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SOME CAUSES OF VARIABILITY IN THE RESULTS OF PLYWOOD SHEAR TESTS

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Introduction

The shear test is a generally accepted method for evaluating the quality of glue joints in plywood, and the plywood shear testing machine, a modified cement-briquet testing machine (fig. 1-A), has been widely adopted for testing glues and plywood. Considerable variation is commonly encountered in the shear-test values obtained on duplicate specimens of plywood. The causes of such variations are usually ascribed to variations in the wood, but they may also be due to differences in the moisture content of the specimens, in their physical shape and arrangement, or in variations in the operation of the testing machine.

The following studies were undertaken at the Forest Products Laboratory in an attempt to determine the causes of variability in shear-strength measurements made on the plywood shear testing machine and to ascertain the importance of the effects of each on the reliability of the results. When these causes were determined and evaluated it was the further purpose of this study to make recommendations toward their elimination.

Possible Causes of Variability

The following 10 factors were considered as possible sources of variation:

1. Misalignment of jaws.
2. Equal offset of both upper and lower jaws.
3. Distance between jaws.

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

4. Side play in the grips.
5. Jaw pressure.
6. Rate of loading.
7. Position of saw cuts with respect to direction of slope of grain in the face plies.
8. Type, depth, and width of saw cuts.
9. Moisture content of shear specimens.
10. Time of exposure of specimens to relatively dry air.

Each factor was investigated by separate experiment designed in such a manner that the results could be analyzed statistically and the importance of individual factors and the interaction between factors could be estimated. The 10 experiments are discussed separately in this report. The results of all studies were analyzed by analysis of variance, and all conclusions are based on those analyses.

Preparation of Specimens

Three-ply 3/16-inch plywood made of yellow birch was used in all experiments. The standard plywood specimen of the dimensions shown in figure 1 was employed in all but experiment 8 where the saw cut was under investigation.

The 1/16-inch veneer was selected for freedom from defects and for straightness of grain, except in experiment 7 where sloping grain was intentionally employed. Unless otherwise indicated the veneer was conditioned to moisture equilibrium with air at 80° F. and 65 percent relative humidity before gluing. In the preparation of the panels, the sheets of veneer were laid up so that any slope of grain in the face plies, however slight, was in the same direction, as indicated in figure 2.

For part (a) of experiment 1, the panels were glued with two sheets of phenol film glue at each glue line, cured under pressure of 150 pounds per square inch at 320° F. for 8 minutes. Unless otherwise stated, for all other experiments the panels were glued with a melamine-formaldehyde resin glue cured in a hot-press at 300° F. for 8 minutes, and the plywood was conditioned after gluing for at least a week in an atmosphere of 80° F. and 65 percent relative humidity.

The panels were cut into shear test specimens in such a way that specimens adjacent end-to-end had their saw cuts in reverse positions with regard to slope of pain as shown diagrammatically in A and B of figure 2. For each variable in each experiment a matched pair of type-A and type-B specimens were selected at random from each panel. Enough panels were prepared to provide either 12 or 20 specimens for each different condition.

Shear Testing

In preparation for the testing, the vertical canter line of the testing grips was marked at the points, C, C as shown in figure 1-C, To do this, a plywood specimen was placed in the Jaws, put under a 100-pound load, and adjusted so that the center line of its core was in line with the center of the hole on which the knife edge rests in the upper grip and the center of the screw at the bottom of the lower grip, as sighted with a transit. The marks C, C were then accurately drawn to coincide with this sighted line. Short millimeter scales were mounted on the faces of the grips with the zero graduations coincident with the marks C, C. Their location was checked with the transit.

A traveling telescope was used to line up each specimen tested in all but experiment 10, using the scales on the grips as reference for the alignment. In experiment 10 the specimens were lined up by eye and the position of the upper saw cut alternated between left and right inasmuch as a prior experiment had shown that the effect of misalignment of jaws would be eliminated by this procedure. In all experiments except 1 (b) the specimens were tested with the saw cut to the upper left and lower right as seen by the operator.

The same machine was used for all experiments, except for experiment 1 (a) in which a second machine was also used.

Unless otherwise indicated, the testing was done in temperature- and humidity-controlled rooms or the specimens were kept in small tightly capped bottles between the time of removal from the constant humidity chambers and the time of testing.

Procedure and Results of

the Experiments on the 10 Variables Studied

Experiment 1 -- Misalignment of Jaws

(a) In the experiment to determine the effect of the misalignment of the jaws of the testing machine the lower jaws were kept centered in the grips but the upper jaws were offset from 2 millimeters to the left to 2 millimeters to the right. Specimens were tested both dry (conditioned at 80° F. and 65 percent relative humidity) and wet (immersed for 3 hours in boiling water) on two different machines. Results are presented in table 1 and figure 3.

The dry shear strength measurements were greatly affected by misalignment of the upper Jaws. Displacement of as little as 1/2 millimeter to the right-or left of alignment with the lower jaws resulted in a joint strength value about 50 Pounds per square inch lower or higher than the value obtained when the jaws were in perfect alignment.

The shear strength was affected by misalignment much less when the specimens Were wet than when they were dry. A displacement of 1 millimeter to the left or right made a difference of about 9 pounds per square inch in the average wet shear value, which was too low to be shown significant; but a displacement of 2 mm. resulted in a significant difference of about 38 pounds per square inch.

The measured value for the shear strength was less when the offset of the upper jaws tended to open the saw cuts as in figure 2 (b), but greater when it tended to close the saw cuts as in figure 2 (d).

The effect of misalignment was found with both machines. (b) In experiment 1 (a) the saw cuts were placed at the upper left and lower right of the operator. In experiment 1 (b), similar tests were made with the saw cuts also at the upper right and lower left. The lower jaws were kept accurately centered in the grips as before and the upper jaws offset 1 mm. to the left, 1 mm. to the right, and centered in line with the lower jaws. The specimens tested with the upper saw cut to the right and to the left were matched. They were tested dry only after conditioning to moisture equilibrium in air at 80° F. and 65 percent relative humidity. The averaged data are given in table 2.

Analysis of the data indicated that there was no significant difference in shear strength of specimens tested with saw cuts to the upper left and to the upper right if both jaws were centered in the grips, but, as found in experiment 1 (a), that there was an important effect of position of the saw cuts if the jaws were not in alignment. If the upper jaws were offset 1 mm. to the side of the upper saw cut (fig. 2 (b)), the average shear strength was 63 pounds per square inch lower then when both jaws were in alignment, but 56 pounds per square inch higher when the upper jaws were offset 1 mm. away from the side of the upper saw cut (fig. 2 (d)). The average of these two results was not significantly different from the average shear strength for specimens tested with upper and lower jaws in line. From this it may be concluded that, if matched specimens are tested with the saw cuts alternately to the upper left and right, the averaged result would not be affected by misalignment of 1 mm. or less. If the SR ecimens were not matched, the effect of misalignment would at least be minimized.

(c) In view of the great difference found in experiment 1 (a) in the effects of misalignment on dry and wet plywood specimens, it seemed desirable to study the effect of misalignment on dry specimens that varied only moderately in moisture content. For this purpose matched specimens were conditioned to three different moisture content values and tested, as in experiment 1 (b), with upper and lower jaws in alignment and with the upper jaws offset 1 mm. to the right and 1 mm. to the left of the lower jaws. The averaged data are given in table 3.

As in previous parts of this experiment there was a striking difference in shear strengths for the different alignments at a particular moisture content and also for different moisture contents at a particular alignment, but the difference in the moisture content of the specimens from 5.3 to 10.2 percent did not significantly influence the effect of the misalignment on the shear strength.

Experiment 2 -- Equal Offset of Both Upper and Lower Jaws

Twenty specimens were tested with both the upper and the lower jaws centered in the grips and symmetrical with the center line of pull, and 20 matched specimens were tested with both the upper and the lower jaws offset 1 mm. to the right of the center line of pull. The average dry shear strengths were 637 and 633 pounds per square inch, respectively, with 100 percent wood failure in all specimens. The small difference between these values indicates that, if the upper and lower jaws are in vertical alignment, equal displacement of both jaws in the same direction up to 1 mm from the center line of pull is unimportant.

Experiment 3 Distance Between Jaws

The jaws in the plywood test grips are normally 1 inch wide and 1 inch long. If the full area of each jaw is in contact with the specimen, the distance between the jaws is 1-1/4 inches. Usually the specimen is inserted so that the full area of the lower jaws is in contact with the specimen, but it frequently happens that only a portion of the upper jaws is in contact due to the failure of the operator to adjust the machine after testing the previous specimen. In practice the distance between the jaws may vary from 1-1/4 to about 1-1/2 inches. It is important to know the effect of this variation on the shear strength results. In Great Britain plywood testing jaws 2-1/4 inches apart are specified, and it was deemed desirable to know how the results would be affected by jaws at this spacing. Accordingly, experiment 3 was conducted to obtain data (a) with jaws 1-1/4 inches apart, (b) with jaws 1-3/4 inches apart, the lower jaws in full contact and the upper jaws in half contact and (c) with jaws 2-1/4 inches apart, using jaws 1 inch wide and 1/2 inch deep. These three conditions are shown in figure 4.

Matched specimens were tested with jaw conditions A, B, and C (fig. 4), not only with jaws centered and in alignment, but also with the upper jaws offset 1 mm. to left and right, to detect any interrelation between effect of misalignment on the effect of distance between the jaws. The averaged results of the tests (each value based on 20 tests) are given in table 4.

The shear strength values were importantly influenced by the position of the jaws on the plywood specimen. The magnitude of the effect was increased or decreased if the misalignment was such as to increase or decrease, respectively, the shear strength value. Higher strengths were obtained with the jaws 1-1/4 inches apart than with the Jaws further apart. With the small jaws in the position shown as C figure 4, values were obtained intermediate between the values obtained with the larger jaws in the positions shown as A and B.

Experiment 4 -- Side Play in the Grips.

In the sketch of the grips in figure 1 it may be seen that the upper half is free to slide up and down between two side plates rigidly screwed to the lower half. Since the freedom between the upper half of the grips and the side plates might have an effect on the test results, it was chosen as one of the variables for study. The side play was regulated by shims under the side plates used to hold the grips in line. Without shims the grips were closely fitted, with just enough play to avoid friction. Three different thicknesses of shims were used and 20 specimens tested dry with each thickness. The average results are given in table 3.

Analysis of the results showed that side play in the grips of as much as 1 mm. had no significant effect on the shear strength measurements.

Experiment 5 -- Jaw Pressure

In tightening the jaws the pressure applied to the shear test specimen will vary with the operator, the length of the handle on the screw, and whether the screw is tightened by hand or by wrench. To determine the effect of jaw pressure on the shear strength measurements, 20 specimens were tested when the jaws were tightened by hand, and 20 matched specimens when the jaws were tightened with a hand wrench, The average shear strengths were 625 pounds per square inch for specimens tightened by hand and 650 pounds per square inch for specimens tightened as tight as possible with the wrench. This difference was highly significant indicating the desirability of uniform tightening of the jaws for all specimens.

Experiment 6 -- Rate of Loading

The plywood shear testing machines are loaded by lead shot running from an orifice. The normal rate of loading is approximately 800 pounds applied to the shear test specimens per minute. In this experiment the size of the orifice was altered so that the rate of flow of shot was both one-half, and about twice the normal rate. At each rate of loading 20 matched specimens were tested dry. The averaged results are given in table 6.

The results indicate little or no difference in the shear strength measurements made by loading at 400, 800, or 1,600 pounds per minute.

Experiment 7 -- Position of Saw Cuts With Respect to Direction of Slope of Grain in Face Plies

To determine the effect of the position of the saw cuts with respect to the direction of slope of grain in face plies the plywood was made with straight-grained face plies and also with the grain of the face plies sloping 1:10 and

1:5 from the glue lines, the direction of slope being parallel in both faces. The cores of the plywood were in all cases straight grained. Matched specimens were cut with saw cuts A and B as shown in figure 2. The specimens were tested dry after conditioning to about 12 percent moisture content; those with a slope of 1:10 and those without slope were also tested wet after boiling in water for 3 hours. In the tests, the upper saw cut was always placed to the operator's left. The test was repeated under three conditions: with the upper jaws (1) centered and in line with the lower jaws; (2) offset 1 mm. to the left; and (3) offset 1 mm. to the right. The results are presented in table 7.

From the data of table 7 it may be seen that there was little difference between the results for saw cuts A and B when there was little or no slope of grain. This result was to be expected, since in this case there was little or no distinction between A and B. When there was slope of grain from the glue line in the face plies of as much as 1:10, however, the location of the saw cuts had a pronounced effect. In the dry tests, type-B specimens averaged 210 pounds per square inch higher than type-A specimens for the 1:10 slope, and 92 pounds per square inch higher for the 1:5 slope. In the tests on wet specimens of 1:10 slope, type-B specimens averaged 60 pounds per square inch higher than those of type A. Of the specimens tested dry all type-A specimens failed 100 percent in the wood, but the percentage of wood failure for the type-B specimens averaged only about 62 percent. Of the specimens tested wet both A and B failed 100 percent in the wood, but the failure of type-A specimens was in a face ply and of type-B specimens in the core.

It may be concluded from these observations that the glue line would be put to a more severe test if the face veneer was not of straight grain, but was selected to have an appreciable slope, such as 1:10, and if the saw cuts into the core were of type B (fig. 2-C), whereupon the measured strength would be higher and, in the dry tests, the percentages of wood failure lower. With a slope of grain of as much as 1:5, the test on the glue line would be less severe, since such specimens often fail at relatively low load by splitting along the grain between the saw cut and the end of the specimen. Since it is not easy to select grain of a particular slope, the practical procedure would be to employ only straight-grained veneer for the faces of the plywood used for glue-joint tests.

Experiment 8 -- Types, Depth, and Width of Saw Cuts

Matched specimens of the plywood were tested with three different depths of saw cuts made with a swage-set saw. The averaged shear strength results, based on 20 specimens each, are given in table 8.

The differences between the shear strength averages are highly significant and indicate the importance of control of the depth of saw cut.

Specimens cut with a spring-set saw cutting through the face plies and core and slightly nicking the opposite face ply gave an average strength of 540 pounds per square inch for 20 specimens. Although this value is less than the

560 pounds per square inch average value for cuts through the face and core by the swage-set saw, the variation among individual specimens was sufficiently large that the difference between these two average values was not statistically significant.

To investigate the effect of width of saw cut, matched specimens from birch plywood panels glued with a room-temperature-setting urea-resin glue and with a thermoplastic resin glue at 300° F. were cut with a swage-set saw two-thirds through the 1/16-inch core, half with a saw cut 3/32-inch wide and half 5/32-inch wide. These specimens were tested both dry and wet after soaking 48 hours. The results of the shear tests are given in table 9.

There was no significant difference between the results for the narrower and wider widths, wherefore it may be concluded that a variation of ± 1/32-inch from the 1/8-inch standard dimension for the width of the saw cuts as shown in Figure 1 would have a negligible effect on the test results.

Experiment 9 -- Moisture Content of Shear-Test Specimens

(a) Birch sapwood and heartwood veneer was conditioned in an atmosphere of 80° F. and 65 percent relative humidity, then glued with melamine glue into three-ply plywood panels. Groups of 20 sapwood and 20 heartwood matched shear-test specimens cut from these panels were conditioned for 8 to 10 days in atmospheres of 5 different relative humidities, soaked for 48 hours in water at room temperature, and boiled in water for 3 hours, after which they were tested for joint strength. The moisture content of the dry specimens at the time of testing was determined by weighing, drying, and reweighing the specimens immediately after testing.

Averaged results are given in table 10 and plotted in figure 5.

The moisture content of the specimens at the time of testing greatly influenced the shear strengths (table 10 and fig. 5). The shear strengths were highest for specimens conditioned and tested at 80° F. and 80 percent relative humidity and having an average moisture content of 11.8 percent. At lower or higher moisture contents there was a sharp reduction in shear strengths. Soaked and boiled specimens were likewise lower in strength.

(b) To ascertain the way in which the moisture content of the veneer at the time of gluing might affect the relation between the joint strength and the moisture content of the plywood at the time of testing, birch veneer was conditioned to moisture equilibrium with air at 80° F. and 30, 65, and 80 percent relative humidity, then glued with melamine and urea resin glue into plywood panels. Shear test specimens cut from these panels were evenly divided into three groups, conditioned to equilibrium in air at 80° F. and 30, 65, and 80 percent relative humidity, and tested. The results are given in table 11.

No significant differences in shear strengths were noted for the various moisture contents at the time of gluing within the limits required for glue joints of high quality. The conclusion is that, within the limits of this experiment, moisture content at time of gluing had little or no influence on the relation between the shear strength and the moisture content at the time of testing, providing the moisture content was within the range required for good glue bonds.

Experiment 10 -- Time of Exposure of Specimens to Relatively Dry Air

Matched specimens were tested after they were conditioned at 80° F. and 80 percent relative humidity and then after they were exposed for several different periods of time to air at 80° F. and 30 percent relative humidity. The specimens had been glued with a hot-setting melamine-formaldehyde and a room-temperature-setting urea-formaldehyde glue. Wet tests after the specimens were boiled for 3 hours were made on the melamine-bonded specimens after the same periods of exposure to 80° F. and 30 percent relative humidity. The results are presented in table 12.

No important change was noted in the dry strengths up to 10 minutes exposure in the dry air, but between 10 and 20 minutes the strengths dropped significantly. Longer exposure up to 240 minutes effected little or no further change in the shear strength. The wet strength of the specimens appeared not to be affected by any of the prior exposures used.

Summary of Conclusions

A study was made to determine some of the causes of variability in plywood shear-strength measurements. Standard shear-test specimens of three-ply 3/16-inch yellow birch (fig. 1) were used, The plywood was made with melamine glue and in a few instances with phenol thermoplastic or urea-resin glues, The independent variables studied included: alignment of jaws., distance between jaws, side play in the grips, Jaw pressure, rate of loading, position of saw cuts with respect to direction of slope in the face plies, type, depth, and width of saw cut, moisture content at time of gluing and testing, and time of exposure of specimens to relatively dry air. Each experiment was so designed that the data could be analyzed statistically.

1. Misalignment of the upper and lower jaws of as much as 1/2 mm. resulted in large differences in dry shear strengths, The difference was higher or lower than the shear strength with perfect alignment depending on whether the saw cuts were narrowed or widened by the misalignment. It would be advisable to bevel the face of the grips and mark the center line of pull at the points C, C in figure 1 so that the operator could align the two sets of jaws more accurately by inserting the specimens with the center of the core in line with the marks C, C. The effect of moderate misalignment of jaws, however, could

be eliminated or minimized by alternating the upper saw cut to the left and right in testing a given set of specimens.

2. Offsetting the specimen an equal distance up to 1 mm. from the center line of force in the grips did not appreciably affect the shear values.

3. Dry shear strengths were sufficiently reduced by an increase in the span between the two sets of jaws that care should be taken at each test to adjust the machine so that the full length of the upper jaws is in contact with each specimen.

4. Side-play in the grips of as much as 1 mm. had little or no effect on the shear-strength values.

5. The force with which the jaws were tightened had only a slight effect on the shear-strength results but enough to justify the attempt to tighten the jaws always to about the same extent.

6. Variation in the rate of loading from 400 to 1,600 pounds per minute were not important.

7. The practical conclusion from the results of tests on specimens made with and without sloping grain in the face plies is that only straight-grained veneer should be employed for the face plies of shear test specimens used for testing the quality of glues in dry joints. Sloping grain in the face plies puts the glued joint to a less or more severe test depending on the slope of grain and the location of the saw cuts with respect to the direction of slope.

8. It is desirable that the depth of the saw cuts in the shear-test specimens be controlled, since variations in the depth of the saw cuts resulted in important variations in shear-strength values. Small variations in width of saw cut were not important.

9. Variations in moisture content of the veneer at the time of gluing had no important effect on the shear strength providing the moisture content was within the range required for good glue bonds.

10. Because the shear strengths were greatly affected by the moisture condition of the specimens at time of testing, the necessity for careful control of moisture content of the specimens at the time of testing is indicated.

11. The average shear strength of the specimens from some panels were importantly and significantly different than those from other panels similarly glued and constructed for the same set. This indicates the desirability of carefully matching face plies of comparative panels and of testing an equal number of specimens from each panel for every testing variable being investigated.

12. In 9 different experiments in this study the averages of the shear strengths of the control specimens (each average based on 20 specimens, 2 from each of 10 panels) fell with ± 6 pounds of 629 pounds per square inch. From this it may be concluded that excellent precision can be obtained in this plywood shear test by carefully controlling all influencing variables.

Table 1.--Average shear test results obtained on three-ply 3/16-inch birch plywood specimens tested with the upper and lower jaws in and out of vertical alignment

Alignment of upper jaws to left or right of lower jaws[1]	Machine No. 1		Machine No. 2	
	Tested dry[2]	Tested wet[3]	Tested dry[2]	Tested wet[3]
2 mm. to left	[4]435-28	[4]431-100	[4]423-34	[4]446-100
1 mm. to left	456-26	446-100	493-28	448-100
1/2 mm. to left	475-40	466-100	510-30	442-100
Centered above lower jaws	534-37	464-100	542-38	452-100
1/2 mm. to right	578-36	462-100	609-52	470-100
1 mm. to right	616-59	464-100	634-45	464-100
2 mm. to right	654-43	469-100	658-58	478-100
Average	535-38	457-100	553-41	457-100

[1] The lower jaws were centered in the grips; the upper jaws were centered directly above the lower jaws or offset to the operator's left or right. The specimen was placed in the jaws with the upper saw cut to the operator's left.

[2] Conditioned to equilibrium in air of 80° F. and 65 percent relative humidity before testing.

[3] Specimens boiled in water 3 hours, cooled and tested wet.

[4] The first value is the joint strength in pounds per square inch; the second is the wood failure in percent. Each value in the table is the average of 12 tests.

Table 2.--Average results of shear tests on matched three-ply 3/16-inch birch plywood specimens tested dry with the upper and lower jaws in and out of vertical alignment and the upper saw cuts on the left and right of the operator

Alignment of upper jaws[1]	Position of upper saw cut	
	At operator's left	At operator's right
1 mm. to left of lower jaws......	[2]573-100	[2]698-100
Centered above lower jaws........	628-100	657-100
1 mm. to right of lower jaws.....	698-100	586-100

[1]Lower jaws centered in grips.

[2]The first value is the average joint strength in pounds per square inch; the second is the average wood failure in percent. Each value is the average of 20 tests.

Table 3.--Average results of shear tests on thee-ply 3/16-inch birch plywood specimens at three moisture contents tested with the upper and lower jaws of the testing machine in and out of alignment

Alignment of upper jaws[1]	Moisture content of specimens (percent)		
	5.3	8.8	10.2
1 mm. to left of lower jaws......	[2]459-100	[2]573-100	[2]652-100
Centered above lower jaws........	544-100	628-100	707-100
1 mm. to right of lower jaws.....	581-100	698-100	774-100

[1]The lower jaws were centered in the grips.

[2]The first value is the average joint strength in pounds per square inch; the second value is the average percentage of wood failure. Each value is the average of 20 tests.

Table 4.--Averaged results of shear tests of three-ply 3/16-inch birch plywood specimens tested with jaws of the testing machine different distances apart and with jaws in and out of alignment

Distance between upper and lower jaws	Position of jaws as shown in figure 4	Alignment of upper jaw		
		1 mm. to operator's left	Centered above lower jaws	1 mm. to operator's right
Inches				
1-1/4	A	[1] 541-100	624-100	701-100
1-3/4	B	490-100	513-100	518-100
2-1/4	C	502-100	538-100	563-100

1 The first value is the average joint strength in pounds per square inch; the second is the average wood failure in percent. Each value is the average of 20 tests.

Table 5.--Averaged shear test results on three-ply 3/16-inch birch plywood specimens tested dry with different amounts of side play between the upper grips and the side plates

Side play	Shear strength	Wood failure
Mm.	P.s.i.	Percent
0.00	630	100
.10	624	100
1.00	635	100

Table 6.--Average shear test results on three-ply 3/16-inch birch plywood specimens teated in a plywood shear testing machine at three different rates of loading

Rate of loading	Shear strength	Wood failure
Pounds per minute	P.s.i.	Percent
400	631	100
800	632	100
1,600	615	100

Table 7. --Average shear test results obtained on three-ply 3/16-inch birch plywood specimens prepared with main of face plies without slope and with slopes of 1:10 and 1:5

Slope of grain of face plies	Saw cut[1]	Alignment of jaws[2]		
		1 mm. to left of lower jaws	Centered above lower jaws	1 mm. to right of lower jaws
Tested dry after conditioning at 80° F. and 65 percent relative humidity				
No slope	A[3]	[4]572-100	[4]623-99	[4]695-100
No slope	B[3]	574-97	634-94	703-100
[5]1:10	A	469-100	552-100	606-100
[5]1:10	B	700-44	760-51	796-36
[5]1:5	A	388-100	435-100	470-100
[5]1:5	B	445-56	554-28	571-50
Tested wet after soaking in boiling water for 3 hours				
No slope	A[3]	464-100	474-100	489-100
No slope	B[3]	470-100	480-100	491-100
[5]1:10	A	428-100	433-100	440-100
[5]1:10	B	484-100	499-100	497-100

[1]For the significance of A and B, see figure 2.

[2]The lower jaws were centered in the grips.

[3]Since there was little or no slope to the face grain, the distinction between A and B in these cases was slight.

[4]The first value is the average shear strength in pounds per square inch; the second is the average wood failure in percent. Each value is the average for 10 specimens.

[5]The grain was parallel to the edges of the specimen, but at an angle with the glue line.

Table 8. --Average shear test results on three-ply 3/16-inch birch plywood specimens cut with a swage-set saw to three different depths

Depth of saw cut	Shear strength	Wood failure
	P.s.i.	Percent
Through the face ply but not into the core..........	659	100
Through the face ply and two-thirds through the core.....................	630	100
Through the face ply and core but not beyond the second glue line..........	560	100

Table 9.--Average shear-test results on three-ply 3/16-inch birch plywood specimens with saw cuts of two different widths

Width of saw cut	Urea-resin glue		Thermoplastic-resin glue	
	Dry	Wet	Dry	Wet
Inches				
3/32	[1]393-29	[1]445-16	[1]712-95	[1]478-86
5/32	389-25	454-6	716-100	492-83

[1]The first value is the average shear strength in pounds per square inch; the second value is the average wood failure in percent. The values are averages for 10 to 15 specimens.

Table 10. --Average shear strengths obtained on three-ply 3/16-inch birch plywood specimens after conditioning at various humidities, soaking, and boiling in water

Exposure conditions		Birch sapwood		Birch heartwood	
Temperature	Relative humidity	Moisture content at time of testing	Shear[1] strength	Moisture content at time of testing	Shear[1] strength
° F.	Percent	Percent	P.s.i.	Percent	P.s.i.
80	30	5.2	494	5.2	512
80	65	8.7	592	8.3	634
80	80	11.3	676	12.3	722
80	90	17.1	656	16.5	682
80	97	18.7	640	18.3	625
Soaked in water 48 hours		....	504	....	520
Boiled in water 3 hours		....	469	....	488

[1] The strength values are averages for 20 specimens. All specimens broke with 100 percent wood failure.

Table 11.--Average shear-test results obtained in specimens of three-ply 3/16-inch birch plywood, prepared from veneer conditioned to equilibrium with air at 80° F. and 30, 65, and 80 percent relative humidity. The specimens were tested after conditioning in air at 80° F and 30, 65, and 80 percent relative humidity

Relative humidity of air at which veneer was conditioned at time of gluing	Relative humidity at which plywood specimens were conditioned at time of testing					
	30 percent		65 percent		80 percent	
	Moisture content at testing	Shear[1] test values	Moisture content at testing	Shear[1] test values	Moisture content at testing	Shear[1] test values
Percent	Percent		Percent		Percent	
			Glued with melamine glue			
30	5.1	477-99	9.3	572-100	13.5	674-100
65	5.7	497-99	9.5	580-99	13.6	688-100
80	5.9	452-91	10.4	513-93	13.8	590-93
			Glued with urea-resin glue			
30	....	417-94	....	435-100	....	537-98
65	....	417-94	....	477-98	....	517-98
80	....	436-97	....	476-95	....	520-100

[1] The first value is the average joint strength in pounds per square inch; the second is the average percentage of wood failure. Each value is the average from 20 specimens.

Table 12.--Average shear-test results obtained on three-ply 3/16-inch birch plywood specimens, glued with melmine and with urea glues, conditioned to equilibrium with air at 80° F. and 80 percent relative humidity, but tested after various periods of exposure to air at 80° F. and 30 percent relative humidity

Length of exposure to 80° F. and 30 percent relative humidity before testing	Arrangement of specimens during exposure to air of 30 percent relative humidity	Tested dry after exposure to 80° F., 30 percent relative humidity		Tested wet after boiling 3 hours
		Glued with: urea resin	Glued with melamine resin	Glued with melamine resin
Minutes				
0	Individually separated	[1] 513-100	[1] 618-100	[1] 472-97
10	..........do..........	508-100	613-98	470-90
20	..........do..........	477-100	549-96	463-96
40	..........do..........	463-99	564-91	471-95
60	..........do..........	465-98	556-97	454-89
120	..........do..........	473-99	531-96	469-93
240	..........do..........	460-99	514-99	482-90
240	Stacked solid.........	477-99	543-92	448-92

[1] The first value is the average joint strength in pounds per square inch; the second value, the average percentage of wood failure. Each value is the average for 20 specimens.

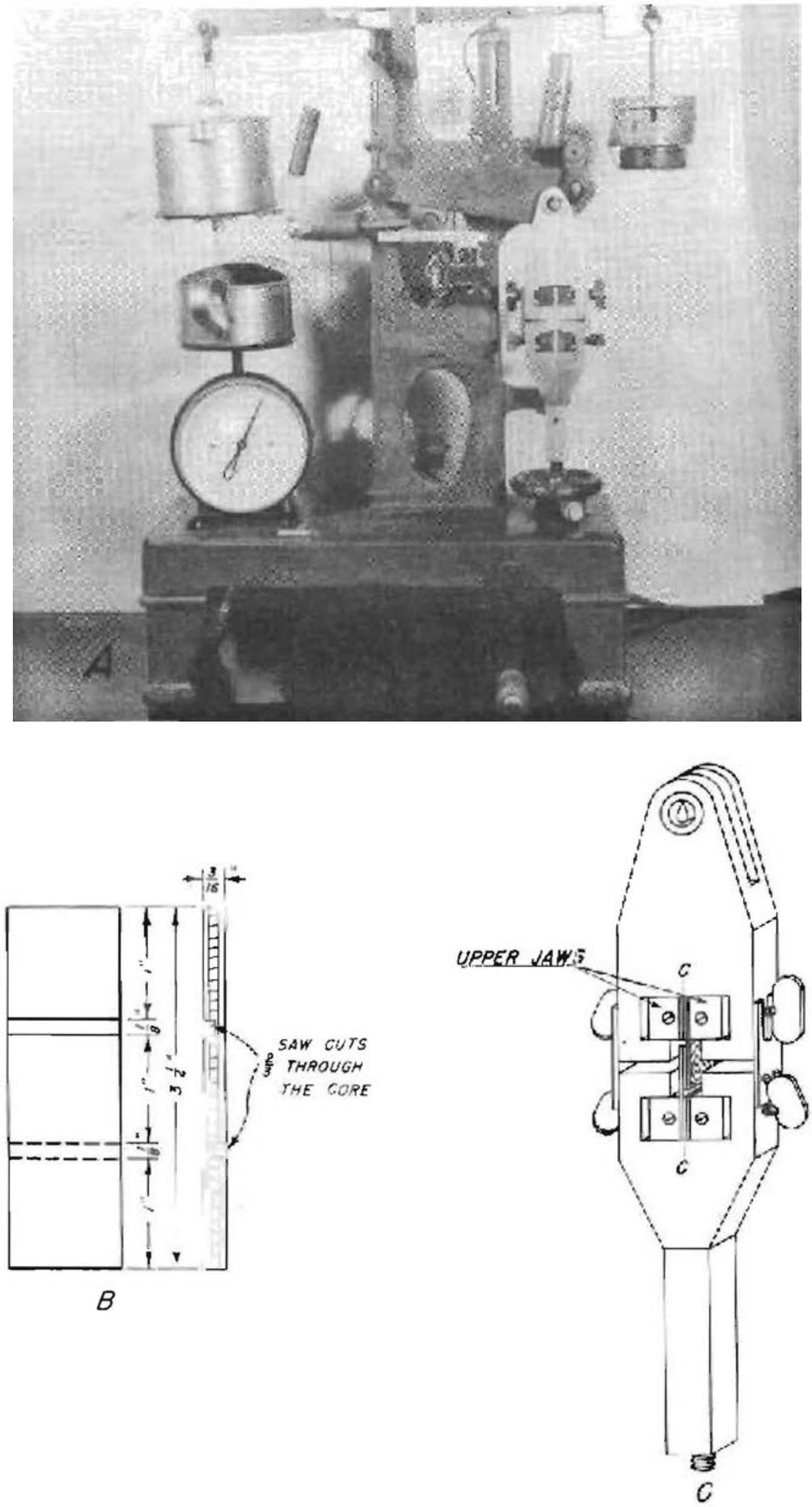

Figure 1.--Plywood joint test: (A) Plywood shear testing machine; (B) diagram of the standard shear test specimen; (C) shear test grips.

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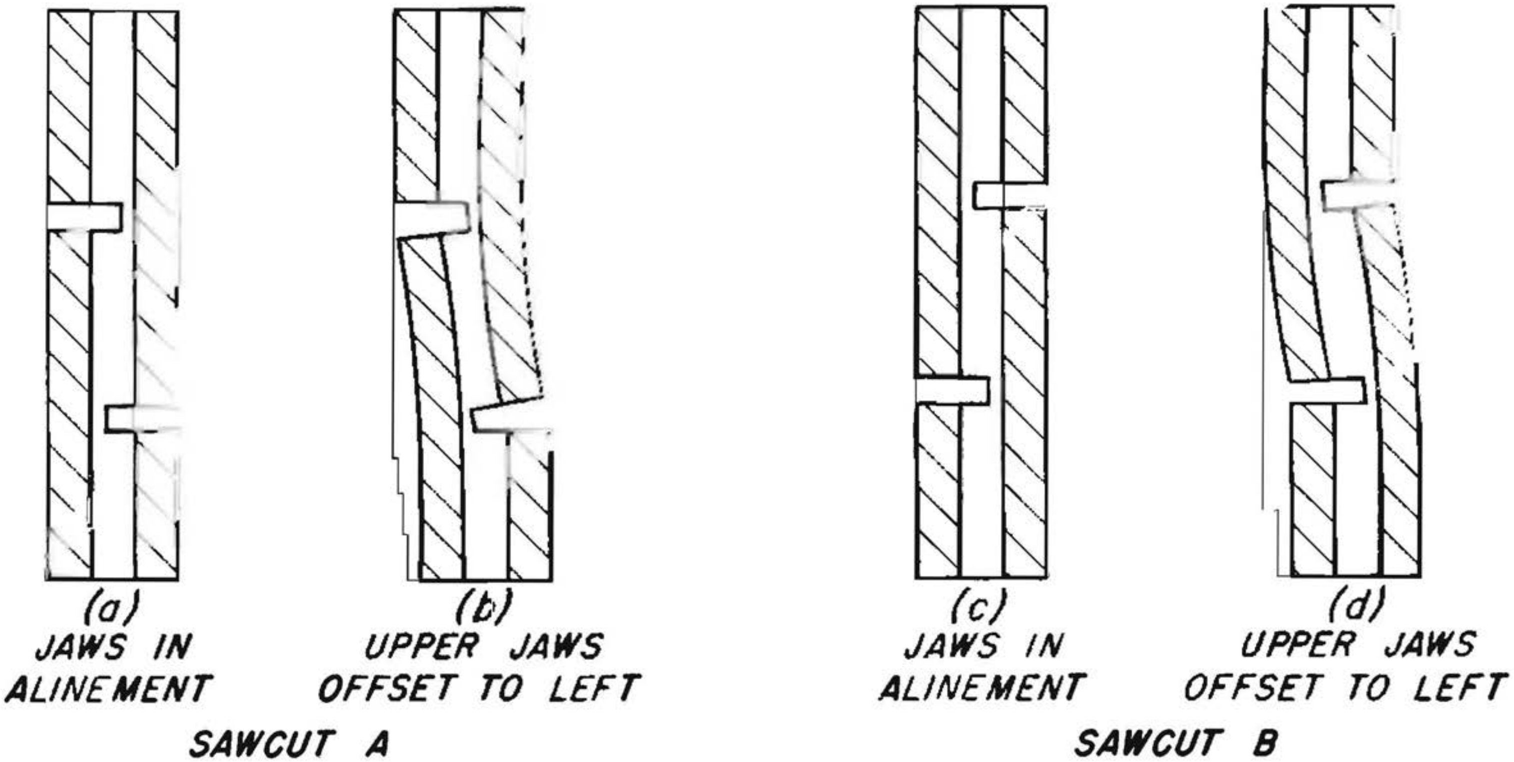

Figure 2.--Two combinations of positions of sawcuts and grain slope (indicated by sloping lines) in face plies of three-ply plywood specimens. In (b) and (d) is illustrated the distortion of the sawcuts caused by misalinement of the upper and lower jaws.

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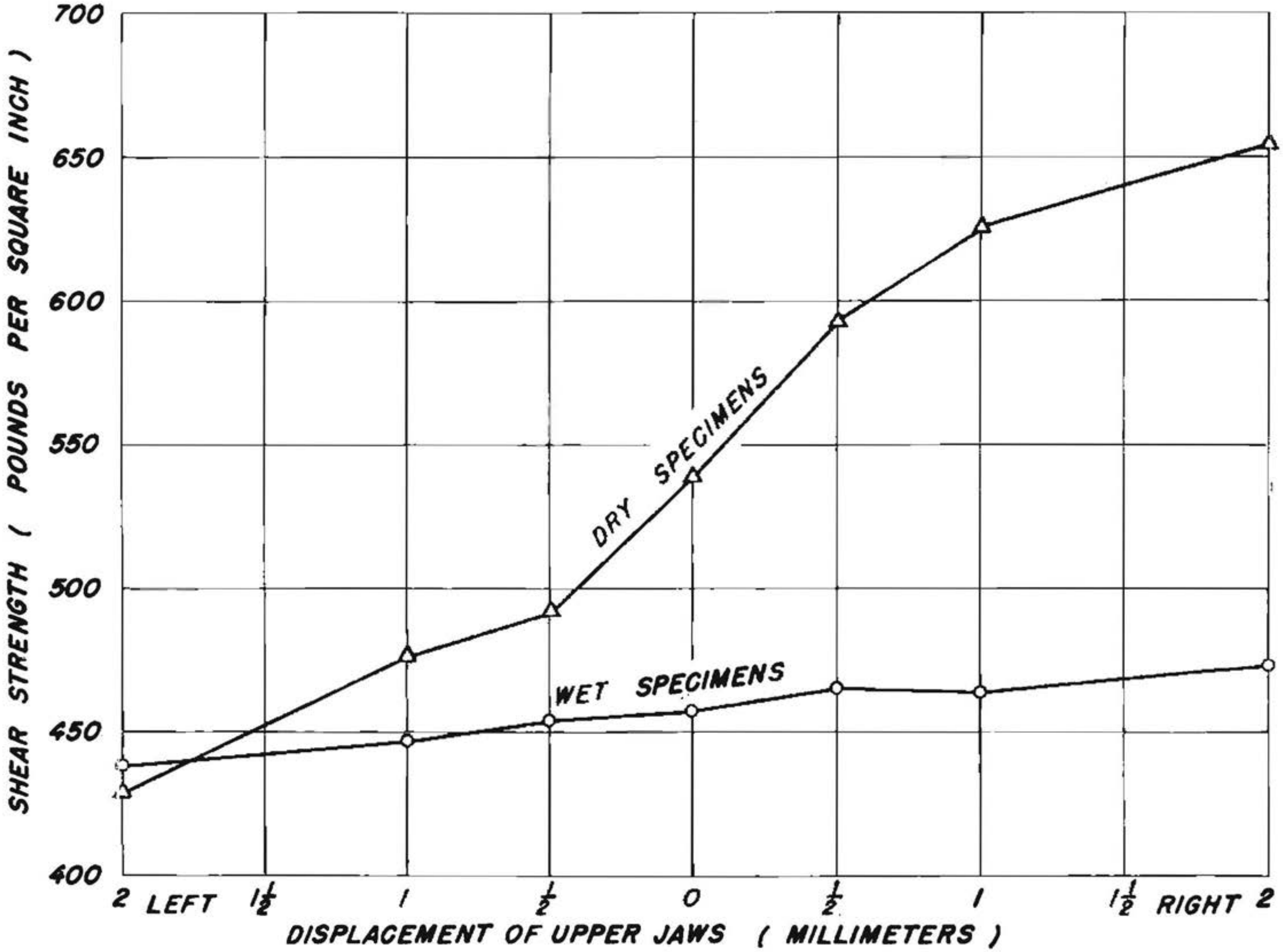

Figure 3.--Shear strength values obtained on wet and dry three-ply 3/16-inch birch plywood specimens tested with the upper jaws in and out of alinement with the lower jaws. The specimens were placed in the machine with the sawcuts to the upper left and lower right as seen by the operator (fig. 28).

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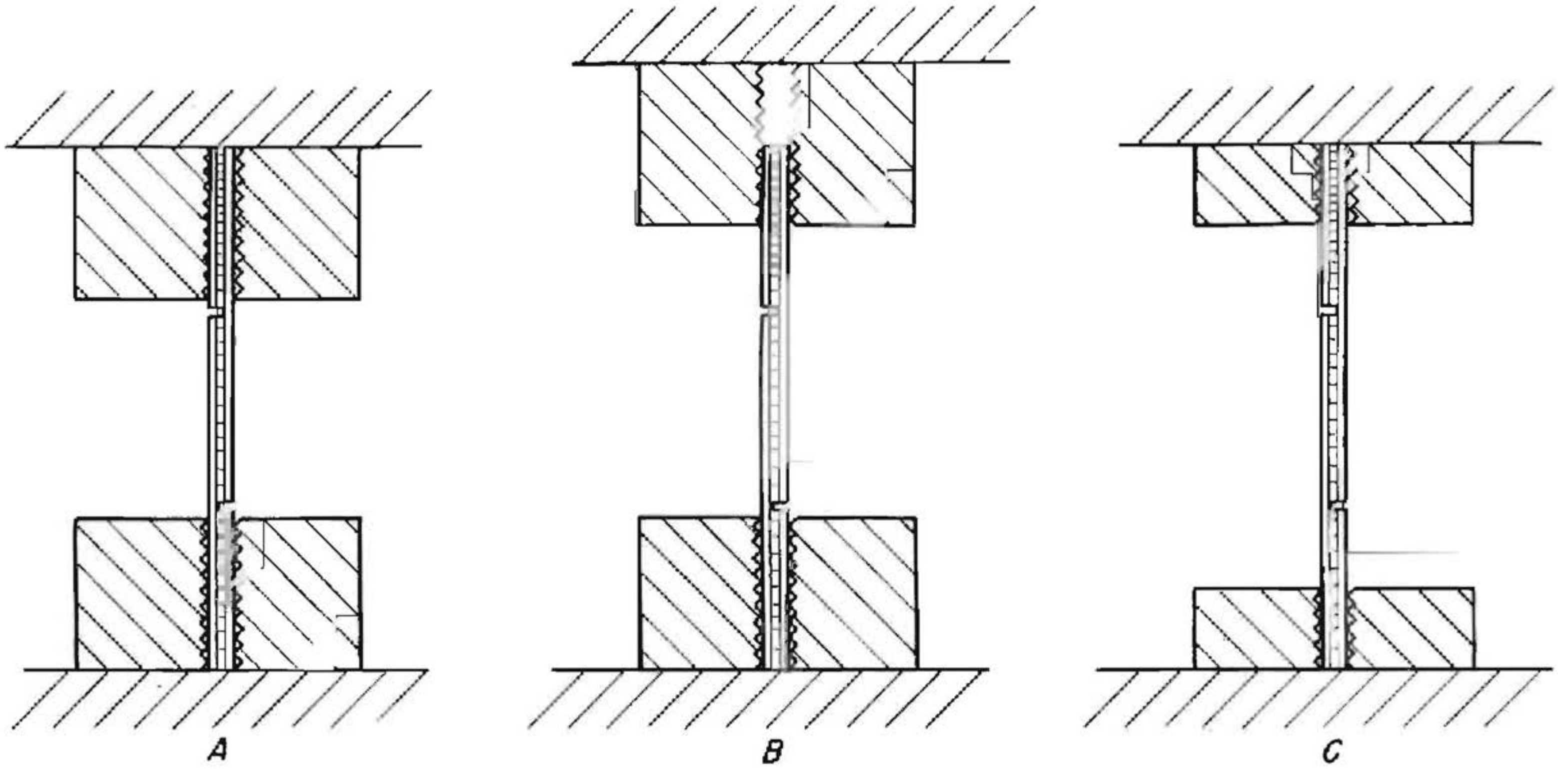

Figure 4.--Diagrammatic sketch of the three conditions of the grips in Experiment 3.

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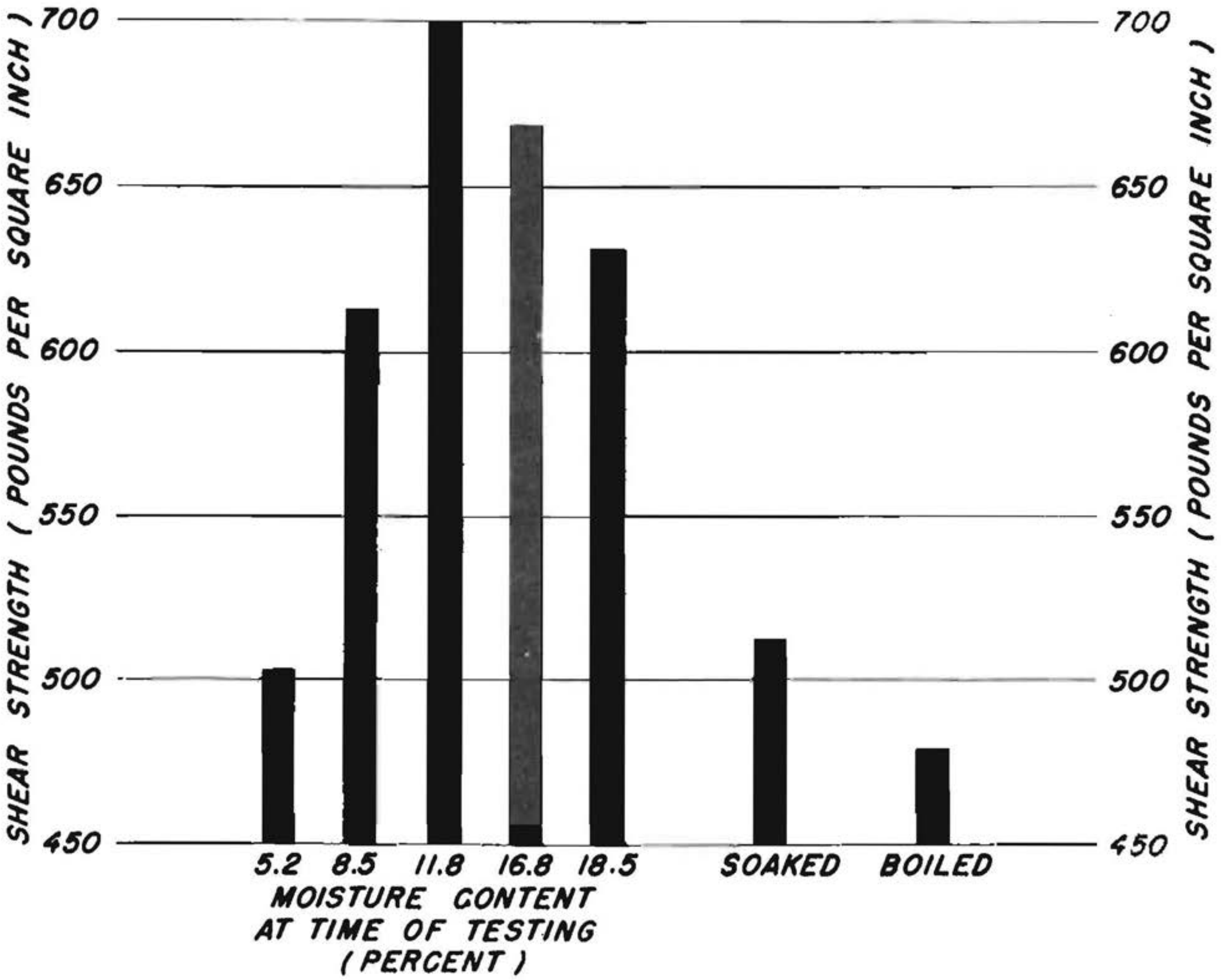

Figure 5.--Average shear strength values obtained on three-ply 3/16-inch plywood made of birch veneer conditioned to equilibrium at 80° F. and 65 percent relative humidity, tested at various moisture contents and after soaking and boiling in water.

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