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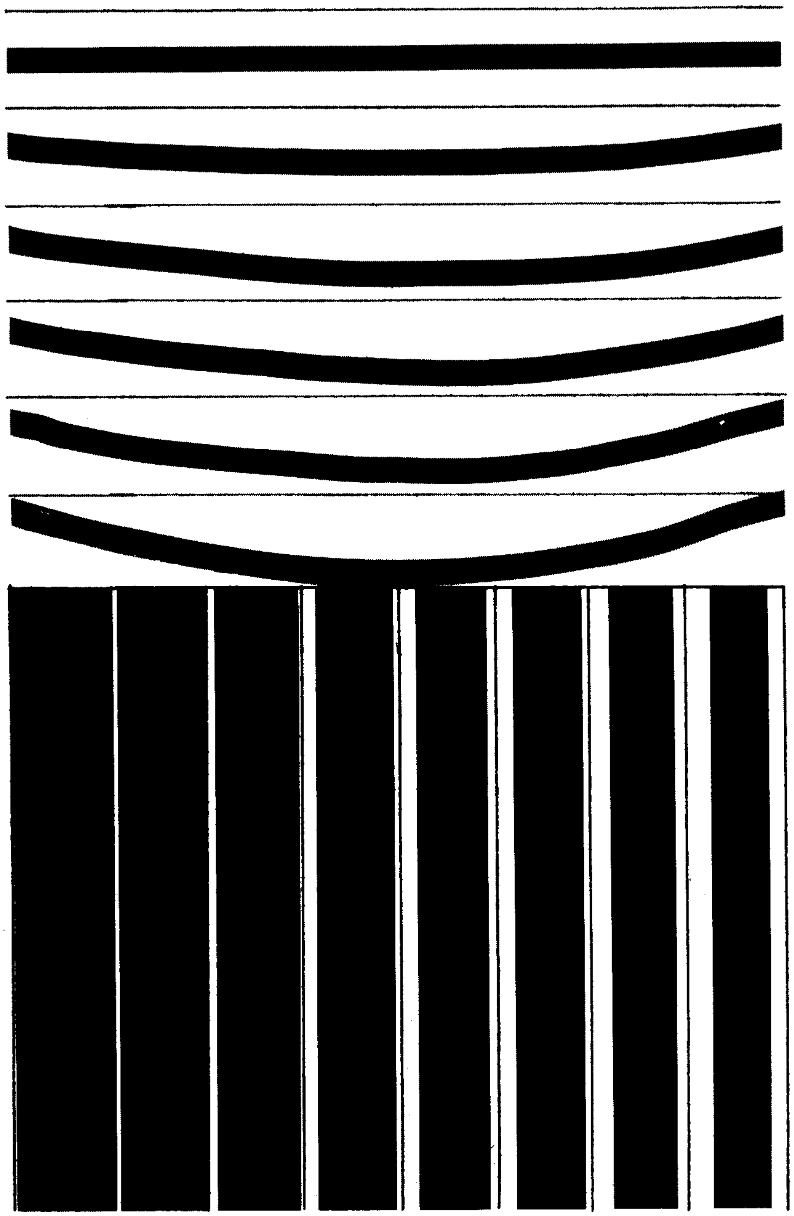
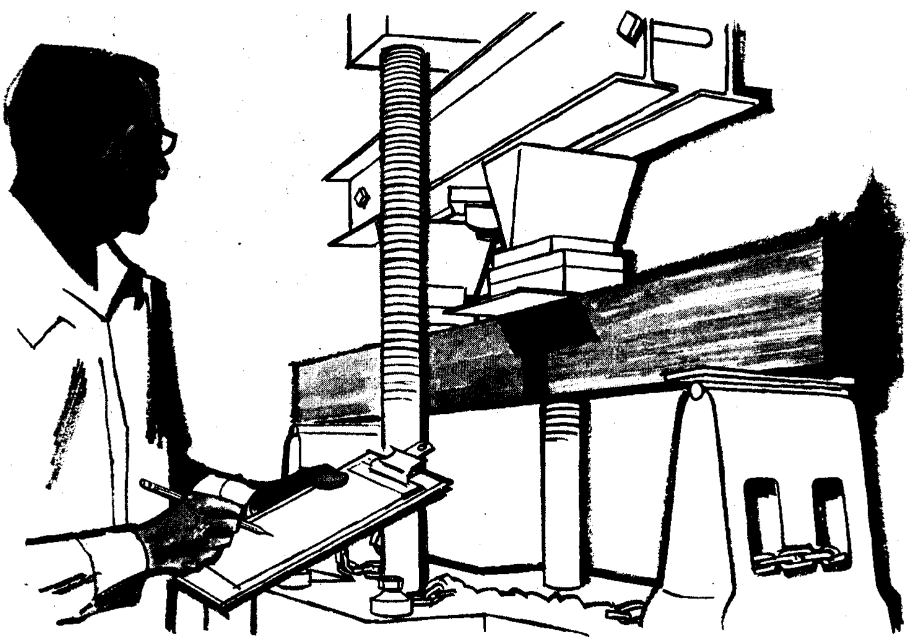


STIFFNESS and SHRINKAGE of GREEN and DRY JOISTS

U S DEPARTMENT OF AGRICULTURE • FOREST SERVICE
FOREST PRODUCTS LABORATORY • MADISON, WIS.



SUMMARY

This report gives information on the edgewise modulus of elasticity, stiffness, and shrinkage of 360 joists in three species, three grades, and two sizes, each species obtained from two sources. Each joist was evaluated nondestructively at four moisture content values ranging from the green condition to about 11 percent. Information is also given on specific gravity, strength ratio, hardness, and direction of the annual rings.

The work showed a relation of modulus of elasticity to grade, with the highest grades having about the same value as that for clear wood. Increases of about 14 percent were observed in drying to 15 percent moisture content and about 20 percent in drying to about 11 percent moisture content. The stiffness showed little change with drying. Shrinkage values to 15 percent moisture content averaged 2.8 percent in width and 2.5 percent in thickness. Douglas-fir and western hemlock had a predominance of flat grain and greater shrinkage inwidth than in thickness. Southern pine had a more uniform distribution from flat to edge grain and greater shrinkage in thickness than in width.

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STIFFNESS and SHRINKAGE of GREEN and DRY JOISTS

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U. S. DEPARTMENT OF AGRICULTURE

INTRODUCTION

The nationwide interest and activity in size and grade standards for softwood construction lumber has raised a number of questions about its physical and mechanical properties in relation to moisture content. Lumber shrinks as it dries, and at the same time its strength and stiffness increase.

The amount of shrinkage is affectedby the direction of the annual rings, the moisture content, the conditions of drying, and the inherent shrinkage characteristics, all of which may vary among individual pieces of a species andgrade. The bulk of the information now available is on small clear specimens of wood, and there has been question of the extent of its application to structural lumber, particularly to that used in light-frame construction.

A great deal of work has been done on the shrinkage of wood and the increase of strength and stiffness with drying in small clear specimens. Much of this is compiled in the Wood Handbook.[2] Recommendations for increases of working

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

[2]Forest Products Laboratory. Wood handbook. U.S. Dept.. Agr., Agr. Handb. No. 72, 528 pp., illus. 1955.

stresses with drying of structural lumber are published by ASTM[3] and NLMA.[4] The Forest Products Laboratory has an extensive and continuing correspondence on the effects of moisture content on shrinkage, strength, and stiffness. Lumber industry laboratories have developed similar information, most of it unpublished.

In regard to machine grading of lumber, laboratory data have been developed on strength and stiffness in various grades and sizes of lumber of the major softwood construction species. Shrinkage studies of softwood dimension lumber have been made by the industry and also at Oregon State University.

The specific objective of this study was to observe the dimensions and the modulus of elasticity of 2-inch joists of three softwood species when green and at three successive stages of drying. This gives information on the shrinkage at various moisture content levels, the effects of drying on the modulus of elasticity, and the stiffness (product of the modulus of elasticity times the moment of inertia of the cross section).

Observations were also made of related properties such as specific gravity, direction of the annual rings, estimated strength ratio, and hardness as determined by a special tool developed by the Western Pine Association. Evaluations of strength were not made.

STUDY MATERIAL

The three species used were Coast Douglas-fir (Pseudotsuga menziesii var. menziesii), western hemlock (Tsuga heterophylla), and southern pine (Pinus sp.). They are commercially designated as Douglas Fir, West Coast Hemlock, and SouthernYellow Pine. Eachwas sampled from two representative sources. The two western species originatedfrom Oregon and Washington. The western hemlock included nine pieces of fir (Abies sp.); since these had properties similar to the hemlock, their values were included with the values from the hemlock. The southern pine was from the "shortleaf region" of Louisiana and Arkansas and is presumed to be either shortleaf or loblolly pine species or both. That from one source was selected to meet the requirements of the "density rule,"[5] while that from the other source was selected to exclude material meeting the requirements of the density rule.

Three grades were selected in each

[3] American Society for Testing and Materials. Tentative methods for establishing structural grades of lumber. ASTM Designation D 245-62T. Philadelphia, 1962.

[4] National Lumber Manufacturers Association. National design specification for stress-grade lumber and its fastenings. Washington, D.C., 1962.

[5] Southern Pine Inspection Bureau. Standard grading rules for southern pine lumber. pp. 58-60. New Orleans, 1963.

species: Construction, Standard, and Utility in the western woods, and No. 1, No. 2, and No. 3 in the southern pines. The two sizes were 2 by 6 inches (nominal) 10 feet long and 2 by 10 (nominal) 16 feet long. The selection was essentially 10 pieces of each size in each grade of each species from each source, a total of 360 pieces.

A representative of the West Coast Lumber Inspection Bureau supervised the selection of the western woods and a representative of the Southern Pine Inspection Bureau supervised the selection of the southern pine. Selected material was inspected and marked for grade by Bureau representatives.

All of the study material was in the green condition when sampled. It was protected from drying during winter shipment by wrapping; after it was received at the Forest Products Laboratory, it was kept from drying until the first test run for stiffness determination was made.

A 6-inch length was cut from one end of each green piece for another study. After the first stiffness run, the material was kiln dried to a nominal 19 percent average moisture content for the second run, then kiln dried to a nominal 15 percent moisture content for the third run, and to a nominal 10 percent moisture content for the fourth run. As shown in tables 1 to 4, the actual moisture content values at the times of the last three runs somewhat exceeded the nominal values.

Table 1.--Summary of stiffness and shrinkage of Douglas-fir joists

Grade	Values for 2 by 6 size[1]							Values for 2 by 10 size[1]							Values for both sizes					
	Average moisture content	Average specific gravity[2]	Modulus of elasticity: Average	Modulus of elasticity: Coefficient of variation	Average stiffness[3]	Average shrinkage: Width	Average shrinkage: Thickness	Average moisture content	Average specific gravity[2]	Modulus of elasticity: Average	Modulus of elasticity: Coefficient of variation	Average stiffness[3]	Average shrinkage: Width	Average shrinkage: Thickness	Average moisture content	Average specific gravity[2]	Modulus of elasticity: Average	Modulus of elasticity: Coefficient of variation	Average shrinkage: Width	Average shrinkage: Thickness
	Pct.		1,000 p.s.i.	Pct.	Million lb.-in.^{2}	Pct.	Pct.	Pct.		1,000 p.s.i.	Pct.	Million lb.-in.^{2}	Pct.	Pct.	Pct.		1,000 p.s.i.	Pct.	Pct.	Pct.
FIRST RUN																				
Construction	84		1,710	26	38.3			55		1,620	23	185			69		1,660	24		
Standard	85		1,460	26	32.8			57		1,200	19	137			71		1,330	26		
Utility	66		1,460	22	32.6			63		1,360	28	158			64		1,410	25		
SECOND RUN																				
Construction	26		1,710	18	36.5	1.5	0.4	18		1,730	24	181	2.1	2.2	22		1,720	21	1.8	1.3
Standard	27		1,500	26	31.9	1.5	.5	18		1,280	18	136	1.8	1.8	23		1,390	24	1.7	1.2
Utility	26		1,550	23	32.8	1.5	.6	19		1,450	28	156	1.7	1.8	22		1,500	25	1.6	1.2
THIRD RUN																				
Construction	21		1,890	18	38.4	2.6	1.3	16		1,790	23	184	2.6	2.5	18		1,840	20	2.6	1.9
Standard	23		1,620	29	33.1	2.5	1.2	16		1,340	17	140	2.2	2.1	19		1,480	26	2.4	1.7
Utility	22		1,660	24	34.1	2.4	1.4	16		1,520	28	160	2.3	2.1	19		1,590	26	2.4	1.7
FOURTH RUN																				
Construction	10	0.49	2,020	17	38.5	4.3	2.9	11	0.48	1,910	22	186	3.9	3.7	11	0.48	1,970	20	4.1	3.3
Standard	10	.45	1,740	26	33.3	4.1	2.5	10	.47	1,480	16	147	3.5	3.2	10	.46	1,610	23	3.8	2.8
Utility	10	.48	1,800	21	34.5	4.1	2.9	11	.49	1,630	28	164	3.6	2.9	10	.48	1,720	25	3.9	2.9

[1]Sample of 20 specimens in each grade of each sire from two sources combined.

[2]Based on ovendry weight and volume at the indicated moisture content.

[3]Product of modulus of elasticity times the moment of inertia of the cross section.

Table 2.--Summary of stiffness and shrinkage of western hemlock[1] joists

Grade	Values for 2 by 6 size[2]							Values for 2 by 10 size[2]							Values for both sizes[2]					
	Average moisture content	Average specific gravity[3]	Modulus of elasticity: Average	Modulus of elasticity: Coefficient of variation		Average shrinkage: Width	Average shrinkage: Thickness	Average moisture content	Average specific gravity[3]	Modulus of elasticity: Average	Modulus of elasticity: Coefficient of variation	Average stiffness[4]	Average shrinkage: Width	Average shrinkage: Thickness	Average moisture content	Average specific gravity[3]	Modulus of elasticity: Average	Modulus of elasticity: Coefficient of variation	Average shrinkage: Width	Average shrinkage: Thickness
	Pct.		1,000 p.s.i.	Pct.		Pct.	Pct.	Pct.		1,000 p.s.i.	Pct.	Million lb.-in.[2]	Pct.	Pct.	Pct.		1,000 p.s.i.	Pct.	Pct.	Pct.
FIRST RUN																				
Construction	97		1,500	16	33.5			76		1,660	19	193			86		1,580	18		
Standard	67		1,410	20	31.7			80		1,320	22	154			74		1,370	21		
Utility	83		1,400	19	31.2			89		1,330	24	156			86		1,370	22		
SECOND RUN																				
Construction	22		1,570	15	32.7	1.9	0.8	20		1,770	18	188	2.4	1.7	21		1,670	18	2.1	1.2
Standard	21		1,510	21	32.0	1.5	.7	21		1,430	21	154	2.0	1.5	21		1,470	21	1.8	1.1
Utility	22		1,470	17	31.1	1.4	.9	20		1,430	24	156	1.6	1.3	21		1,450	20	1.5	1.1
THIRD RUN																				
Construction	16		1,660	14	33.5	2.8	1.4	17		1,830	17	189	2.9	2.3	17		1,740	17	2.9	1.8
Standard	15		1,600	19	32.9	2.3	1.7	17		1,490	21	156	2.8	2.2	16		1,550	20	2.5	1.9
Utility	16		1,580	20	32.6	2.1	1.5	16		1,500	24	159	2.4	2.2	16		1,540	22	2.3	1.8
Fourth RUN																				
Construction	11	0.44	1,770	14	33.7	4.3	2.5	12	0.46	1,970	18	191	4.6	3.5	11	0.45	1,870	17	4.5	3.0
Standard	10	.44	1,750	20	34.0	3.6	2.8	11	.43	1,630	22	160	4.3	3.5	11	.44	1,690	21	4.0	3.2
Utility	10	.44	1,680	17	32.6	3.5	2.8	11	.45	1,610	23	162	3.9	3.1	11	.45	1,640	20	3.7	3.0

[1] Includes 9 specimens of fir (Abies sp.).

[2] Sample of 20 specimens in each grade of each size from two sources combined.

[3] Based on ovendry weight and volume at the indicated moisture content.

[4] Product of modulus of elasticity times the moment of inertia of the cross section.

Table 3.--Summary of stiffness and shrinkage of dense southern pine joists

Grade	Values for 2 by 6 size[1]							Values for 2 by 10 size[1]							Values for both sizes					
	Average moisture content	Average specific graviety[2]	Modulus of elasticity: Average	Modulus of elasticity: Coefficient of variation	Average stiffness[3]	Average shrinkage: Width	Average shrinkage: Thickness	Average moisture content	Average specific gravity[2]	Modulus of elasticity: Average	Modulus of elasticity: Coefficient of variation	Average stiffness[3]	Average shrinkage: Width	Average shrinkage: Thickness	Average moisture content	Average specific gravity[2]	Modulus of elasticity: Average	Modulus of elasticity: Coefficient of variation	Average shrinkage: Width	Average shrinkage: Thickness
	Pct.		1,000 p.s.i.	Pct.	Million lb.-in.[2]	Pct.	Pct.	Pct.		1,000 p.s.i.	Pct.	Million lb.-in.[2]	Pct.	Pct.	Pct.		1,000 p.s.i.	Pct.	Pct.	Pct.
FIRST RUN																				
No. 1	69		1,680	18	40.6			67		1,690	18	197			68		1,680	18		
No. 2	81		1,480	12	35.8			87		1,520	18	177			84		1,500	15		
No. 3	75		1,420	12	34.5			73		1,410	18	165			74		1,420	15		
SECOND RUN																				
No. 1	22		1,780	19	40.8	1.3	1.7	25		1,690	17	190	0.7	1.4	24		1,740	18	1.0	1.6
No. 2	22		1,540	15	35.8	1.0	1.2	26		1,520	17	172	.7	1.1	24		1,530	15	.8	1.2
No. 3	22		1,480	10	34.3	1.1	1.4	23		1,400	18	157	.8	1.3	23		1,440	14	.9	1.4
THIRD RUN																				
No. 1	19		1,850	17	41.2	1.9	2.2	18		1,800	19	194	1.8	2.4	18		1,820	17	1.9	2.3
No. 2	18		1,610	14	36.3	1.7	1.8	18		1,640	18	176	1.9	2.1	18		1,620	16	1.8	2.0
No. 3	18		1,530	10	34.4	1.8	2.0	17		1,520	19	163	2.0	2.2	10		1,520	15	1.9	2.1
FOURTH RUN																				
No. 1	12	0.57	1,980	18	41.2	3.6	3.8	12	0.55	1,920	16	194	3.2	4.1	12	0.56	1,950	17	3.4	4.0
No. 2	12	.55	1,780	16	37.6	3.2	3.3	12	.52	1,750	17	177	3.4	3.6	12	.54	1,760	16	3.3	3.4
No. 3	12	.53	1,670	10	35.1	3.4	3.5	12	.51	1,640	18	167	3.2	3.7	12	.52	1,660	14	3.3	3.6

[1] Sample of 10 specimens in each grade of each size.

[2] Based on ovendry weight and volume at the indicated moisture content.

[3] Product of modulus of elasticity times the moment of inertia of the cross section.

Table 4.--Summary of stiffness and shrinkage of nondense southern pine joists

Grade	Values for 2 by 6 size[1]							Values for 2 by 10 size[1]							Values for both sizes					
	Average moisture content	Average specific gravity[2]	Modulus of elasticity		Average stiffness[3]	Average shrinkage		Average moisture content	Average specific gravity[2]	Modulus of elasticity		Average stiffness[3]	Average shrinkage		Average moisture content	Average specific gravity[2]	Modulus of elasticity		Average shrinkage	
			Average	Coefficient of variation		Width	Thickness			Average	Coefficient of variation		Width	Thickness			Average	coefficient of variation	width	Thickness
	Pct.		1,000 p.s.i.	Pct.	Million lb.-in.[2]	Pct.	Pct.	Pct.		1,000 p.s.i.	Pct.	Million lb.-in.[2]	Pct.	Pct.	Pct.		1,000 p.s.i.	Pct.	Pct.	Pct.
FIRST RUN																				
No. 1	110		1,430	16	34.9			88		1,470	15	172			99		1,450	16		
No. 2	118		1,320	14	32.4			101		1,300	12	153			109		1,310	13		
No. 3	76		1,180	21	28.6			89		1,180	12	138			83		1,180	17		
SECOND RUN																				
No. 1	22		1,410	18	33.0	1.1	0.8	22		1,570	17	173	1.5	1.8	22		1,490	18	1.3	1.3
No. 2	22		1,330	14	31.3	1.0	.5	22		1,390	12	154	1.2	1.4	22		1,360	13	1.1	1.0
No. 3	20		1,220	21	28.4	1.0	1.0	22		1,270	12	141	1.2	1.7	21		1,250	16	1.1	1.3
THIRD RUN																				
No. 1	18		1,540	16	34.6	2.0	2.0	18		1,610	14	173	2.0	2.6	18		1,570	15	2.0	2.3
No. 2	17		1,440	12	32.4	2.0	1.6	18		1,430	14	155	1.8	2.5	17		1,430	13	1.9	2.0
No. 3	17		1,320	20	29.7	1.8	2.0	18		1,330	11	144	1.8	2.7	17		1,320	16	1.8	2.4
FOURTH RUN																				
No. 1	11	0.48	1,670	17	34.9	3.8	3.7	12	0.49	1,730	16	176	3.2	4.2	11	0.49	1,700	16	3.5	3.9
No. 2	10	.49	1,600	16	33.4	4.0	3.4	11	.48	1,580	13	161	3.2	4.1	10	.48	1,590	14	3.6	3.7
No. 3	10	.50	1,480	21	31.2	3.3	3.8	10	.48	1,440	10	148	3.0	4.2	10	.49	1,460	16	3.1	4.0

[1] Sample of 10 specimens in each grade of each size.

[2] Based on ovendry weight and volume at the indicated moisture content.

[3] Product of modulus of elasticity times the moment of inertia of the cross section.

Before the second, third, and fourth stiffness runs, the study material was dried by relatively mild schedules chosen to simulate the effects on green lumber from drying in transit or duringbuilding erection. Dry-bulb temperatures were generally 90° to 100° F. with wet-bulb depressions of 4° to 5° F. before the second run, 7° to 9° F. before the third run, and 12° to 20° F. before the fourth run. Air circulation was slow, generally less than 200 feet per minute. The two sizes were handled separately for part of the operations. Drying times ranged generally from 7 to 14 days, or longer on some of the pieces. The progress of drying was noted at intervals by weighing selected pieces.

Drying of the nondense southern pine after the first run was unintentionally delayed, and bluestain developed, especially in the 2 by 6 size. Smaller amounts of bluestain occurred in shipment of the dense southern pine. Pathological examination indicated that the bluestain probably would not significantly affect the physical or the structural properties. Also, the experimental data did not indicate any significant effect.

EXPERIMENTAL PROCEDURE

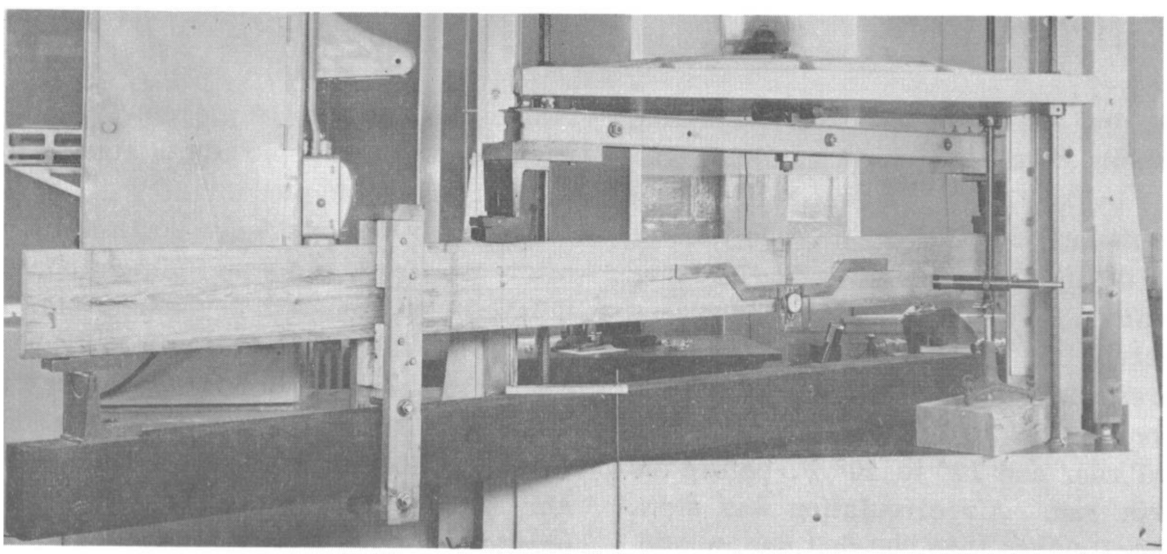
Methods of Test

In each run, each piece was subjected to edgewise bending with quarter-point loading on spans of 14 feet 6 inches for 2 by 10's and 8 feet 6 inches for 2 by 6's. Load was applied up to 1,200 pounds on 2 by 10's and 500 pounds on 2 by 6's, these loads resulting in fiber stresses of about 1,000 pounds per square inch, which were below the proportional limit. Lateral support was provided between the load point and the support at each end. Test procedures followed the ASTM Standard.[6] Figure 1 is a general view of a 2 by 10 in test.

Deflections at midspan with respect to the support points were observed at intervals during the loading. In the first and fourth runs, deflections were observed also on a 36-inch length at midspan to provide values of modulus of elasticity free from shear deformation (fig. 1).

Measurements of cross section near the two quarter-points of length and of overall length were made and the piece was weighed at the time of each run. Thickness was measured at points about 1 inch from each edge. The thickness and width values were used in calculating shrinkage based on the green dimensions.

Figure 1.-- View of 2- by 10-inch joist in bending test. Full-length deflection is observed by means of the telescope and wire and short-span deflection by dial gage and yoke.



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[6]American Society for Testing and Materials. Standard methods of static tests of timbers in structural sizes. ASTM Designation D 198-27, reapproved 1961. Philadelphia, 1962.

After the fourth run, a l-inch section was cut near each quarter-point of lengthfor determination of moisture content and specific gravity. The moisture content was used with the final weight of the piece to calculate its ovendry weight. The ovendry weight was used with the weights at the first three runs to calculate the moisture content values at those runs.

A visual estimate of strength ratio was made on each piece by ASTM methods' after the third run.

After cutting of the piece for moisture content determination, a sketchwas made of the direction of the annual rings at each end of the central half-length. The directions of rings were classified from the sketches as follows:

1. Flat-grained
2. Modified flat-grained
3. Intermediate
4. Modified edge-grained
5. Edge-grained

These categories were described in terms of the angle of rings to the faces in specified proportions of the cross-sectional area. A few pieces not assignable to any of these categories were designated as "mixed."

The central half-length of each piece was also tested for hardness, using three impressions on the wide face by a special tool developed by the Western Pine Association. The tool consists of a mandrel of known weight falling from a preset height and striking a blade that makes a divided impression across the grain of the wood (fig. 2).

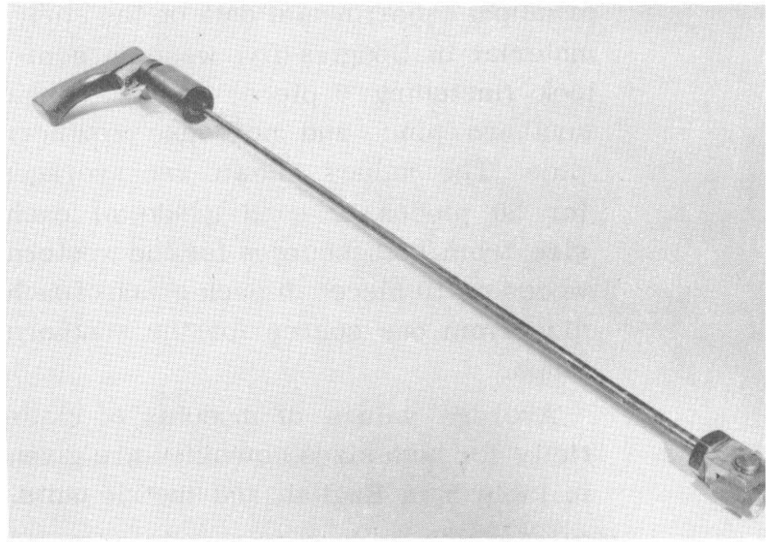

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Figure 2.--General view of Western Pine Association hardness tool. The tool is used in a vertical position with the cutting blade at the lower end and the weight to be dropped held next to the handle.

Processing of Data

The experimental data were recorded on punch cards, one card for each piece in each run, or a total of 1,440 cards. Summations and average values and correlations by the method of least squares were all made on a small-scale digital computer at the Laboratory. Plotting of scatter diagrams was done by hand.

The data from the western species showed minor differences between the two sources, and these were therefore combined in the analysis and report. In the southern pines, however, there was an appreciable difference in most properties between the sample from on; source selected by the "density rule"— and the sample from the other source that excluded dense material. The two were therefore handled, for the most part, in this report as if they were separate species.

Description of Tables and Charts

Tables 1, 2, 3, and 4 summarize the

principal experimental data on the study material in Douglas-fir, western hemlock (including 9 pieces of fir), dense southern pine, and nondense southern pine. The values shown are averages for 20 pieces of each grade of each size from both sources for the western woods or 10 pieces of each grade of each size from one source for the southern pines.

Average values of modulus of elasticity for both sizes combined are given in table 5 in English and metric units. The equivalents are shown in recognition of the growing interest in metric measurement in this country.

Average values of modulus of elasticity from tables 1, 2, 3, and 4 were plotted against the average moisture content values in figures 3, 4, and 5. The modulus of elasticity was on a logarithmic scale because previous work[2] has shown this to give nearly a straight-line relationship to moisture content. Straight lines shown in these charts were drawn by eye andare, for the most part, very close to the

Table 5. --Summary of average modulus of elasticity in English and metric equivalents

Grade	Average modulus of elasticity for both sizes							
	First run, (green)		Second run, (about 22 pct. moisture content)		Third run, (about 18 pct. moisture content)		Fourth run, (about 11 pct. moisture content)	
	1,000 p.s.i.	1,000 kg. per sq. cm.	1,000 p.s.i.	1,000 kg. per sq. cm.	1,000 p.s.i.	1,000 kg. per sq. cm.	1,000 p.s.i.	1,000 kg. per sq. cm.
DOUGLAS-FIR								
Construction	1,660	117	1,720	121	1,840	129	1,970	139
Standard	1,330	94	1,390	98	1,480	104	1,610	113
Utility	1,410	99	1,500	105	1,590	112	1,720	121
WESTERN HEMLOCK								
Construction	1,580	111	1,670	117	1,740	122	1,870	131
Standard	1,370	96	1,470	103	1,550	109	1,690	119
Utility	1,370	96	1,450	102	1,540	108	1,640	115
DENSE SOUTHERN PINE								
No. 1	1,680	118	1,740	122	1,820	128	1,950	137
No. 2	1,500	105	1,530	108	1,620	114	1,760	124
No. 3	1,420	100	1,440	101	1,520	107	1,660	117
NONDENSE SOUTHERN PINE								
No. 1	1,450	102	1,490	105	1,570	110	1,700	120
No. 2	1,310	92	1,360	96	1,430	101	1,590	112
No. 3	1,180	83	1,250	88	1,320	93	1,460	103

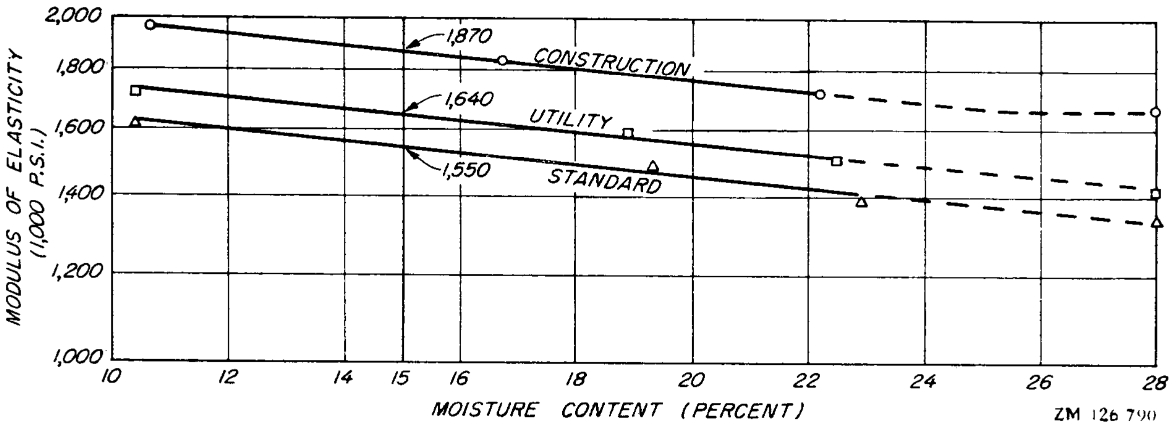

Figure 3.-- Relation of average modulus of elasticity to moisture content in Douglas-fir joists.

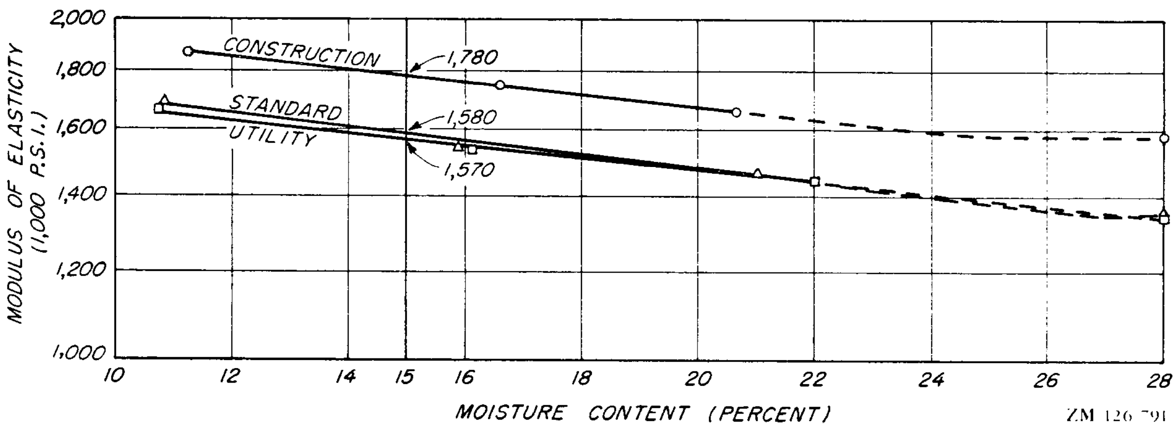

Figure 4.--Relation of average modulus of elasticity to moisture content in western hemlock joists.

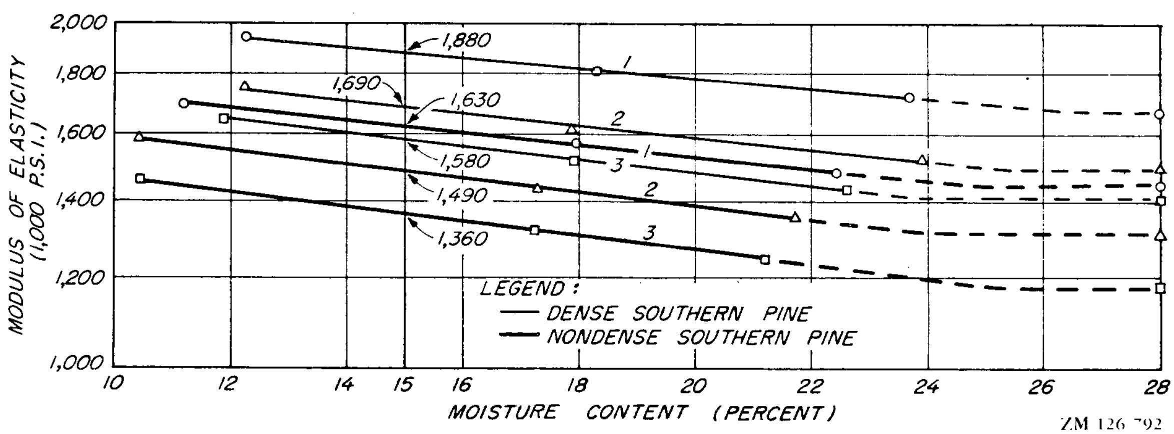

Figure 5.-- Relation of average modulus of elasticity to moisture content in southern pine joists.

plotted points. Values in the green condition were plotted at 28 percent moisture content for convenience, since the same values may be expected at any moisture content above the fiber saturation point. The two sizes were combined and, in the western woods, the two sources were combined. Values of modulus of elasticity at 15 percent moisture content taken from the lines drawn on these three figures were tabulated in table 6, and the increase in drying to that moisture content value was shown. Moduli of elasticity and increases observed in the fourth run were also shown in table 6.

Estimated strength ratios by species and grades are shown in table 7, separately for the two sizes. The two sources of Douglas-fir andwestern hemlockwere combined. Table 8 gives classification of strength ratios by 10 percent classes

Table 6.--Average values[1] of modulus of elasticity green, at 15 percent moisture content, and at fourth run

Grade	Average modulus of elasticity		Increase in drying from green to 15 pct.	Average modulus of elasticit at fourth run[2]	Increase in drying from green to fourth run[2]
	Green	At 15 pct. moisture content			
	1,000 p.s.i.	1,000 p.s.i.	Pct.	1,000 p.s.i.	Pct.
DOUGLAS-FIR					
Construction	1,660	1,870	13	1,970	19
Standard	1,330	1,550	17	1,610	21
Utility	1,410	1,640	16	1,720	22
WESTERN HEMLOCK					
Construction	1,580	1,780	13	1,870	18
Standard	1,370	1,580	15	1,690	23
Utility	1,360	1,570	15	1,640	21
DENSE SOUTHERN PINE					
No. 1	1,680	1,880	12	1,950	16
No. 2	1,500	1,690	13	1,760	17
No. 3	1,420	1,580	11	1,660	17
NONDENSE SOUTHERN PINE					
No. 1	1,450	1,630	12	1,700	17
No. 2	1,310	1,490	14	1,590	21
No. 3	1,180	1,360	15	1,460	24

[1]Values at 15 pet. moisture content are from figs. 3, 4, and 5.

[2]Moisture content at the fourth run was approximately 11 pct.

Table 7.--Average of estimated strength ratios in species and grade groups of joists

Grade	Average strength ratio		
	2 by 6	2 by 10	Average of both sizes
	Pct.	Pct.	Pct.
DOUGLAS-FIR			
Construction	84	77	80
Standard	74	63	68
Utility	64	75	70
WESTERN HEMLOCK			
Construction	93	88	90
Standard	83	79	81
Utility	75	79	77
DENSE SOUTHERN PINE			
No. 1	92	98	95
No. 2	77	80	78
No. 3	74	80	77
NONDENSE SOUTHERN PINE			
No. 1	79	86	82
No. 2	76	75	76
No. 3	50	56	53

and the average values of green modulus of elasticity in each strength-ratio class. All grades were included. Although the strength ratios were estimated on dry joists, the principles for estimatingthem were developed primarily on green material, and the ratios were therefore compared with the moduli of elasticity in the green condition.

The average true moduli of elasticity free from shear deformation in the first and fourth runs are compared in table 9 with the corresponding apparent moduli of elasticity from tables 1, 2, 3, and 4. The two sizes are combined, and in the western species the two sources are combined.

Table 10 gives the average hardness values by the Western Pine Association tool after the fourth run in each of the species and grades in the study. The two sizes were combined, and the two

Table 8.--Average values of modulus of elasticity by strength-ratio classes

Strength-ratio class limits	No. of specimens	Average strength ratio	Average modulus of elasticity[1]	No. of specimens	Average strength ratio	Averge modulus of elasticity[1]	No. of specimens	Average strength ratio	Average modulus of elasticity[1]	No. of specimens	Average strength ratio	Average modulus of elasticity[1]
Pct.		Pct.	1,000 p.s.i.		Pct.	1,000 p.s.i.		Pct.	1,000 p.s.i.		Pct.	1,000 p.s.i.
0-9	--	--	--	--	--	--	--	--	--	--	--	--
10-19	--	--	--	--	--	--	--	--	--	--	--	--
20-29	2	26	930	1	26	1,120	--	--	--	1	27	960
30-39	1	37	1,310	2	34	1,390	1	32	1,310	3	35	1,210
40-49	7	46	1,260	2	45	1,770	--	--	--	6	44	1,290
50-59	17	55	1,290	4	55	1,200	5	53	1,300	11	54	1,180
60-69	32	64	1,340	16	64	1,120	9	66	1,410	8	65	1,290
70-79	23	75	1,530	19	75	1,340	8	73	1,430	9	73	1,330
80-89	11	85	1,610	28	84	1,520	8	83	1,490	7	84	1,260
90-100	26	98	1,720	47	98	1,550	29	99	1,660	15	97	1,490

[1]Values of modulus of elasticity are from the first run (green).

sources were combined in the two western species. Hardness was expressed as the distance in inches between the two parts of the divided impression (fig. 2), that distance increasing with increasing hardness of the wood. Three impressions were made on the wide face of each piece after the fourth run for stiffness.

Figures 6, 7, and 8 are scatter diagrams showing the correlation of the hardness with the specific gravity of each piece after the fourth run. Each of these three figures shows a straight line of best fit calculated by the method of least squares, considering hardness as the dependent variable.

Figures 9, 11, and 13 show the relation of moisture content, to width shrinkage, and figures 10, 12, and 14 the relationto thickness shrinkage based on the green dimension in the three species. Sizes were combined, as were the sources of the two western woods. The figures show individual shrinkage values observed in the second, third, and fourth stiffness runs, The straight-line relationships shown on figures 11, 12, 13, and 14 are based on the third- and fourth-run shrinkage values. They were calculated by the least-squares method with shrinkage as the dependent variable. Where the lines representing the shrinkage relationship intercepted the 15 percent moisture content values, the shrinkage values were calculated.

Table 9.--Comparison of values for apparent and true modulus of elasticity in green and dry joists[1]

Grade	Green joists			Dry joists		
	Modulus of elasticity			Modulus of elasticity		
	Apparent	True	Ratio of true to apparent	Apparent	True	Ratio of true to apparent
	1,000 p.s.i.	1,000 p.s.i.	Pct.	1,000 p.s.i.	1,000 p.s.i.	Pct.
DOUGLAS-FIR						
Construction	1,660	1,770	107	1,970	2,150	109
Standard	1,330	1,450	109	1,610	1,800	112
Utility	1,410	1,520	108	1,720	1,840	107
WESTERN HEMLOCK						
Construction	1,580	1,700	108	1,870	2,040	109
Standard	1,370	1,460	107	1,690	1,800	107
Utility	1,360	1,440	106	1,640	1,750	107
DENSE SOUTHERN PINE						
No. 1	1,680	1,790	107	1,950	2,090	107
No. 2	1,500	1,640	109	1,760	1,900	108
No. 3	1.420	1,460	103	1,660	1,730	104
NONDENSE SOUTHERN PINE						
No. 1	1,450	1,540	106	1,700	1,860	109
No. 2	1,310	1,400	107	1,590	1,700	107
No. 3	1,180	1,270	108	1,460	1,540	105

[1] Average values for both sizes and, in the western species, of both sources. Green values are from first run and dry values from fourth run.

Table 10. --Average hardness values in dry joists by the Western Pine Association tool

Douglas-fir		Western hemlock		Dense southern pine		Nondense southern pine	
Grade	Average hardness	Grade	Average hardness	Grade	Average hardness	Grade	Average hardness
	In.		In.		In.		In.
Construction	0.61	Construction	0.54	1	0.71	1	0.64
Standard	.57	Standard	.51	2	.65	2	.59
Utility	.56	Utility	.54	3	.65	3	.61

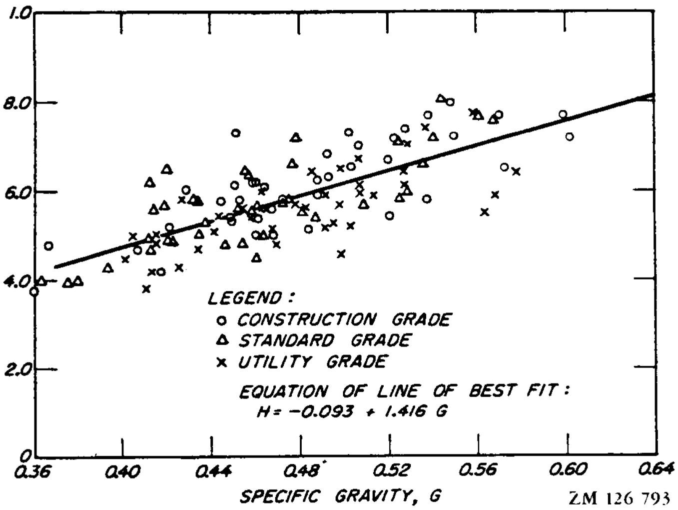

Figure 6.--Relation of hardness to specific gravity in Douglas-fir joists.

Figures 15 and 16 show third- and fourth-run values for 80 pieces of Douglas-fir in which the third-run moisture content was below 20 percent. They also show calculated straight lines based on those data and the intercepts of those lines at 15 percent moisture content.

Table 11 gives the classification of the direction of the annual rings and the corresponding shrinkage from the green condition to the moisture content values reached in the second, third, and fourth runs. Both sizes and both sources were combined. The shrinkage values of the three species to the moisture condition at the fourth run (very nearly 11 percent) are shown as bar charts with the

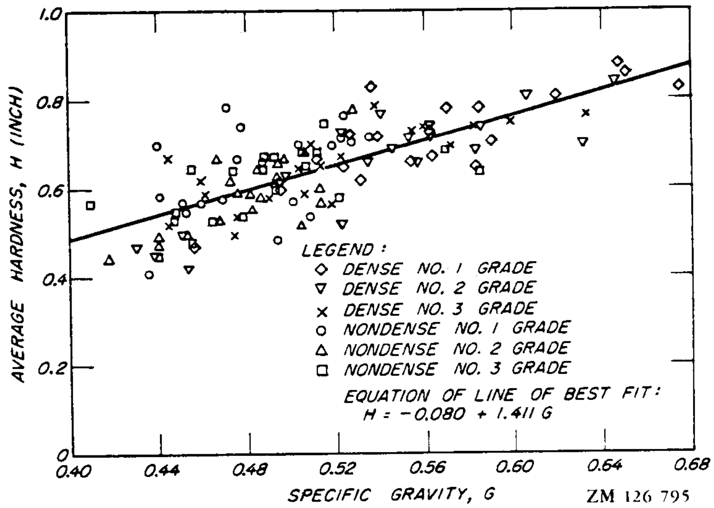

Figure 8.--Relation of hardness to specific gravity in southern pine joists.

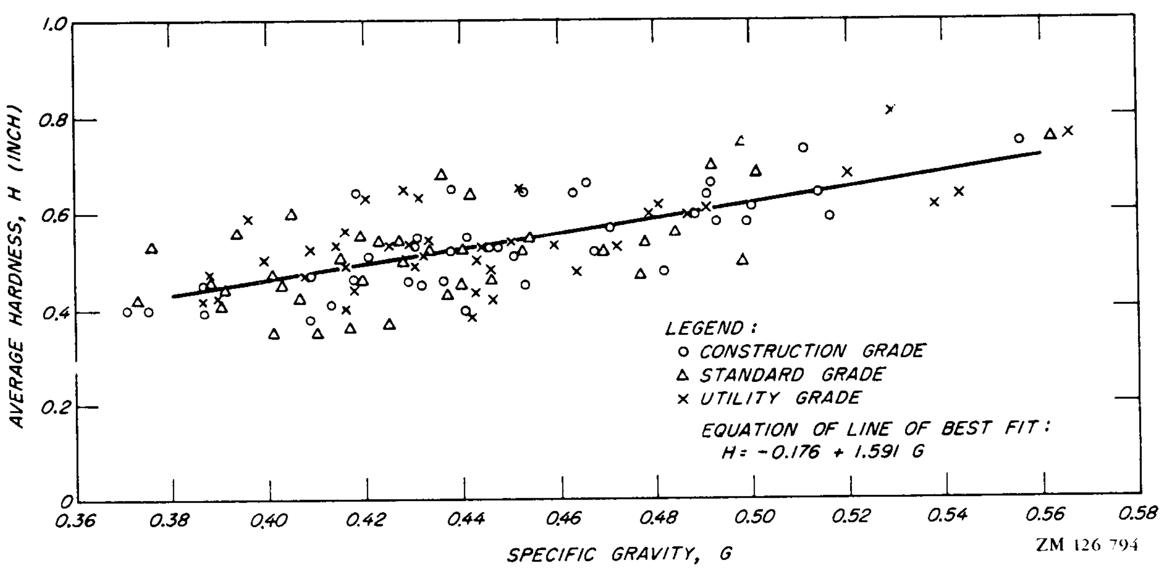

Figure 7.--Relation of hardness to specific gravity in western hemlock joists.

frequency distribution of the ring classes in figure 17. The fourth run was chosen because moisture content values among species and ring classes were more uniform than those in the second and third runs, thus permitting closer comparisons of the shrinkage values.

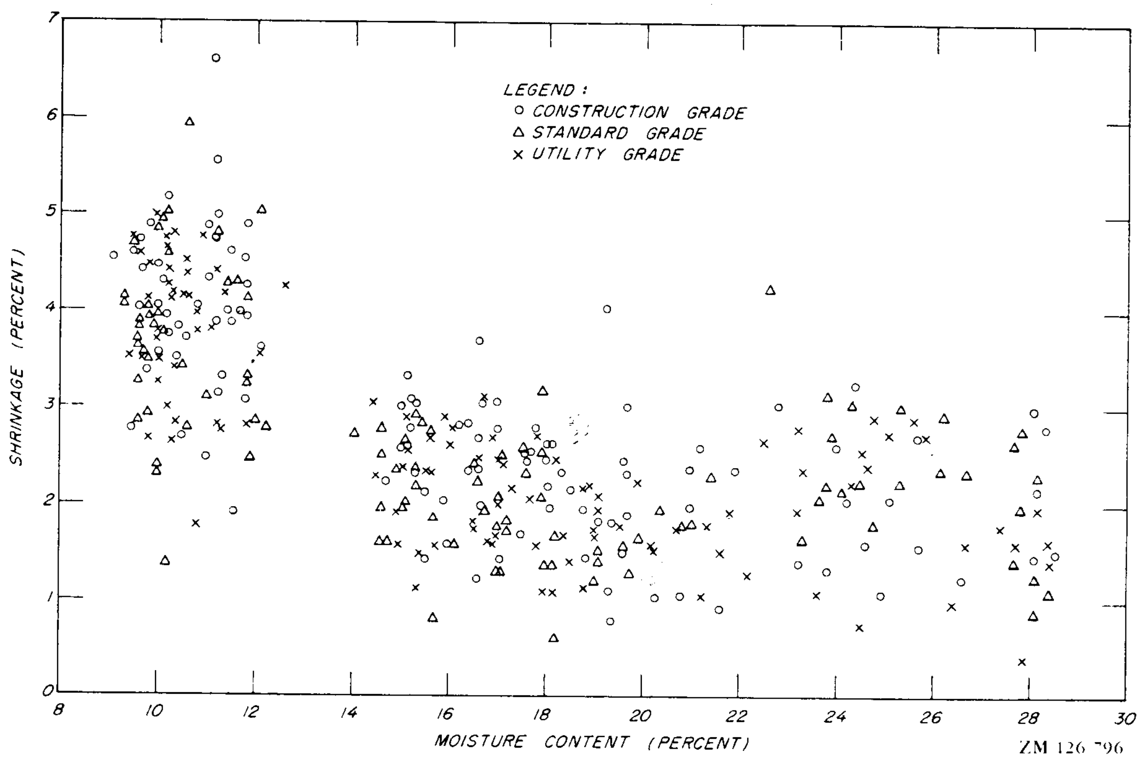

Figure 9.--Relation of shrinkage in width to moisture content of Douglas-fir joists.

Figure 10.--Relation of shrinkage in thickness to moisture content of Douglas-fir joists.

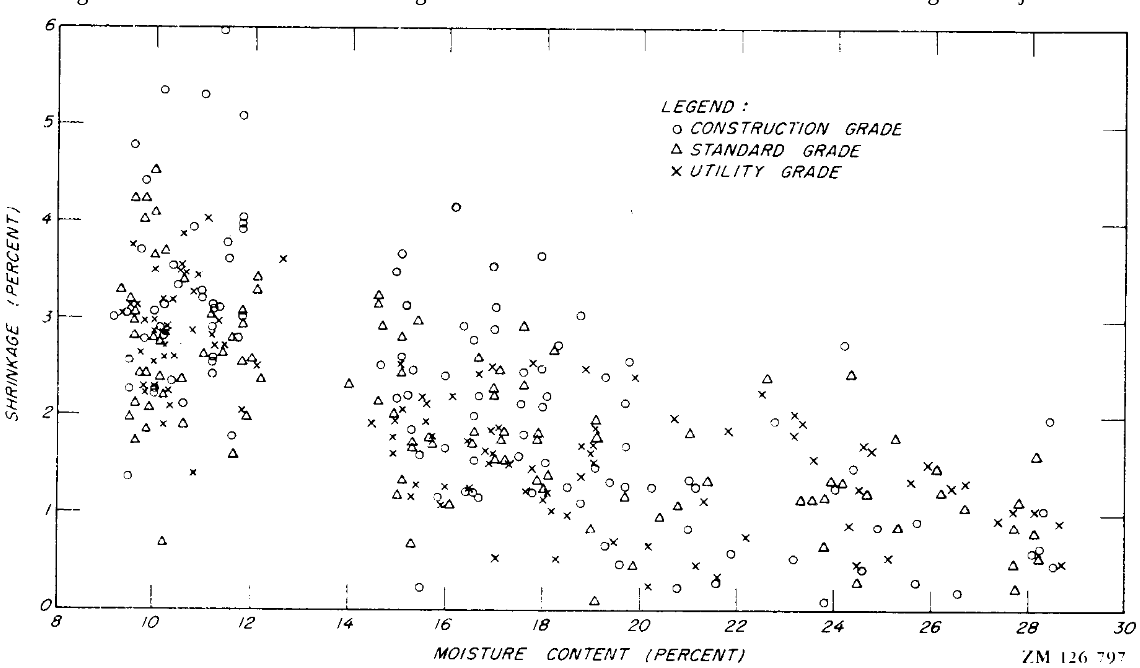

Table 11.--Ring classification and average shrinkage of joists at three moisture contents[1]

Ring classification	Frequency	Second Run: Moisture content	Second Run: Shrinkage from green condition: Width	Second Run: Shrinkage from green condition: Thickness	Third run: Moisture content	Third run: Shrinkage from green condition: Width	Third run: Shrinkage from green condition: Thickness	Fourth run: Moisture content	Fourth run: Shrinkage from green condition: Width	Fourth run: Shrinkage from green condition: Thickness
		Pct.	Pct.	Pct.	Pct.	Pct.	Pct	Pct.	Pct.	Pct.
DOUGLAS-FIR										
Flat-grained	54	24	1.6	0.9	20	2.4	1.4	11	4.0	2.6
Modified flat	36	22	1.8	1.3	18	2.5	1.9	10	4.0	3.1
Intermediate	20	22	1.8	1.4	18	2.4	2.0	10	3.9	3.1
Modified edge	5	18	1.9	2.9	15	2.2	3.4	10	3.2	4.8
Edge-grained	5	22	1.3	1.7	18	1.9	2.7	11	2.9	4.4
WESTERN HEMLOCK										
Flat-grained	48	20	2.4	1.3	16	3.2	1.8	11	4.9	2.8
Modified flat	34	20	1.7	1.0	16	2.5	1.9	11	4.0	3.0
Intermediate	13	22	1.3	9	16	2.2	1.6	11	3.6	2.8
Modified edge	9	26	1.0	1.1	16	1.6	1.9	10	2.9	3.3
Edge-grained	14	22	.8	1.1	16	1.5	2.4	11	2.6	3.8
SOUTHERN PINE										
Flat-grained	18	23	1.0	.8	18	2.0	1.7	11	3.8	3.3
Modified flat	32	23	1.1	1.1	18	1.9	2.0	11	3.6	3.6
Intermediate	36	22	1.2	1.3	18	1.9	2.2	12	3.4	3.8
Modified edge	19	22	1.1	1.8	18	1.7	2.6	11	2.9	4.4
Edge-Brained	14	22	.9	1.5	17	1.6	2.5	11	2.7	4.2

[1] Both sizes and both sources combined.

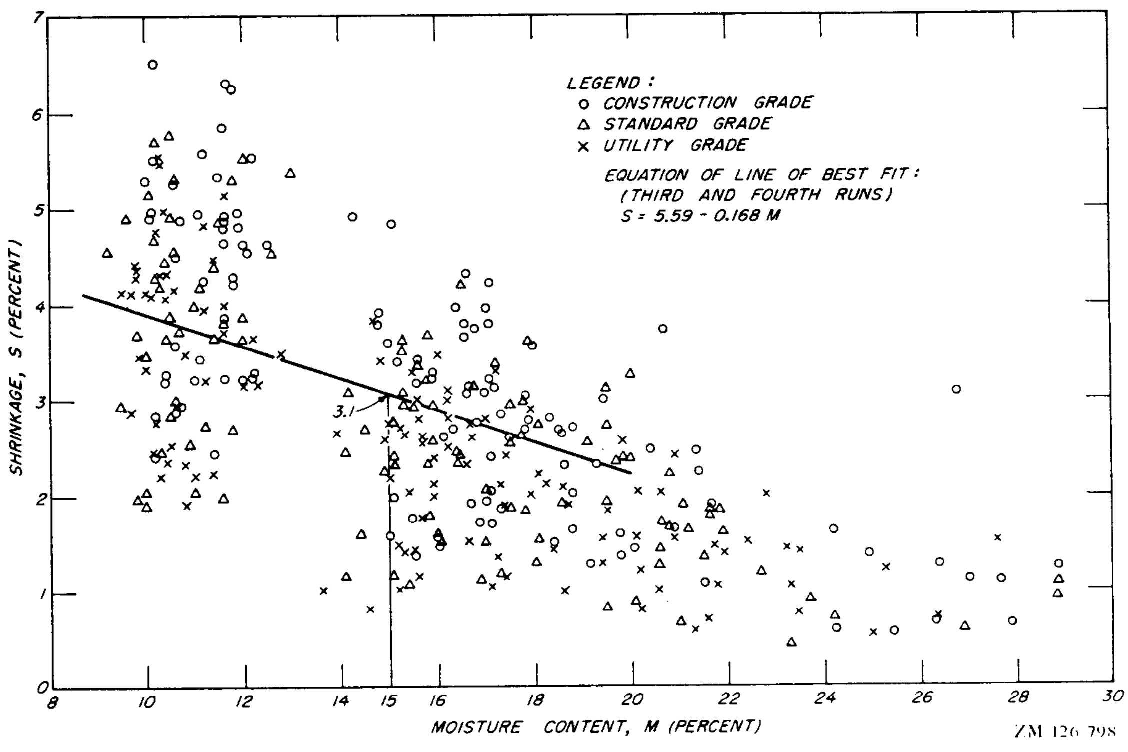

Figure 11 .--Relation of shrinkage in width to moisture content of western hemlock joists.

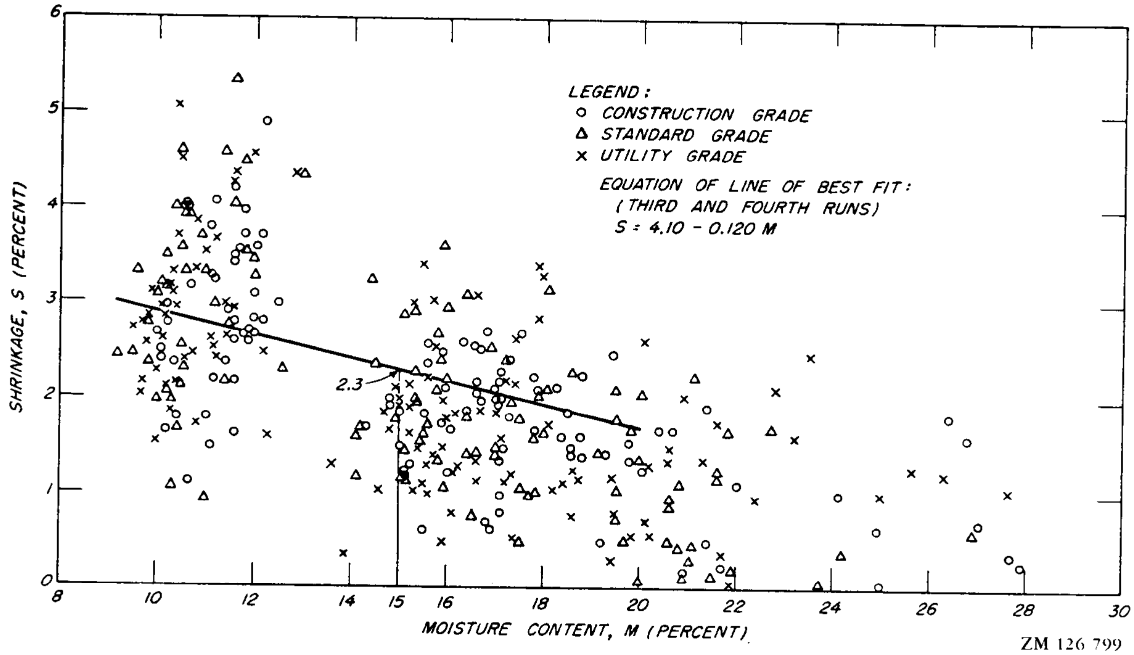

Figure 12.--Relation of shrinkage in thickness to moisture content of western hemlock joists.

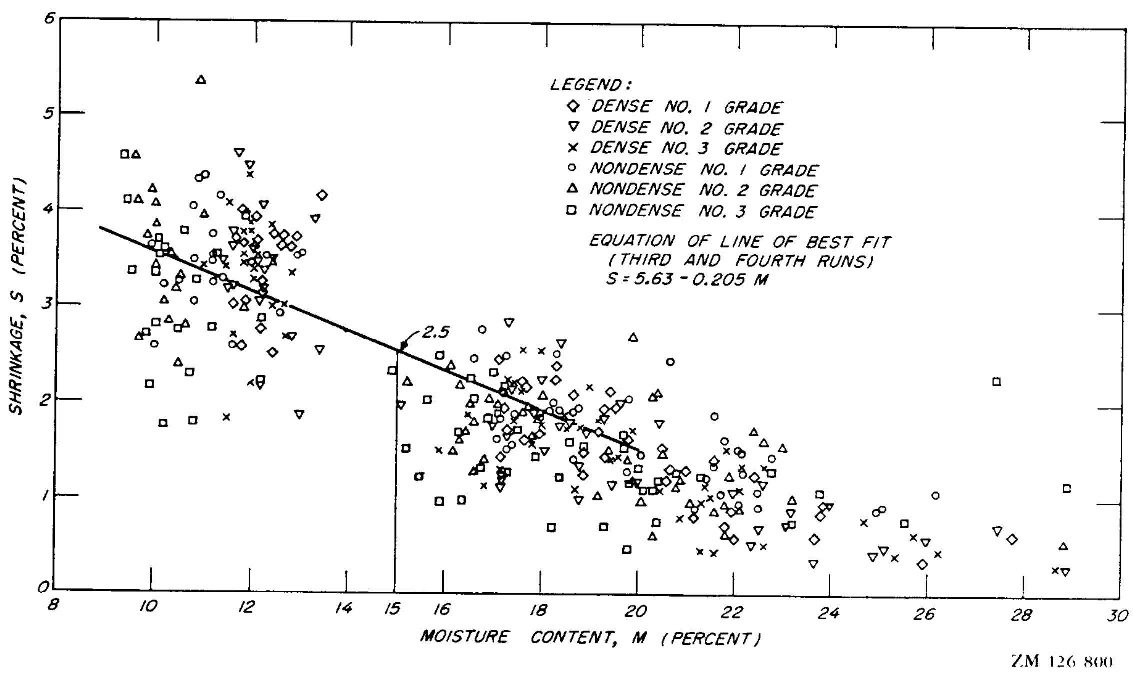

Figure 13.--Relation of shrinkage in width to moisture content of southern pine joists.

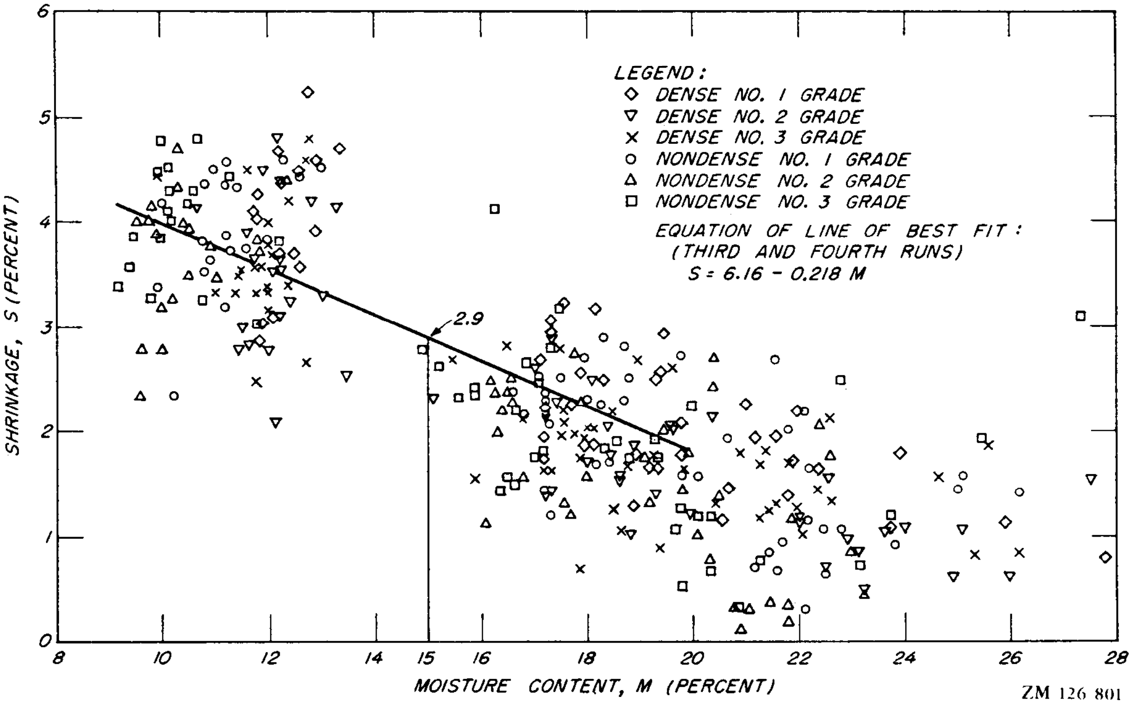

Figure 14.--Relation of shrinkage in thickness to moisture content of southern pine joists.

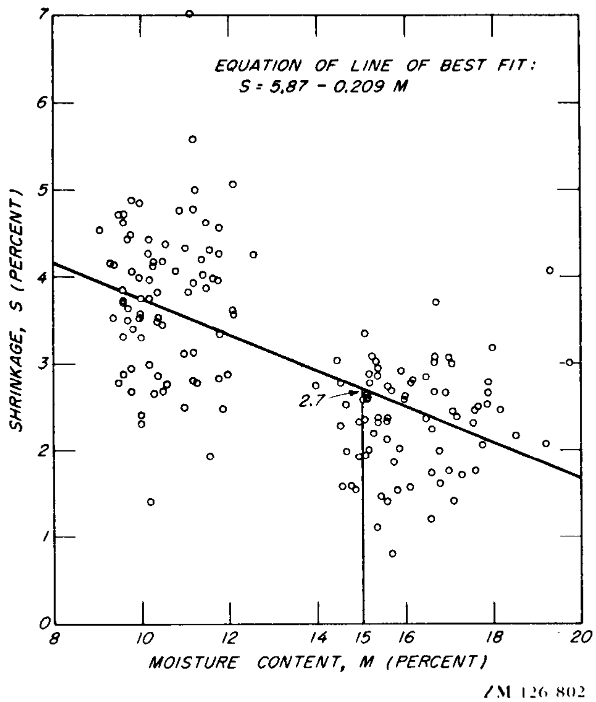

Figure 15.-- Relation of shrinkage in width to moisture content values between 9 and 20 percent in Douglas-fir joists.

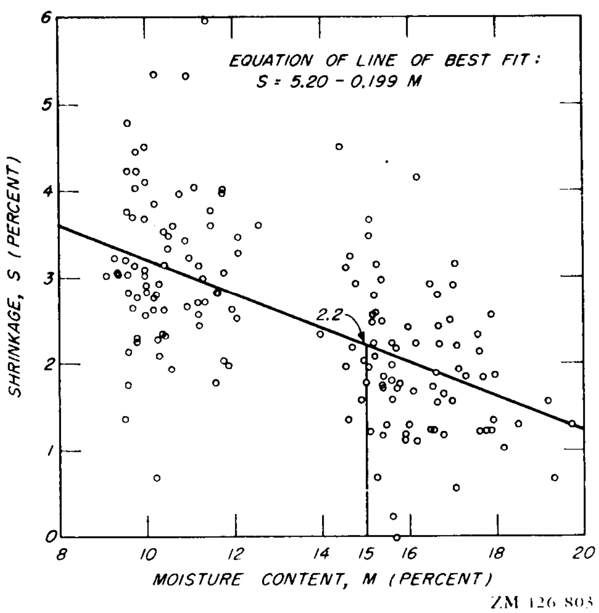

Figure 16.--Relation of shrinkage in thickness to moisture content values between 9 and 20 percent in Douglas-fir joists.

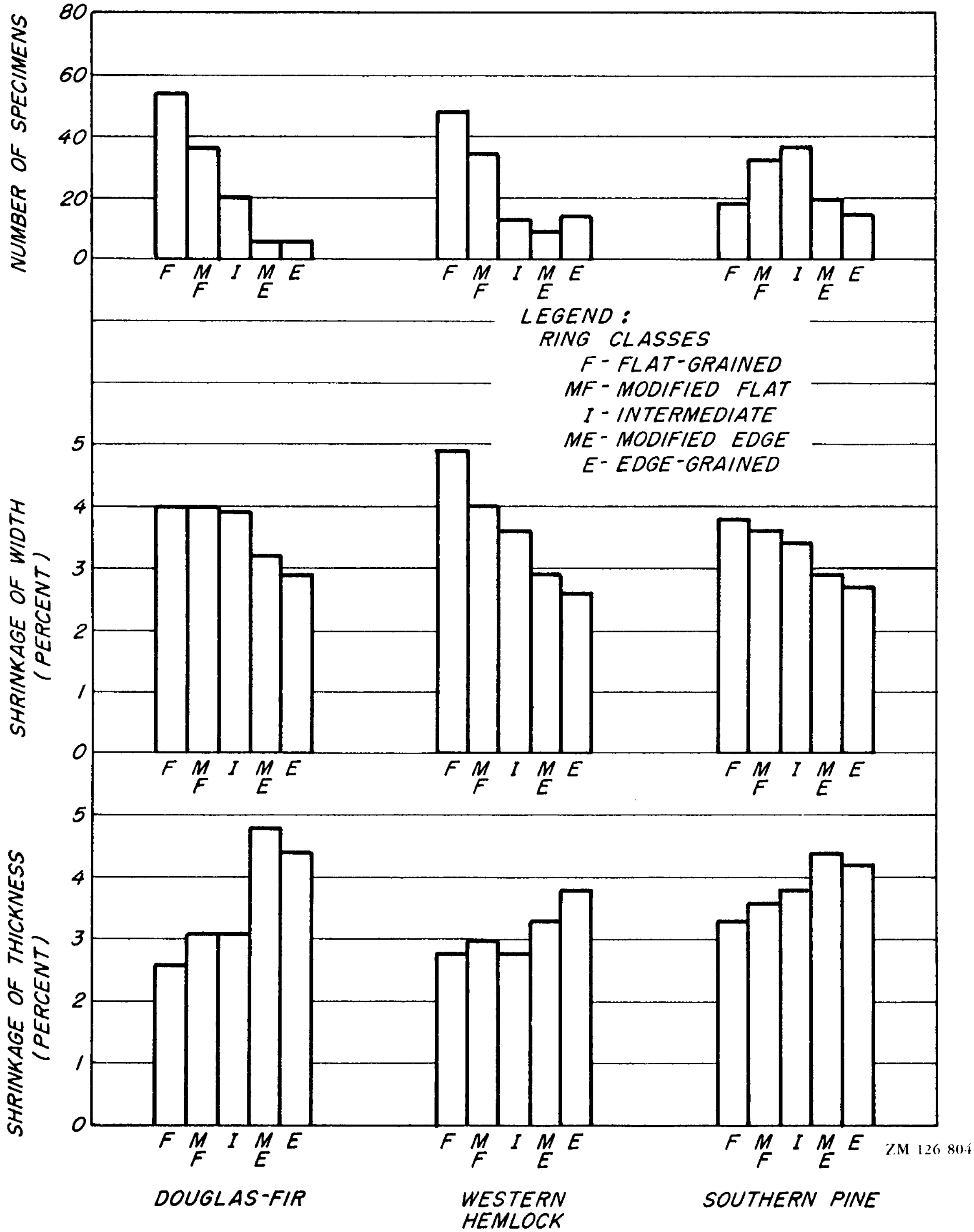

Figure 17.--Ring classification and shrinkage of joists from green condition to approximately 11 percent moisture content.

DISCUSSION OF DATA

Moisture Content and Specific Gravity

Tables 1 to 4 show that the nominal moisture content values of 19, 15 and 10 percent were not reached in drying. The fourth run came closest, with an average for all species of about 11 percent. Drying of the two sizes was partly separated, and some differences of moisture content appeared between the sizes (tables 1 and 3). Since the physical and mechanical properties were analyzed in relation to the actual rather than the nominal moisture content, the failure to reachnominal moisture content values was unimportant.

Average values of specific gravity shown in tables 1 to 4 were close to the published values[1] in Douglas-fir and the southern pines but slightly higher in western hemlock. Specific gravity values showed no consistent differences among the grades in a species.

Modulus of Elasticity

Two moduli of elasticity were observed in this study, an apparent modulus from full-length deflection and a true modulus free from shear deformation on a 36-inch length at midspan. The discussion of modulus of elasticity here refers to the apparent modulus except where it is compared with the true modulus.

Tables 1 to 4 show that the Construction or No. 1 Grades had moduli of elasticity about the same as the published values for clear wood,[1] except in western hemlock, which was higher. The higher value in hemlock was in accordance with its higher specific gravity. In the western woods, Standard and Utility grades had appreciably lower moduli of elasticity than in the Construction Grade, and the difference between Standard and Utility was relatively small. In the southern pines, there was a more uniform progression of values from No. 1 through No. 2 to No. 3. The effects of grade on modulus of elasticity appear also in figures 3, 4, and 5.

As mentioned previously, the difference in modulus of elasticity between sources of the western woods was relatively small. Dense southern pine had higher values than nondense southern pine. Differences between the two sizes were inconsistent and generally small.

The coefficients of variation shown in tables 1, 2, 3, and 4 are standard deviations in percentages of the average values. They showed somewhat more variability in Douglas-fir than in the other species. Lower grades had generally more variability than upper grades in the western woods, but not in southern pine. No relation of variability to moisture content was apparent.

The relations of the moduli of elasticity to moisture content are shown in figures 3, 4, and 5. Table 6 gives the modulus of elasticity and the increase from green values to the value at 15 percent moisture content, the expected average moisture content when lumber of this kind is produced to a 19 percent maximum moisture content. Values at 15 percent were taken from figures 3, 4, and 5. The increases to 15 percent moisture content were quite consistent and averaged about 14 percent.

Table 6 also gives the average increases observed in the fourth run at average moisture content levels that would be expected if 2-inch lumber were dried to 15 percent maximum moisture content. Here also the increases were quite consistent; the average increase was about 20 percent.

Strength ratios were estimated to see if the moduli of elasticity were correlated with them. Table 7 shows average strength ratios not greatly different in the two sizes and generally higher in the higher grades than in the lower grades. In the western woods and in dense southern pine, the difference was greater between Construction and Standard or No. 1 and No. 2 than between Standard and Utility or No. 2 and No. 3, a trend similar to that observed in the average modulus of elasticity values. In the 2 by 10 size of Douglas-fir, the average strength ratio was higher in the Utility than in the Standard Grade.

It was observed that manypieces were placed in the lower grades because of wane, which did not affect the strength ratios. This may explain why the Utility Grade of Douglas-fir had a higher average strength ratio in the 2 by 10 size than in the 2 by 6 and why Utility was higher than Standard in the 2 by 10.

Possibly because of wane, scatter diagrams of strength ratio on modulus of elasticity of individual pieces showed little evidence of correlation. Strength ratios were therefore classified and average moduli of elasticity were calculated for each class (table 8). The correlation shown by table 8 is obscured by erratic moduli of elasticity in those strength ratio classes that had only one or a few specimens. Nevertheless, in the classes with a larger number of specimens, there was a general trend toward higher moduli of elasticity with higher strength ratios.

The true modulus of elasticity is a basic property of the material, unaffected by the size or geometry of the specimen. Table 9 shows that the average true modulus of elasticity on the 36-inch length at midspan exceeded the average apparent modulus of elasticity on the full length in each species and grade group. This was to be expected since the deflection on full length includes shear deformation, which is absent from the short span between the load points.

Table 9 does not show, however, the fact that there were many individual specimens in which the true modulus of elasticity was less than the apparent modulus of elasticity. This condition is believed to have been the result of a large knot or other characteristic near midspan that had more effect on the deflection of the 36-inch length than on the deflection of the full length. This calls attention to the fact that the true and the apparent modulus of elasticity in the same piece were not strictly matched; it shows the possibility of variation of the modulus of elasticity along the length of a piece of lumber of structural size and character.

A further factor contributing to discrepancies between the two moduli of elasticity was the relatively small deflections and limited sensitivity of observations necessitated by the requirement for the loading to be nondestructive.

The difference between the apparent and the true modulus of elasticity depends upon the dimensions and loading of the specimen and upon the shear modulus (modulus of rigidity). From these two moduli of elasticity and the geometry of the specimen, the shear modulus was calculated on the average for the different species and the two moisture content levels (first and fourth runs). The results were inconclusive because of the discrepancies mentioned above.

Species average values of shear modulus ranged from 14,000 to 113,000 pounds per square inch green and from 32,000 to 143,000 pounds per square inch dry, with Douglas-fir showing the lowest values and western hemlock the highest. These values were for the most part lower in relation to the moduli of elasticity than the values commonly assumed for clear wood.[2] Further study is needed on the evaluation of shear moduli in structural lumber.

Stiffness

Stiffness is the product of the full-length modulus of elasticity times the moment of inertia of the cross section of the piece. As lumber dries, the modulus of elasticity increases and the moment of inertia decreases. One objective of this study was to find out if these opposing influences were balanced. Tables 1, 2, 3, and 4 show little change in stiffness among the first, second and third runs. Stiffness in the fourth run was slightly higher than in the first three runs but the increase in the various groups was generally less than 5 percent. This increase in the fourth run only was to be expected from the logarithmic increase of modulus. of elasticity and the straight-line decrease of dimension in drying.

Hardness

The Western Pine Association hardness tool was developed as a grading aid to the selection of pieces of high density or strength. The Association recommended three impressions on each specimen. These were made near the center of one wide face at separated points in the length and thus ranged between specimens from the radial to the tangential surface with respect to the annual rings.

Differences among the three impressions on one specimen were examined for variability. It was found that the average variance among the three impressions, considering all three species together, was about 0.09 inch. It was calculated from this variance that the 95 percent confidence limits for an average of two impressions would be ±0.13 inch, for three impressions ±0.10 inch, or for five impressions ±0.08 inch. Put in another way, the average value would fall between this range of difference from the true value 19 times out of 20. When it is considered that all individual impressions ranged only from about 0.3 to 0.8 inch, it would seem that not less than three impressions are required for satisfactory classification by this tool used in this way.

Average hardness values in table 10 show dense southern pine with the highest values, nondense southern pine and Douglas-fir about the same, andwestern hemlock with the lowest values. Differences among grades were not consistent, but there was a tendency toward higher values in the Construction and No. 1 Grades than in the lower grades. Differences among species or grades are rather small in relation to the variation of individual values within a single grade.

Figures 6, 7, and 8 show a trend toward correlation of hardness with specific gravity, but with considerable scatter of gravity values at a specific hardness level. The lines of best fit in these three charts have similar slopes and intercepts, indicating a relation among species. The relation of hardness to modulus of elasticity was explored but no correlation was found.

Shrinkage

Average shrinkage values in tables 1, 2, 3, and 4 are about the same in all of the species studied when shrinkage of width and of thickness are considered together.

Southern pine differed from the two western species in that its thickness shrinkage exceeded the width shrinkage; this is discussed below in connection with the classification of ring angles. Little difference appearedbetween dense and nondense southern pine (tables 3 and 4) or between sources in the western species.

Size appeared to have little effect on shrinkage between the 2 by 6 and the 2 by 10 except insofar as the two sizes did not reach the same moisture content value in the same run. There was possibly a trend toward lower shrinkage with lower grade, but this was not large nor consistent. It is possible that grades with more knots and cross grain would have less transverse and more longitudinal shrinkage than in the higher grades, but these data do not prove it.

Figures 9, 11, and 13 show width shrinkage and figures 10, 12, and 14 show thickness shrinkage in relation to the moisture content of individual specimens. Considerable scatter of the values appears; this agrees with existing knowledge of the variation of shrinkage among individual pieces of wood.

The nature of the relation of shrinkage to moisture content of wood in the intermediate moisture content regions is represented best by a straight line, but may be curvilinear near the moisture content regions of green condition or of ovendry condition, For this reason, the lines on figures 11, 12, 13, and 14 ignored second-run shrinkage and were based on shrinkage in the third and fourth runs only.

Third-run values of moisture content in western hemlock and southern pine were nearly all below 20 percent. In Douglas-fir, however, there were many third-run values above 20 percent and in the region where the relation to shrinkage may be curvilinear. Figures 15 and 16 show values only for 80 pieces of Douglas-fir in which the third-run moisture content values were below

20 percent, and the straight lines of best fit represent only those values.

The lines of best fit show greater shrinkage in width than in thickness of the western woods but greater shrinkage in thickness than in width of southern pine. The average shrinkage to 15 percent moisture content from the lines of best fit were as follows:

Species	Shrinkage of width (percent)	Shrinkage of thickness (percent)
Douglas-fir	2.7	2.2
Western hemlock	3.1	2.3
Southern pine	2.5	2.9
Average of three species	2.8	2.5

These values are comparable to the 1963 recommendations of the Forest Products Laboratory to the American Lumber Standards Committee of 2.80 percent on width and 2.35 percent on thickness.

The variability of shrinkage at a specific moisture content value is illustrated by the vertical scatter of the plotted points on figures 9 to 14.

The variability is shown numerically in the following tabulation of standard errors of the estimate calculated at the average moisture content value and of coefficients of correlation:

	Standard error of the estimate (percent)	Coefficient of correlation
Douglas-fir,		
width (fig. 15)	0.81	0.61
thickness (fig. 16)	.84	.58
Western hemlock,		
width (fig. 11)	1.06	.47
thickness (fig. 12)	.89	.42
Southern pine,		
width (fig. 13)	.60	.76
thickness (fig. 14)	.66	.75

The standard error of the estimate is accurate only at the average moisture content, but it is a good approximate representation throughout the range of these data. It means, in width shrinkage of southern pine for example, that if the average shrinkage is 2.5 percent, about two-thirds of all shrinkage values at the same moisture content will be in the range from 1.9 to 3.1 percent. Southern pine showed somewhat less variability of shrinkage than the western woods.

Since tangential shrinkage of wood is about twice as much as radial shrinkage, it was expected that individual shrinkage values would show a relation to the attitude of the annual rings in the study material. Average shrinkage values by ring classes are shown in table 11. In progressing from flat to edge grain, there was a general decrease of width shrinkage and a general increase of thickness shrinkage. Exceptions to the general trend were for the most part associated with ring classes containing relatively few specimens and thus of limited significance.

The ring classifications and corresponding shrinkage values in the fourth run (about 11 percent moisture content) may be examined also in figure 17. The upper part of this chart shows how flat and modified flat grain predominated in the western woods, while the southern pine had a more uniform distribution from flat to edge grain. This condition explained why width shrinkage exceeded thickness shrinkage in the western woods but not in southern pine. The middle and lower parts of the chart show the progression of average shrinkage values from flat to edge grain, with some exceptions associated with the smaller classes of rings.

DIGEST OF IMPORTANT FINDINGS

The most important observations from this study were:

(1) The study material appeared to be representative of the species in respect to density and was observed at a range of moisture content values that are typical of lumber production and use.

(2) The average modulus of elasticity of the Construction or the No. 1 Grade was about the same as that of clear wood, while the modulus of elasticity of the lower grades was appreciably reduced. Differences between Standard and Utility Grades of the western woods were relatively small.

(3) The average increase of modulus of elasticity with drying was about 14 percent to 15 percent moisture content and about 20 percent to 11 percent moisture content.

(4) Comparison of the apparent modulus of elasticity on the full span with the true modulus of elasticity on a short span near the center of length showed the apparent modulus to be lower, but with numerous individual exceptions due to variations of modulus of elasticity along the length of pieces of structural lumber.

(5) Stiffness (the product of the modulus of elasticity times the moment of inertia of the cross section) varied little with moisture content.

(6) Hardness values by the Western Pine Association tool showed a trend toward correlation with specific gravity. The range of individual impressions by the tool was rather large in relation to the total range among pieces or species.

(7) Shrinkage values were similar in all three species and in all three grades. The overall average shrinkage to 15 percent moisture content was similar to the values recommended by the Forest Products Laboratory to the American Lumber Standards Committee.

(8) Douglas-fir and western hemlock showed a predominance of flat grain, and their width shrinkage exceeded their thickness shrinkage. Southern pine had a more uniform distribution from flat to edge grain and showed more shrinkage in thickness than in width.

APPENDIX

Calculation of Moduli of Elasticity

The formulas used for the calculation of the true and the apparent moduli of elasticity were derived from well-known principles of engineering mechanics applied to a beam of rectangular cross section.

The apparent modulus of elasticity on the full span from midspan deflection with quarter-point loading (including shear deformation) is

$$E_a = \frac{11\ Pa^3}{64\ bd^3 \Delta}\text{, where}$$

- E_a is apparent modulus of elasticity (in p.s.i.)
- P is total load on the beam (applied at 2 points) (in lbs.)
- a is span between supports (in inches)
- b is breadth of beam (thickness) (in inches)
- d is depth of beam (width) (in inches)
- Δ is deflection at midspan (in inches)

The true modulus of elasticity free of shear deformation on a short span between load points that are at the quarter-points of the full span is

$$E = \frac{3\ Pa\ell^2}{16\ \delta\ bd^3}$$

with notation as before except that

- ℓ is length of the short span (36 inches in this instance)
- δ is deflection of the midpoint with respect to the ends of the short span (in inches)

The two moduli of elasticity are related through the shear modulus of elasticity in the horizontal-longitudinal plane. Assuming the material to be homogeneous, a comparison of E with E_a can be used to calculate the shear modulus by the formula

$$G = \frac{48}{55}\left(\frac{d}{a}\right)^2 \frac{E}{\left(\frac{E}{E_a} - 1\right)}$$

with notation as before, except that

G is shear modulus (in p.s.i.)

Hardness Tool

The Western Pine Association hardness tool has a cutting blade with a re-entrant angle of about 160° (fig 2). The width of the cutting blade is 1.76 inches and its thickness is 0.38 inch. The cutting edge of the blade is milled to an angle of 90°. A weight of 2.68 pounds falls 27.4 inches with an energy of 73.4 inch-pounds to strike the mandrel in which the cutting blade is pivoted.

The Association recommends use of the tool on an edge-grained (radial) surface, and indicates that aflat-grained surface will give a slightly lower hardness reading. The test specimen should be placed on a solid base such as a concrete slab when the impact impression is made by the tool.

In estimating the reliability of the tool, the average variance of three impressions on a specimen was calculated from the formula

$$\bar{s} = \sqrt{\frac{\sum_{o}^{N}\left[\frac{\sum_{o}^{3}(x_n - \bar{x})^2}{2}\right]}{N}}$$

where $\bar{s}$ is average variance

N is number of specimens

x_n is one of the three hardness readings on a specimen

$\bar{x}$ is average of the three hardness readings on a specimen

$\bar{s}$ ranged from 0.078 to 0.099 inch in the three species and a representative value for all three was taken as 0.09 inch. The expression for the 95 percent confidence limits was (approximately)

$$\bar{x} \pm \frac{(2)(0.09)}{\sqrt{n}}$$

where $\bar{x}$ is average of the hardness readings on a specimen

n is number of hardness readings on a specimen

Ring Classification

The names of the ring classes are given in the body of the paper. These ring classes are defined in greater detail as follows:

Flat-Grained: Ring angle less than 30° to wide face on greater than 90 percent of the total area of both ends.

Modified Flat-Grained: Ring angle at least 30° and less than 60° to wide face on greater than 90 percent of the total area of both ends. In the trade, this class is usually included with flat-grained lumber.

Edge-Grained: Ring angle more than 60° to wide face on greater than 90 percent of the total area of both ends.

Modified Edge-Grained: Ring an g 1 e more than 30° and up to 90° to wide face on greater than 90 percent of the total area of both ends. In the trade, this class is usually included with edge-grained lumber.

Intermediate-Grained: Ring angle more than 15° but less than 75° to wide face on greater than 90 percent of the total area of both ends. Most of this class is known in the trade as "bastard-sawn."

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