-steam (D-R)
3. Steam-heated schedule, no restraint, no pre-steam (S)
4. Dehumidification schedule, no restraint, no pre-steam (D)
5. Steam-heated schedule, restraint, pre-steam (S-R-P)
6. Dehumidification schedule, restraint, pre-steam (D-R-P)

Table 1 *.–Preliminary mill data describing the twist problem.*

Sample	Average twist	Percentage not meeting dimensional grade	Percentage not meeting B Select grade
(in.)	(mm)	-----(%)----	
1. S4S, 1 by 4	15.7	86	93
2. Rough, 1 by 3 to 6	11.0	19	100
3. Rough, 1 by 3 to 6	8.2	9	77
4. Rough, 2 by 6	4.6	0	70
5. Rough, 1 by 6	4.9	0	75
Overall =	8.9	22	84

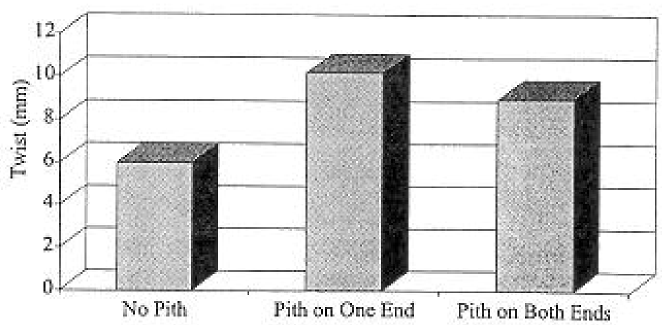

Figure 1.–*Apparent pith effect from the preliminary mill data.*

7. Steam-heated schedule, no restraint, pre-steam (S-P)
8. Dehumidification schedule, no restraint, pre-steam (D-P)

An attempt was made to distribute the specimen boards evenly between treatments according to the board width and the presence of pith. The presence of pith was defined as being visible in either end of the board or being expressed along one-third of the board length on either wide face. Because of the lower number of 6-in. wide boards received it was not possible to adequately represent the board width levels in all 8 treatments. The design was modified to have an equal distribution in treatment groups 1 through 6. Treatment groups 7 and 8 were assigned all 4-in. wide boards. This arrangement allowed us to compare the effect of board width in the treatments with the most likely chance of reducing warp (based on *a-prior* knowledge).

Other factors known to affect warp such as board dimensions, MC, specific gravity, and spiral grain were also measured in each board. Green warp was measured in each board to adjust the dry warp measurements for any effect of growth stresses.

Sample Material

The lumber used in this study was from freshly harvested, suppressed-growth, Douglas-fir trees. The harvest yielded 212 logs that were milled to 4-in. and 6-in. widths and 9.5 ft. long. The log size (Table 2) averaged 6.95-in. in diameter (large end) ranging from 5.10-in. to 10.50-in. with an average taper quotient of 0.93 (ratio of small end to large end diameter). The estimated age of the trees ranged from 70 to 90 years resulting in a growth rate estimate of 20 years per inch of radius.

Table 2.–*Log sizes.*

	Small end	Large end	Taper
	-----(in.)-----		
Average	6.46	6.95	0.93
Standard deviation	0.96	0.97	0.05
Minimum	5.00	5.10	0.61
Maximum	9.30	10.50	1.00

Upon arrival at UCFPL, the lumber was immediately sorted into groups and prepared for testing. To retard drying, the boards were sprayed with water and kept wrapped in plastic except when the boards in a unit were being handled for green measurements. Each board was cut to an 8-ft. length as shown in Figure 2, with the remainder of the board used for MC, specific gravity, and spiral grain measurements.

Drying Schedules

Treatments 1, 3, 5, and 7 followed the steam-heated schedule shown in Table 3. Treatments 2, 4, 6, and 8 followed the dehumidification schedule shown in Table 4.

Treatments 1, 2, 5, and 6 were dried with a top load restraint of 200 lb/ft^2 provided by a 16-in. thick solid concrete block that completely covered the top of the charge (3-ft. wide by 8-ft. long). The concrete was placed on the top of the charge the same day that the green warp was measured and remained on the charge throughout the drying period and for 48 hours after drying as the lumber cooled.

Treatments 5, 6, 7, and 8 were exposed to a steam environment at 175°F for 4 hours. For these pre-steam treatments, the vents were closed and the wet-bulb set point was set at 175°F. After pre-steaming treatments 6 and 8, the dehumidification schedule was started at step 2 of the schedule shown in Table 4 since the kiln was already pre-heated.

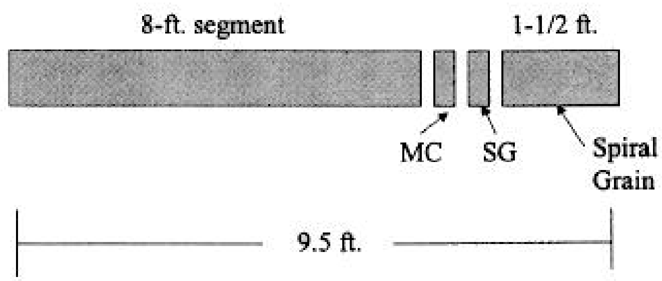

Figure 2.–*An 8-ft. segment of each board was used for the warp/drying portion of the study, two 1-in. segments were used for specific gravity and moisture content measurements and the remainder of the 1-1/2 ft. segment was used for spiral grain measurements.*

Measurement Techniques

Specific gravity, based on the oven-dry mass and green volume, and the initial MC of all sample boards was measured by standard gravimetric methods. The final MC of each board was measured at three locations (quarter points along the length of the board) with both a conductance moisture meter and a capacitance moisture meter. The green and dry board dimensions of width, thickness and length were measured at quarter points along the length of the board. Warp measurements were performed at both the green and final dried MC in each board according to the procedure outlined below. Measurements were made with a wedge/ digital gauge apparatus to 0.01 mm.

- Twist is distortion in the board defined as the displacement of one corner of a board from a flat surface when the other three corners of the wide face were held firmly against the flat surface. Twist was measured at one point at the end of the specimen board. The measured twist value was adjusted to a common 100 mm board width so values between different board widths could be compared.
- Bow is distortion in the board defined as the displacement of the wide face of a board from a flat surface when one end of the board is held firmly against the flat surface. Bow was measured at the width mid-point on the end of the specimen board.
- Crook is distortion in the board defined as the displacement of the narrow face of a board from a flat surface when one end of the board is held firmly against the flat surface. Crook was measured at the thickness mid-point on the end of the specimen board.
- Cup is defined as the maximum distortion from a straight edge placed across the width of a board. Cup was measured at quarter points along the length of the board.
- Spiral grain is defined as the axial cell orientation of the longitudinal elements with respect to the axis of the tree. It was measured as the angle formed by a scribed line in a tangential surface and the long axis of the board. The line was scribed by pulling a sharp point along the length of a section of the board in the earlywood zone of a true tangential surface. If a true tangential surface was not expressed on a surface the measurement section was resawn to create one.

Also documented for each board were the growth rate and the estimated distance from the pith to the surface on which spiral grain was measured.

Results

The basic properties of the study material are reported in Table 5. Where appropriate, these values were compared to the species average values reported in the *Wood Handbook*. Compared to the species average, the specific gravity ($SG_{o,g}$) of the study material is slightly higher (0.47 vs. 0.45), the MC range greater, and the shrinkage to an average 8 percent MC lower. The higher $SG_{o,g}$ and lower shrinkage suggest that the study material is at the high end of quality for the species but the differences are small and probably within the realm of

Table 3.–*Steam-heated kiln schedule.*

Step	MC[a]	Dry-bulb temp.	Wet-bulb temp.
	(%)	----(°F)----	
1	> 30	150	143
2	30 to 25	160	150
3	25 to 20	160	145
4	20 to 15	170	150
5	15 to 8	180	130
6	Condition for 4 hrs.	180	171

[a] Mean of kiln samples.

Table 4.–*Dehumidification kiln schedule.*

Step	MC[a]	Dry-bulb temp.	Wet-bulb temp.
	(%)	----(°F)----	
Warmup	0 to 2 hrs.	90	88
	2 to 4 hrs.	100	98
	4 to 24 hrs.	110	107
	24 to 48 hrs.	120	116
2	> 30	130	123
3	30 to 25	140	130
4	25 to 20	140	125
5	20 to 15	150	130
6	15 to 8	160	110
7	Condition for 4 hrs.	160	151

[a] Mean of kiln samples.

natural species variation. Further study is needed to conclude that the suppressed-growth material is of better quality.

The amount of warp present in the lumber after drying to an average of 8 percent MC is reported in Table 6 as the average warp for each drying treatment. The average bow, crook, and cup are well within the limits allowed for select and finish lumber by the Western Wood Products Association. The B&Better grades allow up to 38.10 mm of bow, 6.35 mm of crook, and 0.79 mm of cup for nominal 6-in. wide boards (crook and bow allowances were adjusted to account for measurement method). Average twist, however, was significantly greater in all drying treatments than the allowed 1.76 mm for B&Better for a 100 mm board width.

Analysis of covariance, multivariate analysis was used to examine the statistical relationships between warp and the treatment and wood property variables (Table 7). Very little relationship was found between crook, bow, cup, and the measured variables, as evidenced by the low R-square values (0.078 to 0.197). The model did a better job of explaining the variation in twist measurements (R-square of 0.405).

Although cup was found to be highly significant with drying treatment and board width, and crook was found to be highly significant with specific gravity, these relationships are suspicious because so much variation was unexplained by the model. For the same reason, the lack of a significant relationship between the other variables and crook, bow and cup cannot be confirmed.

A highly significant effect (probability level of 0.0001) was found between twist and drying treatment, spiral grain angle, board width, the presence of pith, green MC, and specific gravity. The effect was positive for spiral grain and specific gravity, twist increased as the variable increased in value.

Table 5.–*Comparison of study material wood properties to the expected species average.*

	Study material	*Wood Handbook*
Specific gravity ($SG_{o,g}$)	0.47	0.45
MC range (%) (heartwood to sapwood)	22 to 145	37 to 115
Shrinkage to 8% MC (width + thickness)	6.5%	8.61%

Table 6.–*Average warp values for each drying treatment.*

	Drying treatment[a]							
	S-R	D-R	S	D	S-R-PS	D-R-PS	S-PS	D-PS
	(mm)							
Twist	4.0	3.8	6.1	5.2	3.6	4.1	6.7	6.9
Bow	2.3	2.7	2.6	5.8	4.3	2.3	3.2	2.0
Crook	2.7	2.5	3.2	3.5	4.2	2.0	2.7	3.1
Cup	0.2	0.1	0.1	0.4	0.0	0.0	0.1	0.1

[a] S = steam-heated, D = dehumidification, R = restraint, PS = pre-steam conditioning.

Table 7.–*Probability values from the analysis of covariance.*

	Twist	Crook	Bow	Cup
Treatment	0.0001	0.6354	0.1709	0.0001
Spiral grain	0.0001	0.4929	0.0242	0.0638
Board width	0.0001	0.7060	0.0168	0.0001
Pith presence	0.0001	0.0339	0.2207	0.421
Green MC	0.0001	0.1309	0.4576	0.1821
Dry MC	0.8107	0.8547	0.1274	0.7810
Specific gravity	0.0001	0.0001	0.5962	0.2173
R-square	0.405	0.078	0.149	0.197

As green MC increased the amount of twist decreased. This relationship is related to the pith presence; the boards closest to the pith have the lowest green MC (more heartwood) and the boards closest to the bark have the highest MC (more sapwood). More detail on the relationships between twist, drying treatment, the presence of pith and board width are discussed below.

Of the different drying treatments, only the treatments with top-load restraint (treatments 1, 2, 5, and 6) had a statistically significant effect on twist. The restraint offered by 200 lb/ft.^{2} distributed evenly across the top of the lumber stack reduced the average twist to 4 mm or less (Fig. 3). The treatments without the top-load restraint (3, 4, 7, and 8) had twist of 5 mm or greater. Although the restraint reduced the amount of twist it did not eliminate it. The average twist for each restrained treatment was still greater than the lumber grading allowance for B&Better Select.

The average twist for the treatments dried according to the steam-heated schedule (treatments 1, 3, 5, and 7) was not significantly different than the twist in the dehumidification treatments (2, 4, 6, and 8) (Fig. 5). Similarly, there was no significant difference between the treatments that were steam preconditioned (5, 6, 7, and 8) and those that were not preconditioned (1, 2, 3, and 4), as is illustrated in Figure 5.

Combining all of the data, regardless of the drying treatment, some interesting observations are noted concerning pith and board width (Fig. 6). The boards with the pith present had 2 to 3 times more twist than the boards without pith, and this effect was greatest for the small boards (4-in. wide) where the pith boards had an average of 7.8

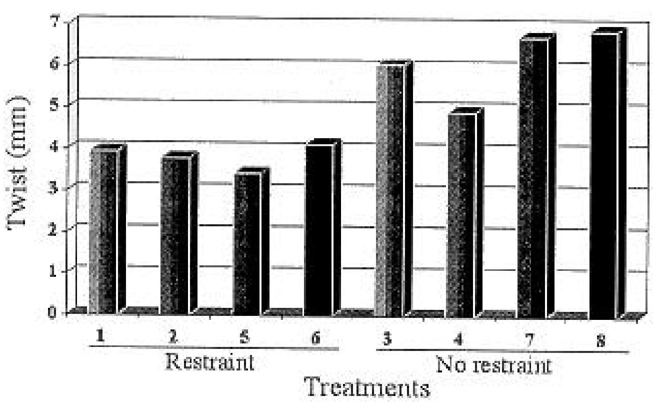

***Figure** 3.–Twist for each drying treatment showing the effect of top-load restraint.*

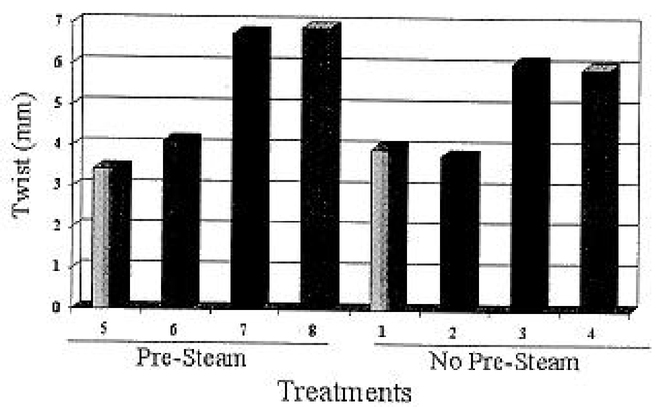

***Figure 5.**–Twist for each drying treatment grouped to show the effect of pre-steam conditioning.*

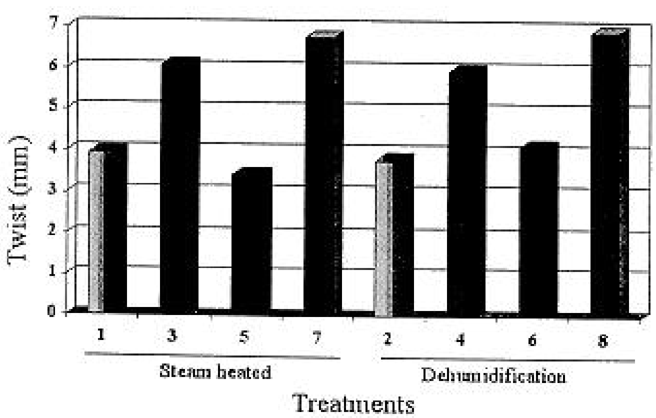

***Figure 4.**–Twist for each drying treatment grouped to show the effect of drying schedule.*

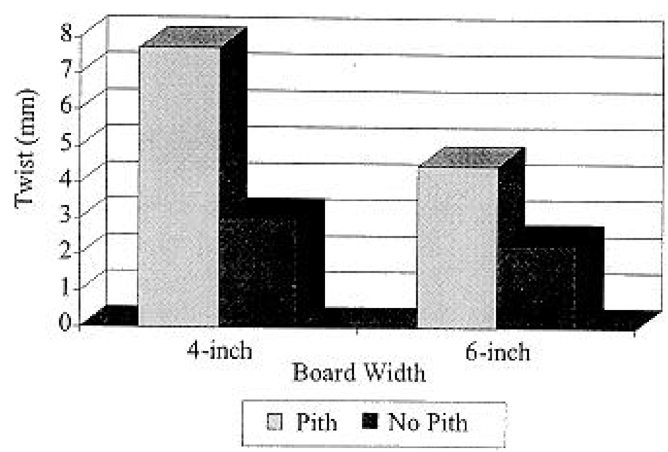

***Figure 6.**–Average twist grouped to show the effect of board width and the presence of the pith in a board.*

mm of twist and the boards without pith had 3.0 mm. A similar relationship existed for the 6-in. wide boards. It is also evident that the 4-in. boards exhibited more twist than the 6-in. boards, for both the pith and no pith categories. Further analysis is necessary to understand this observation but it is likely that it is related to the fact that the 4-in. boards with pith came from the smallest trees in the study.

Conclusions and Summary

Twist was confirmed as a major problem for the utilization of small-diameter, suppressed-growth Douglas-fir. Other forms of warp (cup, bow, and crook) were not severe enough to limit the use of this material in high-grade products.

The average twist in this study material was greater than that allowed in the higher lumber grades. A top-load restraint of 200 lb/ft.^{2} significantly reduced the magnitude of twist but did not reduce it below the grade allowance for high-grade select lumber. The drying schedule and pre-conditioning of the lumber with steam were not effective in reducing twist.

Cup, bow, and crook were not adequately explained by any of the measured parameters and the small amount of these forms of warp found suggests it is not an important consideration in the utilization of suppressed-growth Douglas-fir. Twist was influenced by spiral grain, board width, pith presence, green MC, and specific gravity. All of these factors are related to tree size and the direction of the effect suggests that the smaller the tree the greater the twist. Further study is necessary to validate this observation. The twist model has a high degree of unexplained variation suggesting other factors, such as sawing pattern, may be important. Clearly, if this material is to be used in higher value material it will be necessary to solve the twist problem. It is unlikely that drying methods will be enough. Other solutions are needed.

Issues Related to Handling the Influx of Small-Diameter Timber in Western North America

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