STRENGTH OF GLUED LAMINATED SITKA SPRUCE MADE UP OF ROTARY-CUT VENEERS[1]

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Summary

Wing spars and other wood airplane parts are now either made of solid wood or laminated from sawed stock. One proposed method of increasing the supply is to avoid waste in sawdust and shavings by rotary-cutting the logs into 1/7-inch veneer which would be glued together in suitable thicknesses, widths, and lengths.

The purpose of this investigation was to study the strength of such stock, and the effects of cross grain, scarf joints, and orientation of laminations,

The veneer was fabricated into 2-inch thick stock, most of which was straight-grained and made with continuous laminations. Some was purposely so fabricated as to make planks with cross grain in which the grain slopes were crossed in adjacent plies. Other planks were made up from straight-grained veneer end with scarf joints in alternate plies.

A hot-setting phenolic resin glue was used in making the scarf joints. The individual sheets of veneer were glued together with a urea-resin glue (Plaskon 250-2).

The glue, together with possible slight densification from the pressure applied in gluing, added about 7 percent to the unit weight of the laminated material. Lesser additions would result if glue was used in the film rather than the liquid form.

The tests included static and impact bending, compression parallel to grain, shear parallel to the grain, and toughness.

In these tests the straight-grained laminated Sitka spruce gave average values essentially similar to averages from previous tests on solid Sitka spruce, except that in work values in static bending, a measure of shock resistance, the laminated stock was definitely lower than the solid. This is not, however, confirmed by impact bending and toughness tests, which are also measures of shock-resistance.

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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.

For straight-grained material, as well as for that with grain slopes of 1 in 15 and 1 in 10, beams with laminations vertical (width of laminations in the direction of the applied load) were essentially like beams with laminations horizontal, except that the latter were rather consistently higher in height of drop in impact bending and in work values in static bending. Aside from this the tests confirm previous conclusions that a given slope of grain has the same effect regardless of the orientation of the plane in which the slope lies. (In the present tests the grain sloped across the wide face of the laminations and hence in vertical. planes in beams with laminations vertical and vice versa.)

Laminated material with grain slopes of 1 in 15 showed no significant deficiency as compared to similar straight-grained material in those strength properties used in aircraft design. Deficiency in work values in static bending is apparent and particularly so for specimens tested with two-point loading wherein the stress is constant between the two load points. That this indication is not supported by toughness values nor by results of impact bending tests is very possibly due to the fact that these tests were made only with center loading.

Strength values in laminated material with grain slopes of 1 in 10 are not sufficient to justify use of such material in parts that are highly stressed in compression, bending, or tension parallel to the grain,

A popular concept has been that by interlacing the grain (reversing grain slopes in adjacent laminations) in stock built up from thin laminations the deleterious effects of cross grain on such properties as bending and tension could be overcome and wood with steep grain slopes made equal to straight-grained material. This is not confirmed by the present tests. It is, however, definitely indicated that under flexure (as in static or impact bending or toughness tests) grain sloping oppositely in adjacent laminations is superior to grain of the same slope oriented alike throughout.

Beams with glued scarf joints at a slope of 1 in 15 in alternate laminations and at the same point in the length were deficient as compared to beams with all laminations continuous. The reduction was particularly large in those properties indicative of shock resistance. Tension tests of the veneers disclosed that the scarf joints were not as strong as can be produced by thoroughly good technique. Scarf joints are being successfully used in aircraft parts formed of sawed laminations. Rotary-cut veneers afford opportunity, because of their lesser thickness, for better joint distribution than thicker material. Also, because of the lesser thickness and better distribution, the effect of a jointed lamination at the tension face of a member stressed in bending would be less.

The general conclusion is that on the basis of strength values Sitka, spruce laminated from rotary-cut veneer is satisfactory as an alternate to solid members or members laminated from sawn stock, provided the same requirements for straightness of grain, limitation of defects, and specific gravity of the wood (exclusive of glue) are observed.

Introduction

Practically all spruce airplane wing spars and other airplane parts are now made of lumber either in the solid form or laminated of thin pieces of sawed stock. The yield of suitable airplane lumber' is small. One method proposed for increasing the yield [2] is to cut the logs on a lathe into veneer of a thickness of 1/7 inch or thereabouts, dry the veneers, trim out defects, clip, edge joint, and then edge glue the veneers into sheets of suitable width. The veneer could then be spliced end to end with scarf joints, and as many sheets glued together as needed to obtain the desired thickness of stock. Thus, stock of any thickness, width, and length could be produced.

It is the purpose of this investigation to determine the strength of stock of this type, and to establish the effect of certain factors such as cross grain, position of laminations and of scarf joints.

Material

The veneer was obtained from No. 1 Sitka spruce logs. Some of the logs were taken from the pond of the Harbor Plywood Company and some were obtained from the Polson Logging Company, both of Hoquiam, Washington. The cutting of the veneer, clipping of the defects, drying of the veneer, edge gluing of the sheets, and scarf jointing of some of the sheets was done under the supervision of Laboratory representativesat the plants of the Harbor Plywood Company, Hoquiam, Washington, Portland Plylock plant of the M. and M. Woodworking Company, and the B. P. John Furniture Company at Portland, Oregon.

Immediately after the rotary cutting of the veneer it was run through a commercial drier set to a temperature of 250° to 300° F. The drying period was 30 minutes, and the resulting moisture content of the veneer was 2 percent or less. During the inspection of the veneer it picked up considerable moisture, particularly near the edges, resulting in some warping. It was, therefore, necessary to redry the veneer before further processing, such as edge gluing and scarf jointing. During the second drying the temperature was 300° to 350° F. and the drying period 25 minutes. This again brought the veneer to a moisture content of 2 percent or less. The veneer was edge-glued or scarf-jointed or both edge-glued and scarf-jointed and was shipped to the Laboratory.

Fabrication of Material into 2-Inch Stock

The following procedure was used in preparing end gluing the veneer into 2-inch thick planks for test purposes.

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[2] Forest Products Laboratory unpublished report, "Investigations of Rotary-Cut Aircraft Veneer--Sitka spruce," by E. M. Davis and W. Y. Pillow.

The slope of grain of each sheet was first carefully determined. The material was all rotary-cut and most pieces were free of diagonal grain, but if the sheet had diagonal grain (slope at an angle to the plane of the sheet) steeper than 1 in 25, it was not used, Slight spiral grain was eliminated by edging the veneers parallel to the grain direction, The material was then ripped into 12-inch widths,

Since the moisture of the veneer was approximately 5 percent, no further drying was necessary prior to gluing.

After the material was ripped to 12-inch widths, each piece was weighed. These weights showed that all sheets of veneer met the specific gravity limitation of 0.36 based on oven-dry weight and volume, In arranging the laminations preparatory to gluing, no consideration was given to specific gravity; that is, there was a random arrangement as regards specific gravity, Each plank was made of 15 plies of 1/7-inch veneer.

Specimens with slopes of grain of 1 in 15 and 1 in 10, together with corresponding controls were made. In one-half of those specimens with a slope of grain, the slope in all plies was parallel, whereas in the other half of the specimens, the slope of grain in adjacent plies crossed. The specimens with slope of grain of all plies parallel were cut from straight-grained material after gluing as shown in figure 1. Those with slope of grain crossed in alternate plies had each ply cut to desired slope of grain before gluing and then assembled to give desired arrangement of slope of grain in alternate plies as also shown in figure 1. To obtain this crossing of grain, it was necessary to turn each alternate ply over from its original position as it came from the lathe, Consequently, open. side of veneer was glued to open side and closed side to closed side. Material with straight grain and with slope of all plies parallel was also glued with veneers open side to open side and closed side to closed side to eliminate this factor in later comparisons.

The veneers were glued with urea-resin glue (Plaskon 250-2). The single spread was 18-3/4 grams per square foot of glued surface, the pressure 100 pounds per square inch, the assembly time 30 minutes, the room temperature 70° to 75° F., while the time in pross varied from 5 to 40 hours. Most planks were in the press 20 hours. Preliminary tests indicated that this gluing technique and glue spread would give good glue joints.

To obtain information on the dry weight of the glue used, the weight of the veneer just prior and immediately after the spreading of the glue was recorded. The glue mixture consisted of 100 parts dry glue to 65 parts water, by weight.

After gluing, the planks were placed in the 62 percent 70° F. humidity room and left there until they were of constant weight and approximately uniform moisture content,

Preparation, Cutting, Marking, and Matching of Specimens

Specimens tested in static and impact bending and in compression parallel to grain and shear were 2 by 2 inches in cross section.

Beams with Different Slopes of Grain

Specimens with straight grain and with slope of grain of all plies in the same direction were cut from planks approximately 2 by 12 by 66 inches as shown in figure 1. Specimens with the slope of grain reversed in adjacent plies were obtained from boards 2 by 9-1/2 by 36 inches. The 9-1/2- and 12-inch wide boards were matched end to end, but to obtain material with the slope of grain crossed in adjacent plies, it was necessary to cut and arrange the individual plies for the desired slope of grain prior to gluing, as previously mentioned.

After gluing and conditioning, the planks were planed to a 2-inch thickness. All planing was done on one side and this side of the specimen was placed in compression; no surfacing was done on the tension side of the specimen and this outside lamination was thus of original thickness. The method of marking and matching is shown in figure 1 where

S = static bending; and straight

I = impact bending

V = vertical

H = horizontal

P = parallel

C = crossed

Beams with Scarf Joints in Veneers

These specimens were cut from boards made of 1/7-inch veneer, alternate plies of which had a scarf joint with a slope of 1 in 15. Those scarf joints were placed one above the other and the specimens so cut that the scarf joints were at the middle of the length of the specimen. The specimens were so fabricated that at least one outside ply of full thickness contained a scarf joint. All veneer composing the 2-inch planks from which these specimens were cut were straight-grained. The scarf cutting was done at a plant in the west coast region with a traveling head scarfing machine. A phenol glue was used. After a single spread on each of the two pieces to be joined the glue was allowed to dry and was then set in a hot press. The setting in the press required about 2 minutes.

The method of matching and cutting of the specimens is shown in figure 2, where

S = static bending test

I = impact bending test

V = vertical

H = horizontal

Sc = scarf

Since the material on either side of the scarf is not matched, control specimens were cut from each end of each plank containing scarf joints.

Method of Testing

The 2- by 2- by 30-inch static and impact bending specimens (center loading), and also the shear and compression-parallel-to-grain specimens, were tested in accordance with standard procedure as outlined in American Society for Testing Materials Standards entitled, "Standard Methods for Testing Small Clear Specimens of Timber," serial designation D143-27, except that all static bending tests were continued until the load had dropped to 200 pounds. The work done to to this point is considered "total work." A few of the static bending specimens were tested with third-point loading, the deflection being measured at the center of the span, (In computing values of work, the deflection was multiplied by 0.87 to compensate for measuring deflection at center of span rather than under load points).

The toughness specimens were 5/8 by 5/8 by 10 inches and were tested over an 8-inch span with center loading. Of the four toughness specimens cut from a single impact or static bending specimen, two were tested with the load applied on the tangential face and two with the load applied on the radial face, the two for each load direction being obtained from diagonally opposite corners of the beam.

The schedule of tests is given in the following tabulation:

SCHEDULE OF TESTS

Laminated specimens with and without slope of grain
(Planks 1 to 20, inclusive)

(Specimens 2 by 2 by 30 inches--28-inch span--center or third-point loading)

Kind of test	Laminations	Slope of grain	Grain in adjacent plies	No. of tests	Plank No.
Static bending	Vertical	Straight	....	10	1-10 incl.
		1:15	Parallel	10	1-10 incl.
			Crossed	10	1-10 incl.
		Straight	....	10	11-20 incl.
		1:10	Parallel	10	11-20 incl.
			Crossed	10	11-20 incl.
	Horizontal	Straight	....	10	1-10 incl.
		1:15	Parallel	10	1-10 incl.
			Crossed	10	1-10 incl.
		Straight	....	10	11-20 incl.
		1:10	Parallel	10	11-20 incl.
			Crossed	10	11-20 incl.
Impact bending	Vertical	Straight	....	10	1-10 incl.
		1:15	Parallel	10	1-10 incl.
			Crossed	10	1-10 incl.
		Straight	....	10	11-20 incl.
		1:10	Parallel	10	11-20 incl.
			Crossed	10	11-20 incl.
	Horizontal	Straight	....	10	1-10 incl.
		1:15	Parallel	10	1-10 incl.
			Crossed	10	1-10 incl.
		Straight	....	10	11-20 incl.
		1:10	Parallel	10	11-20 incl.
			Crossed	10	11-20 incl.
				240	
Toughness	Toughness specimens from one-half of the total number of impact and static bending specimens. Four from each specimen, on two of which, taken from diagonally opposite corners, the load was applied to the radial face, and on other two, load was applied to the tangential face. 480 tests.				
Shear parallel to the grain	Two from each static bending and impact bending control specimen, one was tested with the shear plane parallel to glue lines and other with shear plane perpendicular to glue lines. 160 tests.				
Compression parallel to grain	One from each impact and static bending specimen from which toughness specimens were not obtained. 120 tests.				

Laminated specimens with scarf joints
(Planks 21 - 25, inclusive)

(Specimens 2 by 2 by 30 inches--28-inch span--center loading)

Kind of test	Laminations	Slope of grain	Number of tests	
			Scarfed	Controls
Static bending	Vertical	Straight	5	10
	Horizontal	Straight	5	10
Impact bending	Vertical	Straight	5	10
	Horizontal	Straight	5	10
			20	40

Explanation of Tables

Table 1 is a summary of results of tests of laminated Sitka spruce beams with laminations vertical and those with laminations horizontal. For both these placements of laminations, average values are shown for (1) specimens with straight grain, (2) specimens with sloping grain in which the grain in all plies is parallel, end (3) specimens with grain slopes in adjacent plies crossed. Ratios given at the end of the table compare specimens with laminations horizontal to specimens with laminations vertical.

Table 2 is a summery of the results of tests of laminated and solid specimens, all of which were straight-grained. The values for solid specimens are from U.S.D.A. Technical Bulletin No. 479, "Strength and Related Properties of Woods Grown in the United States," except for toughness values, which were taken from an unpublished report entitled "Toughness Tests of Airplane Woods (Sitka Spruce and White Ash)."

Specific gravity values are given for laminated beams based on the oven-dry weight of the wood including the glue, and also when the glue is excluded. The pressure applied during gluing caused a slight compression of the veneers and amounted to from 1 to 2 percent[3]. The specific gravity values enumerated herein are based on volume at test.

The laminated specimens were tested at about 10 percent moisture content, and most strength values for solid wood were, for comparison, adjusted to 10 percent. Sheer was adjusted to 10.7 percent, and no adjustment was made for toughness. No reliable means of adjusting the toughness values for moisture is available. The toughness values for solid specimens were adjusted

Unpublished report, "Preliminary Tests on Laminating 1/7-inch Sitka Spruce Veneer for Airplane Spar Stock," by M. Leonard Selbo, dated July 19, 1943.

for differences in specific gravity to that corresponding to laminated specimens. The specific gravity values for other laminated specimens were so nearly like those for solid specimens that adjustment of strength values for specific gravity differences was unnecessary.

Table 3 includes data on the effect of sloping grain on the strength of laminated beams. Average values are shown according to whether the grain is straight or sloping, the laminations are vertical or horizontal, and the sloping grain in adjacent plies is parallel or crossed. Strength values for specimens with laminations vertical and loaded at the center or third points are also given.

A comparison of the strength of specimens with sloping grain and straight grain expressed as ratios is given at the end of the table.

Table 4 shows average results for laminated Sitka spruce beams containing scarf joints of a slope of 1 in 15 in alternate plies and for laminated beams without scarf joints. Ratios comparing laminated beams with scarf joints and laminated beams without scarf joints are also included.

Discussion of Results

The principal factors investigated included:

(1) Laminations vertical or horizontal,

(2) Strength of 1aminated beams and solid beams,

(3) Slope of grain in laminated beams, and

(4) Scarf joints in laminated beams.

Beams with Laminations Vertical or Horizontal.

The laminated beams were made up of l/?-inch veneer glued together with urea-resin glue (Plaskon 250-2). The glue added some 7 or 8 percent to the oven-dry weight of the wood.

Information on the strength of beams, grouped according to whether laminations are vertical or horizontal and according to whether the material is straight-grained, has a sloping grain with the grain in all plies parallel, or a sloping grain in which the grain in adjacent plies is crossed, is given in table 1.

The ratios, as given at the bottom of the table, for modulus of rupture and modulus of elasticity are, in practically all instances, near 100 percent, indicating that these properties are not affected by the lamination placement. This is true whether the material is straight-grained or has a sloping grain. The ratios for work values and height of drop in impact, properties which measure shock resistance, are in general above 100 percent indicating higher values for horizontal than for vertical laminations.

Laminated and Solid Beams

The differences in strength values with laminations vertical and laminations horizontal are on the whole sufficiently small so that averaging of these values together for comparison of laminated and solid material and for evaluating the effects of slope of grain is considered valid.

Table 2 shows that the specific gravity, exclusive of glue, is practically the same for the laminated beams as for Sitka spruce previously tested.

The modulus of rupture averages slightly higher for the laminated beams with straight grain then for solid beams, but the difference is not considered significant. The modulus of elasticity is appreciably higher for laminated then for solid beams, and it seems likely that the glue has added somewhat to the stiffness. The laminated beams are also slightly higher in maximum crushing strength parallel to the grain. In work values the laminated beams are considerably lower. This apparent deficiency is not, however, substantiated by results of the impact bending tests in which laminated end solid beams have the same average values. Furthermore, in toughness, another measure of shock resistance, the laminated and solid materials had practically the same average values when the load was applied on the radial surface; when the load was applied on the tangential surface, the laminated beams averaged considerably higher in toughness than the solid. Considering all the values measuring shock resistance, it appears that laminated stock is not deficient in this property as compared to solid.

From a consideration of all strength properties, the data indicate that with wood of the same specific gravity laminated and solid stock are, in general, comparable in strength properties.

Laminated Beams with Sloping Grain

The relation of strength values of laminated beams to slope of grain is shown by table 3. Since, as has been previously pointed out, the orientation of laminations does not materially affect the strength of beams, values for beams with laminations horizontal and those for beams with laminations vertical were averaged, and these averages used in computing the ratios shown in table 3,

Some beams with laminations vertical were tested with the load applied at the center and some with the loads at the third points. Since a previous study[4] has shown that the effect of slope of grain on work values is considerably more pronounced with two-point loading, these values are shown separately for the two types of loading. Properties other than work apparently do not differ significantly between center and third-point loadings and, consequently, averages from the two types of loading were used in computing the ratios in table 3.

The ratios in table 3 show that a slope of grain of 1 in 15 slightly lowers most properties, and may considerably decrease the shock resistance, as indicated by work values obtained by third-point loading tests in static bending. Work values from center loading tests in static bending show only small reductions caused by a slope of grain of 1 in 15. Impact bending tests and toughness tests with load applied at the center show even less effect. Apparently the shock resistance of a specimen with a single load at the center is not greatly affected by a slope of 1 in 15, but work values for specimens tested in two-point loading, which more nearly simulates uniform loading, are considerably. reduced. Most of the strength values for specimens with a slope of grain of 1 in 15 crossed in adjacent plies average slightly higher than those for grain of this slope in the same direction in all plies.

The comparisons for material with a slope of grain of 1 in 10 are similar to those for the slope of 1 in 15, hut the deficiencies as compared to straight-grained material are larger. The reduction in work values in static bending with load applied at the third points, is very large. An appreciable reduction is also shown in work values in center loading tests in static bending, drop in impact bending, and toughness values. As for a slope of 1 in 15, the strength properties for material with a slope of grain of 1 in 10 crossed in adjacent plies is somewhat higher in practically all strength properties than when the slope of grain is parallel in all plies.

The suggestion is frequently advanced that in laminating members from comparatively thin material interlacing of fiber direction will compensate for the effect of grain deviations and that consequently restrictions on slope of grain may be made less stringent than for single piece members. It has been further suggested that by such interlacing material superior to that having thoroughly straight grain will result. (Superiority in such respects as resistance to shear, splitting, or cleavage along planes at an angle to glued surfaces is obvious.)

The present tests indicate much the same effects from noninterlaced grain as previously found for the same slopes in single piece beams [4]. On the other hand, some improvement is, in general, indicated for systematic crossing or interlacing. No reason for the indicated superiority in stress at proportional limit in flexure is apparent. The betterment shown in modulus Of elasticity is perhaps due partially to reduction in the contribution of shearing distortion to deflections. With grain slopes crossed in adjacent

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[4] Unpublished report, "The Influence of Spiral and Diagonal Grain on the Mechanical Properties of Sitka Spruce and Douglas-Fir," by T. R. C. Wilson and R. F. Luxford, dated August 27, 1919.

laminations continuity of tension failures is inhibited, and this, no doubt, is the reason for the definite betterment in work values and probably for the indicated superiority in modulus of rupture. In general, the advantage of crossing the grain in adjacent plies is more with respect to resistance to shear and to splitting than with respect to longitudinal stress.

Shear Parallel to the Grain

Tests for shear were made only on straight-grained material. Two specimens were cut from each straight-grained static and impact bending specimen after test. One was tested with the shear plane parallel to but between the glue lines and the other with the shear plane across the glue lines. The specimens with the shear plane "radial" or across the glue lines averaged slightly higher in shear than specimens with the shear plane "tangential" or parallel to the glue line and annual rings (table 3).

There was practically no failure in the glue lines, and the gluing of the laminations is not thought to be a factor. Usually the difference in shear with plane of failure "radial" or "tangential" is not large, and previous tests on solid Sitka spruce have shown a slight advantage when the shearing plane was tangential. As shown in table 2, the average value for shear of laminated stock is practically the same as for solid stock previously tested.

Scarf Joints in Laminations of Laminated Beams

Information on the effect of scarf joints in veneer in laminated glued beams is given in table 4. Only alternate plies contained scarf joints, but one outside ply of full 1/7-inch thickness contained a scarf joint, and, in the bending tests with laminations horizontal, the beam was placed with this lamination at the tension face where it would have the largest effect.

Laminated beams with scarf joints in alternate plies were inferior in all strength properties studied as compared to matched beams without scarf joints. As usual, the greater percentage reductions were in those properties measuring shock resistance (work values in static bending and height of drop in impact bending). The specimens with horizontal laminations were lower in most strength properties as compared to unjointed matched specimens than were those with vertical laminations. Since only alternate plies had scarf joints, it follows that in beams in which the laminations were vertical, scarf joints affected only half the width of the tension face, whereas in beams with laminations horizontal, the scarf joints extended entirely across this face. Since the tensile strength is ordinarily lowered by a scarf joint, the lower efficiency of beams with the scarf joint extending entirely across the tension face is to be expected.

Preliminary to the tests on laminated glued beams with scarf joints, tension-parallel-to-grain tests were made on specimens cut from several sheets of veneer with scarf joints and on end-matched controls. (The specimens were

16 inches long, 1/7-inch thick, 1-1/2 inches wide for a distance of 3 inches from either end, then gradually reduced in width along a curvature of 30-inch radius to a l-inch width at a central portion). The results of these tests showed an average efficiency of the scarf joints of 55 percent compared to controls with failure of the specimens with scarf joints being consistently at the scarf. It is believed that an improvement can be made in the gluing technique used in these scarf joints and, if so, the efficiencies would, of course, be raised.

Conclusions

Following are the conclusions drawn from the test results:

(1) Laminated spruce beams with 1/7-inch laminations average about 7 to 8 percent higher in weight than solid wood because of compression in pressing and the weight of the glue.

(2) Laminated beams and solid beams of the same weight, not considering the weight of the glue, have, in general, equal strength properties.

(3) Vertically-laminated and horizontally-laminated beams. are comparable in most strength properties. When the laminations are horizontal the beams are somewhat more resistant to shock than when the laminations are vertical.

(4) A slope of grain of 1 in 15 lowers most strength properties only slightly, but decreases shock resistance very considerably, The deficiency is somewhat less when the slope of grain in adjacent plies is crossed.

A slope of grain of 1 in 10 appreciably reduces most strength properties. The reduction in shock resistance is especially pronounced. Similar to the finding for a slope of 1 in 15 the reductions in strength for a slope of 1 in 10 are somewhat less when the grain in adjacent plies is crossed.

(5) Scarf joints with a slope of 1 in 15 in laminated beams when at the point of high stress caused a reduction in all strength properties studied. The reduction was especially large in tnose properties measuring shock resistance. Improvements that can undoubtedly be made in the technique of preparing scarf joints would lessen these deficiencies.

Table 1.--Sitka spruce beams with laminations horizontal compared to beams with laminations vertical

Direction of grain	Orientation of laminations	Static bending: Tests	Static bending: Moisture content	Static bending: Specific gravity[1] including glue	Static bending: Specific gravity[1] excluding glue	Static bending: Stress at proportional limit	Static bending: Modulus of rupture	Static bending: Modulus of elasticity	Static bending: Work: Proportional limit	Static bending: Work: Maximum load	Static bending: Work: Total	Impact bending: Tests	Impact bending: Moisture content	Impact bending: Specific gravity[1] including glue	Impact bending: Specific gravity[1] excluding glue	Impact bending: Height of drop causing complete failure (50-pound hammer)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)
		Number	Percent			Lb. per sq. in.	Lb. per sq. in.	1000 lb. per sq. in.	In.-lb. per cu. in.	In.-lb. per cu. in.	In.-lb. per cu. in.	Number	Percent			Inches
Straight	Vertical	8	10.3	0.436	0.407	6720	11580	1763	1.43	8.39	11.16	10	10.3	0.437	0.408	24.2
	Horizontal	6	10.5	.434	.404	6160	11480	1769	1.22	8.28	13.66	10	10.3	.434	.405	26.6
1:15 Parallel	Vertical	8	10.5	.435	.405	6350	10710	1661	1.36	6.61	12.01	10	10.4	.436	.407	25.8
	Horizontal	6	10.5	.435	.405	6240	10920	1646	1.33	7.89	12.42	10	10.3	.434	.405	26.0
1:15 Crossed	Vertical	8	9.8	.446	.415	6400	11340	1604	1.27	6.60	10.33	10	10.2	.441	.412	23.2
	Horizontal	6	10.1	.444	.414	6690	11730	1764	1.42	9.09	12.51	10	10.3	.431	.401	26.4
Straight	Vertical	7	9.6	.436	.408	6620	11850	1774	1.38	8.53	11.76	10	10.0	.437	.408	24.0
	Horizontal	5	9.2	.441	.412	6530	11970	1770	1.35	8.91	12.91	10	9.9	.437	.408	24.8
1:10 Parallel	Vertical	7	9.4	.436	.407	6230	10070	1529	1.42	5.19	11.04	10	10.0	.435	.406	21.6
	Horizontal	5	9.2	.440	.411	6190	11260	1567	1.36	7.25	11.29	10	10.0	.434	.405	23.2
1:10 Crossed	Vertical	7	10.5	.443	.413	6780	11080	1765	1.46	6.28	10.30	10	10.5	.440	.410	21.4
	Horizontal	5	10.5	.445	.415	6840	10790	1702	1.53	6.12	12.14	10	10.3	.432	.403	23.6
Ratios of horizontal to vertical -- in percent																
Straight	....	....	102	100	99	92	99	100	85	99	122	....	100	99	99	110
1:15 Parallel	....	....	100	100	100	98	102	99	98	119	103	....	99	100	100	101
1:15 Crossed	....	....	103	100	100	105	103	98	112	138	121	....	101	98	97	114
Straight	....	....	96	101	101	99	101	100	98	104	110	....	99	100	100	103
1:10 Parallel	....	....	98	101	101	99	112	102	96	140	102	....	100	100	100	107
1:10 Crossed	....	....	100	100	100	101	97	96	105	98	118	....	98	98	98	110

[1] Based on oven-dry weight and volume at test.

Z M 54470 F

Table 2.—Laminated Sitka spruce compared to solid material

Kind of beams	Static bending: Tests	Static bending: Moisture content	Static bending: Specific gravity[1]: Including glue	Static bending: Specific gravity[1]: Excluding glue	Static bending: Stress at proportional limit	Static bending: Modulus of rupture	Static bending: Modulus of elasticity	Static bending: Work: Proportional limit	Static bending: Work: Maximum load	Static bending: Work: Total	Impact bending: Tests	Impact bending: Moisture content	Impact bending: Specific gravity[1]: Including glue	Impact bending: Specific gravity[1]: Excluding glue	Impact bending: Height of drop causing complete failure (50-pound hammer)	Compression parallel to grain: Tests	Compression parallel to grain: Moisture content	Compression parallel to grain: Specific gravity[1]: Including glue	Compression parallel to grain: Specific gravity[1]: Excluding glue	Compression parallel to grain: Stress at proportional limit	Compression parallel to grain: Maximum crushing strength	Compression parallel to grain: Modulus of elasticity
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)
	Number	Percent			Lb. per sq. in.	Lb. per sq. in.	1,000 lb. per sq. in.	In.-lb. per cu. in.	In.-lb. per cu. in.	In.-lb. per cu. in.	Number	Percent			Inches	Number	Percent			Lb. per sq. in.	Lb. per sq. in.	1,000 lb. per sq. in.
Laminated[3]	[4]40	10.0	0.436	0.406	6,620	11,500	1,788	1.36	8.52	12.24	40	10.2	0.436	0.408	24.9	37	10.0	0.436	0.407	4,520	6,590	2,022
Solid[5]	......	12.0	....	.403	6,700	10,200	1,570	1.62	9.4	17.2	......	12.0	....	....	25.0	......	12.0	....	.398	4,780	5,610	....
Solid[5, 6]	......	10.0	....	....	7,340	11,000	1,620	1.88	9.9	17.0	......	10.0	....	....	25.0	......	10.0	....	....	5,260	6,180	....
										Ratios of laminated to solid -- in percent												
....	......	100	....	101	90	104	110	72	86	72	......	102	....	....	100	......	100	....	102	86	106	....

Kind of beams	Toughness: Radial: Tests	Toughness: Radial: Moisture content	Toughness: Radial: Specific gravity[1]: Including glue	Toughness: Radial: Specific gravity[1]: Excluding glue	Toughness: Radial: Toughness	Toughness: Tangential: Tests	Toughness: Tangential: Moisture content	Toughness: Tangential: Specific gravity[1]: Including glue	Toughness: Tangential: Specific gravity[1]: Excluding glue	Toughness: Tangential: Toughness	Shear parallel to grain: Tests	Shear parallel to grain: Moisture content	Shear parallel to grain: Maximum shearing strength
	Face to which load is applied												
(1)	(24)	(25)	(26)	(27)	(28)	(29)	(30)	(31)	(32)	(33)	(34)	(35)	(36)
	Number	Percent			In.-lb. per specimen[2]	Number	Percent			In.-lb. per specimen[2]	Number	Percent	Lb. per sq. in.
Laminated[3]	80	10.0	0.437	0.408	86.8	80	10.0	0.436	0.406	154.5	152	10.7	1,200
Solid[5]	......	11.5	....	.383	73.5	......	11.5	....	.383	113.4	......	12.0	1,150
Solid[5, 6]	......	11.5	....	.408	[7]86.0	......	11.5	....	.406	[7]131.0	......	10.7	1,190
					Ratios of laminated to solid -- in percent								
....	......	87	....	100	101	......	87	....	100	118	......	......	101

[1]Based on oven-dry weight and volume of test.

[2]Specimens 5/8 by 5/8 by 10 inches -- tested over an 8-inch span -- center loading.

[3]Averages include values from static bending and impact bending specimens irrespective of whether laminations were horizontal or vertical.

[4]Of the 40 static bending specimens, 26 were tested under center loading and 14 under third point loading. Averages for work properties include only values from specimens tested under center loading.

[5]Data from U. S. Dept. Agr. Tech. Bul. 479, "Strength and Related Properties of Woods Grown in the United States," except toughness values which were taken from unpublished report, "Toughness Tests of Airplane Woods (Sitka Spruce and White Ash)."

[6]Adjusted to correspond to the moisture content of laminated material as shown in columns 3, 13, 18, and 35.

[7]Adjusted for specific gravity assuming toughness varies as 2-1/2 power of specific gravity. No reliable method of adjusting for moisture differences is available.

Z M 56669 F

Table 3.--Sitka spruce beams with slopes of grain of 1 in 15 and 1 in 10 in laminations compared to beams with straight grained laminations

Direction of grain	Orientation of laminations (static and impact bending)	Method of loading (static and impact bending)	Tests	Moisture content	Specific gravity[1] including glue	Specific gravity[1] excluding glue	Static bending: Stress at proportional limit	Static bending: Modulus of rupture	Static bending: Modulus of elasticity	Work (center load tests): Proportional limit	Work (center load tests): Maximum load	Work (center load tests): Total	Work (1/3 point load tests): Proportional limit	Work (1/3 point load tests): Maximum load	Work (1/3 point load tests): Total
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
			Number	Percent			Lb. per sq. in.	Lb. per sq. in.	1000 lb. per sq. in.	In.-lb. per cu. in.	In.-lb. per cu. in.	In.-lb. per cu. in.	In.-lb. per cu. in.	In.-lb. per cu. in.	In.-lb. per cu. in.
Straight	Vertical	Center	8	10.3	0.436	0.407	6720	11580	1763	1.43	8.39	11.16			
	Vertical	1/3 point	6	10.3	.440	.411	6860	11480	1861				2.36	14.16	21.49
	Horizontal	Center	6	10.5	.434	.404	6160	11480	1769	1.22	8.28	13.66			
Average				10.4	.437	.407	6590	11520	1794	1.34	8.34	12.23			
1:15 Parallel	Vertical	Center	8	10.5	.435	.405	6350	10710	1661	1.36	6.61	12.01			
	Vertical	1/3 point	6	10.1	.432	.404	6440	10280	1686				2.28	9.57	12.97
	Horizontal	Center	6	10.5	.435	.405	6240	10920	1646	1.33	7.89	12.42			
Average				10.4	.434	.405	6340	10640	1664	1.35	7.16	12.19			
1:15 Crossed	Vertical	Center	8	9.8	.446	.415	6400	11340	1804	1.27	6.60	10.33			
	Vertical	1/3 point	6	11.0	.442	.412	6360	10740	1815				2.12	10.53	15.31
	Horizontal	Center	6	10.1	.444	.414	6690	11730	1764	1.42	9.09	12.51			
Average				10.3	.444	.414	6480	11280	1795	1.33	7.67	11.26			
Straight	Vertical	Center	7	9.6	.436	.408	6620	11850	1774	1.38	8.53	11.76			
	Vertical	1/3 point	8	10.1	.428	.399	6740	10870	1796				2.37	12.44	19.58
	Horizontal	Center	5	9.2	.441	.412	6530	11970	1770	1.35	8.91	12.91			
Average				9.7	.434	.405	6650	11490	1782	1.37	8.69	12.24			
1:10 Parallel	Vertical	Center	7	9.4	.436	.407	6230	10070	1529	1.42	5.19	11.04			
	Vertical	1/3 point	8	10.2	.432	.403	6210	9170	1599				2.24	7.05	10.98
	Horizontal	Center	5	9.2	.440	.411	6190	11260	1567	1.36	7.25	11.29			
Average				9.7	.435	.406	6210	10000	1567	1.40	6.05	11.14			
1:10 Crossed	Vertical	Center	7	10.5	.443	.413	6780	11080	1765	1.46	6.28	10.30			
	Vertical	1/3 point	8	10.8	.428	.400	6400	10120	1718				2.22	9.92	14.00
	Horizontal	Center	5	10.5	.445	.415	6840	10790	1702	1.53	6.12	12.14			
Average				10.6	.438	.408	6640	10620	1730	1.49	6.21	11.07			
Ratios of sloping to straight -- in percent															
1:15 Parallel				100	99	100	96	92	93	101	86	100	97	68	60
1:15 Crossed				99	102	102	98	98	100	99	92	92	90	74	71
1:10 Parallel				100	100	100	93	87	88	102	70	91	95	57	56
1:10 Crossed				109	101	101	100	92	97	109	71	90	94	80	72

[1]Based on oven-dry weight and volume at test.

[2]Specimens 5/8 by 5/8 by 10 inches -- tested over an 8-inch span -- center loading.

(Sheet 1 of 3)

Z M 54472 F

Table 3.--Sitka spruce beams with slopes of grain of 1 in 15 and 1 in 10 in laminations compared to beams with straight grained laminations (continued)

Direction of grain	Orientation of laminations (static and impact bending)	Method of loading (static and impact bending)	Impact bending: Tests	Impact bending: Moisture content	Impact bending: Specific gravity[1] including glue	Impact bending: Specific gravity[1] excluding glue	Impact bending: Height of drop causing complete failure (50-pound hammer)	Toughness, Radial: Tests	Radial: Moisture content	Radial: Specific gravity[1] including glue	Radial: Specific gravity[1] excluding glue	Radial: Toughness	Tangential: Tests	Tangential: Moisture content	Tangential: Specific gravity[1] including glue	Tangential: Specific gravity[1] excluding glue	Tangential: Toughness
(1)	(2)	(3)	(17)	(18)	(19)	(20)	(21)	(22)	(23)	(24)	(25)	(26)	(27)	(28)	(29)	(30)	(31)
			Number	Percent			Inches	Number	Percent			In.-lbs. per specimen[2]	Number	Percent			In.-lbs. per specimen[2]
Straight	Vertical	Center	10	10.3	0.437	0.408	24.2	18	9.9	0.440	0.409	86.1	18	9.9	0.439	0.408	155.5
	Vertical	1/3 point						6	10.2	.445	.415	95.5	6	10.0	.445	.413	157.9
	Horizontal	Center	10	10.3	.434	.405	26.6	16	10.3	.438	.409	85.7	16	10.1	.440	.411	154.7
Average				10.3	.436	.407	25.4	40	10.1	.440	.410	87.4		10.0	.440	.409	155.5
1:15 Parallel	Vertical	Center	10	10.4	.436	.407	25.8	18	9.9	.438	.408	93.3	18	9.8	.438	.407	158.0
	Vertical	1/3 point						6	10.2	.435	.406	95.8	6	9.9	.436	.408	143.3
	Horizontal	Center	10	10.3	.434	.405	26.0	16	10.0	.436	.407	92.4	16	9.9	.439	.410	154.8
Average				10.4	.435	.406	25.9		10.0	.437	.407	93.3		9.9	.438	.408	154.5
1:15 Crossed	Vertical	Center	10	10.2	.441	.412	23.2	18	10.0	.446	.415	82.6	18	10.1	.447	.416	145.6
	Vertical	1/3 point						6	10.6	.446	.416	89.1	6	10.2	.444	.413	158.9
	Horizontal	Center	10	10.3	.431	.401	26.4	16	10.1	.448	.418	85.5	16	9.9	.450	.421	155.8
Average				10.3	.436	.407	24.8		10.1	.447	.417	84.7		10.0	.448	.418	151.7
Straight	Vertical	Center	10	10.0	.437	.408	24.0	18	9.7	.436	.408	87.9	18	9.9	.435	.405	162.9
	Vertical	1/3 point						6	10.4	.427	.398	88.5	6	10.6	.424	.396	129.4
	Horizontal	Center	10	9.9	.437	.408	24.8	16	10.1	.435	.406	83.4	16	10.0	.433	.404	151.6
Average				10.0	.437	.408	24.4		10.0	.434	.406	86.2		10.0	.433	.403	153.4
1:10 Parallel	Vertical	Center	10	10.0	.435	.406	21.6	18	9.5	.439	.409	84.8	18	9.4	.440	.411	133.2
	Vertical	1/3 point						6	10.0	.429	.400	80.2	6	10.0	.428	.400	128.2
	Horizontal	Center	10	10.0	.434	.405	23.2	16	9.9	.440	.412	80.9	16	9.9	.443	.414	124.2
Average				10.0	.435	.406	22.4		9.7	.438	.409	82.6		9.7	.439	.411	128.9
1:10 Crossed	Vertical	Center	10	10.5	.440	.410	21.4	18	10.4	.438	.408	84.9	18	10.2	.442	.411	140.3
	Vertical	1/3 point						6	10.0	.432	.404	85.2	6	10.0	.431	.403	145.4
	Horizontal	Center	10	10.3	.432	.403	23.6	16	9.9	.437	.408	81.0	16	10.0	.437	.408	141.2
Average				10.4	.436	.407	22.5		10.1	.437	.408	83.4		10.1	.438	.409	141.4
Ratios of sloping to straight -- in percent																	
1:15 Parallel				101	100	100	102		99	99	99	107		99	100	100	99
1:15 Crossed				100	100	100	98		100	102	102	97		100	102	102	98
1:10 Parallel				100	100	100	92		97	101	101	96		97	101	102	84
1:10 Crossed				104	100	100	92		101	101	100	97		101	101	102	92

(Sheet 2 of 3)

[1] Based on oven-dry weight and volume at test.

[2] Specimens 5/8 by 5/8 by 10 inches -- tested over an 8-inch span -- center loading.

Z M 54944 F

Table 3.--Sitka spruce beams with slopes of grain of 1 in 15 and 1 in 10 in laminations compared to beams with straight grained laminations (continued)

Direction of grain	Orientation of laminations (static and impact bending)	Method of loading (static and impact bending)	Compression parallel to grain: Tests	Compression parallel to grain: Moisture content	Compression parallel to grain: Specific gravity[1] including glue	Compression parallel to grain: Specific gravity[1] excluding glue	Compression parallel to grain: Stress at proportional limit	Compression parallel to grain: Maximum crushing strength	Compression parallel to grain: Modulus of elasticity	Shear parallel to grain, Radial: Tests	Shear parallel to grain, Radial: Moisture content	Shear parallel to grain, Radial: Maximum shearing strength	Shear parallel to grain, Tangential: Tests	Shear parallel to grain, Tangential: Moisture content	Shear parallel to grain, Tangential: Maximum shearing strength
(1)	(2)	(3)	(32)	(33)	(34)	(35)	(36)	(37)	(38)	(39)	(40)	(41)	(42)	(43)	(44)
			Number	Percent			Lb. per sq. in.	Lb. per sq. in.	1000 lb. per sq. in.	Number	Percent	Lb. per sq. in.	Number	Percent	Lb. per sq. in.
Straight	Vertical	Center	9	10.2	0.439	0.410	4820	6670	1981	18	10.3	1225	18	10.5	1132
	Vertical	1/3 point	3	10.8	.434	.405	4340	6420	2088	6	10.3	1232	6	10.6	1149
	Horizontal	Center	6	9.6	.438	.408	4490	6700	2101	15	10.4	1236	15	10.9	1144
Average	...	...	...	10.1	.438	.409	4630	6640	2039	...	10.3	1230	...	10.7	1140
1:15 Parallel	Vertical	Center	9	10.3	.438	.409	4280	6440	1885	...	...	...	...	...	...
	Vertical	1/3 point	3	11.1	.429	.400	4110	6300	1981	...	...	...	...	...	...
	Horizontal	Center	7	10.6	.431	.401	4410	6270	1998	...	...	...	...	...	...
Average	...	...	...	10.5	.434	.405	4300	6360	1942	...	...	...	...	...	...
1:15 Crossed	Vertical	Center	9	10.4	.444	.414	4910	6660	1960	...	...	...	...	...	...
	Vertical	1/3 point	3	10.9	.440	.411	4540	6200	1980	...	...	...	...	...	...
	Horizontal	Center	8	9.3	.440	.409	4880	6730	1964	...	...	...	...	...	...
Average	...	...	...	10.2	.442	.412	4840	6620	1965	...	...	...	...	...	...
Straight	Vertical	Center	8	9.8	.437	.408	4500	6600	1988	17	10.7	1238	17	10.8	1192
	Vertical	1/3 point	5	10.3	.431	.402	4440	6320	2071	8	10.9	1244	8	11.0	1159
	Horizontal	Center	6	9.7	.434	.405	4280	6630	1977	12	10.8	1266	12	10.9	1214
Average	...	...	...	9.9	.435	.405	4420	6540	2006	...	10.8	1250	...	10.9	1190
1:10 Parallel	Vertical	Center	8	10.0	.437	.409	4520	6210	1765	...	...	...	...	...	...
	Vertical	1/3 point	5	10.5	.427	.399	4100	5820	1835	...	...	...	...	...	...
	Horizontal	Center	5	9.7	.433	.403	4240	6220	1778	...	...	...	...	...	...
Average	...	...	...	10.1	.433	.406	4330	6100	1788	...	...	...	...	...	...
1:10 Crossed	Vertical	Center	8	10.5	.439	.410	4300	6360	1976	...	...	...	...	...	...
	Vertical	1/3 point	5	10.9	.434	.408	3950	6320	2034	...	...	...	...	...	...
	Horizontal	Center	7	10.3	.436	.405	4300	6580	1920	...	...	...	...	...	...
Average	...	...	...	10.5	.437	.407	4210	6430	1971	...	...	...	...	...	...
							Ratios of sloping to straight -- in percent								
1:15 Parallel	...	...	...	104	99	99	93	96	95	...	...	...	...	...	...
1:15 Crossed	...	...	...	101	101	101	105	100	96	...	...	...	...	...	...
1:10 Parallel	...	...	...	102	100	100	98	93	89	...	...	...	...	...	...
1:10 Crossed	...	...	...	106	100	100	95	98	98	...	...	...	...	...	...

[1]Based on oven-dry weight and volume of test.

(Sheet 3 of 3)

Table 4.--Sitka spruce beams with scarf joints (slope 1:15) in alternate laminations compared to beams with all laminations continuous.

Type of specimen	Orientation of laminations	Static bending[1]										Impact bending[1]				
		Tests	Moisture content	Specific gravity[2]		Stress at proportional limit	Modulus of rupture	Modulus of elasticity	Work			Tests	Moisture content	Specific gravity[2]		Height of drop causing complete failure (50-pound hammer)
				Including glue	Excluding glue				Proportional limit	Maximum load	Total			Including glue	Excluding glue	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)
		Number	Percent			Lb. per sq. in.	Lb. per sq. in.	1000 lb. per sq. in.	In.- lb. per cu. in.	In.-lb. per cu. in.	In.-lb per cu. in	Number	Percent			Inches
With scarf joints	Vertical	5	10.9	0.422	0.393	6160	10380	1745	1.21	5.71	7.61	5	11.0	0.422	0.392	20.0
Without scarf joints (Matching one end[3])	Vertical	5	11.3	.421	.392	6270	11120	1771	1.24	7.93	11.13	5	10.9	.428	.399	24.8
Without scarf joints (Matching other end)	Vertical	5	11.2	.420	.391	6560	11000	1775	1.35	7.49	10.66	5	10.7	.424	.395	24.4
Average..................	....	10	11.2	.420	.392	6420	11060	1773	1.30	7.71	10.90	10	10.8	.426	.397	24.6
With scarf joints	Horizontal	5	10.7	.424	.395	5940	8910	1738	1.14	4.05	7.95	5	10.6	.424	.395	20.4
Without scarf joints (Matching one end[3])	Horizontal	5	11.1	.425	.396	6170	11040	1793	1.19	7.31	13.01	5	10.9	.426	.397	27.6
Without scarf joints (Matching other end)	Horizontal	5	10.9	.422	.393	6350	11240	1762	1.27	8.61	12.27	5	10.9	.423	.394	26.4
Average..................	....	10	11.0	.424	.394	6260	11140	1778	1.23	7.96	12.64	10	10.9	.424	.396	27.0

Ratios of jointed to continuous -- in percent

....	Vertical	....	97	100	100	96	94	98	93	74	70	....	102	99	99	81
....	Horizontal	....	97	100	100	95	80	98	93	51	63	....	97	100	100	76

[1] Failures at scarf joints were very largely in the wood.
[2] Based on oven-dry weight and volume at test.
[3] A control specimen adjacent to each end of each beam containing scarf joints was tested.

Z M 54474 F

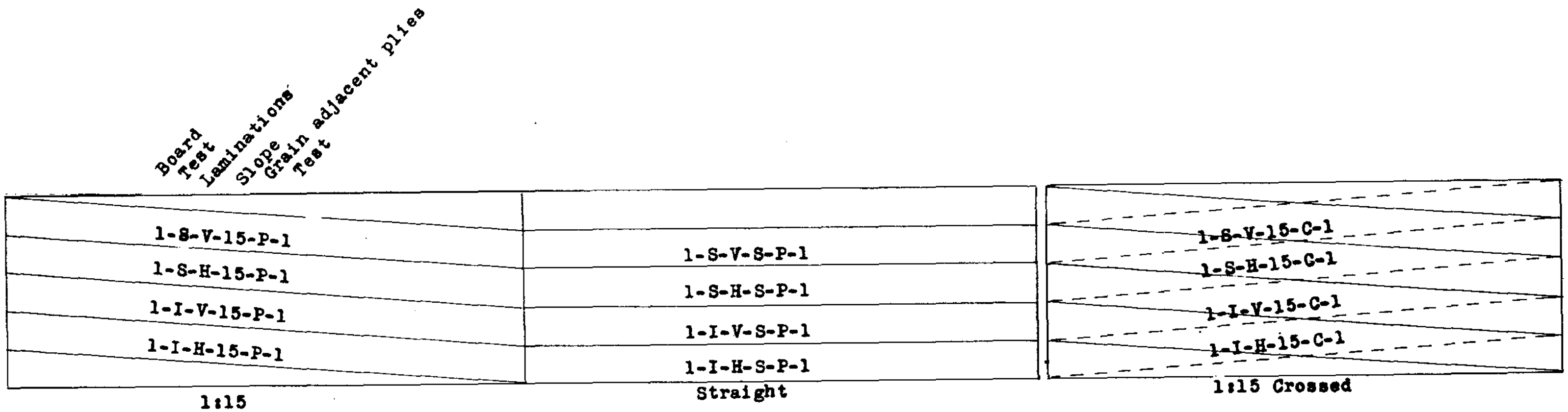

Fig. 1.

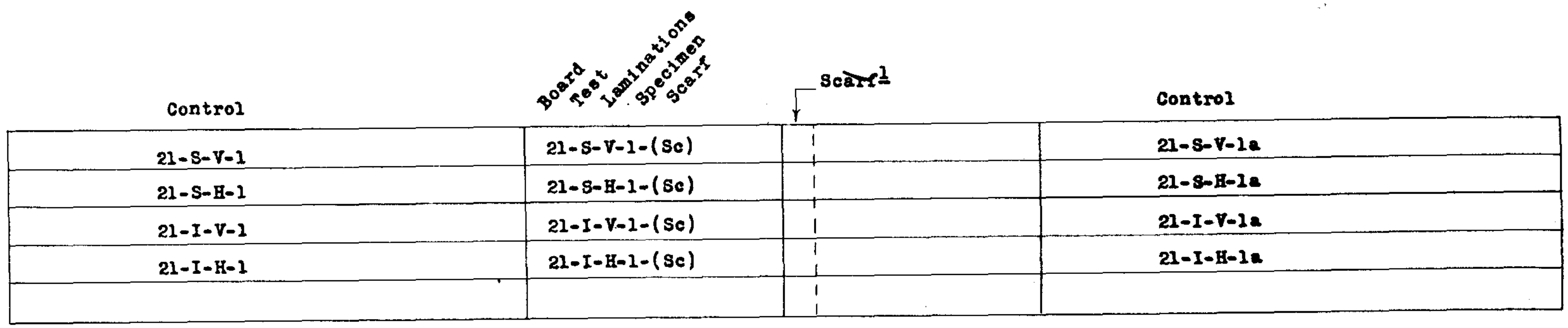

Fig. 2.

CUTTING AND MARKING DIAGRAMS

[1] Alternate plies. All face plies to contain scarf joints.

Z M 54475 F