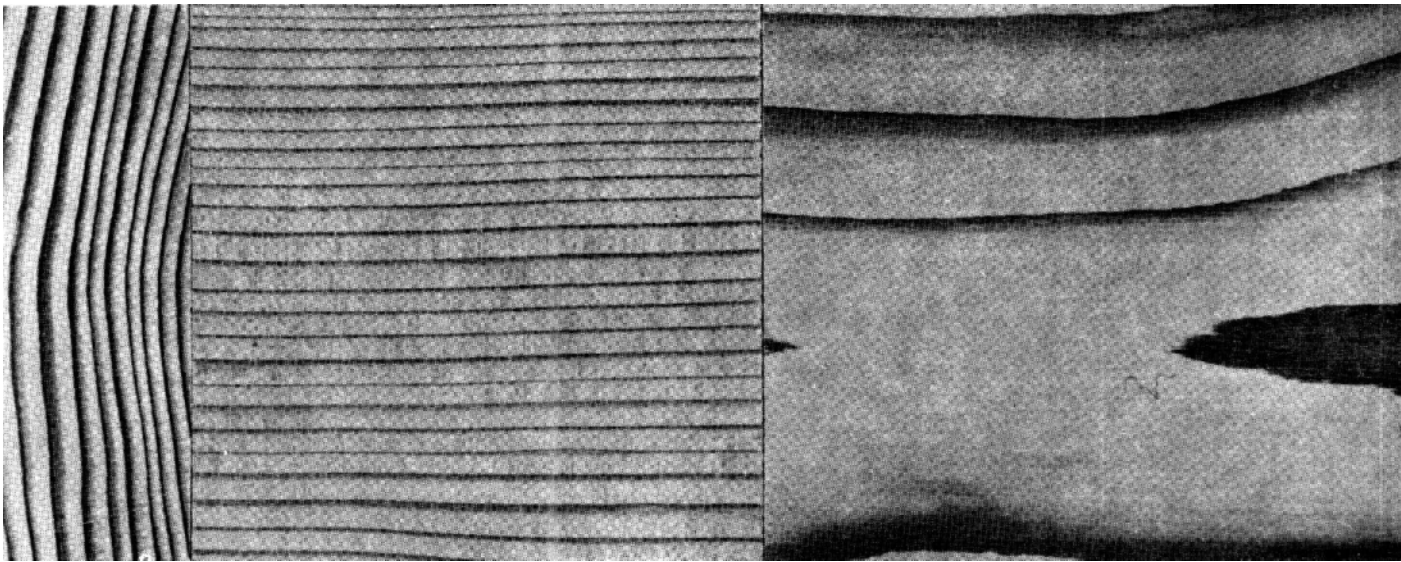


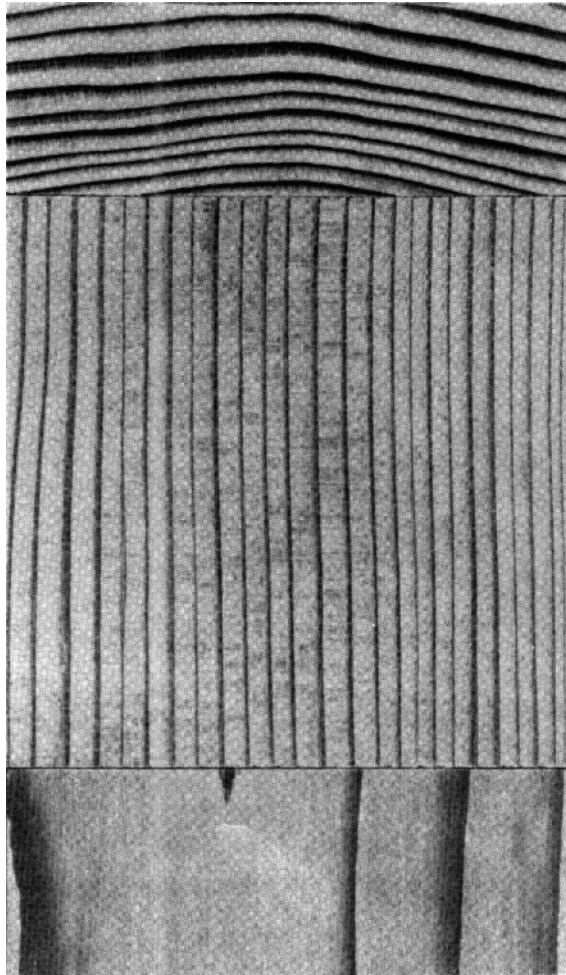
STRENGTH and RELATED PROPERTIES
of
WHITE FIR



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FOREST PRODUCTS LABORATORY • MADISON, WIS.

SUMMARY

Strength and related properties of white fir (*Abies concolor*) were reevaluated by combining previous data with that developed from recent samples obtained from Jackson and Lake Counties, Oregon, and Calaveras and Plumas Counties, California. New average strength values compare favorably to the previous averages for the species, although new averages for air-dry wood were slightly higher. Slight increases in species stiffness of green and air-dry wood and notable increases in shear strength of air-dry wood were of most significance.





STRENGTH and RELATED PROPERTIES of **WHITE FIR**

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INTRODUCTION

White fir [*Abies concolor* (Gord. & Glend.) Lindl.], also known as white balsam, balsam fir, and silver fir, grows over a broad range extending from southern Oregon, southern Idaho, and western Wyoming south into Mexico.² In virgin forests it is usually found mixed with other western species, although it comprises nearly pure stands in some sections of the Sierra Nevada.³

White fir is one of nine timber species given high priority in current research at the Forest Products Laboratory in the

Western Wood Density Survey. Previously available data on strength and related properties of white fir result from evaluations made between 1912 and 1920 at the Forest Products Laboratory on material from 20 trees grown in three general locations: Madera County, California (5 trees), San Miguel County, New Mexico (5 trees), and Plumas County, California (10 trees). In view of the limited data, an additional sample of white fir was acquired in conjunction with the wood density survey.

¹Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

²Little, E. L., Jr. Check list of native and naturalized trees of the United States (including Alaska). U.S. Dept. Agr., Agr. Handb. 41, 472 pp. 1953.

³Harlow, W. M., and Harrar, E. S. Textbook of dendrology. McGraw-Hill Book Company, New York, 561 pp., illus. 1958.

Logs from cuttings made in 1960 provided the material for the new sample. During 1961-1962 a determination of the strength and related properties of white fir was made from samples of five trees

from each of four counties--Jackson and Lake Counties, Oregon, and Calaveras and Plumas Counties, California.

This report presents the reevaluation of species properties.

DESCRIPTION OF MATERIALS

Material for the further evaluation of strength and related properties of white fir was obtained from two locations in Oregon and two locations in California. The Oregon locations were situated in the Rogue River National Forest, Jackson County, at an elevation of 3,500 to 4,000 feet and in the Fremont National Forest, Lake County, at an elevation of 5,500 to 6,000 feet. The sites have similar climatic conditions, but precipitation is somewhat lower in Lake County. One of the locations in California was situated in Calaveras County on privately owned land at an elevation of about 5,400 feet, while the other was situated in Plumas National Forest, Plumas County, at an elevation of about 4,000 feet where precipitation averages are considerably higher than either site in Oregon. All four sites are mountainous.

At each site, c-d bolts (8- to 16-foot height) were cut from five trees that represented the observed variation in density of white fir at that location. In addition, an a-b bolt (0- to 8-foot height) and another bolt higher in the same tree were selected from one of the sample trees at each location. Descriptions of the trees are presented in table 1. Although the trees from California were generally younger than those from Oregon, they had attained diameters at breast height



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Figure 1. --Cross section of tree 41, at a height of 12 feet, from Jackson County, Oregon. Compression wood is present in the eccentric growth of the northeast quadrant.

comparable to, and heights generally in excess of, those from Oregon. The trees from Lake County, Oregon, were oldest but generally produced the least merchantable height.

A number of the sample trees contained some compression wood. This was more prevalent in the material from California than from Oregon. A cross section of tree 41, shown in figure 1, displayed the eccentricity and wide rings that are indicative of compression wood. Of particular interest is the compression wood

Table 1.--Descriptions of trees of white fir (*Abies concolor*)
sampled from Jackson and Lake Counties, Oregon,
and Calaveras and Plumas Counties, California

Tree No.	Age ¹	Diameter breast height outside bark	Diameter inside bark, c bolt	Total height	Merchant-able height	Field description of log condition
	<u>Yr.</u>	<u>In.</u>	<u>In.</u>	<u>Ft.</u>	<u>Ft.</u>	
JACKSON COUNTY, OREGON						
41	230	37	30	157	98	None given
49	238	28	21	124	82	End check top of c-d bolt
50	190	33	28	141	99	None given
55	189	26	20	137	105	None given
56	211	33	26	130	94	Decay in top stem
LAKE COUNTY, OREGON						
8	322	37	28	103	70	None given
21	320	38	30	136	96	None given
23	287	32	25	105	41	Rot in upper part of stem
26	280	31	23	96	76	Shake and heart rot butt at a-b bolt..
30	258	35	24	104	70	None given
CALAVERAS COUNTY, CALIFORNIA						
61	169	39	31	146	144	No visible defects
66	210	38	30	158	120	Shake and 12-inch end check through pith
69	140	29	22	132	92	Shake and check 12 inches from pith
76	103	27	22	159	94	No visible defects
88	147	35	28	137	105	No visible defects
PLUMAS COUNTY, CALIFORNIA						
97	212	28	20	124	81	No visible defects
98	170	39	30	145	109	Incipient decay in 2-inch core
119	165	41	35	157	112	No visible defects
123	197	38	24	140	106	Incipient decay interior 16 inches and slight heart checks
124	204	34	26	152	119	Incipient decay interior 17 inches and 5-inch heart checks

¹Age of c-d bolts

produced in the recent growth, as shown by the eccentric growth in the northeast quadrant. During this study, some of the material from that quadrant behaved peculiarly, which led to the observation

that wood from that zone contained pre-existing compression failures that extended out to the initial compression wood rings. Representative growth of white fir is shown in figure 2.

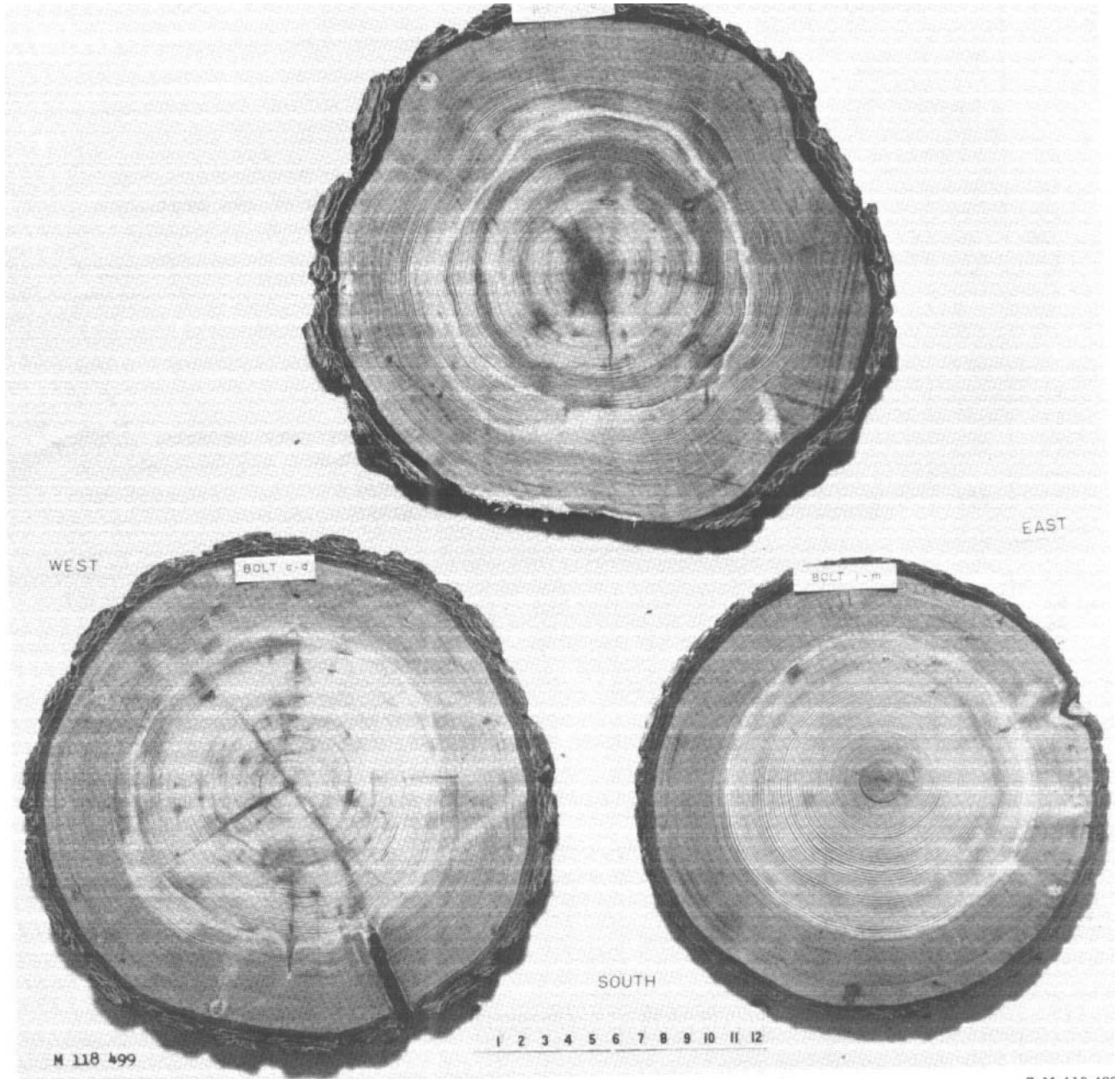


Figure 2.--Cross sections of tree 55, from Jackson County, Oregon, at heights of 4, 12, and 48 feet, considered representative of the growth of white fir.

PROCEDURES

Selection, preparation, and evaluation of material from the white fir bolts followed standard procedures.⁴ Individual data that were affected by pre-existing compression failures, such as was obvious in material from tree 41, or by the presence of knots or other

strength-reducing characteristics were excluded from this evaluation. Although some specimens had a brown stain, data of these specimens were not excluded, as the mechanical properties were in agreement with strength-specific gravity relationships of normal specimens.

PRESENTATION OF RESULTS

Data on mechanical properties are presented in table 2 for both green and air-dry wood. Data on shrinkage of white fir are presented in table 3. Variations of strength and related properties in green wood are presented in table 4. For gen-

eral information, data on shrinkage and mechanical properties of wood from various heights in one tree from each of the sites recently sampled are presented in appendixes I and II.

DISCUSSION OF RESULTS

Species averages show that the growth rate of recently sampled white fir was slower than that sampled previously but specific gravity was nearly the same. Both properties showed more variation in material between recently sampled sites than between previous ones, which might reflect the somewhat different selection methods.

Volumetric shrinkage from green to oven-dry averaged somewhat higher for

the recent sample than it did for the previous sample, although shrinkages in the radial and tangential directions remained about the same. Radial and tangential shrinkages of the sample from San Miguel County, New Mexico, appear incongruous with volumetric shrinkage, which might indicate that all shrinkage specimens did not represent material of comparable specific gravity.

Although average mechanical proper-

⁴American Society for Testing and Materials. Standard methods of testing small clear specimens of timber. ASTM D143-52. 1952.

Table 2.--Mechanical properties of white fir in green and air-dry condition¹

Location	No. of trees	Moisture content	Specific gravity ²	Static bending						Toughness	
				Stress at propor- tional limit	Modulus of rupture	Modulus of elas- ticity	Work			Radial	T a n
							Propor- tional limit	Maximum load			
		<u>P c t .</u>		<u>P . s . i .</u>	<u>P . s . i .</u>	<u>1,000</u> <u>p . s . i .</u>	<u>In . - lb.</u> <u>per</u> <u>cu. in.</u>	<u>In . - lb.</u> <u>per</u> <u>cu. in.</u>	<u>In . - lb.</u> <u>per</u> <u>cu. in.</u>	<u>In . - lb.</u>	<u>In . - lb.</u>
Recent Samples											
Jackson County, Oregon	5	75	0.35	3,200	5,400	1,120	0.51	5.9	10.7	130	240
	5	12	.36	5,900	9,400	1,430	1.37	7.6	13.4	130	210
Lake County, Oregon	5	61	.31	2,700	4,700	850	.48	5.6	8.4	100	120
	5	12	.32	5,000	7,800	1,040	1.38	5.1	5.6	100	110
Calaveras County, California	5	130	.38	3,500	5,800	1,190	.59	6.2	16.5	180	280
	5	12	.40	6,200	10,100	1,460	1.50	8.3	14.9	140	230
Plumas County, California	5	151	.41	4,000	6,700	1,460	.64	6.8	17.7	140	240
	5	12	.44	7,000	11,300	1,770	1.56	9.4	17.9	160	260
Average	20	105	.36	3,400	5,700	1,150	.56	6.1	13.3	140	220
	20	12	.38	6,000	9,700	1,430	1.45	7.6	13.0	130	200
Previous Samples											
Madera County, California	5	156	.35	3,900	6,000	1,130	.77	5.2	15.7	...	...
	5	12	.37	6,400	9,000	1,420	1.60	5.4	13.4	...	...
San Miguel County, New Mexico	5	123	.31	2,900	4,900	920	.54	5.1	7.6	...	...
	5	12	.34	5,300	8,200	1,140	1.40	5.8	7.4	...	...
Plumas county, California	10	91	.36	4,300	6,000	1,040	1.02	5.1	...	...	...
	10	12	.39	7,100	10,000	1,490	1.93	7.8	...	...	...
Previous Species											
Average	20	115	.35	3,800	5,700	1,030	.84	5.1	$\frac{5}{11.6}$	...	...
	20	12	.37	6,500	9,300	1,380	1.72	6.7	$\frac{5}{10.4}$	...	...
Based on all data											
New average	40	110	.35	3,600	5,700	1,090	.70	5.6	$\frac{6}{12.8}$	140	220
	40	12	.38	6,200	9,500	1,400	1.58	7.2	$\frac{6}{12.1}$	130	200

¹The values in the first line for each location are from tests of green material;
those in the second line are from tests of seasoned material adjusted to an average
air-dry condition of 12 percent moisture content.

²Specific gravity based on test volume and oven-dry weight.

³Height of drop causing complete failure (50-pound hammer).

⁴Load required to embed a 0.444-inch ball to 1/2 its diameter.

Impact bend- ing ³	Compression parallel to grain			Compres- sion perpen- dicular to grain	Hardness ⁴		Maximum shearing strength	Cleavage	Tension perpen- dicular to grain
	Stress at propor- tional limit	Modulus of elas- ticity	Maximum crushing strength		End	Side			
<u>In.</u>	<u>P.s.i.</u>	<u>1,000 p.s.i.</u>	<u>P.s.i.</u>	<u>P.s.i.</u>	<u>Lb.</u>	<u>Lb.</u>	<u>P.s.i.</u>	<u>Lb. per in. of width</u>	<u>P.s.i.</u>
20	2,000	1,430	2,710	230	410	320	730	160	310
23	3,990	1,660	5,560	520	800	480	1,190	180	310
17	1,740	1,010	2,280	200	370	270	690	150	310
15	2,830	1,220	4,660	540	680	390	1,120	170	340
24	2,160	1,450	2,890	320	480	370	740	180	310
25	3,780	1,710	5,840	610	860	560	1,300	200	360
25	2,580	1,840	3,410	310	510	400	810	170	330
28	4,690	2,160	6,960	660	990	650	1,380	210	370
22	2,120	1,430	2,820	260	440	340	740	170	320
23	3,820	1,690	5,750	580	830	520	1,250	190	340
18	2,610	1,330	2,800	⁷ 360	380	330	730	170	260
15	3,780	1,620	5,400	⁷ 530	670	430	970	170	260
18	1,810	1,100	2,210	⁷ 230	370	280	730	150	250
16	3,840	1,340	4,690	⁷ 500	650	410	930	160	230
25	.....	.....	2,920	⁷ 310	380	370	770	180	330
18	.....	.....	5,660	⁷ 450	800	460	900	150	280
22	⁵ 2,210	⁵ 1,220	2,710	300	380	330	750	170	290
17	⁵ 3,810	⁵ 1,480	5,350	480	730	440	930	160	260
22	⁶ 2,150	⁶ 1,360	2,770	280	410	340	750	170	300
20	⁶ 3,820	⁶ 1,620	5,550	530	780	480	1,090	180	300

⁵Average value based on 10 trees.

⁶Average value based on 20 trees.

⁷Average value adjusted from original data obtained by procedures that differ from present standards.

Table 3.--Shrinkage and other physical characteristics of white fir

Location	No. of trees	Rings per inch	Specific gravity ¹	Shrinkage, green to--								
				75° F., 64 percent relative humidity					Ovendry			
				Moisture content	Radial	Tan- gential	Longi- tudinal	Volu- metric	Radial	Tan- gential	Longi- tudinal	Volu- metric
				<u>Pct.</u>	<u>Pct.</u>	<u>Pct.</u>	<u>Pct.</u>	<u>Pct.</u>	<u>Pct.</u>	<u>Pct.</u>	<u>Pct.</u>	<u>Pct.</u>
Recent samples												
Jackson County, Oregon	5	16	0.35	12.8	1.6	4.2	0.00	6.1	3.3	7.5	0.13	10.1
Lake County, Oregon	5	22	.31	12.9	1.3	3.3	.00	5.2	2.6	6.0	.14	8.8
Calaveras county, California	5	12	.38	13.1	1.5	3.7	.09	5.6	3.2	6.9	.22	9.9
Plumas County, California	5	15	.41	13.0	1.8	4.1	.02	6.8	3.9	7.6	.18	11.7
Average	20	16	.36	12.9	1.6	3.8	.03	5.9	3.3	7.0	.17	10.1
Previous samples ²												
Madera County, California	5	10	.35	....	...	...	....	...	3.4	7.0	....	10.2
San Miguel County, New Mexico	5	11	.31	....	...	...	....	...	3.1	6.9	....	9.0
Plumas County, California	10	12	.36	....	...	...	....	...	...	...	....	9.3
Average	20	11	.35	....	...	...	....	...	⁴ 3.2	⁴ 7.0	....	9.4
Species average based on all data	40	14	.35	³ 12.9	³ 1.6	³ 3.8	³ .03	³ 5.9	⁵ 3.3	⁵ 7.0	³ .17	9.8

¹Specific gravity based on green volume and oven-dry weight.²Markwardt, L. J., and Wilson, T. R. C. Strength and related properties of woods grown in the United States. U.S. Dept Agr. Tech. Bul. 479, 99 pp., illus. 1935.³Average value based on 20 trees.⁴Average value based on 10 trees.⁵Average value based on 30 trees.

ties of white fir generally followed expected trends of increasing with specific gravity for the recent shipments, some exceptions were noted. Material from Calaveras County, California, generally averaged higher in strength than material from Jackson County, Oregon, as would be expected from its density; however, modulus of elasticity was nearly the same, possibly due to the extent of com-

pression wood in material from the first location.

Tangential toughness (load applied to a tangential surface) in both green and air-dry wood of the Lake County, Oregon, sample was considerably lower than would be expected in comparison to radial toughness and the behavior of wood from the other sites. Normally, tangential toughness is considerably higher than

Table 4.--Variation of strength and related properties of white fir in the green condition¹

Item	Number of specimens	Mean	Standard deviation	Coefficient of variation	Standard error of mean	Coefficient of variation of 50 species ²	Units for columns (3), (4) and (6)
(1)	(2)	(3)	(4)	(5) Pct.	(6)	(7) Pct.	(8)
AVERAGE VALUES							
Specific gravity	689	0.35	0.049	14	0.002	10	.....
Shrinkage, volumetric--green to ovendry	156	9.9	1.66	17	.13	16	Pct.
Shrinkage, radial--green to ovendry	88	3.3	.71	21	.08	15	Pct.
Shrinkage, tangential--green to ovendry	90	6.9	1.14	16	.12	14	Pct.
STATIC BENDING (FLEXURE)							
Fiber stress at proportional limit	330	3,540	791	22	44	22	P.s.i.
Modulus of rupture	330	5,720	1,018	18	46	16	P.s.i.
Modulus of elasticity	330	1,130	263	23	15	22	1,000 p.s.i.
Work to proportional limit	330	.64	.251	39	.014	38	In.-lb. per cu. in.
Work to maximum load	330	5.7	1.84	32	.10	34	In.-lb. per cu. in.
Total work	121	12.7	6.34	50	.58	.....	In.-lb. per cu. in.
TOUGHNESS							
Loaded on radial surface ³	172	146	43	29	3.3	.....	In.-lb. per specimen
Loaded on tangential surface ³	171	234	77	33	5.9	.....	In.-lb. per specimen
IMPACT BENDING--50-POUND HAMMER							
Drop causing complete failure	204	21	5.3	25	.4	25	In.
COMPRESSION PARALLEL TO GRAIN							
Crushing strength et proportional limit	425	2,130	586	28	28	24	P.s.i.
Maximum crushing strength	690	2,760	572	21	22	18	P.s.i.
Modulus of elasticity	465	1,430	411	29	19	29	1,000 p.s.i.
COMPRESSION PERPENDICULAR TO GRAIN							
Crushing strength at proportional limit ³	107	267	115	43	11.1	28	P.s.i.
HARDNESS-BALL TEST							
End	175	420	89	21	6.7	17	Lb.
Side	175	335	75	22	5.7	20	Lb.
SHEAR PARALLEL TO GRAIN							
Maximum shearing strength	282	738	93	13	5.6	14	P.s.i.
CLEAVAGE							
Load to cause splitting	232	165	30	18	2.0	.....	Lb. per in. of width
TENSION PERPENDICULAR TO GRAIN							
Maximum tensile strength	216	301	80	26	5.4	25	P.s.i.

¹Each specimen given equal weight.²U.S. Forest Products Laboratory. Wood handbook. U.S. Dept. Agr., Agr. Handb. 72, 528 pp., illus. 1955.³Based on results of the recent sample only.

radial toughness in softwoods.⁵ Similarly, green wood from Plumas County, California, was lower in toughness for its specific gravity than material from the other sites and was also lower than air-dry wood of the same sample. Green wood is usually somewhat tougher than air-dry wood.^{5,6} Compressive strengths perpendicular to the grain of greenwood from Plumas County, California, and air-dry wood from Jackson County, Oregon, appear somewhat lower on the basis of specific gravity than material from the other recent sample sites.

Average mechanical properties of the recent samples were generally comparable to those of the previous samples on the basis of average specific gravities, although some exceptions were noted. Shearing strength of air-dry wood of the recent samples was considerably higher than those of the previous samples although this difference was not apparent in green wood. End hardness of green and air-dry wood and side hardness of air-dry wood in the recent samples were somewhat higher than those in the previous samples. Based on specific gravity averages, modulus of rupture of green wood of the previous samples was somewhat higher than that of the recent samples, but modulus of elasticity of green and air-dry wood and modulus of rupture of air-dry wood were not much different by the same comparison. In a similar manner, impact strength of air-dry wood tended to be higher in

recent samples than in previous samples, although this tendency was not apparent in green wood.

At the time the previous sample was evaluated the strain rate used for compression perpendicular-to-grain tests was twice that specified in the present standard.⁴ Forest Products Laboratory data indicated that the proportional limit stress in compression perpendicular to grain evaluated by the present standard was about 0.81 times that evaluated by the previous standard. Average proportional limit stresses in compression perpendicular to the grain for the previous samples have been adjusted by that factor. On that basis and for material of comparable specific gravity, recent samples averaged somewhat lower for green wood and somewhat higher for air-dry wood than previous samples.

Combining all data of the species has raised most mechanical property averages slightly with the exception of proportional limit stresses in static bending for green and air-dry wood and compressions parallel and perpendicular to the grain in green wood where slight reductions were evident. Important increases were noted in modulus of elasticity in static bending of green wood, shearing strength of air-dry wood, and modulus of elasticity in compression parallel in green and air-dry wood; however, the previous species averages for modulus of elasticity in compression parallel did not include data from the sample from

⁵Draw, J. T., Markwardt, L. J., and Youngquist, W. G. Results of impact tests to compare the pendulum impact and toughness test methods. Forest Prod. Lab. Rpt. 2109, 19 pp., illus. 1948.

⁶U.S. Forest Products Laboratory. Wood handbook. U.S. Dept. Agr., Agr. Handb. 72, 528 pp., illus. 1955.

Plumas County, California, which had the highest average specific gravity in the previous sample.

Variations in the combined data of recent and previous samples were not greatly different than reported for 50 species⁶ when based on the coefficient of variation as shown in table 4. For a few properties, such as specific gravity, radial shrinkage, and compression perpendicular to the grain, the coefficient

of variation was notably higher in white fir. The variation in specific gravity probably resulted from the method of selecting the recent sample as the sample at each site was intentionally stratified on the basis of tree specific gravity. The usual practice has been based on selecting trees representative of the species without regard to tree specific gravity.

CONCLUSIONS

Although the recently sampled trees were selected to provide a stratified density sample, evaluation of data based on small clear specimens of wood from that and the previous sample leads to the following conclusions:

(1) Average specific gravity for the recent sample was practically the same as for the previous sample.

(2) Average shrinkage values were comparable to those of the previous sample.

(3) Mechanical properties, although generally comparable, were slightly higher in air-dry wood of the recent sample than those of the previous sample. Of most significance were somewhat higher modulus of elasticity values for green and air-dry wood and notably higher values for shear strength of air-dry wood.

(4) Toughness of air-dry wood was slightly lower than that of greenwood.

APPENDIX I

Shrinkage and other physical characteristics of white fir from various heights in one tree of each recent sample

Location	Bolt No.	Ring per inch	Specific gravity ¹	Shrinkage, green to--								
				75° F., 64 percent relative humidity					Ovendry			
				Moisture content	Radial	Tan- gential	Longi- tudinal	Volu- metric	Radial	Tan- gential	Longi- tudinal	Volu- metric
				Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.	Pct.
Jackson County, Oregon Tree 55	a-b	20	0.40	12.7	1.8	4.3	0.00	6.6	3.5	7.6	0.13	10.0
	c-d	16	.37	12.7	1.8	4.2	-.03	6.8	3.5	7.6	.09	11.0
	l-m	12	.33	12.7	1.4	3.2	-.01	5.6	3.0	6.1	.14	9.6
Lake County, Oregon Tree 26	a-b	25	.33	12.7	1.4	3.3	.00	4.6	2.9	6.2	.17	7.8
	c-d	25	.33	12.8	1.4	3.2	.01	5.3	3.0	6.1	.16	8.9
	k-l	21	.32	12.7	1.2	2.9	.09	3.7	2.5	5.4	.30	6.8
Calaveras County, California Tree 61	a-b	12	.35	13.1	1.6	4.0	.07	6.0	3.3	7.2	.24	10.0
	c-d	11	.34	13.2	1.4	4.0	.10	5.2	3.0	7.3	.27	9.9
	k-l	10	.31	13.1	1.3	3.1	.19	4.5	2.7	5.9	.31	8.2
Plumas County, California Tree 98	a-b	11	.40	12.8	1.9	4.8	-.01	5.7	3.8	8.5	.07	11.1
	c-d	12	.38	12.8	1.7	4.2	-.01	6.2	3.7	7.6	.11	10.6
	s-t	10	.34	12.9	1.3	3.7	-.03	5.6	2.8	6.6	.16	9.1

¹Specific gravity based on green volume and oven-dry weight.

Mechanical properties of white fir from various heights in one tree of each recent sample

- ¹ Specific gravity based on test volume and overdry weight.
- ² Height of drop causing complete failure (50-pound hammer).
- ³ Load required to embed a 0.444-inch ball to 1/2 its diameter.