TRIALS OF DIFFERENT METHODS FOR REDUCING WARP IN YOUNG-GROWTH PONDEROSA PINE STUDS

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INTRODUCTION

This study was undertaken in response to an inquiry from industry[1] as to practical methods for reducing warp in studs cut from young-growth ponderosa pine. The following report described an investigation of drying the above-mentioned species under top-load restraint using three different drying methods.

The problems of greater degrade losses in lumber cut from small diameter logs, as compared to old-growth large diameter logs, arises from the fact that the former material contains a much higher proportion of juvenile and possibly compession wood. A large number of the boards produced from such logs will also contain the pith or will have both heartwood and sapwood which has a possible potential for warp.

The growing awareness of this problem has lead to a variety of past investigations aimed at reducing warp in softwood dimension lumber. The various techniques tried can be grouped into three general areas:

(a) Alternations of drying schedules (Arganbright and Olson, 1970).
(b) Altered sawing patterns (Hallock, 1969).
(c) Drying under restraint (Koch, 1974; Mackay and Rumball, 1972; Kuhnau and Erickson, 1976).

With the exception of the first, each of these techniques has lead to significant reductions in warp. However, the group of techniques involving drying under top-load restraint appear more practical than others because they are either less expensive, or easier to implement into a production system.

The most promising of these techniques is high-temperature drying under restraint. Unfortunately, it has never been tried on ponderosa pine. The use of high-temperature drying schedules (without restraint) is frequently said to lead to less warp (Knight, 1970) but there is little data to actually confirm this. There is, on the other hand, considerable data for radiata pine showing the effectiveness of top-load restraint. MacKay and Rumball (1972) found that the number of radiata pine studs meeting grade increased from 13.4% using no restraint to 84.3% when restrained under a load of 220 lbs/ft^2. This technique is now being commercially used in Australia with the drying of dimension radiata pine lumber (Anon, 1976).

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[1]The support of the Louisiana-Pacific Corp. is gratefully acknowledged.

The purpose of this research was to evaluate the technical feasibility of reducing warp in young-growth ponderosa pine studs using the following three different drying techniques:

1) Air-drying under a top-load restraint of approximately 200 lb/ft^2.
2) Conventional kiln-drying under top-load restraint together with initial plasticization.
3) High-temperature kiln-drying with top-load restraint and with initial plasticization.

MATERIAL AND PREPARATION

A given test unit used in this study was 3 feet wide by 8 feet long by 38 inches high. This resulted in approximately 150 boards or about 800 board feet per test run. This required some 10,000 bd. ft. of material to be supplied by the cooperator. Care was taken at the mill in selecting the material to insure that as much distortion-prone material was included as possible. For this reason, boards from smaller-diameter logs were selected rather than medium-diameter. All this material was shipped from the mill to the U. C. Forest Products Laboratory. Each board was then numbered and alternately placed into one of the 12 drying units. This was done to assure that a large number of boards from the same log would not be found in any one test unit.

Due to the limited kiln capacity, a portion of the test material remained solid-piled until a kiln was available. To avoid mold and stain development, this portion of the material was hand-dipped with a commercial anti-stain solution, completely sealed in plastic and stored out-of-doors.

As previously mentioned, test runs consisted of a 3' x 8' x 38" unit. Using these dimensions and a required top-load restraint of 200 lbs/ft^2, it was calculated that a concrete block 16" thick by 8' long by 3' wide would yield the approximate load required. Thus, forms were constructed and 4 reinforced-concrete blocks formed to these dimensions (Fig. 1).

EXPERIMENTAL PROCEDURES

A total of 12 different test runs were made which are listed in Table 1. Each of the tests being tried had a control for comparative purposes. That is, air-drying under restraint was compared to air-drying without restraint. Since the material used in any given test charge might not have been totally representative, it was also felt absolutely necessary to use at least one replication for each test.

The air-drying tests with restraint were used because of the simplicity of the method and its ease of implementation into the cooperator's present operation. The use of conventional and high-temperature drying with restraint seem to be self-evident.

All test units were stuck flush at both ends and on center with 1/2" thick by 1 1/2" wide stickers. All four air-drying units were stuck at the same time and placed on an asphalt work area with prevailing winds blowing parallel to the 8 foot length of the units. Each unit was 5' from the other with no nearby obstructions (Fig. 1). The air-drying conditions at the Laboratory are in no way similar to those of the cooperator's site. This was not felt to be a problem, however, that would significantly affect the test results since the objective of the work was to compare the different techniques and not drying times needed.

The kiln runs were made using two 1000 bd. ft. experimental dry kilns, one operating at conventional temperatures and the second capable of reaching 240°F. Air velocities for the conventional-temperature test runs were adjusted to 300 fpm on the leaving air side and 600 fpm for the high-temperature test runs. Air circulation was reversed every 6 hours when using the conventional schedule. No fan reversal was used in the high-temperature drying.

As mentioned in the introduction, the use of an initial plasticization period prior to starting the kiln schedule has been investigated with use of restraint. In this light, both conventional and high-temperature schedules used in the restrained loads were subjected to a 4 hour pre-plasticization period before starting the schedule. The plasticization treatment consisted of setting the wet-bulb to 180°F with the dry bulb off.

The schedules used for the conventional kiln-drying runs and that for the high-temperature runs are given in Table 2.

Since warp development appears to be strongly related to final moisture content, it is important to dry each different charge to the same final moisture content if possible. A target final moisture content of 15% was chosen since at this value the majority of the pieces would be below the 19% moisture content Lumber Standards requirement. Twenty boards, located on the outside edges of the units were periodically metered with an electrical resistance meter to determine when the charge had reached the desired final moisture content.

Table 1. List of Test Runs

Test Run Number	Type of Test
1	Control for air drying (Replication 1)
2	Control for air drying (Replication 2)
3	Air drying under 200 lb/ ft^2 top-load restraint (Replication 1)
4	Air drying under 200 lb/ ft^2 top-load restraint (Replication 2)
5	Control for kiln drying (Replication 1)
6	Control for kiln drying (Replication 2)
7	Kiln drying under 200 lb/ ft^2 top-load restraint (Replication 1)
8	Kiln drying under 200 lb/ ft^2 top-load restraint (Replication 2)
9	Control for high temperature drying (Replication 1)
10	Control for high temperature drying (Replication 2)
11	High temperature drying under 200 lb/ ft^2 top-load restraint (Replication 1)
12	High temperature drying under 200 lb/ ft^2 top-load restraint (Replication 2)

Table 2. Schedules used in kiln drying runs

Time (hrs.)	Dry bulb temperature (°F)	Wet bulb temperature (°F)	Wet bulb depression (°F)	EMC (%)
*0-12	135	118	17	9.0
12-24	140	123	17	9.0
24-36	145	122	23	7.3
36-48	150	127	23	7.3
48-60	160	130	30	5.8
60-72	170	140	30	5.7
72-84	170	130	40	4.4
84-96	170	125	45	3.7
96-final	170	120	50	3.2

High Temperature Schedule

Time (hrs.)	Dry bulb temperature (°F)	Wet bulb temperature (°F)
*0- 4	210	no control
4-12	220	-
12-24	225	-
24-final	230	-

* optional pre-plasticization treatment not included

Moisture Content and Warp Assessment

After drying and at the time when warp was assessed the moisture content of each piece was measured using an electrical resistance meter at points 2 feet from each end. The two measurements were averaged to give the estimated final moisture content of the piece. The insulated pins of the meter were driven to a depth of 1/5th the board's thickness in order to give an average board moisture content. This was particularly necessary for those boards dried by high temperatures because of the steep moisture gradient across the board's thickness.

The permissible limits of warp in an 8 foot stud by WWPA grading standards are as follows:

Crook - 1/4", Twist - 3/8", Bow - 3/4", Cup - 1/32"

After drying, every board was examined using the standards for warp listed above. Those exceeding these limits in any one type of warp were classed as out-of-grade and the actual amount of warp measured to the nearest 32nd of an inch.

Warp measurements were made by simply using a ruler divided into 32nds and a string. Crook and bow were measured as the maximum deviation from the taut string while being held at each end of the board. Twist was measured by placing a weight on one end of the stud and measuring the maximum deviation of the other end from the flat plane on which the piece lay. An example of warp assessment measurements being taken on a test specimen is shown in Figure 2.

Table 3. Percentage of boards in and out of grade

Test Run No.	No. of Pieces	Moisture Content		No. of Boards		Ranking of Recovery	Percent of Boards		Average percentage of duplicate runs	
		Avg.	Std. Dev.	In Grade	Out of Grade		In Grade	Out of Grade	In Grade	Out of Grade
NR-1AD	148	16.2	2.84	75	73	7	50.7	49.3	54.0	46.0
NR-2AD	150	14.3	1.77	86	64	3	57.3	42.7		
R-3AD	147	13.7	1.54	80	67	4	54.4	45.6	53.5	46.4
R-4AD	150	15.0	2.39	79	71	6	52.7	47.3		
NR-5CKS	150	12.6	2.28	68	82	11	45.3	54.7	42.6	57.4
NR-6CKS	150	10.8	1.50	60	90	12	40.0	60.0		
R-7CKS	149	11.9	2.59	90	59	1	60.4	39.6	60.2	39.8
R-8CKS	150	12.0	2.81	89	61	2	60.0	40.0		
NR-9HTS	150	13.4	3.58	71	79	10	47.3	52.7	47.6	52.4
NR-10HTS	150	10.1	0.90	72	78	8	48.0	52.0		
R-11HTS	149	8.7	0.45	71	78	9	47.6	52.3	50.6	49.4
R-12HTS	149	9.1	2.54	80	69	5	53.7	46.3		

From this data a tally of boards both in and out of grade was made for each drying method tested. Cup measurements were not taken because after numerous measurements had been made it was established that cup was not large enough to warrant further measurements.

RESULTS

The percentage of boards in and out of grade due to excessive warp are listed in Table 3 grouped by test runs. In this table drying units have been listed from one to twelve with the letter R representing restraint and NR non-restrainted units. The letters AD are for air-drying; CKS, conventional temperature kiln schedule; and HTS, high-temperature kiln schedule. Some test runs had less than 150 boards, since occasionally pieces of white fir were inadvertently included, and these boards were removed from the tests.

Two general comments should be made before discussing the results given in Table 3. The authors strongly feel that warp is definitely related to final moisture content, and data to be shown shortly supports this. That is, the lower the moisture content of a piece the greater its warp will be. Thus for two units that are dried to different moisture contents, the lower final moisture content unit would have greater fall-down than the unit of higher final MC, even if both were dried identically.

A conscientious effort was made to obtain the same average charge moisture content for each run. This is, however, difficult to do unless the material is extremely uniform. The use of high-temperature drying with its steep within board moisture gradients also adds to the difficulty. The air-drying units could not be brought to a lower EMC because of the prevailing out-of-doors EMCs which occurred during the drying period.

The second comment concerns the replicate runs. Theoretically one would expect the results from these to be the same, which they obviously are not. The reason they are not (for example, percent of boards in grade) is that they were not always brought to exactly the same final moisture content, and further that the material in each was undoubtedly not exactly the same. That is, one charge may have contained more boards from near the pith than its matched replicate run. If one compares each set of duplicate tests one can see that in the worst case (air-drying) the difference in percent of boards in grade between the two duplicate runs was 6.6%. In a rough sense, this indicates that it is probably invalid to assume any real difference exists between the different drying tests where the difference is smaller than 6.6%.

The best result in terms of percent of boards meeting grade occurred with kiln drying at conventional temperatures with restraint; in this case 60.2% met grade. Conventional kiln drying without restraint led to the greatest fall-down, with only 42.6% of the two charges making grade.

Restraint seemed to have little beneficial effect on the air-drying units. The percent of boards making grades being 54.0 when no restraint was used and 53.5 when restraint was used. Both are lower than the amount (60.2%) obtained for restraint with conventional kiln drying. Comparisons of the air-drying tests with the other two methods must be made noting that the final moisture contents of the runs were higher than the kiln-drying runs. We feel that the level of degrade for the air-drying runs would have been much higher had their moisture content been reduced, as would often be the case in summer/fall air drying.

High-temperature drying was the least successful of the three methods. As with air drying, the use of restraint appeared to have no effect at all. One should note, however, that these runs had on the average the lowest final moisture content. The percentage of boards in grade would probably have been higher if the moisture content had been higher. High-temperature drying both with and without restraint were better than conventional kiln drying without restraint.

The percentage of boards meeting grade are shown according to type of warp developed in Table 4 (the same board may show up as much as 3 times had it exceeded grade for crook, twist and bow). These data clearly show that the use of restraint had the greatest effectiveness in reducing twist. In the case of conventional kiln drying there was only a 2.0% loss with restraint as compared to 20.7% for the two runs without restraint. While there was also some improvement in reducing crook and bow it was much less than for twist. It is felt that the reason for the limited effectiveness with bow and crook was a result of two factors:

1. Uneven lumber thickness (thick/thin stock) which results in a lack of restraint on thin pieces near a thicker one and
2. insufficient use of stickers which permitted the boards to distort between the 4 foot sticker placement.

The development of warp as related to position within the unit is given in Table 5. One might expect the degrade to decrease the lower one goes down into the unit since the restraint is greater due to the added weight of the tiers above it. In an attempt to verify this, the number of pieces not making grade were determined in each 1/5th of the unit's height and then this was expressed as a percentage of the total number of boards in the unit. In contrast to what was expected there does not appear to be any definite pattern in amount of warp as one goes from the top to the bottom courses. The reason for this may, however, be due to the fact that units were only 38" high and the difference in weight between the top course and bottom course at the start of drying is calculated to only have been 84 lbs/ft^2. That is, the top tier had 188 lbs/ft^2 while the bottom tier had 272 lbs/ft^2.

The above results and discussion are extremely important when it comes to projecting to a commercial sized charge of 8 or 9 feet in height. That is, can one assume that the recovery factor given in Table 3 would be applicable for commercial units under similar restraint without making adjustment factors for height? It seems to us unlikely that an improvement of 20% (as with conventional drying under restraint) would apply to an 8 foot high unit. We conclude this in part based on the observation that warp is normally worse in the upper courses in commercial practice. Assuming that no improvement was found in the courses lower than 38" from the concrete slab, the overall improvement would be reduced to only 7.1%. This is

Table 4. Percentage of boards meeting grade by type of warp

Test Run No.	No. of Pieces	Moisture Content		Percent of Boards Meeting Grade by Type of Warp		
		Avg.	Std. Dev.	Crook	Twist	Bow
NR-1AD	148	16.2	2.84	60.1	89.2	82.4
NR-2AD	150	14.3	1.77	66.0	92.7	87.3
R-3AD	147	13.7	1.54	59.9	97.3	85.7
R-4AD	150	15.0	2.39	62.0	92.7	81.3
NR-5CKS	150	12.6	2.28	64.7	81.3	81.3
NR-6CKS	150	10.8	1.50	51.3	77.3	80.0
R-7CKS	149	11.9	2.59	65.1	99.3	85.2
R-8CKS	150	12.0	2.81	69.4	96.7	82.7
NR-9HTS	150	13.4	3.58	62.7	84.0	76.7
NR-10HTS	150	10.1	0.90	59.3	84.0	77.3
R-11HTS	149	8.7	0.45	57.1	98.7	79.2
R-12HTS	149	9.1	2.54	64.4	96.6	80.5

Table 5. Percentage of boards not meeting grade due to warp according to vertical position within the drying unit

Vertical position within unit	Percentage of total degrade lost in a charge due to warp for test unit											
	NR-1 AD	NR-2 AD	R-3 AD	R-4 AD	NR-5 CKS	NR-6 CKS	R-7 CKS	R-8 CKS	NR-9 HTS	NR-10 HTS	R-11 HTS	R-12 HTS
Top 1/5*	9.4	12.0	8.8	6.7	11.3	11.3	9.4	8.7	15.3	16.0	8.7	6.7
Second 1/5	10.1	6.0	8.8	7.3	10.0	12.7	8.1	8.0	10.7	8.6	10.1	7.4
Third 1/5	10.1	9.3	8.2	8.0	9.3	10.7	8.7	10.0	14.0	9.3	11.4	9.4
Fourth 1/5	8.1	8.7	11.6	6.7	9.3	10.0	5.4	10.0	6.0	6.7	12.1	12.8
Bottommost 1/5	11.5	6.0	8.2	9.3	15.3	14.7	8.7	5.3	8.0	11.3	9.4	10.1

* Each 1/5 of unit contained 4 tiers of boards.

obviously not just, but serves to indicate the minimum improvement one might expect.

As is obvious, any increase in recovery is offset by the loss of volume or throughput in the kiln as a result of the space taken up by the concrete slab. The 16 inch slab used in this study would reduce kiln throughput for an 8 ft. high charge by 16.7%, which is considerable. No attempt has been made here to determine the economic tradeoff between lower production and higher quality. It may be possible also to reduce the weight/ ft^2 needed which would decrease the throughput loss from the space reduction.

As mentioned earlier, it is felt that the amount of degrade due to warp is directly related to final moisture content. This was verified by a separate test made on 50 boards selected from those air-dried boards which did not meet grade. These boards were first conditioned to 14% EMC, then 8%, and finally 4%, with warp measurements taken at each EMC level in the same manner described earlier. Moisture content was averaged from electrical resistance readings taken at two points on the boards. The moisture content at the 4% level was measured by cutting samples from the boards after the warp measurements had been completed. The relationship between moisture content and warp is shown in Figures 3, 4, and 5 and Table 6. These data clearly prove the point that warp increases as moisture content decreases. The significance of this result is that some control over falldown may be possible by simply controlling the final moisture content with the idea of keeping it as high as possible, consistent with shipping weight and customer constraints.

CONCLUSIONS

1. The results of this study show that top-load restraint can be an effective method for reducing warp losses in young-growth ponderosa pine studs.

2. In the best case, i. e., conventional kiln-drying under restraint with an initial plasticization treatment, falldown was reduced from 57.4% to 39.8%, although this would probably be less when adjusted for the height of a commercial-sized unit.

3. Still greater improvements could probably be obtained with increased sawing accuracy and the use of 5 stickers in the unit rather than 3. The use of more stickers would reduce losses due to bow and perhaps crook.

4. Drying to as high as possible a final moisture content would also give greater recoveries.

5. The use of restraint with air-drying or high-temperature drying did not appear to be effective.

6. High-temperature drying, while somewhat better than conventional kiln drying without restraint was not as effective as conventional kiln drying with restraint or air-drying.

7. The 16-inch thick concrete slab used would reduce kiln throughput roughly 17%. It is highly likely that a thinner block would work just as effectively, which would help minimize this problem.

8. While the use of restraint appears feasible, it is suggested that additional testing be done to minimize the weight/ ft^2 needed and further to confirm the real advantage of using more stickers.

9. These recommendations deserve further investigation and it is felt that they can lead to much greater recoveries for warp-prone material.

Table 6. Effect of moisture content on warp

	Moisture Content		Average and standard deviation by type of warp measured in 32nd of an inch					
			Crook		Bow		Twist	
No. of Obs.	$\bar{X}$	σ	$\bar{X}$	σ	$\bar{X}$	σ	$\bar{X}$	σ
50	13.4	0.91	22	33	20	37	8	8
50	8.0	0.51	32	46	32	56	11	10
50	5.4	0.43	52	73	47	76	14	12

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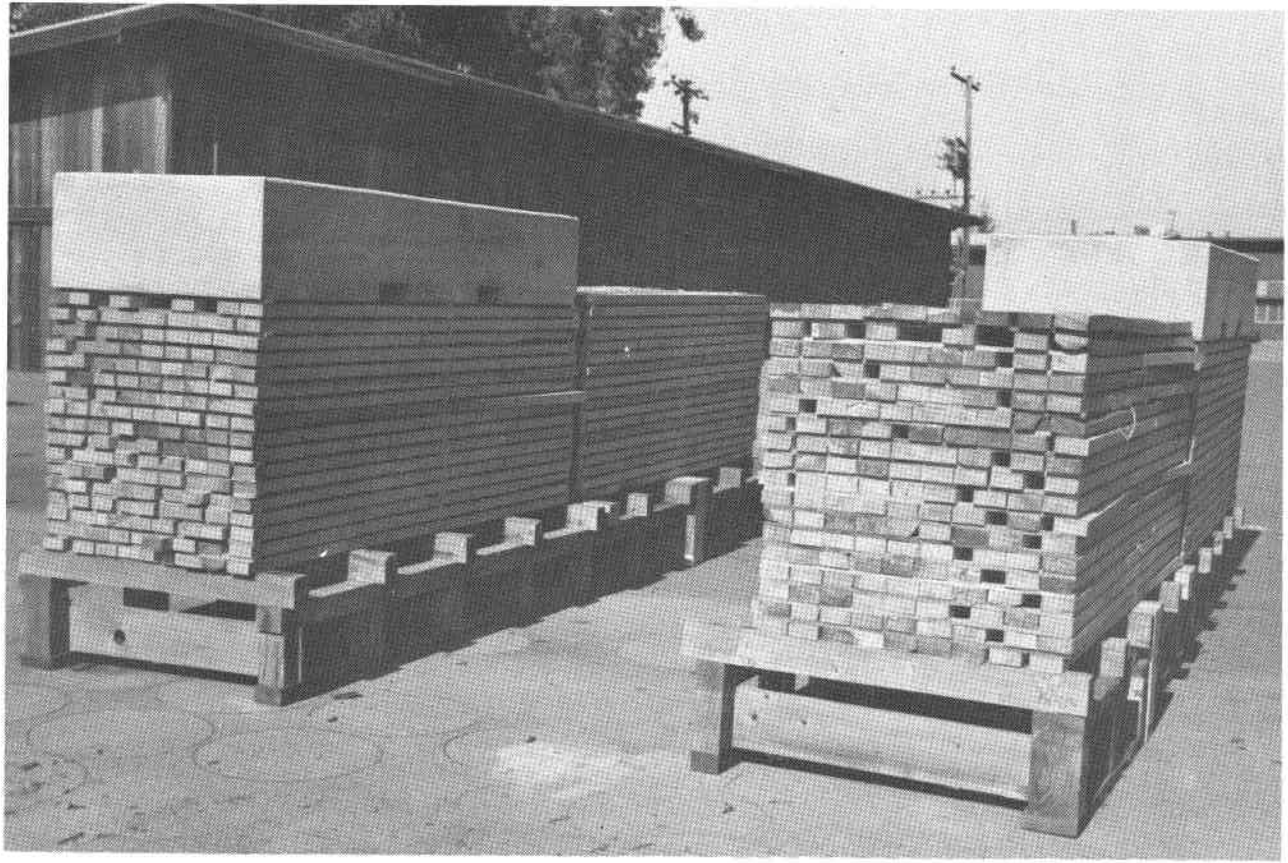


Figure 1. Air drying units with and without top load concrete restraint blocks.

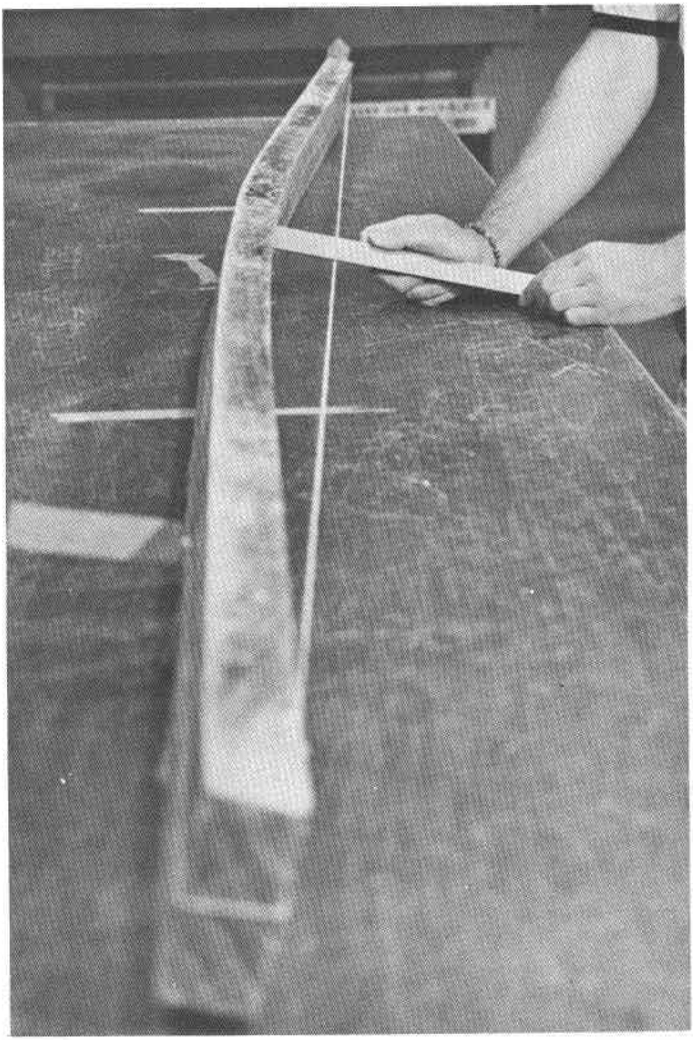


Figure 2. Measurement of bow in warped stud.

Figure 3

Amount of crook vs. moisture content

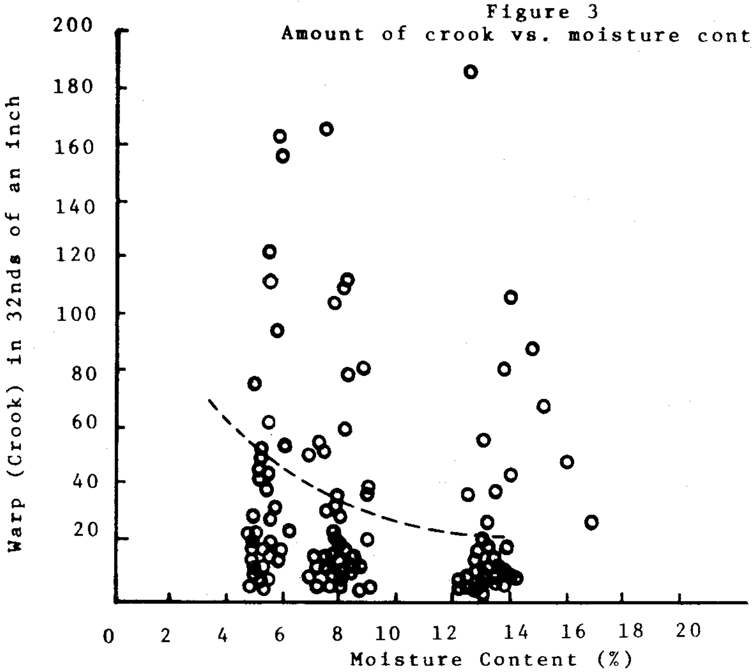
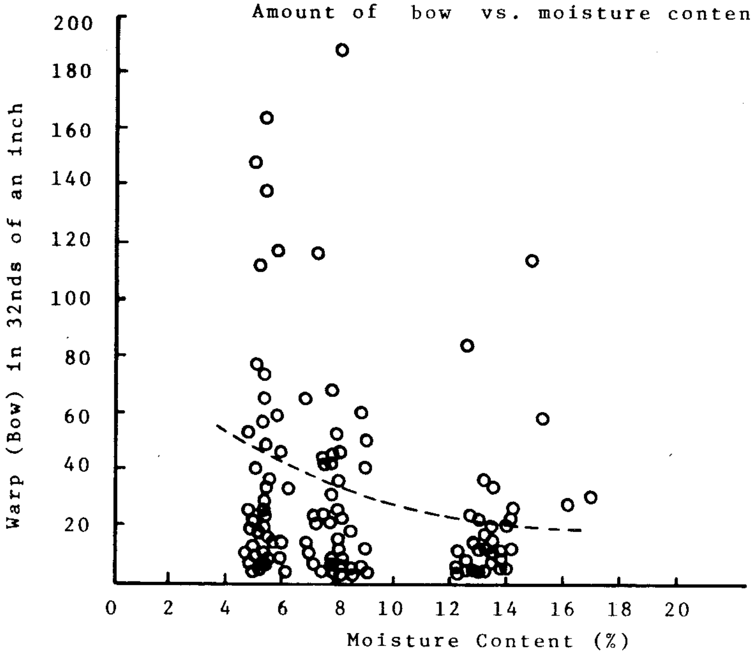


Figure 4

Amount of bow vs. moisture content



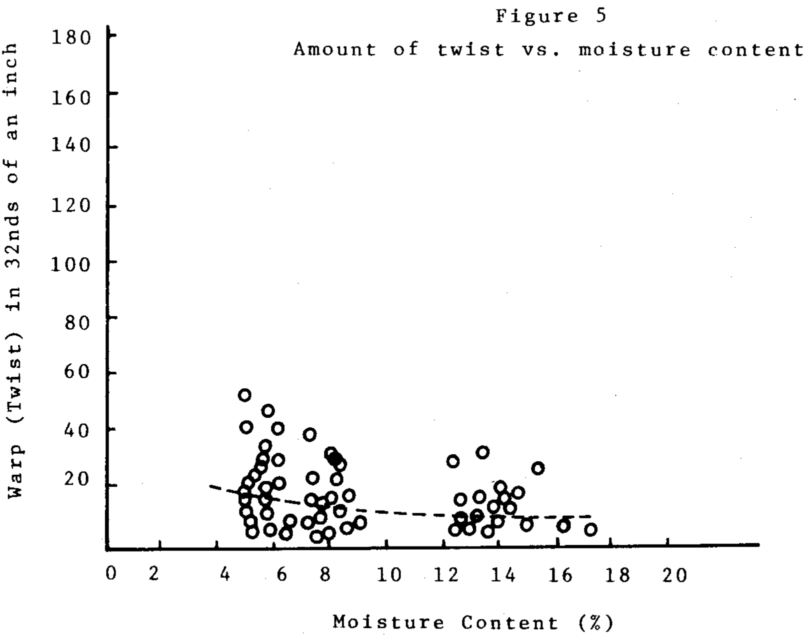


Figure 5
Amount of twist vs. moisture content
Warp (Twist) in 32nds of an inch
180
160
140
120
100
80
60
40
20
0
2
4
6
8
10
12
14
16
18
20
Moisture Content (%)