THE EFFECTS OF HEIGHT, RADIAL POSITION, AND WETWOOD ON WHITE FIR WOOD PROPERTIES[1]

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ABSTRACT

Critical measurements and location of externally detectable defects were determined for 20 white fir [*Abies concolor* (Gord. and Glend.) Lindl.] trees. Boards sawn from these trees were identified with regard to tree, height above ground, and radial position within the stem. Size and location of defects, and grade and drying sort of each board were also recorded. Moisture content, specific gravity, toughness, shrinkage, and liquid absorption were determined on samples taken at three heights and three radial positions from eight of the trees. The data indicated that the sinker sort (the one requiring the longest drying time) came primarily from the center portion of the lowest two 16-ft logs, while the corky (the one requiring the shortest drying time) and sap sorts were, respectively, from the center and outer portions of logs above the second 16-ft log. Approximately 43% of the board volume came from the lowest 32 ft of stem. The highest values of moisture content, specific gravity, tangential and radial toughness, and tangential and radial shrinkage generally occurred in the butt log, decreasing with height, and in the outer third of radial position, decreasing with approach toward the pith. Longitudinal shrinkage was lowest at the butt and increased with height. Because most typical wetwood symptoms occurred in the center of butt logs, it is concluded that, except for the association with drying time, wetwood has little or no detrimental effect on those white fir wood properties investigated.

INTRODUCTION

Wetwood (Hartley, Davidson, and Crandall 1961; Wilcox 1968) has been credited with possible responsibility for considerable loss in merchantable volume of coniferous sawtimber (Aho 1966), but no data are available to confirm this assumption. In an earlier paper on the properties of wetwood in white fir (Wilcox 1968), it was reported that wood properties such as moisture content, specific gravity, toughness, and shrinkage varied widely depending upon the position in the tree from which the sample had been taken, but there appeared to be little effect of the presence of wetwood. Variation with height appeared to be more significant than that associated with radial position. By comparing the fundamental properties of the drying segregations into which white fir boards are sorted during commercial processing (Smith and Dittman 1960a; 1960b) with those determined on samples from known positions in the tree, it was inferred that drying segregation ("sort") also was highly dependent upon location within the tree. The relationship could only be inferred, however, as the identity of boards with respect to position in the tree normally is not known. It also was apparent from these data (Wilcox 1968) that, while board segregation was intended as an estimate of drying time, it also provided an estimate of other wood properties.

Many problems in the processing of white fir lumber appear to arise from the drying of boards having material that normally would be placed in two different drying

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sorts present in the same board; however, there are no data available to substantiate this or to suggest what portions of the tree such boards come from. Because fundamental properties of the wood affect its quality as a raw material and throughout processing, and because both fundamental properties and processing segregations appeared to be related to position in the tree, a study was devised to measure each of these factors in a manner that would allow the examination of the relationships between all factors. This paper reports the results of a portion of that study.

MATERIALS AND METHODS

Twenty white fir [*Abies concolor* (Gord. and Glend.) Lindl.] trees were selected for the study from a single mixed conifer site in El Dorado County, California. The selection area, located on the west side of the Sierra Nevada mountains at an elevation of 6200 ft, was a relatively young stand on a good site in a predominantly white fir–incense cedar–sugar pine timber type. Sample trees were representative of the range of diameters, heights, and externally indicated defects commonly found in trees logged in this area. Eight of these trees were selected as a representative subset for which various fundamental properties were determined at nominal heights above ground of 1, 34, and 72 ft. The diameters at breast height (4.5 ft above ground) of the full set of sample trees ranged from 17.2 to 46.9 inches, with a mean of 30.7; ages ranged from 79 to 176 years, with a mean of 131; and heights ranged from 88 to 182 ft, with a mean of 131.

In the field, each tree was assigned a number. This identity was maintained throughout processing. All visible defects and other tree surface characteristics were recorded for the standing tree and again after felling and bucking. Tags, containing the identifying tree and log numbers, were stapled on the ends of each log so that the log's position in the standing tree would remain known throughout processing. At the mill yard, each log was carefully examined on all sides and the locations of all knots and defects were diagrammed (Jackson, Henley, and Jackson 1963; Pong and Jackson 1971).

Prior to sawing, the large end of each log was painted in a target pattern with three colors. The width of each band of color covered approximately one-third of the large-end radius of the log. The paint color on the ends of the resulting boards delineated, to the nearest one-third of the radius, the radial position within the log from which the boards had come. All material cut from a given log was color-coded at the headsaw as the log was initially broken down. From this code, crewmembers numerically identified each board with the appropriate number of the log from which the board was derived. On the green chain, each board was stamped with a consecutive number, visually sorted, and then marked for drying sort by mill personnel according to previously published guidelines (Smith and Dittman 1960a; 1960b), and then graded by a certified grader. Normally, mill practice does not call for grading white fir in the green condition, but in order to provide a comparison of board quality before and after drying (Pong 1971), boards were graded on the green chain as well. During dry-sorting, a photographic record of each board was automatically made on color film using a cinepulse camera pulsed by an automatic photoelectric triggering mechanism (Pong, Bass, and Claxton 1970). The film record contained for each board the end color code, sequential board number, log number, drying sort, green and dry grades, pencil trim, defects and other surface conditions, width, length, and thickness.

To determine locations in the stem that give rise to each drying sort, each board was visually rated to the nearest 10% as to the percentage of its end area occupied by each of the radial position color codes. To insure accuracy, this rating was independently made on all boards by two people. The percentage rating was then multiplied by the nominal board-end area to arrive at a measure of the board-end area, in square inches, coming from each radial position (each ⅓ radius). Calculations were made

TABLE 1. *Mean board-end area (sq inches)*

Drying sort		Sinker			Corky			Sap			Height across all sorts and radial positions	
Radial position		Pith	Middle	Outer	Pith	Middle	Outer	Pith	Middle	Outer	Mean	Sample size
Height (16-ft logs)	Parameter											
1	Mean	14.9	11.2	9.2	11.2	4.8	0	19.2	8.6	9.7	11.7	392
	Sample size	105	172	78	1	1	1	4	14	16		
2	Mean	12.7	10.8	10.0	23.2	2.4	0	13.9	7.9	9.0	10.6	414
	Sample size	68	132	93	3	1	1	24	52	40		
3	Mean	12.7	10.3	9.8	15.6	10.6	8.0	12.6	8.6	9.4	10.3	355
	Sample size	23	53	44	12	14	1	49	84	75		
4	Mean	9.2	11.4	9.9	13.9	11.2	4.0	10.2	10.8	10.4	10.9	293
	Sample size	12	20	16	32	38	3	28	71	73		
5	Mean	0	0	0	13.7	9.8	3.3	9.3	9.8	10.0	9.8	202
	Sample size	1	1	1	27	32	13	14	49	64		
6	Mean	8.9	9.0	14.6	13.7	12.9	2.9	7.8	10.0	8.9	10.1	223
	Sample size	5	7	8	26	36	12	22	51	56		
7	Mean	0	0	0	12.7	9.4	4.6	7.7	7.6	10.2	9.0	95
	Sample size	1	1	1	15	21	7	7	17	25		

		Sinker	Corky	Sap
Sort across all heights and radial positions	Mean	11.2	11.2	9.8
	Sample size	842	297	835

		Pith	Middle	Outer	
Radial position across all heights and sorts	Mean	12.9	10.3	9.3	
	Sample size	479	867	628	Total sample size = 1974

in square inches of end area rather than in board feet, thereby ignoring board length for two reasons: (a) consideration of length as a variable would include taper (the difference between large-end and small-end log diameters) as a confounding variable, and (b) board length was held relatively constant throughout the experimental run at a nominal 16 ft. Actual mean board length for the entire set of boards included in the sample from which these data were derived was 15.2 ft, which when rounded to the nearest 2-ft-length class justifies an assumption of a constant 16-ft average board length. These data for board end areas from each radial position were further classified by drying sort and height.

For study of fundamental properties, a disk approximately 15 inches long was removed from each of the eight trees at each of the three sample heights at the time of bucking. At the same time another disk about 3 inches thick was also removed. From this disk blocks approximately 1 by 1 by 3 inches in size were immediately split, sealed in watertight, tared bottles and later used for determination of fresh moisture content. The measurement for each 32-ft log, the usual hauling length, was therefore displaced up the stem approximately 1½ ft by each set of sample disks removed.

The sample disks were processed and tested in the same manner as reported earlier (Wilcox 1968). Absorption was calculated from the same experimental data and in the same manner as retention in an

TABLE 2. *Analysis of variance table for data represented in Table 1*

Source	SS	df	MS	F	$\hat{w}^2$
Sort	912.48	2	456.24	11.93**[a]	0.01
Height	629.27	6	104.88	2.74*	0.00
Radial position	3008.75	2	1504.38	39.33**	0.04
Sort × height	1090.42	12	90.87	2.38**	0.01
Sort × radial position	1861.01	4	465.25	12.16**	0.02
Height × radial position	1903.90	12	158.66	4.15**	0.02
Sort × height × radial position	601.68	24	25.07	0.66	0.00
Residual	73,096.90	1911	38.25		
Total	83,104.42				

[a]** = significant at 1% level.
* = significant at 5% level.

earlier publication (Arganbright and Wilcox 1969) and is the quotient of weight increase due to oil absorption divided by initial oven-dry weight. Data were analyzed by analysis of variance using the program NYBMUL (Anon 1969; Finn 1968) on the U.C. Berkeley CDC 6400 computer. Dunn's multiple comparison procedure (Kirk 1968) was used to determine the variable levels responsible for significant differences; the proportion of the total variation accounted for by each variable ($\hat{w}^2$) (Kirk 1968, p. 134) also was computed.

RESULTS

Mill data

Table 1 shows the results of determination of board-end area. The difference between the total number of boards in the study (1078) and the total sample size of data in Table 1 is the result of including boards containing more than one radial position color code in the data for different radial position categories. Results of statistical analysis of these data appear in Table 2. Dunn's procedure showed that for the variable radial position, differences between all levels were significant; for sort the differences between sinker vs. sap and corky vs. sap were significant; while for height, only the differences between height 1 (butt log) and heights 3, 5, 6, and 7 were significant.

The means shown in Table 1 represent the square inches of board-end area that an average board in each category would be expected to have (the majority of boards in the study were 2 × 12 inches with a nominal end area of 24 sq inches). Perhaps of greater interest are the data for total board-end area for each category (Table 3), obtained by multiplying each mean value in Table 1 by the number of boards contributing to each category. These data indicate that for this sample the bulk of the sinker sort came from the pith and middle thirds of the lowest two logs, particularly the middle third; the bulk of the corky sort came from above the third log and from the pith and middle thirds in nearly equal proportions; and the bulk of the sap sort came primarily from above the second log and from the middle and outer thirds in nearly equal proportions. In commercial practice the sort indicates the amount of time required to dry lumber in a kiln, with corky requiring the shortest, sap an intermediate, and sinker the longest amount of time according to an approximate ratio of 1:2:4. Approximately 45% of the board-end area (or board volume, assuming a constant length) was sinker, 39% was sap, and 16% was corky; 30%, 42%, and 28% of the board-end area came from the pith, middle, and outer radial thirds of the logs, respectively; and approximately 43% came from the lowest two logs, or the first 32 ft of stem above the stump.

Fundamental properties data

In order to determine the effect of location in the stem upon wood properties, data were segregated by height and radial posi-

TABLE 3. *Total board-end area (sq inches)*

Drying sort	Sinker				Corky				Sap				
Radial position	Pith	Middle	Outer	Total across all radial positions	Pith	Middle	Outer	Total across all radial positions	Pith	Middle	Outer	Total across all radial positions	Total for height
Height (16-ft logs)													
1	1564.5	1926.4	717.6	4208.5	11.2	4.8	0	16.0	76.8	120.4	155.2	352.4	4576.9
2	863.6	1425.6	930.0	3219.2	69.6	2.4	0	72.0	333.6	410.8	360.0	1104.4	4395.6
3	292.1	545.9	431.2	1269.2	187.2	148.4	8.0	343.6	617.4	722.4	705.0	2044.8	3657.6
4	110.4	228.0	158.4	496.8	444.8	425.6	12.0	882.4	285.6	766.8	759.2	1811.6	3190.8
5	0	0	0	0	369.9	313.6	42.9	726.4	130.2	480.2	640.0	1250.4	1976.8
6	44.5	63.0	116.8	224.3	356.2	464.4	34.8	855.4	171.6	510.0	498.4	1180.0	2259.7
7	0	0	0	0	190.5	197.4	32.2	420.1	53.9	129.2	255.0	438.1	858.2
Total for sort by radial position	2875.1	4188.9	2354.0		1629.4	1556.6	129.9		1669.1	3139.8	3372.8		

	Sinker	Corky	Sap
Total for sort across all radial positions	9418.0	3315.9	8181.7

	Pith	Middle	Outer
Total for radial position across all sorts	6173.6	8885.3	5856.7

Grand total = 20,915.6

TABLE 4. *Mean values of fundamental properties data by radial position and height*

		Moisture content[1]				Specific gravity[2]				Tangential toughness[3]				Radial toughness[3]			
Radial position		Pith	Middle	Outer	Across all radial positions	Pith	Middle	Outer	Across all radial positions	Pith	Middle	Outer	Across all radial positions	Pith	Middle	Outer	Across all radial positions
Height (nominal, feet)	Parameter																
1	Mean	172	164	175	171	0.38	0.40	0.41	0.40	268	322	325	312	237	232	271	247
	Sample size	24	21	24	69	26	43	39	108	10	19	17	46	8	20	16	44
34	Mean	118	148	185	149	0.33	0.37	0.36	0.36	184	197	211	200	119	119	131	125
	Sample size	27	18	24	69	17	33	42	92	7	17	16	40	5	15	18	38
72	Mean	92	128	180	133	0.32	0.36	0.35	0.35	114	136	182	159		107	106	106
	Sample size	12	12	12	36	6	13	25	44	1	6	8	15	0	7	9	16
Mean across height		134	150	180		0.35	0.38	0.38		227	245	253		192	171	178	
	Sample size	63	51	60		49	89	106		18	42	41		13	42	43	
Mean for test					154				0.38				245				177
Total sample size					174				244				101				98

		Tangential shrinkage[4]				Radial shrinkage[4]				Longitudinal shrinkage[4]				Absorption[5]			
		Pith	Middle	Outer	Across all radial positions	Pith	Middle	Outer	Across all radial positions	Pith	Middle	Outer	Across all radial positions	Pith	Middle	Outer	Across all radial positions
1	Mean	8.2	8.3	8.9	8.5	4.9	5.3	5.0	5.1	0.06	0.01	0.10	0.06	0.415	0.465	0.371	0.412
	Sample size	22	36	36	94	22	36	36	94	22	36	36	94	5	6	8	19
34	Mean	7.8	8.3	8.6	8.3	4.5	4.6	4.3	4.4	0.12	0.11	0.14	0.13	0.706	0.474	0.401	0.471
	Sample size	26	30	56	112	26	30	56	112	26	30	56	112	2	6	7	15
72	Mean	6.1	7.3	7.8	7.3	3.5	3.9	4.0	3.9	0.17	0.13	0.18	0.16	0.544	0.550	0.480	0.522
	Sample size	6	9	16	31	6	9	16	31	6	9	16	31	2	3	3	8
Mean across height		7.8	8.2	8.6		4.6	4.9	4.5		0.10	0.06	0.13		0.508	0.486	0.401	
	Sample size	54	75	108		54	75	108		54	75	108		9	15	18	
Mean for test					8.3				4.6				0.10				0.454
Total sample size					237				237				237				42

[1] % of oven-dry weight.
[2] Green to oven-dry.
[3] Inch-pounds.
[4] Green to oven-dry; % of green dimension.
[5] Weight increase due to oil absorption ÷ initial oven-dry weight.

TABLE 5. *Analysis of variance table for data represented in Table 4*

Source	SS	df	MS	F	$\hat{\omega}^2$
Height within test	3,641,089.03	16	227,568.06	246.18**[a]	0.49
Radial position within test	1,078,362.65	16	67,397.67	72.91**	0.14
Height × radial position within test	1,489,035.68	32	46,532.37	50.34**	0.20
Residual	1,200,788.98	1299	924.39		
Total	7,409,276.34				

[a]** = significant at 1% level.

tion, using the same criteria for these variables as was employed in the mill data. Table 4 gives the mean values for these data. Because of the noncomparable nature of data in the various tests, a nested design was employed for the analysis of variance.

TABLE 6. *Dunn's multiple comparisons for data of Tables 4 and 5*

Variable	Levels compared[a]		Significance of differences among means[b] Height	Radial position
Test				
Moisture content	1 vs	2	*	n.s.
	1	3	**	**
	2	3	n.s.	**
Specific gravity	1	2	**	**
	1	3	**	**
	2	3	n.s.	n.s.
Tangential toughness	1	2	**	n.s.
	1	3	**	n.s.
	2	3	n.s.	n.s.
Radial toughness	1	2	**	n.s.
	1	3	**	n.s.
	2	3	n.s.	n.s.
Tangential shrinkage	1	2	n.s.	n.s.
	1	3	**	**
	2	3	**	*
Radial shrinkage	1	2	**	n.s.
	1	3	**	n.s.
	2	3	*	*
Longitudinal shrinkage	1	2	**	n.s.
	1	3	**	n.s.
	2	3	n.s.	**
Absorption	1	2	n.s.	n.s.
	1	3	*	*
	2	3	n.s.	n.s.

[a] For height: level 1 = 1 ft, 2 = 34 ft, and 3 = 72 ft; for radial position: level 1 = pith, 2 = middle, and 3 = outer.
[b]** = significant at 1% level; * = significant at 5% level; n.s. = not significant at 5% level.

Results of this analysis are shown in Table 5, and results of application of Dunn's multiple comparison procedure to these data appear in Table 6. It is apparent from Tables 4 and 6 that moisture content, specific gravity, tangential and radial toughness, and tangential and radial shrinkage were generally highest, where differences are significant, in the butt log (decreasing with height) and in the outer radial position (decreasing with approach toward the pith). One exception to this occurs in the consistently high values in the middle radial position of the radial shrinkage data. Longitudinal shrinkage tended to be greatest in the outer radial position and decreased with approach toward the pith, as in the other tests, but it was lowest in the butt log and increased with height. Absorption was more variable but tended to be greater in the center two-thirds of the log than in the outer third, and to be lowest in the butt log and increase with height.

DISCUSSION AND CONCLUSIONS

It must be remembered that these data apply only to this sample. The accuracy of any interpolation to white fir in general depends upon the degree to which the sample is representative of white fir trees. With this in mind, however, it is useful to derive some hypotheses from these data with regard to white fir lumber.

The data closely agree with those of an earlier sample (Wilcox 1968), except for showing a higher mean specific gravity of wood in the present sample concomitant with greater toughness and transverse shrinkage. A consistent increase in specific gravity with distance from the pith was also observed in the present sample; this was not recorded in the previous sample.

The values for $\hat{w}^2$ in Table 2 indicate that little of the variability in mill data (Table 1) is accounted for by the selected independent variables. However, in the fundamental properties data (Tables 4 and 5) the two independent variables account for large portions of the variability with height the most important factor, accounting for nearly 50%.

With regard to mixtures within the same board of wood which normally would be placed in two different sorts, it is apparent from Table 3 that such mixtures must involve primarily sap-corky combinations arising from upper logs. This follows from the fact that both sorts appear to come primarily from above the second or third logs, and both rely heavily upon material from the middle one-third of the log radius. Unfortunately, these are also the regions in the tree having the greatest differentials in fresh moisture content (Table 4). As upper logs also tend to be smaller in diameter than lower logs, any board coming from this region would have a greater tendency to include material from all radial positions than would boards from lower logs. Mixed boards coming from upper logs would tend to be included in the sap sort (which comprises approximately 40% of the board volume) because, for drying purposes, they would have to be treated for the highest moisture content present to prevent them from being inadequately dried by the end of the treatment.

Over 40% of the total volume of boards in this study came from the lowest two logs. According to our data, boards from these logs should have the highest specific gravity and the narrowest range of moisture content of any in the tree (Table 4). This would suggest that boards of the highest quality could result from these logs, and that problems in drying associated with large moisture differentials within the same board could be minimal, leading to a greater continuity of board quality during each step in processing. Our data show that more than 80% of the board volume in the lowest two logs is of the sinker sort. These logs are also the portion of the tree that has properties most typical of wetwood (Wilcox 1968). If what we have suggested is correct, this would indicate that the presence of wetwood has little or no adverse effect on quality of white fir. Furthermore, this suggestion places greater value on the lowest two logs in white fir, because these logs appear potentially to provide not only the highest quality boards but also nearly half the total volume of boards in the tree. The relationship between stem location, drying sort, lumber grade, and degrade will be explored in another paper.

Some of the boards falling into the sap sort also come from lower logs, and would share the properties discussed above. However, because the sap sort must also contain many of the mixed sort boards, which may be responsible for some processing difficulties and degrade, it might be advantageous to make an additional segregation into which mixed boards could be sorted. This would make the properties of the residual sap sort more uniform and would protect potentially high-quality sap boards cut from the lower logs. It would also remove boards that may cause drying problems to a separate, smaller group where it would be possible to dry them on a different schedule. This could reduce degrade in this group of boards if, in fact, this is a problem. Data dealing with these hypotheses also will be considered in the paper dealing with lumber quality and degrade.

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