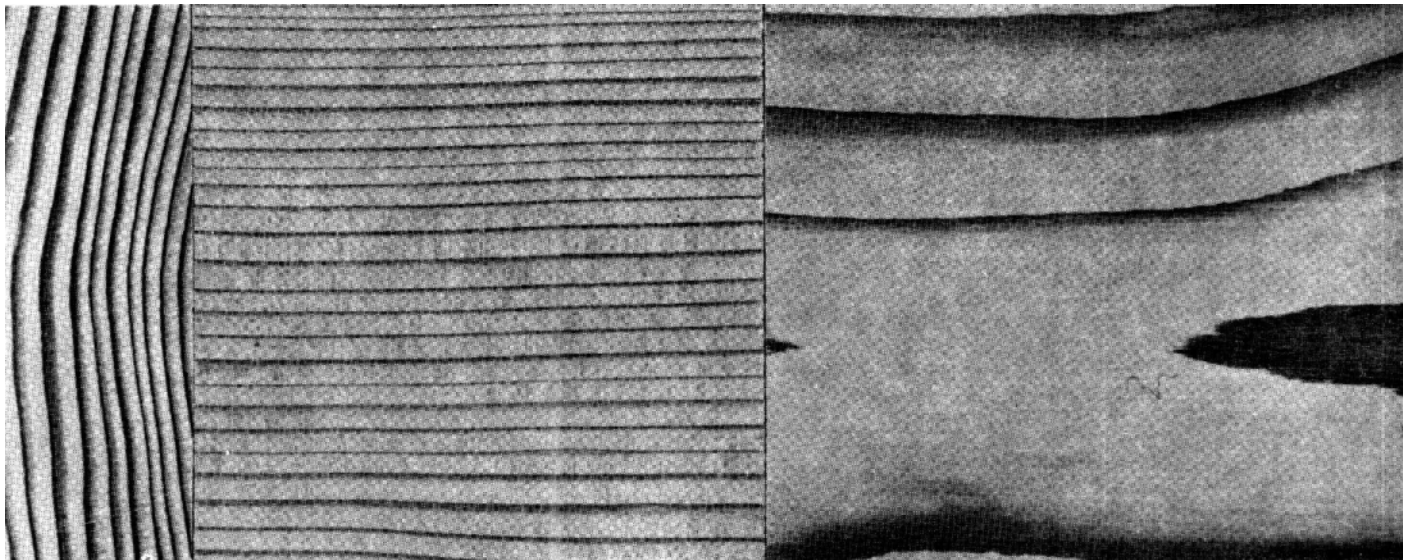


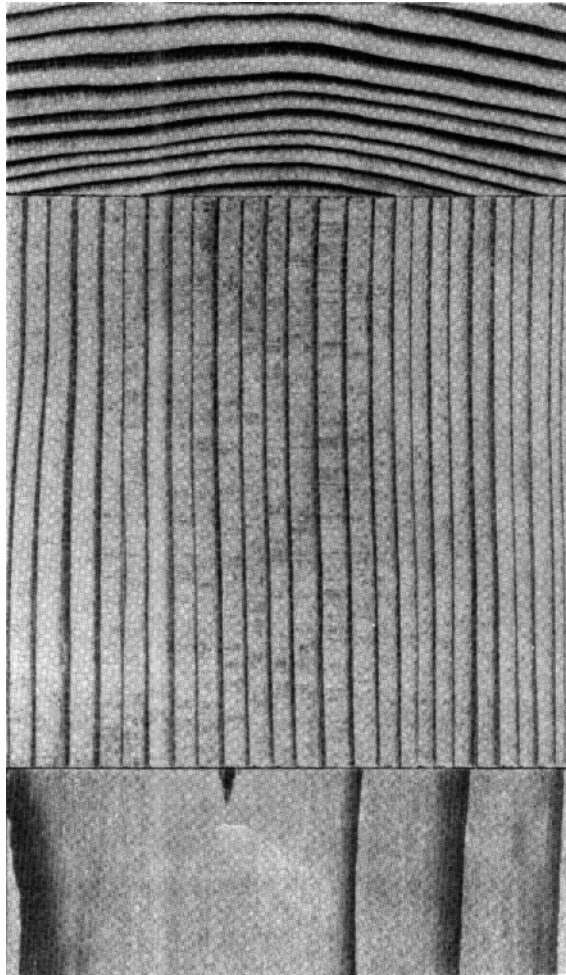
STRENGTH and RELATED PROPERTIES
of
WHITE FIR



U. S. DEPARTMENT OF AGRICULTURE • FOREST SERVICE
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.





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FOREST SERVICE
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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.

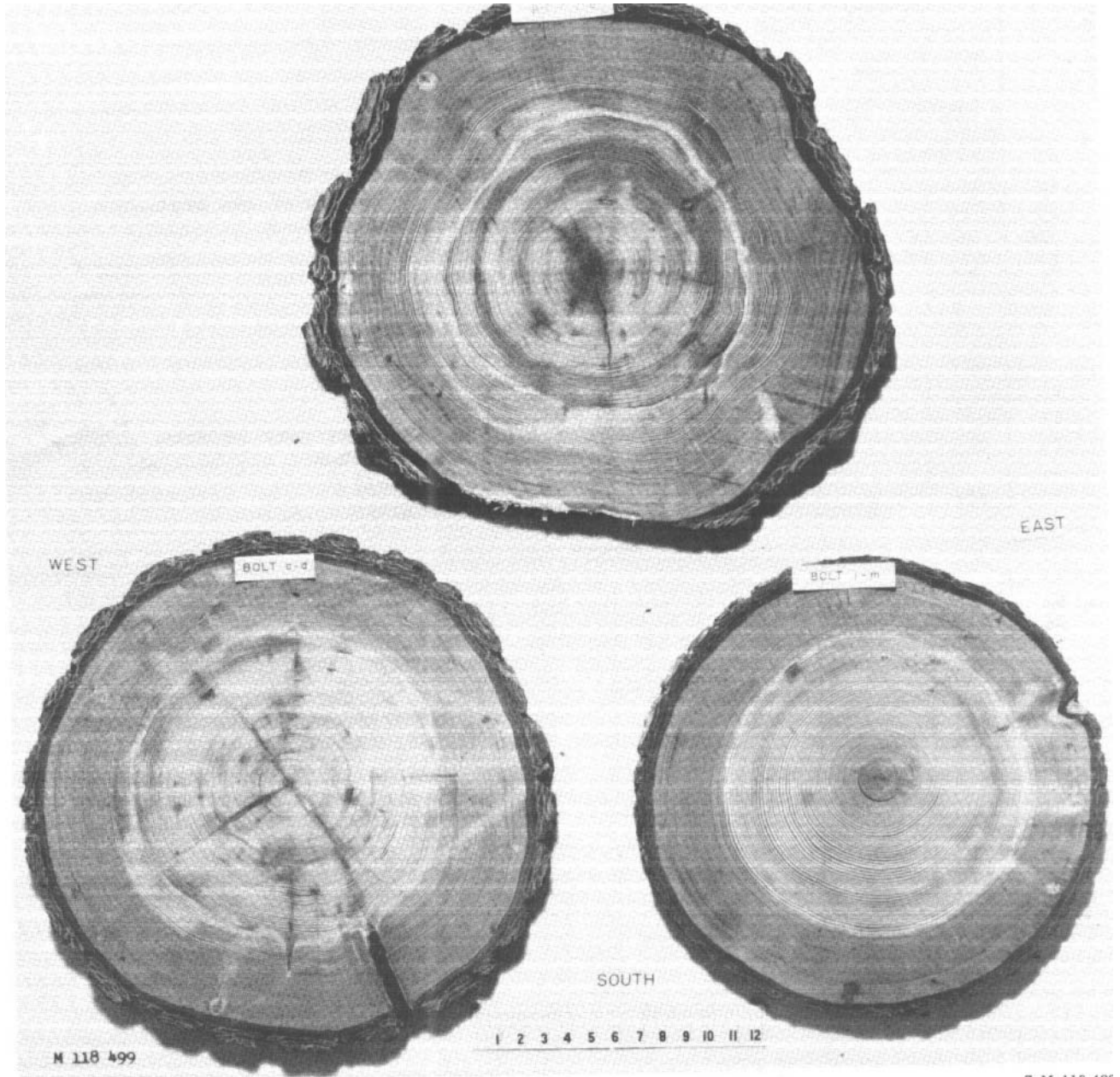


Figure 2.--Cross sections of tree 55, from Jackson County, Oregon, at heights of 4, 12, and 48 feet, considered representative of the growth of white fir.

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 proportional limit	Modulus of rupture	Modulus of elasticity	Work			Radial	T a n
							Proportional limit	Maximum load			
		Pct.		P.s.i.	P.s.i.	1,000 p.s.i.	In. - lb. per cu. in.	In. - lb. per cu. in.	In. - lb. per cu. in.	In. - lb.	In. - lb.
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	$\frac{5}{7}$ 11.6	...	...
	20	12	.37	6,500	9,300	1,380	1.72	6.7	$\frac{5}{6}$ 10.4	...	...
Based on all data											
New average	40	110	.35	3,600	5,700	1,090	.70	5.6	$\frac{6}{1}$ 12.8	140	220
	40	12	.38	6,200	9,500	1,400	1.58	7.2	$\frac{6}{1}$ 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 bending ³	Compression parallel to grain			Compression perpendicular to grain	Hardness ⁴		Maximum shearing strength	Cleavage	Tension perpendicular to grain
	Stress at proportional limit	Modulus of elasticity	Maximum crushing strength		End	Side			
					P. s. i.	1,000 p. s. i.			
20 23	2,000 3,990	1,430 1,660	2,710 5,560	230 520	410 800	320 480	730 1,190	160 180	310 310
17 15	1,740 2,830	1,010 1,220	2,280 4,660	200 540	370 680	270 390	690 1,120	150 170	310 340
24 25	2,160 3,780	1,450 1,710	2,890 5,840	320 610	480 860	370 560	740 1,300	180 200	310 360
25 28	2,580 4,690	1,840 2,160	3,410 6,960	310 660	510 990	400 650	810 1,380	170 210	330 370
22 23	2,120 3,820	1,430 1,690	2,820 5,750	260 580	440 830	340 520	740 1,250	170 190	320 340
18 15	2,610 3,780	1,330 1,620	2,800 5,400	⁷ 360 ⁷ 530	380 670	330 430	730 970	170 170	260 260
18 16	1,810 3,840	1,100 1,340	2,210 4,690	⁷ 230 ⁷ 500	370 650	280 410	730 930	150 160	250 230
25 18	..... .....	..... .....	2,920 5,660	⁷ 310 ⁷ 450	380 800	370 460	770 900	180 150	330 280
22 17	⁵ 2,210 ⁵ 3,810	⁵ 1,220 ⁵ 1,480	2,710 5,350	300 480	380 730	330 440	750 930	170 160	290 260
22 20	⁶ 2,150 ⁶ 3,820	⁶ 1,360 ⁶ 1,620	2,770 5,550	280 530	410 780	340 480	750 1,090	170 180	300 300

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 Pct.	Radial Pct.	Tan- gential Pct.	Longi- tudinal Pct.	Volu- metric Pct.	Radial Pct.	Tan- gential Pct.	Longi- tudinal Pct.	Volu- metric Pct.	
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.

APPENDIX II

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

Bolt Rings No. per inch	Moisture content	Specific Gravity ¹	Static bending				Toughness		Impact bending ²	Compression parallel to grain			Hardness ³		Maximum shearing strength	Cleavage perpendicular to grain	Tension perpendicular to grain		
			Stress at proportional limit	Modulus of elasticity	Modulus of rupture	P.s.i.	Propor-tional limit	Maximum load		Total work	Radial	Tan-gential	Stress at proportional limit	Maximum crushing strength				Modulus of elasticity	End	Side
		Pct.	In.-lb. per cu. in.	In.-lb. per cu. in.	In.-lb. per cu. in.	In.-lb. per cu. in.	In.-lb.	In.-lb.	In.	P.s.i.	P.s.i.	P.s.i.	P.s.i.	P.s.i.	P.s.i.	P.s.i.	P.s.i.		
TREE 55 OF SAMPLE FROM JACKSON COUNTY, OREGON																			
a-b 20	114	0.40	3,900	6,400	1,240	0.68	6.8	15.1	200	290	23	2,330	3,140	1,540	470	390	880	210	410
c-d 16	80	.37	3,600	5,900	1,280	.56	6.3	11.5	140	230	21	2,340	3,050	1,640	470	350	770	160	280
l-m 12	92	.33	3,200	5,300	1,070	.55	5.9	8.6	100	170	16	1,760	2,550	1,350	380	290	710	150	320
a-b 17	13	.41	6,200	10,000	1,480	1.48	9.1	14.7	140	220	25	3,900	5,880	1,770	920	610	1,440	230	390
c-d 16	13	.38	6,200	9,500	1,590	1.34	8.1	14.9	140	220	22	4,420	5,700	1,870	820	480	1,210	170	220
l-m 12	13	.34	5,500	8,300	1,300	1.30	5.6	9.1	110	180	19	3,580	5,290	1,530	680	410	1,040	140	300
TREE 26 OF SAMPLE FROM LAKE COUNTY, OREGON																			
a-b 25	103	.33	2,700	5,100	820	.52	6.1	11.3	160	220	23	1,680	2,320	830	400	350	750	180	400
c-d 25	61	.33	3,000	5,000	920	.55	5.5	9.0	100	130	20	1,810	2,400	1,040	390	290	700	170	390
k-1 21	46	.32	2,500	4,900	800	.46	5.7	5.7	...	...	16	1,630	2,180	770	380	270	680	160	380
a-b 22	13	.35	5,000	7,800	1,040	1.35	5.3	5.3	110	110	18	2,420	4,500	1,210	690	390	1,140	200	410
c-d 24	13	.34	5,100	8,800	1,180	1.29	6.9	7.5	130	100	18	2,890	4,890	1,340	750	450	1,140	190	380
k-1 20	13	.32	4,700	6,600	940	1.33	3.6	...	70	80	16	2,360	4,300	1,140	690	380	1,130	170	370
TREE 61 OF SAMPLE FROM CALAVERAS COUNTY, CALIFORNIA																			
a-b 12	178	.35	3,100	5,400	1,120	.49	5.3	15.8	200	280	21	2,080	2,660	1,340	480	410	640	160	320
c-d 11	130	.34	3,000	4,900	1,050	.47	4.6	12.9	160	280	21	1,810	2,460	1,300	410	370	720	160	300
k-1 10	116	.31	2,600	4,700	990	.38	4.4	8.4	120	210	21	1,380	2,190	1,220	380	290	660	140	260
a-b 12	13	.37	5,100	8,800	1,280	1.15	7.3	14.6	150	250	23	3,340	5,150	1,544	770	520	1,240	200	390
c-d 12	13	.36	5,600	8,800	1,350	1.36	7.0	17.6	130	230	23	3,470	5,020	1,600	740	470	1,180	200	380
k-1 10	13	.32	4,800	7,500	1,130	1.16	5.6	9.1	90	150	17	3,130	4,400	1,350	660	400	1,070	180	320
TREE 98 OF SAMPLE FROM PLUMAS COUNTY, CALIFORNIA																			
a-b 11	151	.40	4,000	6,600	1,400	.64	6.1	17.4	180	250	24	2,400	3,300	1,720	560	490	770	170	360
c-d 12	167	.38	3,800	6,200	1,330	.60	6.4	15.6	140	240	22	2,820	3,100	1,610	460	390	710	170	310
s-t 10	71	.34	3,200	5,400	1,070	.54	4.9	8.4	100	150	15	2,040	2,590	1,260	440	330	650	160	330
a-b 11	13	.42	6,500	10,600	1,590	1.54	8.8	19.0	150	270	27	4,040	6,220	1,940	890	550	1,310	220	360
c-d 12	13	.40	6,400	10,100	1,600	1.47	6.9	15.5	140	240	22	4,120	6,220	1,900	870	560	1,080	180	310
s-t 10	12	.35	5,700	8,500	1,280	1.41	5.1	8.1	90	180	18	3,680	5,200	1,500	760	440	1,220	170	330

¹ Specific gravity based on test volume and oven-dry 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.