EFFECT OF HYDRAULIC-EQUIPMENT OILS ON THE BENDING AND COMPRESSIVE STRENGTH OF SITKA SPRUCE

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In Cooperation with the University of Wisconsin

EFFECT OF HYDRAULIC-EQUIPMENT OILS ON THE BENDING AND COMPRESSIVE STRENGTH OF SITKA SPRUCE[1]

By

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Summary

This report presents the results of static bending and compression tests of Sitka spruce soaked in petroleum-base and castor-oil-base hydraulic fluids at normal temperatures. Comparison of results from unsoaked controls and specimens soaked in petroleum-base fluid shows that the petroleum-oil exposure does not significantly affect the compressive or bending strength of Sitka spruce. Soaking of Sitka spruce by castor-oil-base fluid, however, does reduce these strength properties. The amount of such reduction for either property depends upon the degree of impregnation, which is affected by the soaking period in relation to the size of the section. In compression tests, the amount of reduction in strength depends upon whether end soaking as well as radial and tangential soaking takes place.

Introduction

Parts of wood aircraft are at times soaked by oils or other fluids that leak from containers or machinery, or are spilled. Such soaking commonly occurs in the vicinity of the hydraulic shock absorbers or the hydraulic brake system. Few data are available on the effect of such fluids on the strength properties of wood. The Army-Navy-Civil Committee on Aircraft Design Criteria recommended a brief preliminary investigation of this subject by the Forest Products Laboratory. The object of this preliminary study was to determine the effect of petroleum- and castor-oil-base fluids on the bending strength of Sitka spruce. The study has been expanded to include the effect of these fluids on the compressive strength parallel to grain.

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[1]This mimeograph is one of a series of progress reports prepared by the Forest Products Laboratory to further the Nation's war effort. Results here reported are preliminary and may be revised as additional data become available.

Material

Fluids: Two types of oil for these tests, to represent fluids commonly used in hydraulic equipment on aircraft, were obtained from the Army Air Forces Materiel Command. The first was a petroleum base, grade L (light), conforming to Specification No. 3580-C, and the second was a castor oil base, grade C (light), conforming to Specification No. 3586-B.

Wood: Veneer and solid wood were cut at the Forest Products Laboratory from a single Sitka spruce log received from Hoquiam, Washington, in October 1942. The veneer was run through a steam-heated drier; the solid wood was kiln-dried under an aircraft schedule.

Matching

Veneer specimens, 1 by 5 inches, for static-bending tests were cut from a single sheet of 1/8-inch veneer as shown in figure 1. The arrangement provided 11 specimens for each fluid, and 39 control specimens matched on groups of 4 controls for each oil-soaked specimen.

Solid wood static-bending specimens 1 by 1 by 16 inches were cut from five 2-1/2- by 2-1/2-inch sticks and from two 3- by 8-inch sticks as shown in figure 2. These sticks and the veneer were taken from the same annual ring area of the log. From the smaller sticks, five specimens were designated for each type of oil, each specimen having one ring-matched control. The two larger sticks provided six additional specimens for each type of oil, each specimen lying between two ring-matched controls.

Compression specimens were cut from the solid wood static-bending specimens after test. One 1- by 1- by 4-inch compression specimen and a moisture section were cut from each control. Two 1- by 1- by 4-inch compression specimens were cut from each oil-soaked specimen and designated as series 1 and 2 for different soaking periods.

Exposure

The specimens were conditioned at 80° F. and 65 percent relative humidity for about 18 days until they reached constant weight. The untreated control specimens were then tested, and the specimens to be oil-soaked were completely submerged in the designated fluid in covered containers which were stored in the 80° F., 65 percent relative humidity room.

The compression specimens, which were cut from the bending controls immediately after the bending tests, were reconditioned for several days before being tested in compression parallel to grain.

Series-1 compression specimens from the oil-soaked bending specimens were replaced in the proper fluid after being cut, and were resoaked for about 14 days before test.

Series-2 specimens were similarly placed in the fluid after being cut, and were resoaked for about 25 days before test.

Because of difficulties encountered in testing those specimens of series 1 and 2 which had been soaked in castor-oil-base fluid, they were resoaked in the oil for 1 to 3 days, after which they were reduced to 2 inches in length by cutting off the damaged ends, and tested immediately. Those cut from series-1 specimens were designated as series 3, and those from series 2, as series 4.

All oil-soaked specimens were allowed to drain for about 1 hour before test. Any surplus oil remaining on the surface was removed with a cloth at the time the specimens were taken from the conditioning room to the test floor.

Methods of Test

Load-deflection measurements were made on each specimen in accordance with standard Laboratory procedure. Veneer specimens were tested on a 3-inch span, solid wood static-bending specimens on a 14-inch span.

Moisture sections were cut from all control specimens. Since it was impossible to obtain moisture content or specific gravity values for treated specimens by any usual procedure, no attempt was made to secure such data. Tables 1, 2, and 3 present moisture content and specific gravity data for veneer and solid wood control specimens. These tables indicate the approximate basic moisture content at which oil absorption took place.

Results of Tests

The test data are presented in tables 4 to 7. Table 4 gives the values of fiber stress at proportional limit, the modulus of rupture, and the modulus of elasticity for each soaked veneer static-bending specimen, together with the average of the matched control specimens and the ratio of the strengths of the oil-soaked specimens to the average control strengths. In table 5 similar data are presented for the 1- by 1- by 16-inch static-bending specimens. Table 6 gives the values of fiber stress at proportional limit, the maximum crushing strength, and the modulus of elasticity for each soaked compression specimen, together with the average of the corresponding controls and the ratio of the strength of the oil-soaked specimens to the average control strength. Table 7 is a summary showing the average soaking period and the increase or decrease in the strength of each group of oil-soaked specimens compared with the strength of the corresponding group of control specimens.

Discussion of Results

Moisture Content

As previously discussed, the moisture content of soaked specimens is unknown. Since all specimens were conditioned to equilibrium under the same temperature and relative humidity, however, the results for soaked specimens may be compared with those for the unsoaked specimens to show the effect of the two types of fluid upon material at the moisture content existing at the time of soaking.

Tables 1 and 2 show that the average moisture content of the veneer specimens was 8.4 percent, while the average for the solid wood specimens was 10.55 percent. A disagreement in the equilibrium value is to be expected as a result of differences in the drying temperatures of the veneer and solid wood, and as a result of the manner in which they approached the equilibrium condition.

Static-bending Tests on Veneer

The results of static-bending tests on the veneer are summarized in lines 1 and 2 of table 7. In line 1 the average strength of the specimens soaked in petroleum-base-fluid is greater, for all strength properties, than that of the unsoaked control specimens. While this may be significant, the indicated gains ranging from 12.0 to 20.2 percent, an examination of table 4 shows that the strengths of individual specimens were in some instances less than the strength of the matched control specimens.

Line 2 shows that the average strength of the specimens soaked in castor-oil-base fluid is decidedly less than that of the corresponding unsoaked controls. For the castor-oil-base fluid the effect is significant, for the reduction in strength values range from 30.8 to 48.8 percent. Furthermore, the strength values for individual specimens (table 4) are, in all tests, less than those of the corresponding controls.

Examination of the treated veneer specimens showed that the oil had penetrated at least 80 percent of the volume in all specimens, and that the penetration was complete in about one-third of them. There was no apparent difference in the amount of penetration by the two fluids used.

Static-bending Tests on Solid Wood

The results from static-bending tests on the solid wood specimens are less significant than those from the veneer. Line 3 in table 7 shows that the average strength of the specimens soaked in petroleum-base fluid is slightly greater for modulus of rupture, and slightly less for fiber stress at proportional limit and for modulus of elasticity than that of the control specimens. These average deviations of about 3.5 percent cannot be considered significant for an examination of table 5 shows that, for all properties, the strengths of some individual specimens are higher and some are lower than those of the matched controls.

Line 4 in table 7 shows that the average strength of specimens soaked in castor-oil-base fluid is less, for all properties, than that of the corresponding controls. The indicated reductions range from 2.9 to 11.8 percent for the three properties considered. Although these reductions are not large, they are probably significant when considered in connection with the greater effect noted on the veneer, which was more fully impregnated. In table 5, the values of fiber stress at proportional limit and of modulus of elasticity for the individual specimens treated with castor oil fluid are lower than for the corresponding controls in all but one specimen, whereas the values of modulus of rupture show no conclusive difference.

Examination of the treated specimens after test showed that both types of oil had penetrated approximately 1/16 inch into radial and tangential faces, and 3/16 inch into the ends.

Compression

Petroleum-base fluid, end-soaked (series 1 and 2).--Line 5 in table 7 shows that the average strength of series-1 specimens soaked in petroleum-base fluid is greater for fiber stress at proportional limit and for maximum crushing strength, and less for modulus of elasticity than the matching control specimens. Columns 5, 14, and 23 in table 6 show the strength ratios for individual specimens.

Line 7 in table 7 shows that the average strength of series-2 specimens is greater for fiber stress at proportional limit, and less for maximum crushing strength and modulus of elasticity than the matching controls. The values for individual specimens are given in columns 7, 16, and 25 in table 6.

Comparison of the results for these two groups of end-matched specimens shows that the average strength values of series-2 specimens for each property, after 11 days of additional soaking in the petroleum-base fluid, were less than those of series 1. These reductions are small and cannot be considered significant for the fiber stress at proportional limit and the modulus of elasticity of a number of the individual specimens of series 2 are higher than the values for the corresponding specimens of series 1. For maximum crushing strength, however, the individual values for specimens of series 2 are lower than those of series 1.

The results obtained from these two series of tests indicate that the soaking of specimens in petroleum-base fluid does not have a significant effect on compressive properties. In appearance, the failure of the specimens was similar to that of the controls.

Castor-oil-base fluid, end-soaked (series 1 and 2).--Line 6 in table 7 shows that the average strength of series-1 specimens soaked in castor-oil-base fluid is reduced 32.5 percent for fiber stress at elastic limit and 40.1 percent for maximum crushing strength, from the average of the controls. This reduction is significant, especially since the strength ratios for individual specimens (columns 5 and 14 in table 6) all indicate a decrease from the corresponding control values. The average for modulus of elasticity is 0.9 percent higher than that for the controls, but the values for individual specimens (column 23, table 6) were sometimes less than those for the matched control specimens.

The average values for series-2 specimens, shown in line 8 of table 7, are less for all properties than those for the unsoaked controls. These reductions, ranging from 12.9 to 44 percent, are undoubtedly significant. The strength ratios for individual specimens, moreover, (columns 7, 16, and 25 in table 6) show a decrease for the soaked specimens compared to the matched controls, with one exception.

These two series of compression specimens were end-matched, and since the Laboratory procedure resulted in 12 days additional soaking for series 2, some information regarding the effect of time of soaking is available. The average values for series-2 specimens and the results from individual specimens in 28 of 31 cases are somewhat lower than those for series 1. No data regarding the amount of penetration in the two cases being available, the results are not conclusive, although a reduction of strength properties with longer soaking is indicated.

In these compression tests of specimens soaked with castor-oil-base fluid, failure occurred by crushing of the oil-soaked ends. This probably caused the large reductions obtained for maximum crushing strength and fiber stress at proportional limit. A smaller effect is to be expected for modulus of elasticity values, since the apparatus for measuring deformation was attached to the central portion of the specimen having relatively slight impregnation.

Castor-oil-base fluid, no end soaking (series 3 and 4).--The results of tests made to evaluate the effect of castor-oil-base fluid on compression properties without end soaking are summarized in lines 9 and 10 of table 7. Line 9 shows reduction of the average values, ranging from 5.3 to 10.3 percent, for the soaked specimens compared with the matched controls. The reductions from unsoaked controls do not appear to be significant, although the ratios for individual specimens in columns 9, 18, and 27 indicate a decrease in strength over the corresponding controls in all but four cases. However, the lesser reduction in strength as compared to specimens tested with soaked ends is noteworthy.

The strength values for soaked specimens of series 3 and 4 might appear to be not directly comparable to control values because these soaked specimens were 1 by 1 by 2 inches at time of test, whereas the controls were 1 by 1 by 4 inches. However, the best information available indicates that this difference in the height-width ratio for these specimens is negligible. It would therefore appear that any difference in strength as compared to the series-1 and -2 specimens resulted from elimination of the saturated specimen ends.

The change of height ratio and of end conditions had little effect on the average modulus of elasticity according to these comparisons, which appears reasonable since the strains were measured over the middle half of the length of test specimens in all cases.

The results for the specimens of series 4, which were soaked an additional 10 days, did not confirm the general decrease in properties noted from the results of series 3. Line 10 of table 7 indicates an actual increase of two strength properties and decrease of the third property for soaked specimens of series 4. The individual strength ratios in columns 11, 20, and 29 of table 6 likewise disagree with the comparable results from series 3. The reasons for this are not apparent.

Discussion of Factors Influencing Results

Effect of type of fluid.—Army Air Corps Specification 3580 for petroleum-base fluid requires that "the oil shall consist of hydro-carbon compounds similar to those naturally occurring in petroleum." Specification 3586-B for the castor-oil-base fluid used in these tests states that "the ingredients shall consist of bodied castor oil, propylene glycol, alcohol, hydroxy-ethyl butyl ether, diamylamine, phosphoric acid and cresylic acid," and that "the fluid shall contain not more than 1.0 percent of water by volume."

It is evident that the two fluids are of radically differing composition, which undoubtedly explains the marked difference in effect on the strength properties investigated. Although the percentage of water in the castor-oil-base fluid is very low, continued selective absorption by the wood might increase its moisture content by a substantial amount, sufficient to influence strength. It is more probable, however, that the presence of alcohol and other ingredients is a more important factor in causing a reduction of strength.

Studies at the Forest Products Laboratory have indicated a definite change in strength properties as a result of treatment of wood with various organic compounds, including alcohol. Erickson and Rees[2] have investigated the effect of several chemicals on the swelling and the crushing strength of wood. The summary of their conclusions states in part:

> "A definite inverse relationship was found between the swelling of wood and its maximum crushing strength when the swelling agents were organic liquids, chiefly alcohols. For the same degree of swelling, the blocks in organic liquids were stronger than those swollen with water vapor or liquid. ... The degree of swelling does not appear to be a dependable criterion of the change in crushing strength of wood; specific effects of the chemicals often dominate the results."

[2]Journal of Agricultural Research, May 1, 1940, Vol. 60, No. 9, pp. 593-603.

Specification 3586-B for composition of castor-oil-base fluid requires 48 percent alcohol by volume. Evidently this quantity, together with other ingredients, is sufficient to produce the substantial decrease in strength noted in this series of tests.

The most recent specification for this fluid, No. 3586-C, substitutes aliphatic amine for diamylamine, and presents alternative requirements as to composition, but it is believed these differences would not modify the effect of the oil on strength properties.

Effect of impregnation.--The degree of impregnation, assumed to increase with soaking period, affected the results of static-bending and compression tests for both types of oil, but those from tests of specimens impregnated with petroleum-base oil were erratic. The specimens soaked in castor-oil-base fluid showed a consistent decrease in strength and elastic properties with increase in impregnation except in the tests of series 4. While the apparent decreased effect of castor-oil-base fluid on compressive strength with no end soaking should be further investigated, it would appear that this does not materially affect the conclusions, inasmuch as an equivalent impregnation could result from long continued soaking of the radial or tangential faces.

Conclusions

The conclusions from this study, based on static-bending and compression tests of Sitka spruce soaked in hydraulic-equipment fluids at normal temperatures are as follows:

(1) Soaking of wood by petroleum-base fluid did not significantly affect these strength properties.

(2) Soaking of wood by castor-oil-base fluid reduced the compressive and bending strength. The amount of such reduction for either property was dependent upon the impregnation. This was affected by the soaking period in relation to the size of the section and, for compression tests, was dependent upon whether end as well as radial and tangential soaking took place.

(3) For tests in which an investigation of the effect of such fluid on strength properties of wood is the principal objective, small thin specimens afford more information than do larger specimens, because they permit more complete penetration.

Table 1.--Moisture content and specific gravity of 1/8-inch veneer control specimens

Specimen No.	Moisture content	Specific gravity (based on weight when oven dry and volume at test)
	Percent	
B1A-154-A3	8.3	0.334
B1A-154-B2	7.5	.361
B1A-154-B4	8.4	.313
B1A-154-C1	8.3	.330
B1A-154-C3	8.2	.328
B1A-154-C5	8.0	.320
B1A-154-D2	7.5	.338
B1A-154-D4	7.7	.310
B1A-154-E1	8.4	.321
B1A-154-E3	7.8	.328
B1A-154-E5	7.8	.324
B1A-154-F2	8.6	.334
B1A-154-F4	8.0	.304
B1A-154-G1	8.2	.322
B1A-154-G3	8.7	.308
B1A-154-G5	8.3	.309
B1A-154-H2	8.4	.324
B1A-154-H4	8.5	.306
B1A-154-J1	8.5	.314
B1A-154-J3	8.0	.308
B1A-154-J5	8.5	.313
B1A-154-K2	8.6	.314
B1A-154-K4	8.5	.302
B1A-154-L1	8.4	.313
B1A-154-L3	8.7	.306
B1A-154-L5	8.2	.301
B1A-154-M2	8.8	.306
B1A-154-M4	8.9	.303
Bla-154-N1	8.6	.307
B1A-154-N3	8.5	.319
B1A-154-N5	8.7	.302
B1A-154-O2	8.8	.316
B1A-154-O4	8.6	.302
B1A-154-P1	8.8	.311
B1A-154-P3	9.0	.326
B1A-154-P5	8.2	.314
B1A-154-Q2	9.0	.328
B1A-154-Q4	8.8	.327
B1A-154-R3	8.5	.327
Average	8.4	.317

Table 2.--Moisture content and specific gravity of solid wood static-bending control specimens

Specimen No.	Moisture content	Specific gravity (based on weight when oven dry and volume at test)
	Percent	
B1A-I4-1A	10.2	0.328
B1A-I4-2B	10.5	.338
B1A-L5-1A	10.2	.334
B1A-L5-2B	10.6	.332
B1A-L24-1A	10.4	.323
B1A-L24-2B	10.0	.342
B1A-L25-1A	9.9	.334
B1A-L25-2B	9.6	.344
B1A-M12-1B	10.2	.324
B1A-M12-2A	10.4	.316
B1A-M24-1A	10.1	.326
B1A-M24-1C	11.0	.322
B1A-M24-1E	11.4	.320
B1A-M24-1G	10.7	.331
B1A-M24-2A	10.4	.310
B1A-M24-2C	11.7	.306
B1A-M24-2E	10.8	.313
B1A-M24-2G	10.9	.309
B1A-N24-1A	10.8	.326
B1A-N24-1C	10.8	.320
B1A-N24-1E	10.5	.327
B1A-N24-1G	10.8	.329
B1A-N24-2A	10.9	.320
B1A-N24-2C	10.5	.324
B1A-N24-2E	10.7	.338
B1A-N24-2G	10.4	.334
Average	10.55	.326

Table 3.--Moisture content and specific gravity of solid wood compression control specimens

Specimen No.	Moisture content	Specific gravity (based on weight when oven dry and volume at test)
	Percent	
B1A-L4-1A(CP)	9.8	0.326
B1A-L4-2B(CP)	9.4	.340
B1A-L5-1A(CP)	9.5	.330
B1A-L5-2B(CP)	9.4	.326
B1A-L24-1A(CP)	9.6	.319
B1A-L24-2B(CP)	9.4	.338
B1A-L25-1A(CP)	10.9	.328
B1A-L25-2B(CP)	10.5	.330
B1A-M12-1B(CP)	9.6	.326
B1A-M12-2A(CP)	9.0	.316
B1A-M24-1A(CP)	9.5	.326
B1A-M24-1C(CP)	9.8	.324
B1A-M24-1E(CP)	11.1	.321
B1A-M24-1G(CP)	9.9	.335
B1A-M24-2A(CP)	9.8	.315
B1A-M24-2C(CP)	10.2	.306
B1A-M24-2E(CP)	10.1	.317
B1A-M24-2G(CP)	11.2	.310
B1A-N24-1A(CP)	10.8	.326
B1A-N24-1C(CP)	11.0	.319
B1A-N24-1E(CP)	9.7	.326
B1A-N24-1G(CP)	9.5	.332
B1A-N24-2A(CP)	11.0	.316
B1A-N24-2C(CP)	11.1	.319
B1A-N24-2E(CP)	10.8	.336
B1A-N24-2G(CP)	9.3	.341
Average	10.1	.325

Table 4.--Results of tests to determine the effect of petroleum-base and castor-oil-base hydraulic fluids on the static-bending strength of Sitka spruce veneer specimens 1/8 by 1 by 5 inches, center loading, 3-inch span

Hydraulic fluid base	Specimen No.	Fiber stress at proportional limit: Average of controls	Fiber stress at proportional limit: Treated	Fiber stress at proportional limit: Ratio of treated to average of controls	Modulus of rupture: Average of controls	Modulus of rupture: Treated	Modulus of rupture: Ratio of treated to average of controls	Modulus of elasticity: Average of controls	Modulus of elasticity: Treated	Modulus of elasticity: Ratio of treated to average of controls
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
		Lb. per sq. in.	Lb. per sq. in.		Lb. per sq. in.	Lb. per sq. in.		1,000 lb. per sq. in.	1,000 lb. per sq. in.	
Petroleum	B1P-154-C2	8,320	8,320	1.000	10,480	11,710	1.117	1,620	1,894	1.169
	B1P-154-D3	7,240	8,580	1.185	8,890	12,440	1.399	1,496	2,118	1.416
	B1P-154-D4	6,340	7,320	1.155	8,100	9,000	1.111	1,202	976	.812
	B1P-154-G2	5,680	8,540	1.504	8,210	11,380	1.386	1,239	2,023	1.633
	B1P-154-H3	5,450	4,950	.908	7,840	8,740	1.115	1,146	934	.815
	B1P-154-J4	4,860	4,280	.881	7,160	6,300	.880	1,057	932	.882
	B1P-154-L2	4,910	5,840	1.189	7,440	7,620	1.024	1,251	1,302	1.041
	B1P-154-M3	4,320	6,060	1.403	6,610	8,920	1.349	1,141	1,377	1.207
	B1P-154-M4				7,060	12,520	1.773			
	B1P-154-P2	5,190	4,790	.923	7,660	7,370	.962	1,190	1,135	.954
	B1P-154-Q3	5,770	6,460	1.120	8,540	9,780	1.145	1,265	1,426	1.127
	Average	5,808	6,514	1.122	7,999	9,616	1.202	1,261	1,412	1.120
Castor oil	B1C-154-B3	7,330	2,580	.352	9,330	4,790	.513	1,468	908	.619
	B1C-154-C4	7,180	3,150	.439	8,760	5,040	.575	1,398	738	.528
	B1C-154-E2	6,830	3,020	.442	8,650	5,480	.634	1,387	968	.698
	B1C-154-F3	5,700	2,830	.496	8,350	4,330	.519	1,202	792	.659
	B1C-154-G4	4,990	3,360	.673	7,770	5,650	.727	1,019	972	.954
	B1C-154-J2	5,420	2,900	.535	7,630	5,390	.706	1,267	793	.626
	B1C-154-K3	3,920	2,140	.546	6,820	4,510	.661	1,001	697	.696
	B1C-154-L4	3,980	2,870	.721	6,600	5,060	.767	976	791	.810
	B1C-154-N2	4,830	2,370	.491	6,520	4,640	.712	1,206	722	.599
	B1C-154-O3	5,010	2,150	.429	7,250	4,540	.626	1,190	714	.600
	B1C-154-P4	5,730	3,800	.663	8,550	5,620	.657	1,263	1,167	.924
	Average	5,538	2,834	.512	7,839	5,005	.638	1,216	842	.692

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Table 5.--Results of tests to determine the effect of petroleum-base and castor-oil-base hydraulic fluids on the static-bending strength of Sitka spruce specimens 1 by 1 by 16 inches, center loading, 14-inch span

Hydraulic fluid base	Specimen No.	Fiber stress at proportional limit: Average of controls	Fiber stress at proportional limit: Treated	Fiber stress at proportional limit: Ratio of treated to average of controls	Modulus of rupture: Average of controls	Modulus of rupture: Treated	Modulus of rupture: Ratio of treated to average of controls	Modulus of elasticity: Average of controls	Modulus of elasticity: Treated	Modulus of elasticity: Ratio of treated to average of controls
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
		Lb. per sq. in.	Lb. per sq. in.		Lb. per sq. in.	Lb. per sq. in.		1,000 lb. per sq. in.	1,000 lb. per sq. in.	
Petroleum	B1P-L4-2A	5,590	6,520	1.166	9,940	10,440	1.050	1,646	1,514	0.920
	B1P-L5-1B	5,880	6,060	1.031	9,320	10,460	1.122	1,423	1,506	1.058
	B1P-L24-1B	6,040	6,140	1.017	9,150	10,140	1.108	1,336	1,426	1.067
	B1P-L25-2A	6,340	5,980	.943	9,280	8,940	.963	1,470	1,479	1.006
	B1P-M12-2B	6,380	5,730	.898	8,420	8,860	1.052	1,325	1,268	.957
	B1P-M24-1B	6,130	5,820	.949	9,200	9,390	1.021	1,510	1,390	.921
	B1P-M24-1F	6,640	5,840	.880	9,470	9,540	1.007	1,454	1,360	.935
	B1P-M24-2D	5,610	5,660	1.009	7,830	8,580	1.096	1,400	1,301	.929
	B1P-N24-1D	6,860	6,110	.891	9,580	10,220	1.067	1,466	1,497	1.021
	B1P-N24-2B	6,200	6,080	.981	9,070	9,260	1.021	1,474	1,369	.929
	B1P-N24-2F	6,320	5,640	.892	9,880	8,940	.905	1,529	1,365	.893
	Average	6,181	5,962	.965	9,195	9,525	1.036	1,458	1,407	.965
Castor oil	B1C-L4-1B	6,370	5,700	.895	9,780	9,530	.974	1,462	1,332	.911
	B1C-L5-2A	4,850	6,000	1.237	10,080	9,360	.929	1,574	1,383	.879
	B1C-L24-2A	6,500	5,700	.877	9,450	9,580	1.014	1,441	1,489	1.033
	B1C-L25-1B	6,510	5,670	.871	9,290	8,990	.968	1,495	1,278	.855
	B1C-M12-1A	6,450	5,600	.868	9,220	9,320	1.011	1,478	1,300	.880
	B1C-M24-1D	6,480	5,360	.827	9,210	9,220	1.001	1,477	1,312	.888
	B1C-M24-2B	6,060	5,080	.838	8,420	7,840	.931	1,407	1,235	.878
	B1C-M24-2F	5,570	5,140	.923	8,230	8,300	1.009	1,409	1,205	.855
	B1C-N24-1B	6,780	5,320	.785	9,920	8,640	.871	1,490	1,256	.843
	B1C-N24-1F	7,080	6,280	.887	9,360	9,740	1.041	1,456	1,332	.915
	B1C-N24-2D	6,700	5,300	.791	9,440	8,910	.944	1,493	1,303	.873
	Average	6,305	5,559	.882	9,309	9,039	.971	1,471	1,311	.891

Z M 56889 F

Table 6.--Results of tests on Sitka spruce to determine the effect of petroleum-base and castor-oil-base hydraulic fluids on the compressive strength parallel to grain

Hydraulic fluid base	Specimen No.	Fiber stress at proportional limit									Maximum crushing strength									Modulus of elasticity								
		1- by 1- by 4-inch specimens					1- by 1- by 2-inch specimens				1- by 1- by 4-inch specimens					1- by 1- by 2-inch specimens				1- by 1- by 4-inch specimens					1- by 1- by 2-inch specimens			
		Average of controls	Series 1[1]		Series 2[2]		Series 3[3]		Series 4[4]		Average of controls	Series 1[1]		Series 2[2]		Series 3[3]		Series 4[4]		Average of controls	Series 1[1]		Series 2[2]		Series 3[3]		Series 4[4]	
			Treated	Ratio[5]	Treated	Ratio[5]	Treated	Ratio[5]	Treated	Ratio[5]		Treated	Ratio[5]	Treated	Ratio[5]	Treated	Ratio[5]	Treated	Ratio[5]		Treated	Ratio[5]	Treated	Ratio[5]	Treated	Ratio[5]	Treated	Ratio[5]
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)	(24)	(25)	(26)	(27)	(28)	(29)
		Lb. per sq. in.	Lb. per sq. in.		Lb. per sq. in.		Lb. per sq. in.		Lb. per sq. in.		Lb. per sq. in.	Lb. per sq. in.		Lb. per sq. in.		Lb. per sq. in.		Lb. per sq. in.		1,000 lb. per sq. in.	1,000 lb. per sq. in.		1,000 lb. per sq. in.		1,000 lb. per sq. in.		1,000 lb. per sq. in.	
Petroleum	BIP-14-2A	3,970	4,580	1.154	3,690	0.929	....	....	....	....	4,940	5,350	1.083	4,600	0.931	....	....	....	....	1,633	1,442	0.883	1,543	0.945	....	....	....	....
	BIP-15-1B	3,280	4,620	1.409	4,850	1.479	....	....	....	....	5,080	5,060	.996	4,860	.957	....	....	....	....	1,640	1,654	1.009	1,601	.976	....	....	....	....
	BIP-124-1B	4,100	4,080	.995	4,410	1.076	....	....	....	....	4,790	5,170	1.079	4,530	.946	....	....	....	....	1,611	1,593	.989	1,554	.965	....	....	....	....
	BIP-125-2A	4,240	3,430	.809	4,830	1.139	....	....	....	....	4,960	5,050	1.018	4,840	.976	....	....	....	....	1,594	1,608	1.006	1,858	1.163	....	....	....	....
	BIP-M12-2B	3,770	4,110	1.090	3,320	.881	....	....	....	....	4,310	4,840	1.123	4,780	1.109	....	....	....	....	1,544	1,521	.985	1,464	.948	....	....	....	....
	BIP-M24-1B	3,320	3,830	1.154	3,060	.922	....	....	....	....	4,620	4,870	1.054	4,700	1.017	....	....	....	....	1,637	1,650	1.008	1,578	.964	....	....	....	....
	BIP-M24-1F	3,875	4,460	1.149	3,540	.912	....	....	....	....	4,930	5,180	1.051	4,940	1.002	....	....	....	....	1,630	1,506	.924	1,604	.984	....	....	....	....
	BIP-M24-2D	3,745	4,080	1.091	4,240	1.134	....	....	....	....	4,590	4,680	1.020	4,410	.961	....	....	....	....	1,536	1,527	.994	1,333	.869	....	....	....	....
	BIP-E24-2B	3,430	4,100	1.195	3,810	1.114	....	....	....	....	4,715	5,000	1.059	4,800	1.017	....	....	....	....	1,627	1,599	.982	1,579	.970	....	....	....	....
	BIP-E24-2F	4,205	4,740	1.129	5,070	1.207	....	....	....	....	4,720	5,140	1.089	5,120	1.085	....	....	....	....	1,744	1,718	.985	1,658	.951	....	....	....	....
	Average	3,792	4,203	1.108	4,082	1.076	....	....	....	....	4,765	5,034	1.056	4,758	.999	....	....	....	....	1,620	1,582	.977	1,577	.973	....	....	....	....
Castor oil	BIC-14-1B	4,080	2,910	.713	2,560	.627	....	....	....	....	4,460	2,980	.668	2,660	.596	....	....	....	....	1,575	1,538	.977	1,377	.874	....	....	....	....
	BIC-15-2A	3,550	2,480	.699	2,700	.761	3,880	1.093	4,160	1.172	4,920	2,930	.596	2,740	.557	4,660	0.947	4,940	1.004	1,620	1,674	1.033	1,460	.901	1,732	1.069	1,436	0.886
	BIC-124-2A	3,860	2,720	.705	2,500	.648	3,620	.938	4,330	1.122	5,060	2,950	.583	2,780	.549	4,910	.970	4,970	.982	1,754	1,614	.922	1,493	.851	1,535	.875	1,384	.789
	BIC-125-1B	4,160	1,590	.382	2,370	.570	3,410	.820	3,890	.935	4,980	2,820	.566	2,450	.492	4,570	.918	4,640	.932	1,670	1,676	1.004	1,366	.818	1,239	.742	1,606	.963
	BIC-M13-1A	3,970	2,740	.690	2,370	.584	3,500	.882	4,270	1.076	4,880	2,820	.578	2,600	.533	4,590	.941	4,960	1.016	1,468	1,712	1.151	1,492	1.003	1,422	.956	1,348	.906
	BIC-M24-1D	3,430	2,810	.819	2,100	.612	3,750	1.093	3,910	1.140	4,665	2,820	.605	2,700	.579	4,450	.955	4,970	1.066	1,640	1,678	1.023	1,408	.859	1,460	.890	1,460	.890
	BIC-M24-2B	3,685	2,400	.652	2,170	.590	3,460	.940	4,290	1.166	4,555	2,680	.588	2,580	.566	4,320	.947	4,720	1.035	1,512	1,538	1.017	1,356	.897	1,430	.946	1,304	.865
	BIC-M24-2F	3,810	2,720	.714	2,120	.556	2,840	.745	3,470	.912	4,465	2,740	.614	2,570	.576	4,020	.901	4,690	1.052	1,508	1,608	1.066	1,287	.850	1,476	.979	1,528	1.013
	BIC-E24-1B	3,080	2,180	.708	2,500	.812	3,560	1.156	4,660	1.513	4,450	2,780	.625	2,580	.580	4,400	.989	4,800	1.079	1,782	1,557	.874	1,372	.770	1,396	.783	1,562	.877
	BIC-E24-1F	3,945	2,800	.712	2,380	.604	3,380	.858	4,300	1.091	4,950	2,880	.582	2,820	.570	4,240	.857	5,240	1.059	1,634	1,634	1.000	1,588	.972	1,264	.774	1,538	.942
	BIC-E24-2D	3,745	....	....	....	....	3,650	.984	4,680	1.251	4,785	2,860	.594	2,720	.569	4,750	.994	5,140	1.075	1,680	1,796	1.069	1,375	.818	1,615	.961	1,530	.911
	Average	3,756	2,533	.675	2,372	.632	3,508	.934	4,196	1.117	4,763	2,842	.599	2,655	.560	4,491	.947	4,902	1.034	1,624	1,639	1.009	1,415	.871	1,457	.897	1,470	.905

[1]Series-1 compressions soaked about 38 days as part of 16-inch bending specimen; resoaked about 14 days in 4-inch length; tested with soaked ends.
[2]Series-2 compressions soaked about 38 days as part of 16-inch bending specimen; resoaked about 25 days in 4-inch length; tested with soaked ends.
[3]Series-3 compressions soaked about 39 days as part of 16-inch bending specimens; resoaked about 17 days in 4-inch length; cut to 2-inch length at time of test; no end soaking.
[4]Series-4 compressions soaked about 39 days as part of 16-inch bending specimens; resoaked about 27 days in 4-inch length; cut to 2-inch length at time of test; no end soaking.
[5]Ratio equals strength of treated specimen divided by average strength of adjacent control specimens.

Z M 56888 F

Table 7.—Summary of soaking periods, and change in strength attributed to soaking of Sitka spruce static-bending and compression specimens in petroleum-base and castor-oil-base hydraulic fluids

Line No.	Size of specimen	Type of fluid	Series No.	Approximate time of soaking: Sides	Approximate time of soaking: Ends	Increase (+) or decrease (-) in strength of soaked specimens compared to controls[1]: Fiber stress at proportional limit	Modulus of rupture	Modulus of elasticity	Maximum crushing strength
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	Inches			Days	Days	Percent	Percent	Percent	Percent
				Static-bending tests on veneer					
1	1/8 by 1 by 5	Petroleum base	....	38	....	+12.2	+20.2	+12.0	....
2	1/8 by 1 by 5	Castor oil base	....	40	....	-48.8	-36.2	-30.8	....
				Static-bending tests on solid wood					
3	1 by 1 by 16	Petroleum base	....	37	....	- 3.5	+ 3.6	- 3.5	....
4	1 by 1 by 16	Castor oil base	....	39	....	-11.8	- 2.9	-10.9	....
				Compression tests on end-soaked specimens					
5	1 by 1 by 4	Petroleum base	1	51	14	+10.8	....	- 2.3	+ 5.6
6	1 by 1 by 4	Castor oil base	1	53	14	-32.5	....	+ .9	-40.1
7	1 by 1 by 4	Petroleum base	2	62	25	+ 7.6	....	- 2.7	- .1
8	1 by 1 by 4	Castor oil base	2	65	26	-36.8	....	-12.9	-44.0
				Compression tests on specimens with no end soaking					
9	1 by 1 by 2	Castor oil base	3	56	0	- 6.6	....	-10.3	- 5.3
10	1 by 1 by 2	.......do..........	4	66	0	+11.7	....	+ 9.5	+ 3.4

[1] The figures shown in columns 7 to 10 represent the difference between unity and the average ratios shown in columns 5, 8, and 11 in tables 4 and 5, and columns 5, 7, 9, 11, 14, 16, 18, 20, 23, 25, 27, and 29 in table 6, expressed as percentages.

Z M 56891 F

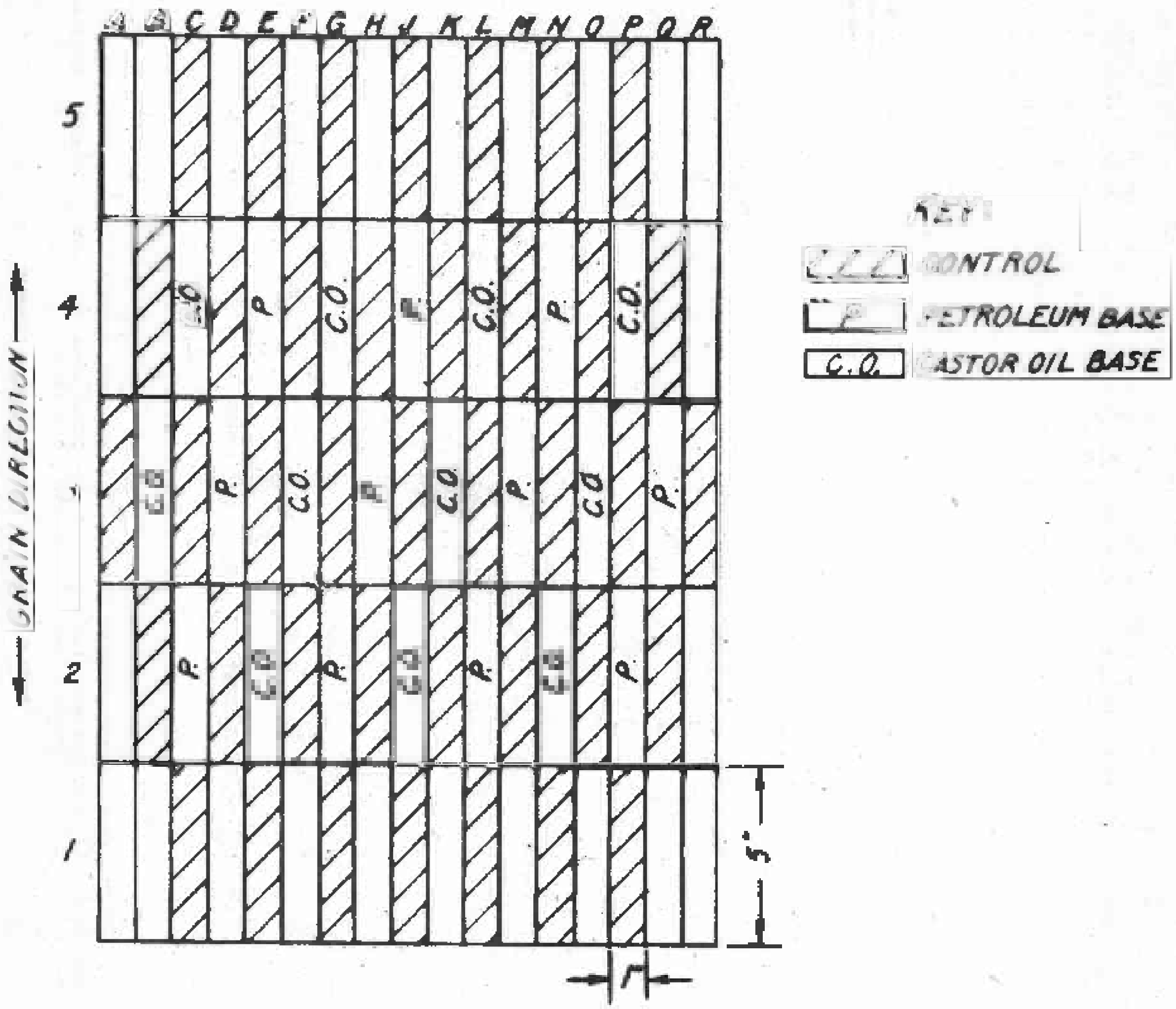

Figure 1.--Matching and cutting plan for veneer static-bending tests.

M 57376 F

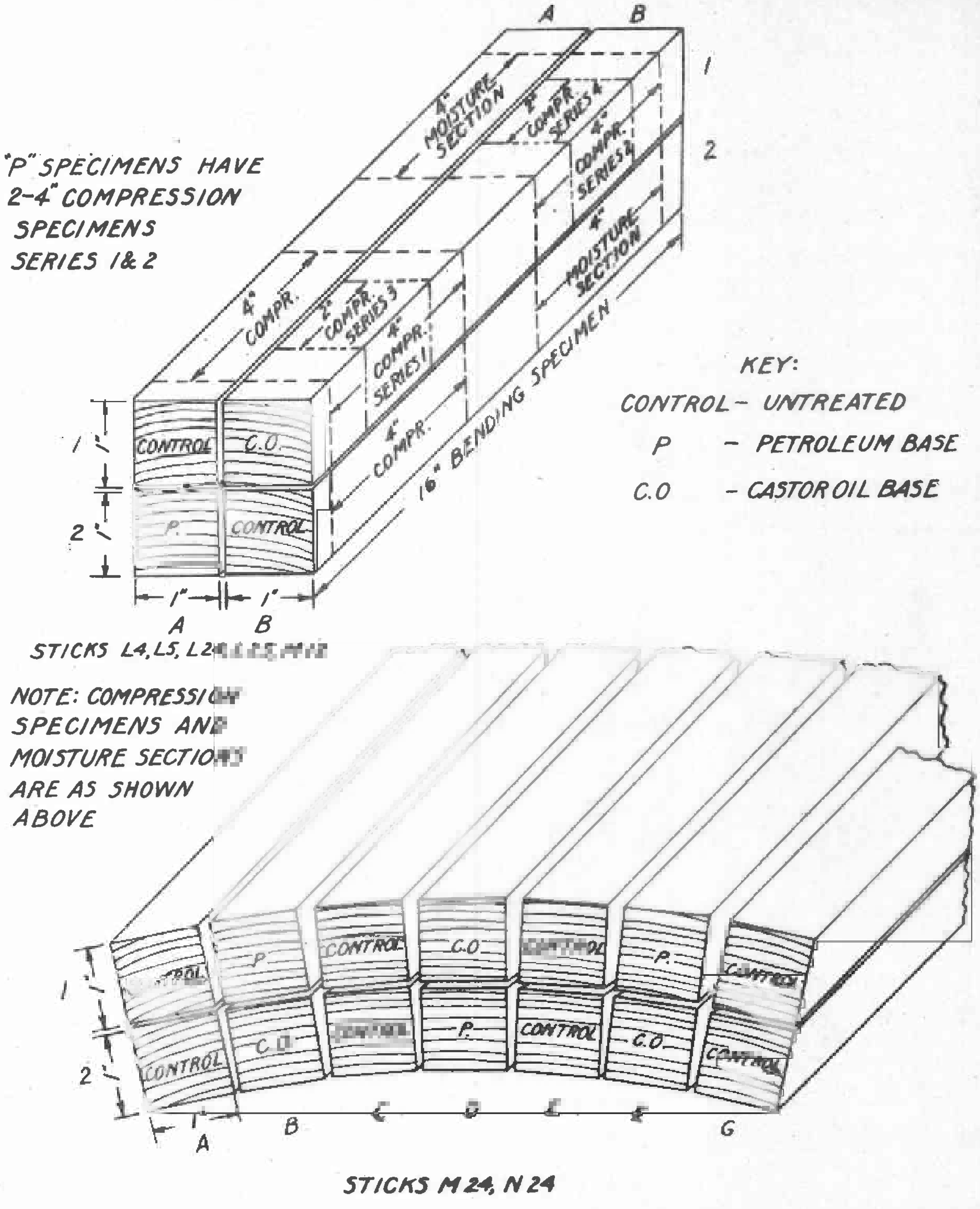

Figure 2.--Matching and cutting plan for solid wood static-bending and compression tests.

Z M 57579 F