A COMPARISON OF SHEARING STRENGTHS OF GLUED JOINTS AT VARIOUS GRAIN DIRECTIONS AS DETERMINED BY FOUR METHODS OF TEST

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A COMPARISON OF SHEARING STRENGTHS OF GLUED JOINTS AT VARIOUS GRAIN DIRECTIONS AS DETERMINED BY FOUR METHODS OF TEST[1]

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Summary

In the assembly of wood aircraft, glued joints are frequently employed wherein the grain directions of the members are at an angle. Although the shearing strength perpendicular to the grain, on the basis of available data, has been taken as one-third of that parallel to the grain, information has been lacking on the strength of joints involving grain directions intermediate between 0° and 90°.

This report covers the results of tests of the shearing strength of approximately 4,300 glued specimens in which the grain direction of one member was varied with respect to the direction of loading. In general, this member was a 1/8-inch veneer incorporated in the specimen at the shearing zone. Six softwoods and three hardwoods were investigated, of which two of each classification were subjected to the following four methods of test each modified to adapt it to the purpose:

1. Standard shear test for wood, according to the American Society for Testing Materials, Serial Designation D143-27.

2. Block shear glue joint test as used by the Forest Products Laboratory and designated as "Block Shear Strength Test" in Army-Navy Specification AN-G-8.

3. Double shear test.

4. Plywood glue shear test, Specification AN-NN-P-511b, also designated as "Plywood Shear Strength Test" in Army-Navy Specification AN-G-8.

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[1]This is one of a series of progress reports prepared by the Forest Products Laboratory relating to the use of wood in aircraft issued in cooperation with the Army-Navy-Civil Committee on Aircraft Design Criteria. Original report published in 1945.

The influence of method of cutting was investigated by subjecting rotary-cut, quarter-sliced and quarter-sawed Douglas-fir and Sitka spruce to the first two of these methods of test. Results of tests were analyzed by comparing the shearing strengths at various grain directions with the 0° value for each series of tests and by comparing the results obtained by different methods of testing.

No definite or consistent relationship was found to exist among the four test methods considered. The effects of such factors as classification of wood, species, and method of cutting differed in their individual effects on the results obtained by each test method. A consistent relationship was found to exist, however, between the shearing strengths parallel and perpendicular to the grain and those at intermediate angles, and the results show that the Hankinson formula[2] can be used to determine values for intermediate angles when the values at 0° and 90° are known.

The average value for the shearing strength perpendicular to the grain was at least one-third of that parallel to the grain for all species when planed from solid wood or when cut in accordance with Specification AN-NN-P-511b. The average value for hardwoods was at least one-half.

The shearing strength parallel to the grain can be assumed to apply without correction to glued joints when the angle of grain between members does not exceed 15°.

Introduction

The widespread use of glued fastenings in modern wood aircraft construction created a demand for more complete design data. On the basis of available data, the shearing strength of a glued fastening with the grain of one face parallel and the other perpendicular to the direction of loading has been taken as one-third of that for one in which the grain of both faces is parallel. Information has been lacking as to the strength of joints involving grain directions itermediate between 0° and 90°.

The purpose of this investigation was to compare the shearing strengths of glued fastenings determined by different laboratory methods of testing, and to evaluate the shearing strengths of joints in which the grain direction of one face is parallel to the direction of loading and the other is at angles varying from 0° to 90° with the direction of loading.

Tests of small, secondary glue joints, designed to simulate those used in aircraft construction, are feasible, but are difficult to perform. Such tests are not included in this study but form the subject of a concurrent investigation.

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[2] A formula derived empirically by R. L. Hankinson from tests made for the Army Air Service on the bearing strength of wood at various angles with the grain. It was checked by the Forest Products Laboratory in tests on aircraft bolts bearing at various angles with the grain.

Description of Material

The species, specific gravity, and manner of cutting of material for each series of tests and the grain angles and methods of test used for each series were as follows:

Material	Specific gravity, oven dry based on volume at 12 percent moisture content
Test[3] No. 4 at grain angles of 0°, 15°, 22-1/2°, 30°, 45°, 60°, 67-1/2°, 75°, 90°	
Plain-sawed Sitka spruce	0.36
Plain-sawed Douglas-fir	.49
Quarter-sawed sweetgum	.55
Test[3] Nos. 1, 2, 3, 4 at grain angles of 0°, 15°, 30°, 45°, 60°, 75°, 90°	
Rotary-cut Sitka spruce	0.34
Rotary-cut Douglas-fir	.44
Rotary-cut yellow-poplar	.46
Rotary-cut sweetgum	.58
Test[3] Nos. 1 and 2 at grain angles of 0°, 22-1/2°, 45°, 67-1/2°, 90°	
Quarter-sawed Sitka spruce	0.37
Quarter-sliced Sitka spruce	.41
Quarter-sawed Douglas-fir	.45
Quarter-sliced Douglas-fir	.41
Test[3] No. 1 at grain angles of 0°, 22-1/2°, 45°, 67-1/2°, 90°	
Rotary-cut noble fir	0.37
Rotary-cut sugar pine	.33
Rotary-cut yellow birch, Series A	.58
Rotary-cut yellow birch, Series B	.58
Rotary-cut yellow birch, Series C	.61
Test[3] No. 1 at grain angles of 0°, 30°, 60°, 90°	
Rotary-cut Port Orford white-cedar	0.44
Test[3] No. 1 at grain angles of 0°, 45°, 90°	
Rotary-cut yellow birch, Series D	0.59
Rotary-cut Western hemlock	.39

[3] Later described under "Methods of Testing."

Quarter-sliced and rotary-cut veneers were of 1/8-inch nominal thickness for all species except sugar pine and Western hemlock which were 1/10-inch thick. For each series of tests, sheets of veneer were cut consecutively from the same log or flitch except for rejected sheets. The four sets of yellow birch specimens were from different logs.

Quarter-sawed Sitka spruce and quarter-sawed Douglas-fir were obtained from a single plank of each species. For the two methods of test to which these materials were subjected, parallel sheets 16 feet long were cut from the center of each plank, dressed to 1/8-inch thickness, and cut into three 64-inch lengths. Test pieces of 1/8-inch flat-sawed Sitka spruce and Douglas-fir were cut from random pieces of a single plank of each species. Quarter-sawed sweetgum was cut from boards matched for density.

Clear, straight-grained pieces were selected for specimens from these veneer sheets. Solid Douglas-fir, Sitka spruce, or sugar maple was used to build up block shear specimens to the required thickness. Four-ply yellow-poplar plywood 1/4-inch thick of balanced construction was manufactured from 1/16-inch rotary-cut veneer.

Except as noted in table 1 and on the appropriate charts, all wood was conditioned at 70° F. and 64 percent relative humidity for at least 4 days both before and after preparation of the specimens. Exception was made in only one case where the moisture content thus produced in the wood was thought to be too high to give best results when using phenol-formaldehyde film glue with a wood of high shearing strength.

Matching and Preparation of Specimens

The type of specimen for each of the four methods of test employed was adapted to the study of the shearing strength of glued joints at various grain angles by placing in the shearing zone a glued joint in which the grain of one interface was placed parallel to the direction of loading and the other at a predetermined angle between 0° and 90°. Three-ply construction was used for all specimens. Test pieces 1/8-inch thick and of various grain directions were glued between longitudinally-grained outer plies. Additional wood was glued to these plies as required to provide specimens of the desired thicknesses. Shear specimens employing compressive loading were used for three of the methods of test (figs. 1 through 3). Plywood glue shear specimens (fig. 4) were used for the fourth method of test, which employed tensile loading.

Preparation of Shear Specimens for Compressive Loading

Rectangular panels sufficiently large to yield eight test pieces were cut from each material. The panels of each material were prepared in sets comprising one of each desired grain direction from each of three sheets of veneer. For series of tests employing not more than five grain directions, the panels were taken with centers of gravity in line along the grain of each sheet. For series employing seven grain directions, however, it was necessary to stagger the panels, thus using three sheets of rotary-cut veneer, 26 inches wide, for each series. This procedure sometimes necessitated replacing defective pieces with others from succeeding sheets. Each set of panels (or pair of sets in double shear) provided the specimens for one method of test.

The panels of quarter-sawed Sitka spruce and quarter-sawed Douglas-fir were glued between face-matched solid pieces of the plank from which they were cut. The panels of rotary-cut or quarter-sliced materials were glued between longitudinally-grained pieces of the same size cut from remaining pieces of the same sheet or from additional sheets of the same veneer. These three-ply assemblies were then built up to specimen size with solid wood backing as follows:

Test Species	Backing species
Sitka spruce	Sitka spruce
Yellow-poplar	Sitka spruce
Western hemlock	Sitka spruce
Sugar pine	Sitka spruce
Port Orford white-cedar	Sitka spruce
Douglas-fir	Douglas-fir
Sweetgum	Douglas-fir
Noble fir	Douglas-fir
Yellow birch (3-grain angles)	Douglas-fir
Yellow birch (5-grain angles)	Sugar maple

After gluing, the assemblies for each series and each method of test were cut into individual specimens, and 20 for each grain direction were selected for test.

Preparation of Plywood Glue Shear Specimens

The plywood glue shear specimens of the first series were of flat-sawed Sitka spruce, flat-sawed Douglas-fir, and quarter-sawed sweetgum. For each species, one test piece of specimen size for each of nine grain directions was cut in longitudinal order from each of twenty, 4- by 24-inch sheets. The 20 test pieces thus obtained for each grain direction were glued between yellow-poplar plywood covers (fig. 4).

For the second series, a strip large enough for two plywood glue shear specimens was cut from one side of each of the three-ply panels of rotary-cut Sitka spruce, Douglas-fir, yellow-poplar, and sweetgum from which the other three types of shear specimens were to be obtained. Two additional plies of like material were glued to either side of this strip, and 20 specimens for each grain angle and each species were prepared from the assemblies thus produced.

Assembly Gluing

Wherever it was possible, a phenol-formaldehyde thermosetting resin film glue was used. In certain cases, noted in table 1, a urea-formaldehyde cold-setting resin glue was used for expediency. This glue was used also for the noncritical joints of built-up specimens. It was not intended, however, to compare the strengths of joints made with the different types of glue. The glues selected were intended to develop the full strength of the wood.

Methods of Testing

The various shear test methods employed, each modified to adopt it to the purpose, are as follows:

1. A.S.T.M. standard shear test for wood, Serial Designation D143-27.

2. Block shear glue joint test as used by the Forest Products Laboratory and designated as "Block Shear Strength Test" in Specification AN-G-8.

3. Double shear test.

4. Plywood glue shear test, Specification AN-NN-P-511b, (also designated as "Plywood Shear Strength Test" in Specification AN-G-8).

Specimens used in methods 1 and 2 were tested in the shearing tools illustrated in figures 5 and 6. In methods 1, 2, and 3, a compressive load was applied continuously throughout the test at a rate of head movement of 0.015 inch per minute. The specimens in test 4 were gripped in jaws of the type illustrated in figure 7. Tensile load was applied at a rate of approximately 700 pounds per minute.

In the A.S.T.M. method (No. 1), shearing takes place in a single plane, 2 inches wide and 2 inches deep, but the shearing edges of the tool are offset horizontally 1/8 inch, permitting selection of the weakest plane within the zone thus created. In the block shear glue joint test (No. 2), shearing takes place in a single plane, 2 inches wide and 1-1/2 inches deep. In this test, however, the shearing edges of the tool are in the same vertical plane, hence failure can take place only in or closely adjacent to this plane. In the double shear test (No. 3), shearing takes place in two symmetrical planes, 2 inches wide and 1-1/2 inches deep. As in the A.S.T.M. test, a 1/8-inch offset permits failure to occur in the weakest plane on each side. A small clamp was placed around the base of the double shear specimen to prevent the legs from spreading during test. Figure 8 illustrates this method of test.

Explanation of Tables and Charts

Results of each series of tests are listed in table 1. Each value listed represents the average shearing strength of 20 specimens, corrected to the average specific gravity of the species as given in U. S. Department of Agriculture Technical Bulletin No. 479. Since no relationship between specific gravity and shearing strength of wood for directions other than parallel to grain has been developed, a linear relationship was assumed in making these corrections.

The relationship between shearing strength and the angle of grain between faces of glued joints, as determined by the modified A.S.T.M. standard shear test for wood, with the grain of one face parallel to the direction of load, is shown on a separate graph for each of the nine species tested (figs. 9 and 10). Similar graphs are included for each of the four species tested under the block shear glue joint test (fig. 11); the double shear test (fig. 12); and the plywood glue shear test (fig. 13). the plotted values are those of table 1. These data consistently define curves that are similar for all series of tests. The shapes of these curves approximate that of the Hankinson empirical formula, which is used to determine the bearing strength of wood under bolts when the loads are applied at various angles to the grain, and is stated as follows:

$$N = \frac{PQ}{P \sin^2 \theta + Q \cos^2 \theta}$$

where

P = the strength when load is applied parallel to grain
Q = the strength when load is applied perpendicular to grain
N = the strength when load is applied at any angle, θ, with the grain.

On each of the graphs (figs. 9 through 13) the Hankinson curve best fitting the test data is shown.

A graphical summary of the test data is shown in figure 14. Series D of yellow birch, and unlike species glued to yellow-poplar, are not included. For each series of tests and for each method of test, the average shearing strength at each grain direction employed is plotted as a percentage of the average shearing strength parallel to the grain. The data for softwoods and for hardwoods are plotted on separate graphs. On each graph is shown a curve of the Hankinson formula using Q = 1/3 P for softwoods and 1/2 P for hardwoods.

A scholten nomograph (fig. 15) provides a graphical solution of the Hankinson formula for rapid determination of the shearing strength of glued joints at any angle when the values for 0° and 90° are known. This nomograph is similar to the one shown on page 117 of ANC-18 "Design of Wood Aircraft Structures," June 1944, but has been extended to include a greater range of 90° values, and presents a sketch of an appropriate glue joint.

Analysis of Results

A wide variation exists between the shearing strengths determined by the four methods of test. In a comparison of any two types of test, the amount of variation differs between species, between methods of cutting and between hardwoods and softwoods. Using the modified A. S. T. M. standard shear test for wood (method No. 1) as a basis for comparison, shearing strengths as determined by the other three tests at 0° and 90° are expressed as percentages in table 2.

The plotted data for each series of tests define the same general type of curve for each species and for each method of test, with the greatest shearing strength occurring at 0° to 22-1/2°, declining rapidly from 30° to 45°, and then more slowly to the lowest value at 90°.

When a Hankinson curve is fitted to the test data (figs. 9 through 13), a majority of the plotted points tend to fall on or near this curve. The shearing strengths at 15° and 22-1/2°, as determined by the modified A.S.T.M. standard shear test for wood, were equal to or greater than those at 0°. The 15° and 22-1/2° values thus lie above the mathematical curve. The block shear glue joint test and the double shear test displayed this tendency to a lesser degree. At other angles, minor variations are equally distributed about the curve. When a Hankinson curve was determined between test values at 0° and 90°, the values obtained from the curve for intermediate angles were generally somewhat lower than the test results.

For the hardwoods tested, the Hankinson curve resulting when Q (the shearing strength at 90°) is one-half of P (the shearing strength at 0°) approximates the lowest value obtained at any grain angle by any method of testing (fig. 14). A similar curve, when Q is one-third of P, closely follows the lowest values obtained in tests of those softwoods complying with Specification AN-NN-P-511b. The shearing strengths of rotary-cut Sitka spruce and Douglas-fir, which are not permitted by that specification, are somewhat below this curve at angles approaching 90°.

Although the materials cut by different methods were not matched, the shearing strengths obtained for quarter-sawed, planed wood were the highest at all grain angles for each species compared. The ratio of shearing strength at 90° to that at 0° (Q/P) was highest for the quarter-sliced and lowest for the rotary-cut specimens.

The shearing strengths obtained for 0° by means of the plywood glue shear test were relatively low, hence those for 90° represent much higher percentages of the strengths at 0° for all species. For those species glued to yellow-poplar and tested by means of the plywood glue shear test, the shearing strengths at the smaller angles for specimens involving sweetgum are not representative since failure occurred in the yellow-poplar. Thus the ratios of shearing strength at 90° to that at 0° are somewhat greater than when the specimens were glued to matched wood of the same species. The results of these tests suggest that the plywood glue shear test should not be considered in drawing conclusions as to the relative shearing strengths at different grain directions.

Difficulty was encountered in gluing yellow birch with a moisture content of 10.5 percent when using thermosetting phenol-formaldehyde film glue (Series D). Glue failures were numerous in specimens of this series. Supplementary tests were made using a moisture content of 10.2 percent with a cold-setting urea-formaldehyde glue (Series A) and using moisture content values of 7.4 percent (Series B) and 8.5 percent (Series C) with the thermosetting phenol-formaldehyde film glue. Since the material for each series was obtained from a different log, no comparison of the merits of these gluing techniques should be attempted on the basis of these results. In both series A and series B, glue failures were practically eliminated,and the relative shearing strengths at various grain angles were comparable to those of other species. These appear to be representative of yellow birch and are shown on the graph of this species in figure 6. The material used for series C was exceptionally high in shearing strength, and what might seem to be an inconsistently low value parallel to the grain still exceeded the established shearing strength of yellow birch.

Conclusions

No definite relationship was found to exist between the four test methods considered. The effects of factors such as classification of wood, species, and method of cutting differed in their individual effects on the results obtained by each test method. The block shear glue joint test, which restricts the zone in which failure may occur, produced the highest shearing strength values. The plywood glue shear test, in which eccentric loading is inherent, resulted in the lowest shearing strengths parallel to grain.

In the test methods considered, a consistent relationship was found to exist between the shearing strengths parallel and perpendicular to the grain and those at intermediate angles. The Hankinson formula, originally developed for bearing strengths of wood at various angles to the grain direction, can be used to determine shearing strength values for intermediate angles when those at 0° and 90° are known, and the values can be determined graphically from the Scholten nomograph.

For all of the species tested that were cut in accordance with Sepcification AN-NN-P-511b, the average values for the shearing strengths perpendicular to the grain were at least one-third of the shearing strength parallel to the grain, in all methods of test used. The average values for the hardwoods tested were at least one-half the shearing strength parallel to the grain. Using these factors to obtain the shearing strength at 90°, the shearing strength for a glued joint at any grain angle may be determined by the Hankinson formula from handbook values of shearing strength parallel to the grain.

For grain angles not exceeding 15°, the shearing strength parallel to the grain can be assumed to apply without correction.

Table 1.--Shearing strength, as determined by four different methods of test of glued joints in which the grain of one interface is at an angle to the direction of loading

Method of test	Angle of grain	Average shearing strength of 20 specimens[1]																				
		Sitka spruce					Douglas-fir					Sweetgum		Yellow-poplar	Yellow birch				Western hemlock	Sugar pine	Noble fir	Port Orford white cedar
		Flat-sawed[2]	Quarter-sawed	Quarter-sliced		Rotary-cut	Flat-sawed[2]	Quarter-sawed	Quarter-sliced		Rotary-cut	Rotary-cut	Quarter-sawed	Rotary-cut	Rotary-cut				Rotary-cut	Rotary-cut	Rotary-cut	Rotary-cut
		Glue B[4]			Glue A[3]		Glue B[4]			Glue A[3]		Glue A[3]	Glue B[4]	Glue A[3]	Glue B[4]	Glue A[3]			Glue A[3]	Glue A[3]	Glue A[3]	Glue A[3]
															Series A	Series B	Series C	Series D				
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)
	Degrees	Pounds per square inch																				
Modified A.S.T.M. standard shear test for wood	0		1,030		654	1,014		1,116		898	1,092	894		871	1,880	1,765	2,030	1,606	694	882	842	1,036
	15					946					1,077	1,007		876								
	22-1/2		946		739			1,203		745					1,887	1,735	2,375			825	720	
	30					649					805	1,005		741								992
	45		597		550	545		837		598	578	882		542	1,429	1,391	1,876	1,632	559	437	524	
	60					410					439	718		678								638
	67-1/2		434		362			679		437					1,081	1,244	1,439			371	439	
	75					332					434	752		584								
	90		364		302	296		540		384	359	597		582	929	1,114	1,266	1,184	319	310	398	540
Block shear glue joint test	0		1,560	1,315		1,192		1,752	1,484		1,179	1,159		1,012								
	15					1,081					1,210	1,102		1,111								
	22-1/2		1,208	1,107				1,559	1,164													
	30					752					875	1,093		924								
	45		715	715		618		1,007	818		670	841		709								
	60					443					466	664		766								
	67-1/2		507	470				702	594													
	75					349					435	795		663								
	90		440	420		291		578	483		377	638		564								
Double shear test	0					794					956	874		744								
	15					836					920	720		739								
	30					525					580	802		717								
	45					389					431	676		596								
	60					296					333	516		566								
	75					241					318	601		510								
	90					223					270	431		482								
Plywood glue shear test	0	512				478	440				449	528	399	459								
	15	432				460	438				436	478	450	458								
	22-1/2	466					412						439									
	30	470				457	388				400	480	443	432								
	45	428				384	383				364	420	394	399								
	60	388				334	385				331	395	390	375								
	67-1/2	377					402						330									
	75	358				299	328				324	373	369	364								
	90	358				298	324				300	364	360	330								

[1]Corrected to the average specific gravity of the species using $S = S_T \frac{G_A}{G_T}$. Approximate moisture content at test was 10 percent in specimens glued with Glue A and 12 percent in those glued with Glue B.

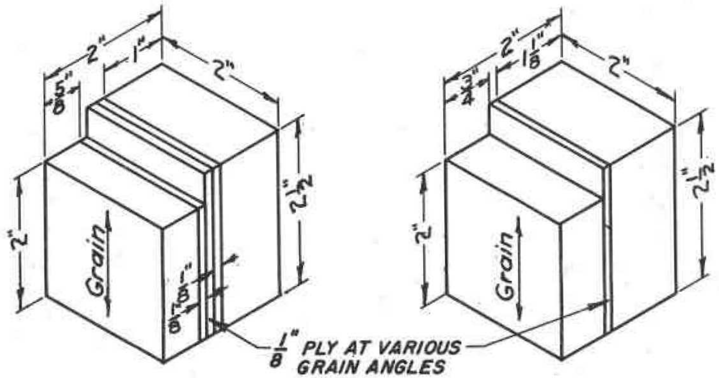
[2]Test pieces glued to yellow-poplar.

[3]Phenol-formaldehyde thermo-setting film glue.

[4]Urea-formaldehyde cold-setting glue.

Table 2.--Comparison of the shearing strength values obtained by three different methods of test with those obtained by the A.S.T.M. standard shear test of wood

Type of test	Percent of A.S.T.M. standard shear test value			
	At 0° grain angle		At 90° grain angle	
	Average of all tests	Range of variation	Average of all tests	Range of variation
	Percent	Percent	Percent	Percent
Block shear glue joint test				
Softwoods	150	108-201	116	98-139
Hardwoods	123	116-130	102	97-107
Double shear test				
Softwoods	83	78-87	75	75-75
Hardwoods	92	85-98	78	72-83
Plywood glue shear test				
Softwoods	44	41-47	92	84-100
Hardwoods	56	53-59	59	57-61



ROTARY-CUT OR QUARTER-SLICED

QUARTER-SAWED

FIGURE 1.--SPECIMENS FOR MODIFIED A.S.T.M. STANDARD SHEAR TEST OF WOOD

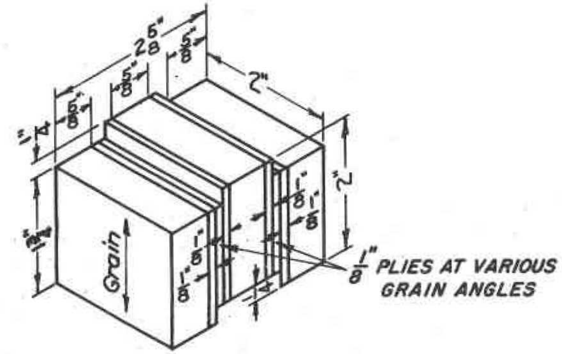
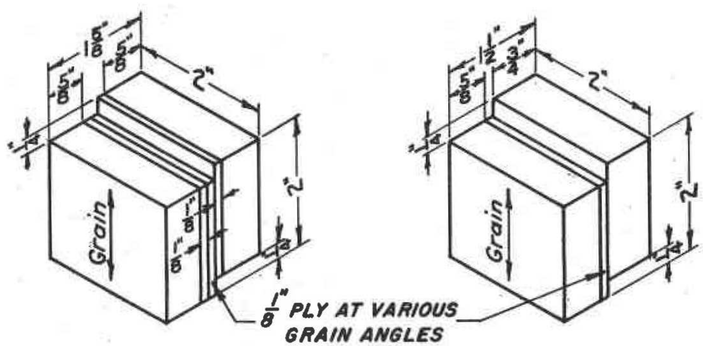


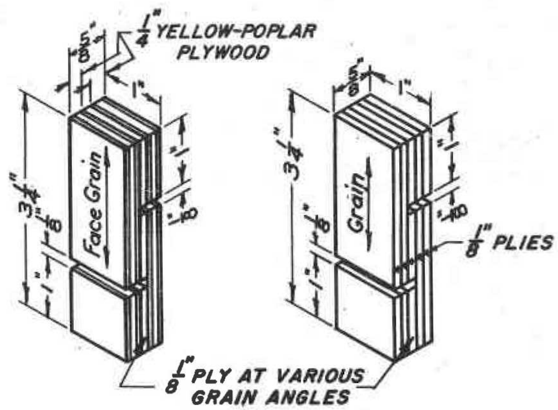
FIGURE 3.--SPECIMEN FOR DOUBLE SHEAR TEST



ROTARY-CUT OR QUARTER-SLICED

QUARTER-SAWED

FIGURE 2.-- SPECIMENS FOR BLOCK SHEAR GLUE JOINT TEST



QUARTER-SAWED OR PLAIN-SAWED

ROTARY-CUT

FIGURE 4.--SPECIMENS FOR PLYWOOD GLUE SHEAR TEST

Z M 57617 F

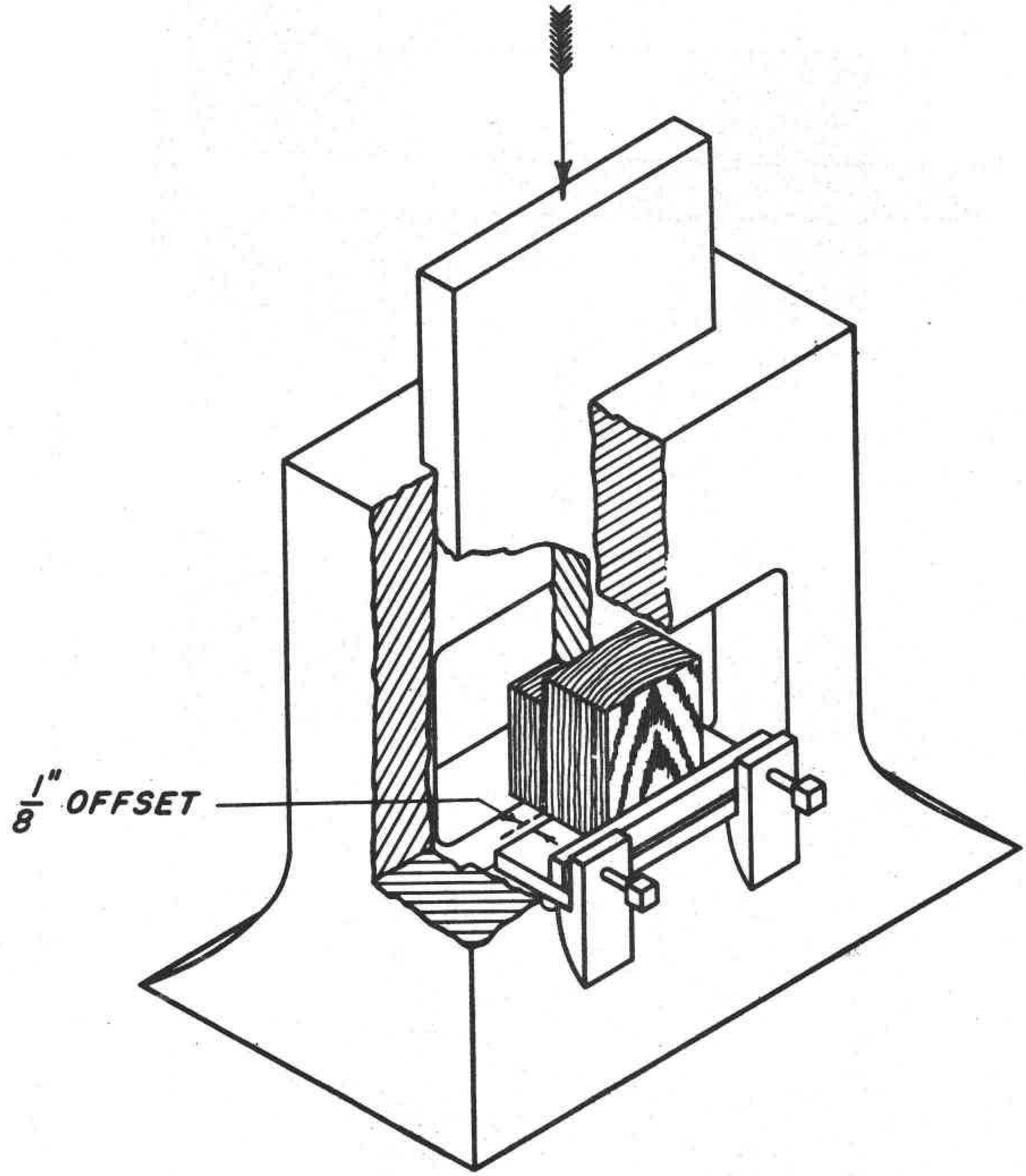


Figure 5.--Shearing tool used for the A.S.T.M. standard shear test of wood.

Z M 57618 F

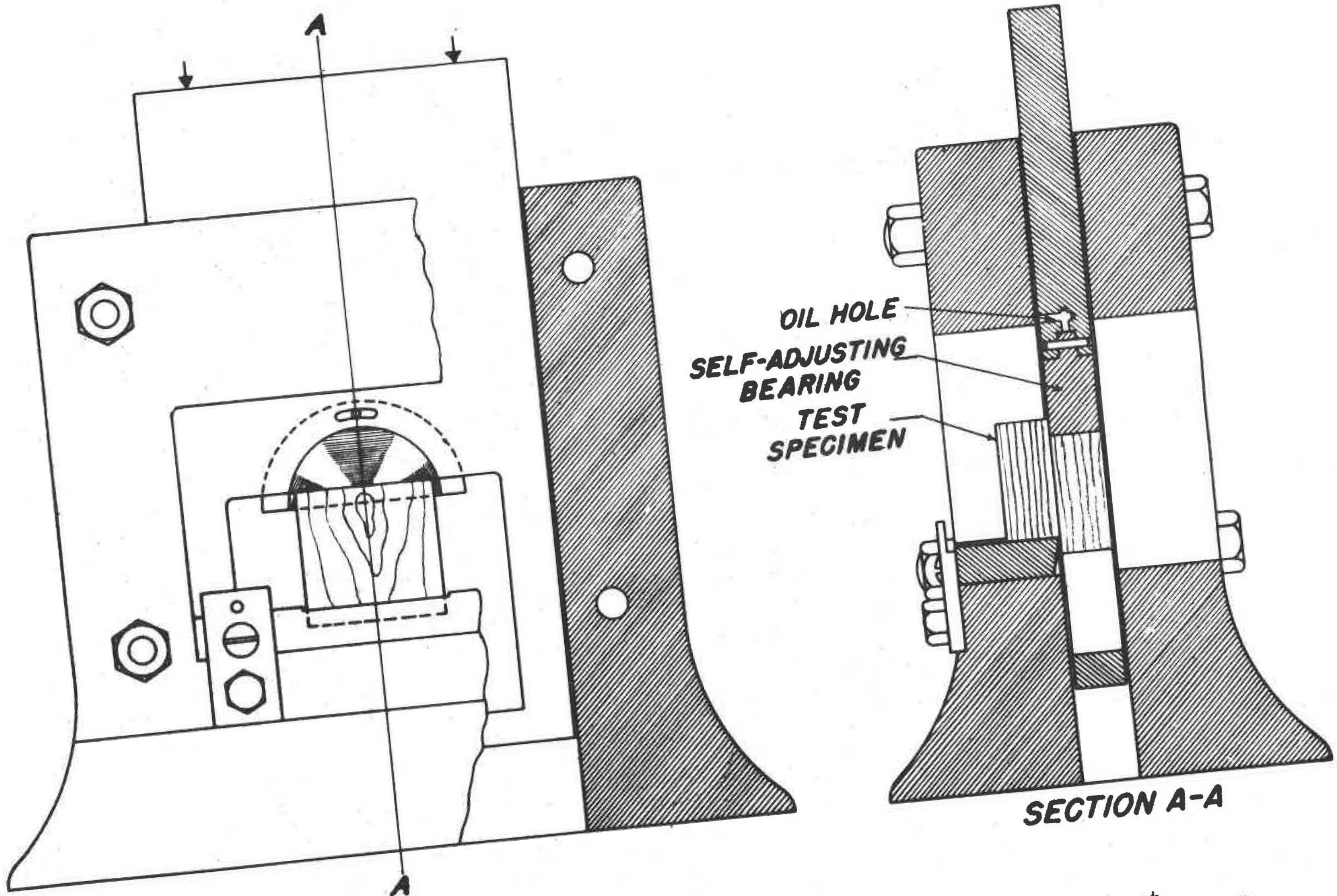


Figure 6.--Shearing tool used for the block shear glue joint test.

Z M 57619 F

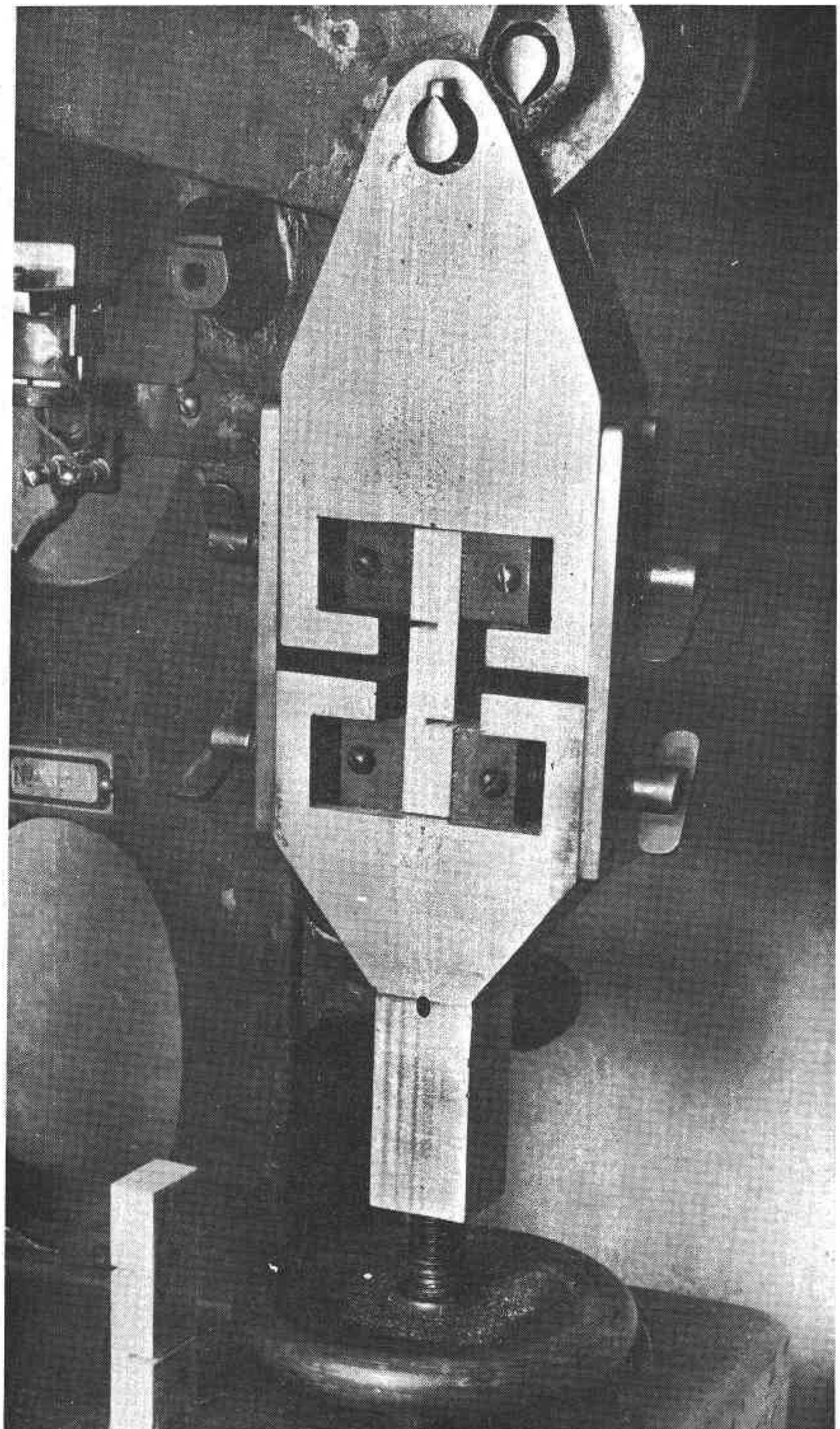


Figure 7.--Apparatus used for the plywood glue shear test.

Z M 57620 F

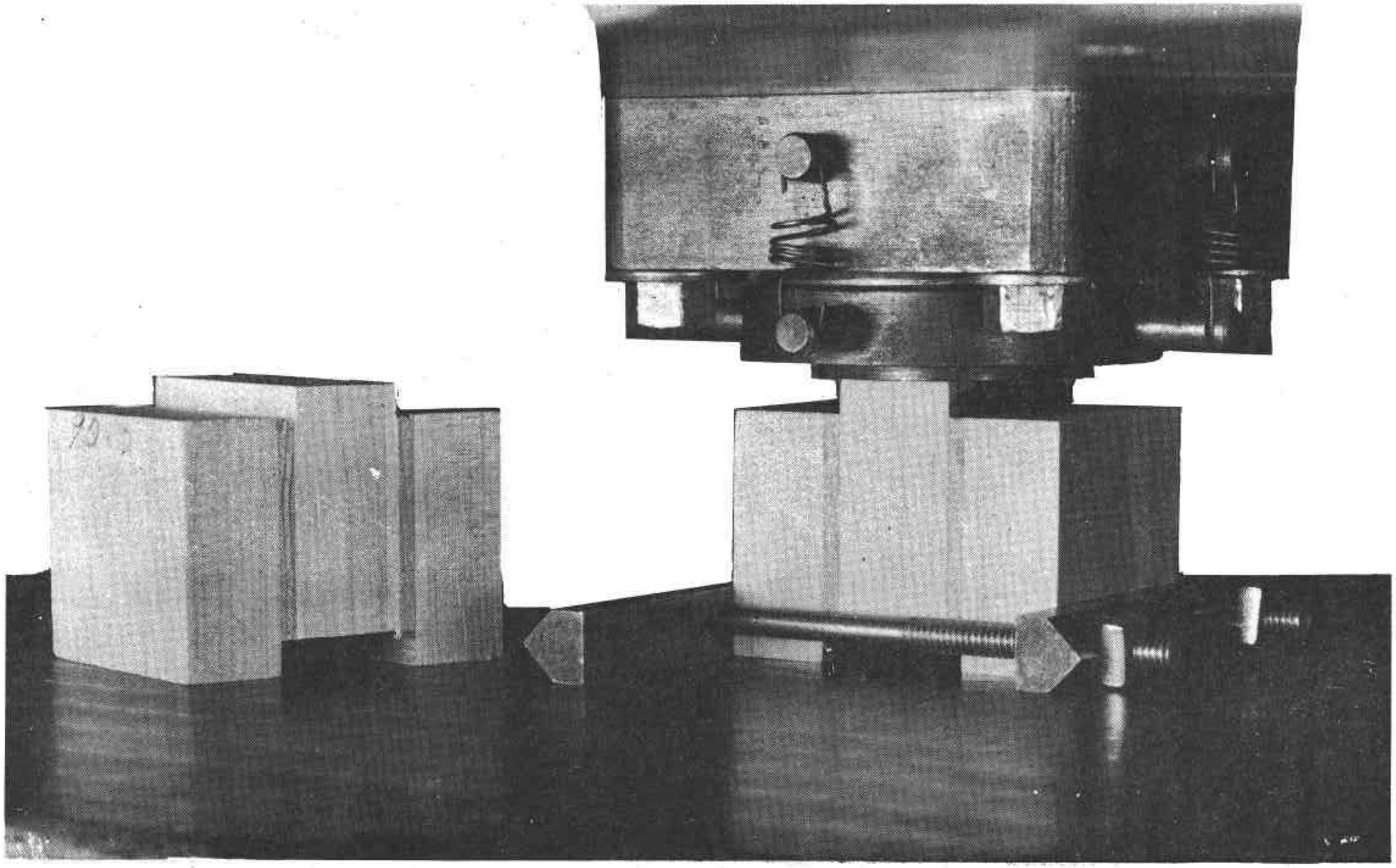


Figure 8.--Apparatus used for the double shear test.

2 M 57621 F

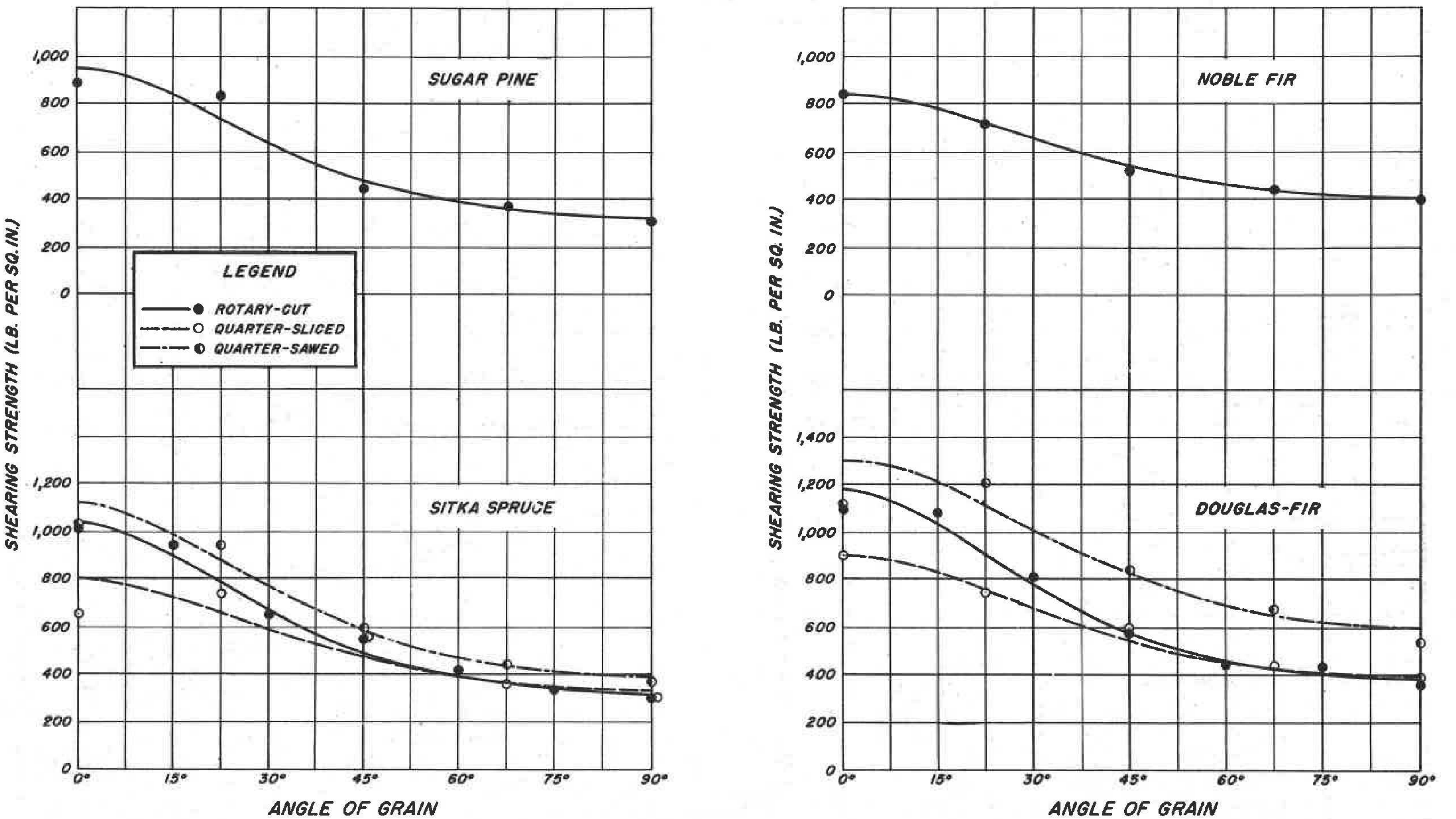


Figure 9.--Shearing strengths of glued joints in which the grain of one interface is at an angle to the direction of loading, as determined by the A.S.T.M. standard shear test. The Hankinson curve best fitting the test data is shown for each series of tests.

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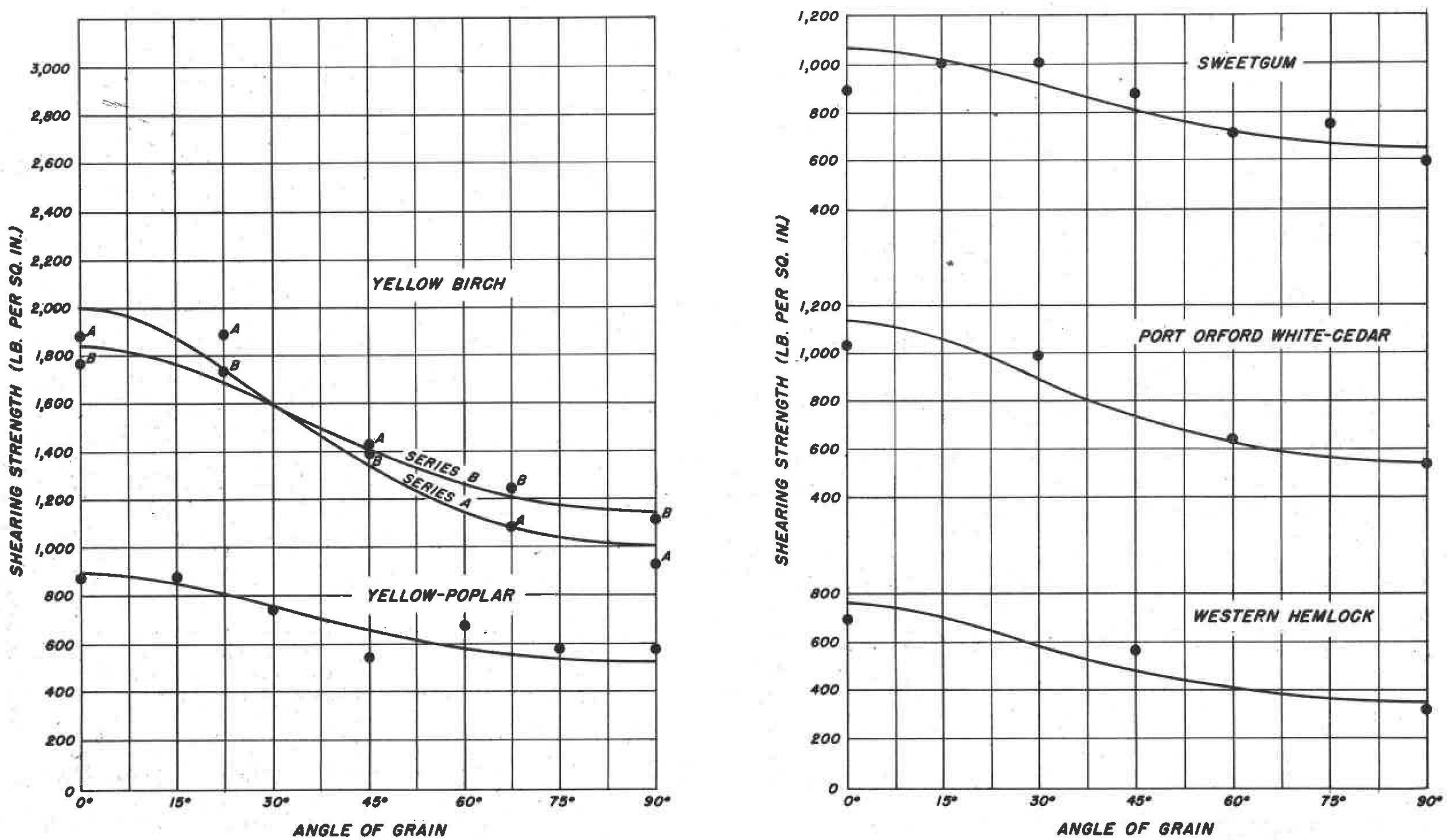

Figure 10.--Shearing strengths of glued joints in which the grain of one interface is at an angle to the direction of loading, as determined by the A.S.T.M. standard shear test. The Hankinson curve best fitting the test data is shown for each series of tests.

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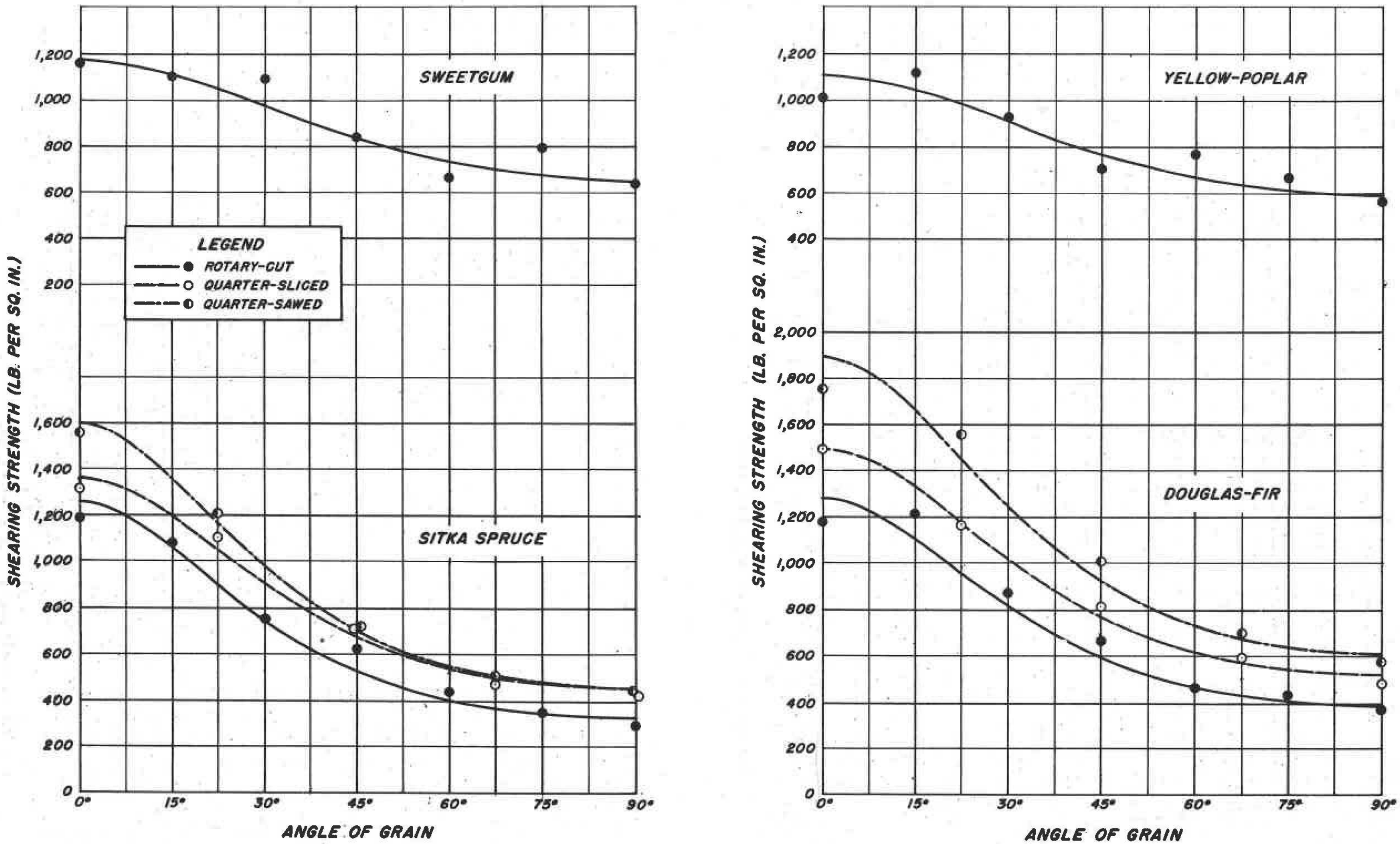

Figure 11.--Shearing strengths of glued joints in which the grain of one interface is at an angle to the direction of loading, as determined by the block shear glue joint test. The Hankinson curve best fitting the test data is shown for each series of tests.

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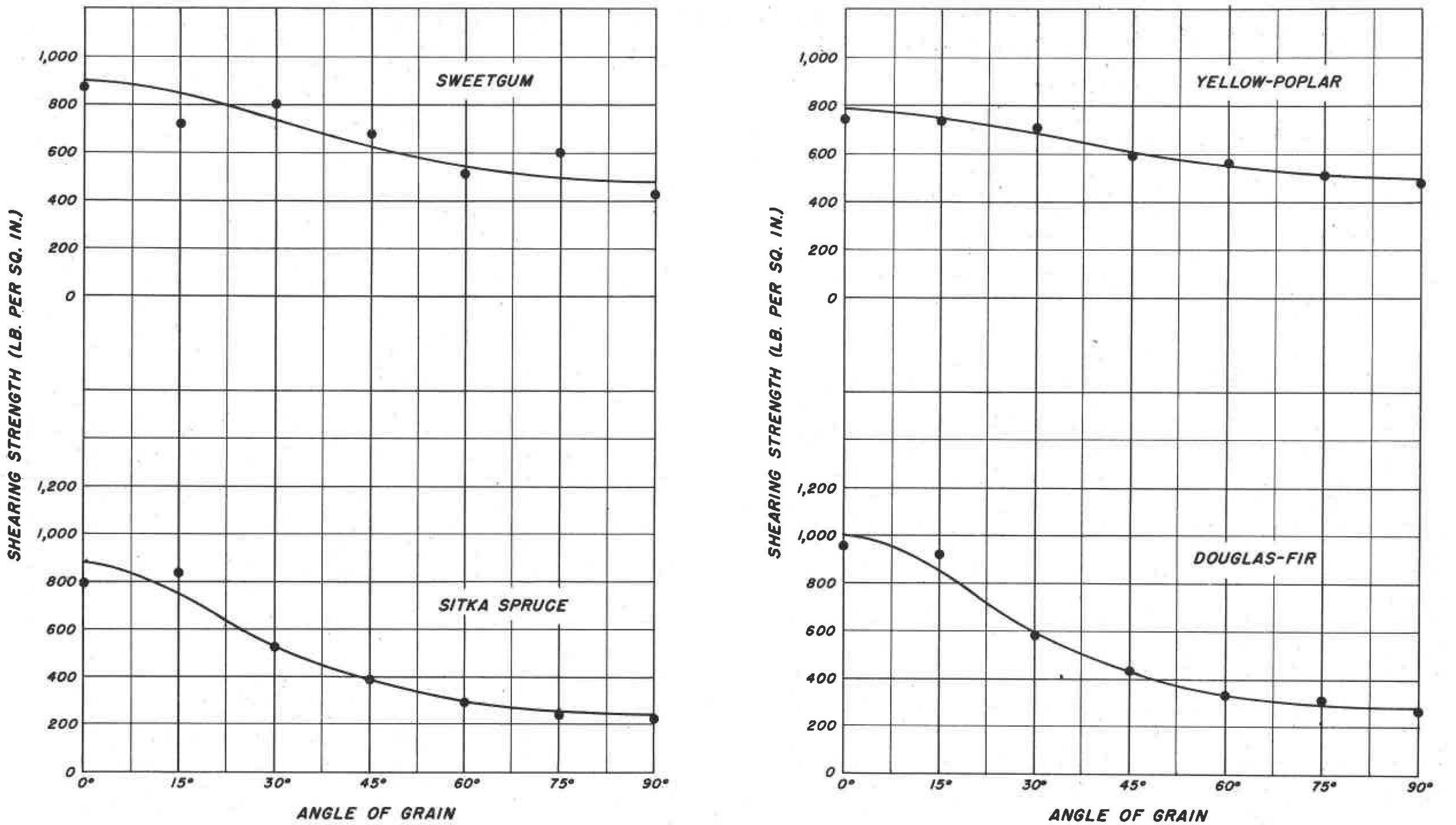

Figure 12.--Shearing strengths of glued joints in which the grain of one interface is at an angle to the direction of loading, as determined by the double shear test. The Hankinson curve best fitting the test data is shown for each series of tests.

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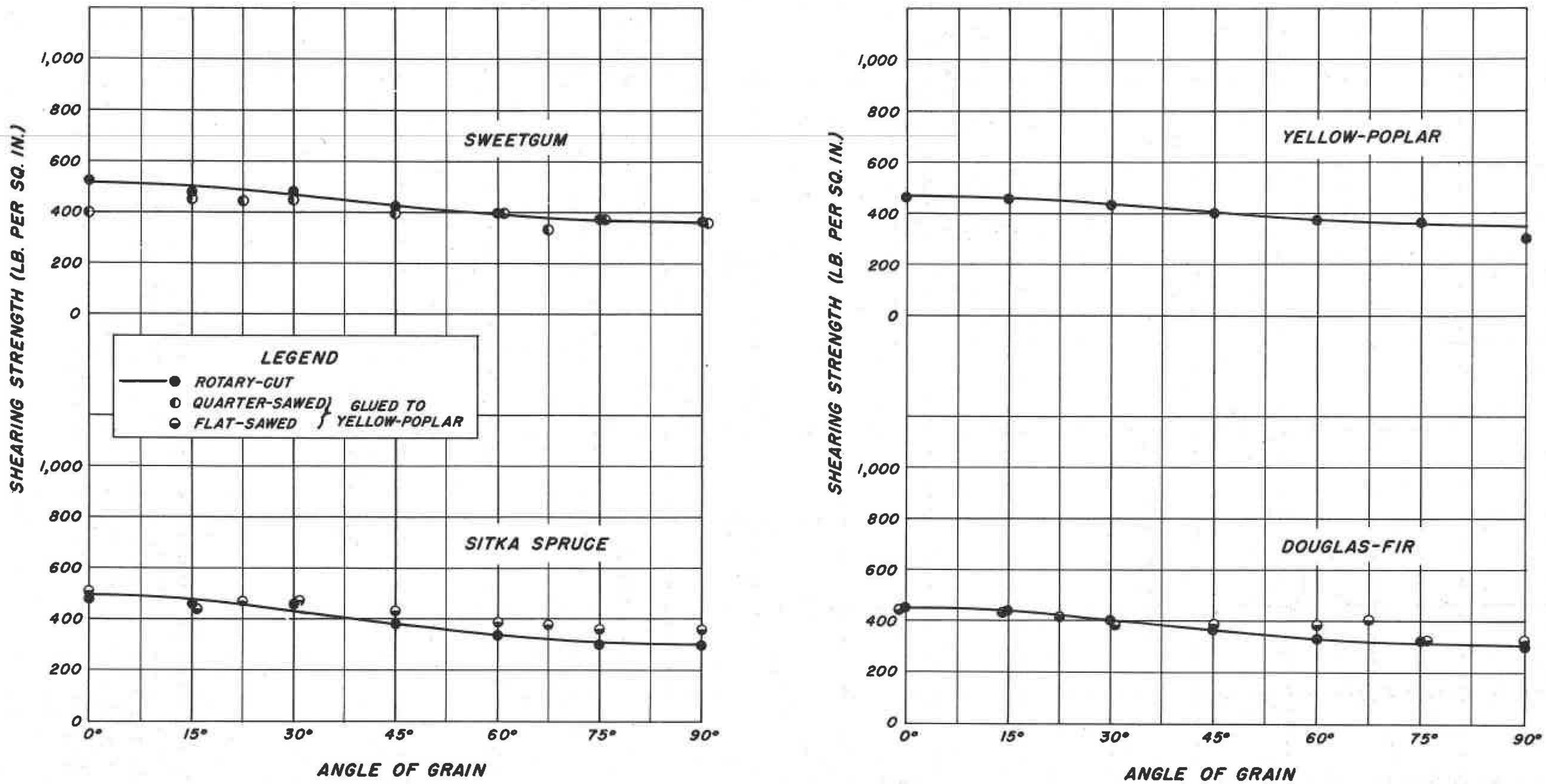

Figure 13.--Shearing strengths of glued joints in which the grain of one interface is at an angle to the direction of loading, as determined by the plywood glue shear test. The Hankinson curve best fitting the test data is shown for each series of tests.

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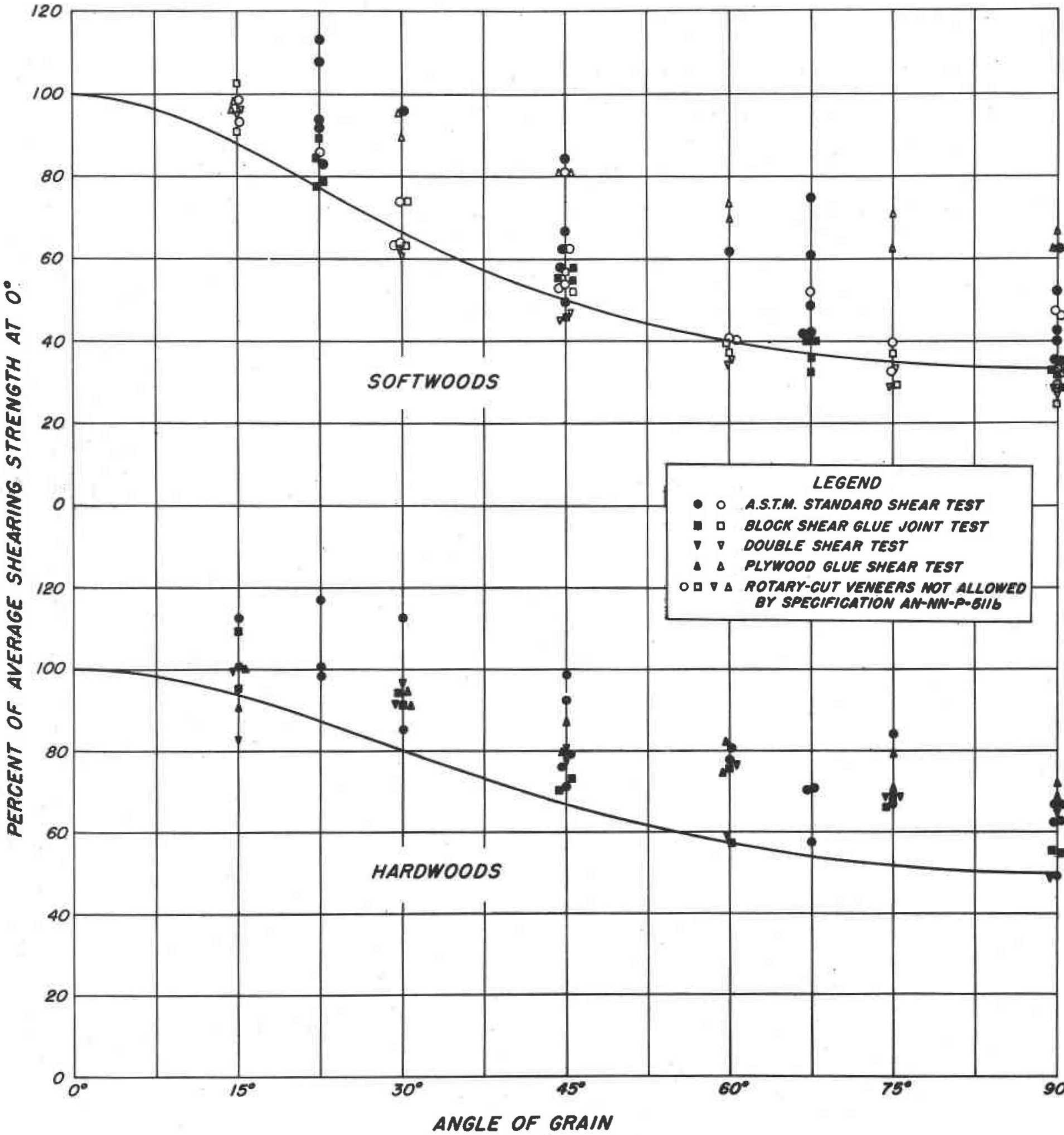

Figure 14.--Summary of all tests of shearing strength of glued joints in which the grain of one interface is at an angle to the direction of loading. The percentage (N) of the parallel shearing strength (P) that may safely be used at any grain direction is shown by curves of the Hankinson formula,

$N = \frac{PQ}{P \sin^2 \theta + Q \cos^2 \theta}$, wherein Q = 1/3 P for softwoods, Q = 1/2 P for hardwoods.

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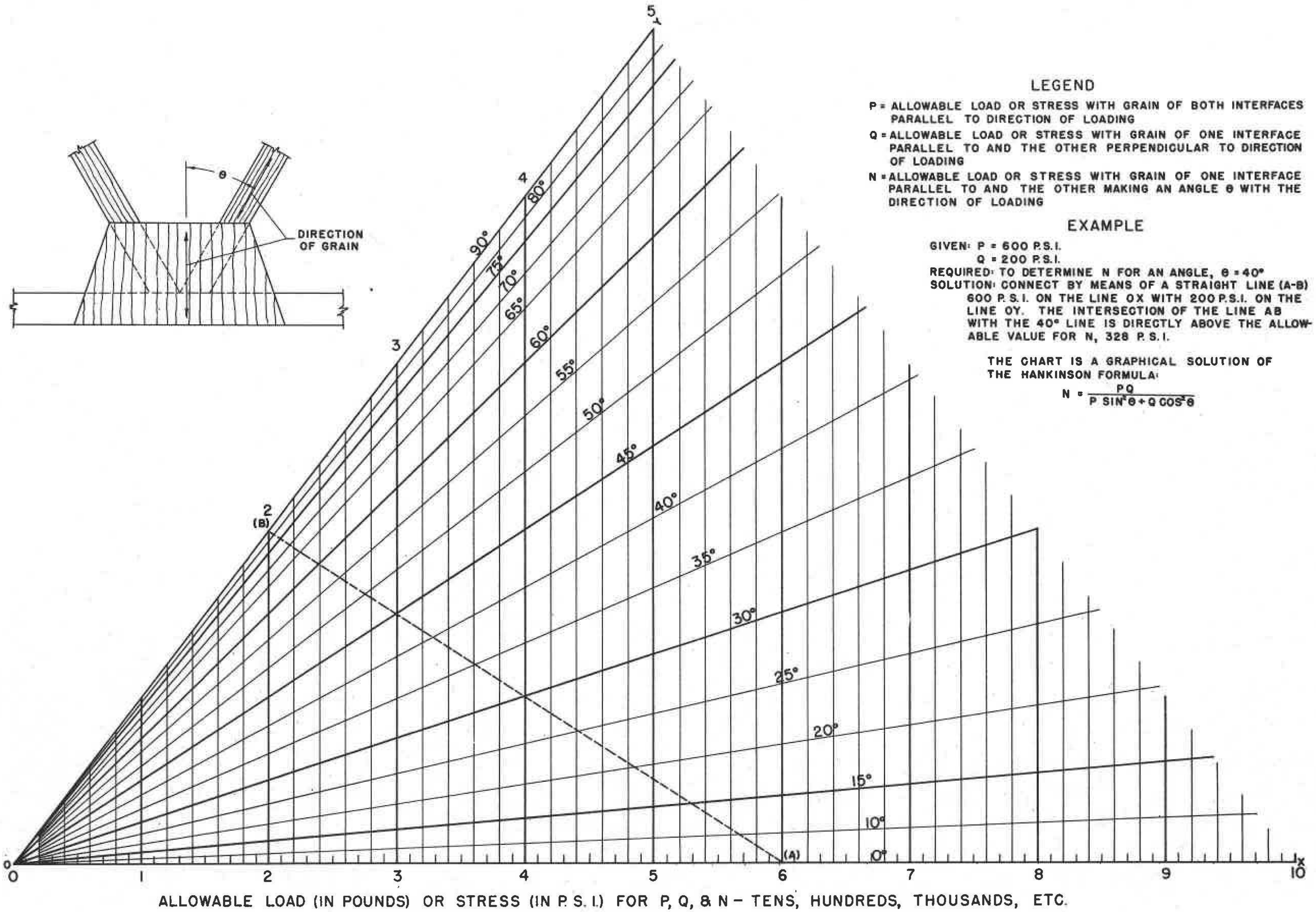

Figure 15.--Scholten nomograph for determining allowable shearing strengths of glued joints at various angles to the grain.

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