SEVERE WARP DEVELOPMENT IN YOUNG-GROWTH PONDEROSA PINE STUDS

John R. Shelly, Donald G. Arganbright, and *Michael Birnbach*

Forest Products Laboratory, College of Natural Resources
University of California, Richmond, CA 94804

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ABSTRACT

Anatomical and physical characteristics of severely warped, young-growth, ponderosa pine studs, dried by two different methods, were analyzed with respect to bow, crook, and twist. Statistical analysis revealed that: (1) drying method had no effect on the relationship between warp and the wood characteristics studied; and (2) a large portion of the variation in warp could not be explained by any of the measured factors. Of the characteristics analyzed, the presence of the pith appeared to have the greatest effect on warp severity. Contrary to expectation, little compression wood was found and was consequently of minor importance in the development of severe warp. Although studs with a layer of heartwood along one face were prone to severe crook, there was no apparent relationship between warp and the percentage of heartwood in a stud. Other factors such as density, knots, and grain angle could not be identified as major factors in the development of severe warp.

Keywords: Compression wood, diagonal grain, heartwood, kiln-dried, knots, juvenile wood, spiral grain, warp.

Severe warp of young-growth lumber during drying is a common occurrence for many species. If this warp-prone material is given special consideration during manufacturing, degrade losses can be minimized. For example, Hallock (1969) has shown that the yield of "in-grade" studs from young-growth material can be substantially increased by using particular sawing patterns. Other investigations have shown that warp can be further minimized by employing special drying techniques, such as drying under top load restraint and at high temperatures (Arganbright et al. 1978; McKay and Rumball 1971).

Although the use of good manufacturing practices can minimize warp in young-growth material, it continues to be a problem. In a recent study, Arganbright et al. (1978) reported degrade due to warp as high as 51% for kiln-dried young-growth ponderosa pine studs. By trying different drying techniques, they were able to obtain a 17% reduction in "out-of-grade" studs; however, 34% remained out-of-grade.

More efficient utilization of young-growth material would be realized if warp-prone material could be segregated prior to drying. To accomplish this goal, it is necessary to understand the mechanism of severe warp and be able to identify characteristics that cause it.

It is generally believed that warp in young-growth material is a function of the anatomical characteristics of wood near the pith (juvenile wood) and of how it differs from more mature wood. Many investigations have been aimed at analyzing this relationship.

The most obvious cause of warp in lumber that contains juvenile wood is the difference in longitudinal shrinkage between juvenile and mature wood. This difference is commonly attributed to the relatively large amount of compression wood associated with juvenile wood (Voorhies 1971; Gaby 1972; DuToit 1963)

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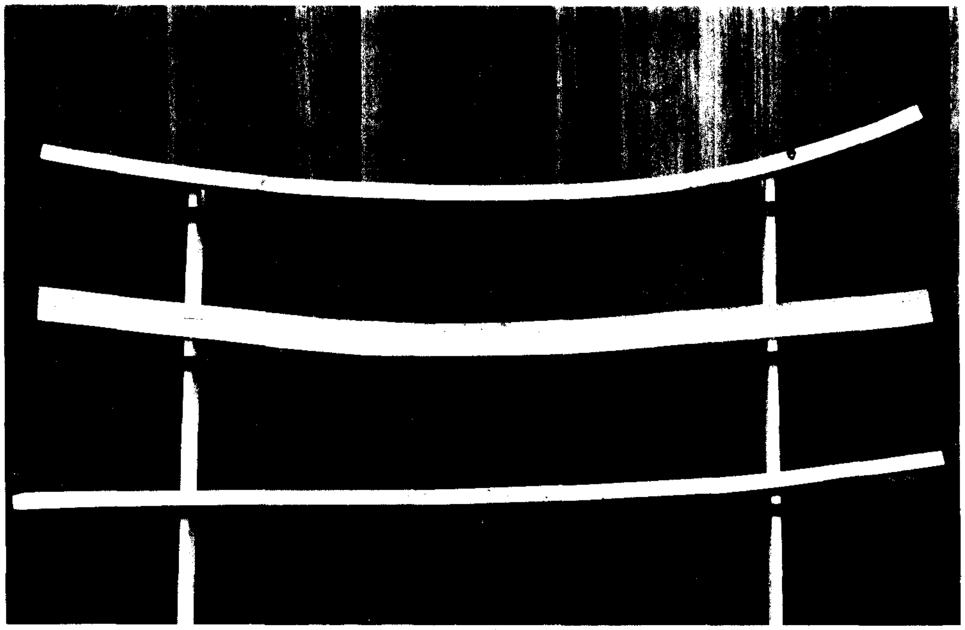

FIG. 1. Severely warped ponderosa pine studs showing bow, crook, twist (top to bottom).

and the large fibril angle common to wood laid down in the early stages of growth (Voorhies 1971).

Another factor that may influence severe warp, particularly twist, is spiral grain (Kloot and Page 1959; Balodis 1972; Noskowiak 1963). In general, the angle of the grain (with respect to the longitudinal axis of the pith) increases with increasing age to a maximum value at about 10 years, then it decreases and eventually changes direction (Noskowiak 1963). Although this pattern is highly variable for different species, it does indicate greater spiral grain for young-growth material, which in turn leads to greater twist (Van der Merwe 1973; Balodis 1972).

Other factors such as the presence of both heartwood and sapwood in the same piece (Arganbright et al. 1978), presence of knots (Kloot and Page 1959), and the angle of the grain with respect to the stud surface (diagonal grain) may also have an effect on the development of warp in this type of material.

The effect of many of these factors on warp has been analyzed independently, but few investigators have attempted to analyze them jointly. A study of warp in young-growth radiata pine analyzed the combined effects of grain angle and knots but did not find any significant relation (Kloot and Page 1959). Gaby (1972), studying the effect of compression wood and location of the pith on warp in southern pine, concluded that predictions based on these factors were unreliable because of excessive variation that was not explained.

The purpose of the study reported here was to determine which anatomical and physical properties were responsible for the severe warp that occurred in a sample of young-growth ponderosa pine studs, and if the effects of these properties were dependent on the method of drying. On the basis of these findings the results were analyzed to determine if severe warp could be predicted, thus establishing a criterion for drying segregation. The specific parameters considered (with respect to bow, crook, and twist) included: (1) knots, (2) moisture content, (3) density, (4) compression wood, (5) heartwood, (6) pith, (7) diagonal grain, and (8) spiral grain.

SAMPLE MATERIAL

The studs (8 foot × 2 inch × 4 inch) used in this study were selected from warped studs used in a previous study (Arganbright et al. 1978). Samples were selected only from the studs that had fallen out-of-grade because of severe warp. Although this decision eliminated the possibility of observing the effects of the test parameters in boards that did not warp, it provided for a larger sample size of severely warped material. From the out-of-grade studs, 40 studs were selected from each of four test runs. Two of the test runs had been air-dried without any top load restraint, and the other two were kiln-dried with top load restraint (1074 kg/m^2) using a conventional drying schedule. The severity of warp that was encountered is illustrated in Fig. 1.

EXPERIMENTAL PROCEDURES

The studs were conditioned in a dry kiln for two weeks to obtain an equilibrium moisture content of approximately 9% in order to eliminate MC as a variable.

Warp was measured as the maximum deviation from a flat plane (Arganbright et al. 1978). After warp was measured, the studs were cut into specimens as illustrated in Fig. 2.

The average and difference between maximum and minimum values for moisture content and density were measured, for each stud, on the two ½-inch wafers. The moisture content (MC) was calculated from the current and oven-dry weights, and density ($D_{0,0}$) was based on the oven-dry weight and oven-dry volume.

The average amount of compression wood was estimated from the three ⅛-inch wafers (to the nearest 10%) using the technique of passing light through the specimen and observing the opaque compression wood.

The average percentage of heartwood (to the nearest 10%), the position of the heartwood/sapwood boundary, and the presence of the pith were also determined from the ⅛-inch wafers. If the heartwood/sapwood boundary was such that one edge or face (of any of the three wafers) was all heartwood, the stud was classified as a crown stud. If the pith was present in any of the wafers, the stud was listed as containing the pith.

The grain angle of each stud was assessed by measuring the diagonal grain on the radial face and the spiral grain on the tangential face of the two 12-inch specimens. The measurement technique consisted of tracing the grain angle with a scribe and measuring the angle formed with the estimated longitudinal axis of the stud (Koehler 1955). From these data the average value, maximum value, and the difference between the maximum and minimum values were determined.

The influence of knots on the development of warp was assessed qualitatively by noting the cases of severe warp near or around the knots. At best, this approach was a crude estimate of the effect of knots and is valuable only in the sense that it identifies the more obvious cases.

The data were statistically analyzed using multiple regression techniques with bow, crook, and twist as dependent variables.

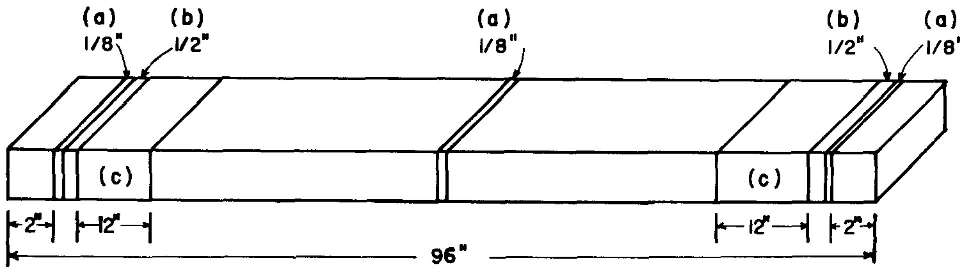

FIG. 2. Breakdown of studs into measurement specimens. (a) specimens used in measuring compression wood, heartwood, position of heartwood, and presence of pith. (b) MC and $D_{0,0}$ specimens. (c) Diagonal and spiral grain specimens.

RESULTS AND DISCUSSION

A comparison of the means of each variable (independent and dependent) revealed that there was no significant difference (at the 5% probability level) between the results of the air-dried and kiln-dried studs. For this reason, the following discussion is presented only for the air-dried studs, but it applies equally to the kiln-dried studs.

The results of this study are limited by the fact that warp was not analyzed in the studs that remained in grade. However, from an analysis of the physical and anatomical characteristics of the "out-of-grade" studs, inferences about the probable cause of severe warp in the material could be made.

The average warp of the samples was 3.5 cm in bow, 3.0 cm in crook, and 1.3 cm in twist. To put this into perspective, the allowable warp according to the Western Wood Products Association grading standards (converted into metric units) are: 1.90 cm in bow, 0.64 cm in crook, and 0.95 cm in twist. Although bow was the largest form of warp, crook was the most severe in terms of the allowable

TABLE 1. *Mean warp of air-dried studs for various categories of density, pith, heartwood boundary, and grain angle.*

Sample group	Sample size	Bow (cm)	Crook (cm)	Twist (cm)
$D_{0,0} > 0.43$	30	3.8 (3.1)[1]	4.2 (3.3)	1.1 (0.9)
$D_{0,0} < 0.43$	47	3.2 (3.8)	2.2 (2.3)	1.3 (1.1)
Pith	36	4.0 (3.4)	3.8 (3.4)	2.0 (1.9)
No pith	44	3.0 (3.5)	2.4 (2.3)	0.8 (0.8)
Crown	16	3.1 (1.7)	5.0 (3.8)	1.4 (1.0)
No crown	64	3.4 (3.7)	2.6 (2.6)	1.3 (1.1)
D. grain > 2.4°	30	3.7 (3.8)	3.5 (2.7)	1.2 (1.1)
D. grain < 2.4°	50	3.3 (3.2)	2.7 (2.9)	1.4 (1.0)
S. grain > 4.9°	37	3.5 (3.9)	3.0 (2.8)	1.5 (1.2)
S. grain < 4.9°	43	3.4 (3.0)	3.0 (2.9)	1.1 (1.0)
Overall		3.5 (3.4)	3.0 (2.9)	1.3 (1.1)

[1] Standard deviations are given in parentheses.

TABLE 2. *Variables with statistically significant relationship with warp, as determined by multiple regression.*

Warp	Test group	Significant variable[1]	Regression coefficient	95% confidence interval	R^2
Bow	air-dried	% compression wood	0.740	±0.37	0.17
	kiln-dried	none	—	—	—
Crook	air-dried	none	—	—	—
	kiln-dried	$D_{0,0}$	18.80	±12.78	0.10
Twist	air-dried	pith	1.17	±0.39	0.30
	kiln-dried	pith	0.74	±0.29	0.26

[1] Variable was significant at 5% probability level, all other variables were not significant.

standard. That is, crook was 4.7 times more severe than the allowable standard compared to 1.8 times for bow and 1.4 times for twist.

Not only was the warp found to be very severe, it was also highly variable, as can be seen by the large standard deviations obtained (Table 1). Analysis of the data revealed certain trends, but a single factor could not be found that consistently explained the severity of the warp.

Some of this large variation may be explained by the nature of the drying process. That is, as Arganbright et al. pointed out in their previous study (1978), the amount of warp that the studs developed may also be a function of how the boards are stacked to dry. For example, if the studs are of uneven thickness, a thick stud would be restrained more than a thin stud right next to it. Also it is generally agreed that lumber at the bottom of a stack warps less (more restraint) than lumber in the top layers of the stack. Thus, it is possible that some of the variation in warp was caused by the position of the stud in a drying unit, relative to the other studs.

It was apparent that some of the parameters measured had little effect on the development of severe warp. For example, variation in moisture content within and between studs was negligible, as expected, since the studs were conditioned to a 9% EMC before they were measured. Also, only 7% of the studs contained any compression wood and it was always present in only small amounts (less than 10% of the cross section). Nor was there any ascertainable relationship between warp and the percentage of heartwood or the presence of knots. Although it appeared that the more severely warped studs were affected by the presence of knots, all the studs had a high frequency of knots; thus it was not possible to ascertain whether the relationship was causal or coincidental.

Grain angle apparently had little effect on the severity of warp of the out-of-grade studs. The mean warp was similar for sample groups with spiral and diagonal grain greater and lesser than the respective averages of 4.9° and 2.4° (Table 1).

As expected, average warp was greater in studs that contained the pith (Table 1). This effect appeared to be greatest for twist (significant at 5%). The differential shrinkage characteristics and the expected greater fibril angle and spiral grain of the juvenile wood associated with the pith are the most likely causes for this relationship.

Other noteworthy differences in means were not observed for bow and twist; however, the degree of crook appeared to be affected by the average density and the location of the heartwood/sapwood boundary. The studs with density greater than the average of 0.43 or a heartwood crown exhibited nearly twice as much crook as studs less dense than the average or without crown (Table 1).

Two possible explanations for the apparent effect of density on crook but not bow or twist are that: (1) the observation is due to an anomaly, or (2) there is more restraint to warp in the vertical plane than the horizontal plane of a stack of lumber; thus the greater shrinkage that occurs with greater density has less of an effect on warp in the vertical plane (bow or twist) than it does in the horizontal plane (crook).

The effect of the position of the heartwood boundary suggests a basic difference between longitudinal shrinkage of heartwood and sapwood that may affect warp. That is, the higher green MC of sapwood combined with its faster drying rate may result in different rates of development of shrinkage in the heartwood and sapwood, or the possible presence of juvenile wood in the heartwood zone may result in a longitudinal shrinkage differential between the two zones. The fact that the majority of the crown boards observed had the heartwood along the narrow face explains why the effect was only noted for crook.

Generally, the observations made above were supported by multiple regression analysis. Exceptions were the lack of significant effect of crown on crook, and an apparent significant relationship between compression wood and bow (Table 2). However, note that the regression results are of questionable value because of the nature of the data. That is, the data were collected only from "out-of-grade" studs. Thus, the effect of the parameters on studs without warp of acceptable magnitude was not sampled.

The wide limits of the 95% confidence intervals and the low values of the multiple correlation coefficients support the initial observation that a large portion of the variation in warp could not be explained by any of the parameters considered. In other words, warp could not be effectively predicted by these parameters.

Based on the results, general observations are possible concerning the formation of severe warp. The presence of the pith was probably the major factor in causing severe warp in the ponderosa pine sampled. However, the large portion of "out-of-grade" studs that did not contain any pith (55%) and the great variability encountered indicate that it was not the sole cause. Variation in spiral grain from the pith to the outer surface was not measured, but may be a major contributor to severe warp and should be considered in future studies.

CONCLUSIONS

Severe warp in "out-of-grade" young-growth ponderosa pine studs could not be adequately explained by any of the factors examined. Regression analysis revealed a large portion of unexplained variation in bow, crook, and twist. Consequently, a basis for predicting severe warp could not be obtained. However, the following conclusions were made:

1. Method of drying had no effect on the relationship between the anatomical or physical properties of wood and the severity of warp.

2. Compression wood was found in only small amounts and did not greatly affect the development of severe warp.
3. Studs that contained pith had more severe warp than studs without pith.
4. Presence of a heartwood layer along one narrow face (crown) tended to increase the severity of crook.
5. The effect of knots on warp was not measurable.
6. Diagonal grain was not a major problem and contributed little to the severity of warp.
7. Neither average grain angle nor density had an apparent influence on bow or twist, although they had a slight influence on crook.

REFERENCES

ARGANBRIGHT, D. G., J. A. VENTURINO, AND M. GORVAD. 1978. Warp reduction in young-growth ponderosa pine studs dried by different methods with top-load restraint. For. Prod. J. 28(8):47–52.

BALODIS, V. 1972. Influence of grain angle on twist in seasoned boards. Wood Sci. 5(1):44–50.

DUTOIT, A. J. 1963. A study of the influence of compression wood on the warping of *Pinus radiata* D. Don. timber. South African For. J. No. 44:11–15.

GABY, L. J. 1972. Warping in southern pine studs. USFS Res. Paper SE For. Exp. Sta. No. SE-96.

HALLOCK, H. 1969. Sawing to reduce warp of lodgepole pine studs. USDA For. Serv. Res. Pap. FPL 102, Madison, WI.

KLOOT, N. H., AND M. W. PAGE. 1959. A study of distortion in radiata pine scathings. Div. For. Prod. Tech. Paper No. 7. CSIRO, Australia.

KOEHLER, A. 1955. Guide to determining slope of grain in lumber and veneer. Mimeo No. 1585. USDA For. Serv., FPL, Madison, WI.

MCKAY, J. F. G., AND B. L. RUMBALL. 1971. Drying of distortion-prone juvenile core radiata pine for house studs. Aust. Timber J. 37(6):43–57.

NOSKOWIAK, A. F. 1963. Spiral grain in trees . . . . A review. For. Prod. J. 13(7):266–275.

VAN DER MERWE, J. J. 1973. Strength and warp in kiln dried South African pine timber as affected by drying process, spiral grain, and other factors. CSIR Spec. Rep. HOUT 56, South Africa.

VOORHIES, G. 1971. The cause of warp in young-growth ponderosa pine lumber. Arizona Forestry Notes No. 6, School of Forestry, Northern Arizona University.