Supplement to

COMPRESSION, TENSION, AND SHEAR TESTS ON
YELLOW-POPLAR PLYWOOD PANELS OF SIZES
THAT DO NOT BUCKLE WITH TESTS MADE AT
VARIOUS ANGLES TO THE FACE GRAIN

SHEAR TESTS

INFORMATION REVIEWED
AND REAFFIRMED
1962

InformationReviewedandReaffirmed
March 1966

No. 1328-C
SHEAR TESTS\textsuperscript{1}

By

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Summary

Incorporated in this report are the results of three series (A, B, and C) of shear strength tests on 367 yellow-poplar plywood panels that did not buckle before failure. The angle between the edge of the panel and the direction of the face grain (figs. 35 and 36)\textsuperscript{3} varied from +45° to -45°, by 15° increments. The angle was taken as positive in the counterclockwise direction.

In series A, two thicknesses of veneer (1/16 and 1/32 inch) were used in fabricating the plywood. The 1/16-inch veneers were made into plywood of three, five, and seven plies. The 1/32-inch veneers were made into plywood of five, seven, and nine plies. In series B and C, 1/16-inch veneers were made into five-ply plywood. The veneers were laid with the grain of adjacent plies at right angles and a phenolic resin film glue was used as the bonding agent.

Three different methods of test were used, one in series A; all three methods were compared in series B, and an additional comparison between the first and third methods was made in series C.

\textsuperscript{1}This report 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. Original report published 1945.

\textsuperscript{2}Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

\textsuperscript{3}The figures and table numbers of this report are consecutive to those of the previous reports of this series, 1328-B and 1328-A.
The shear strength of the plywood tested, whether made of either 1/16-inch or 1/32-inch veneers, did not vary appreciably with the number of plies.

The plywood made of 1/32-inch veneers showed a higher shear strength than the corresponding plywood made of 1/16-inch veneers for all angles of the grain except +45° and -45°. The shear strengths at these angles were about equal for the two thicknesses of veneer.

Minimum shear strength values were obtained when the face grain of the plywood was parallel or perpendicular to the sides of the panel.

The method of test employed affects the magnitude of the shear strength, especially when the direction of the face grain is +45° or -45° (figs. 35 and 36) to the edge of the panel. The effect is negligible when this angle is 0°.

The revised apparatus yields stress-strain curves that are more normal in appearance than those obtained with the original apparatus.

Introduction

Because of the use of plywood for structural purposes, particularly in aircraft, it is desirable to determine its strength at various angles to the face grain. This report presents data obtained from three series (A-B-C) of shear tests made on panels of such size that they did not buckle before failure. The specimens in series A were matched to specimens that were tested in compression and tension. The results of the compression and tension tests are discussed in previous reports of this series. The specimens of series B and C were not matched to those in series A, but were tested to determine differences in the experimental techniques used. It is the purpose of this report to present the shear test data; with such conclusions as can be drawn from them alone.

Material

Series A

The veneers used in this series were rotary cut from a single yellow-poplar log and were selected from a restricted region in that log. The veneers were cut in two thicknesses, 1/16 and 1/32 inch.
The plywood was fabricated from these veneers by the hot-press method using a phenolic-resin film glue as the bonding agent. Each panel was made of veneers of a single thickness. The 1/16-inch veneers were made into 24- by 24-inch panels of three, five, and seven plies, and the 1/32-inch veneers into similar panels of five, seven, and nine plies. The veneers were made into plywood panels 24 inches square to provide sufficient material for a series of compression, tension, and shear tests on matched plywood. Prior to the shear tests, portions of the 24-inch square panels were used to provide specimens for the compression and tension tests, the results of which have been discussed in previous reports of this series. The remaining portions of the panels were retained for the tests for this report.

The panels made of 1/16-inch veneers and those made of 1/32-inch veneers were divided into three groups according to the number of plies. Each of these groups was subdivided into seven smaller subgroups designated A to G inclusive, according to the angle at which the shear stress was applied.

All specimens of subgroup A were cut so that the angle between the edge of the panel and direction of face grain was +45°, measured from the edge of the panel. In subgroup B, the face grain was at +30° to the edge of the panel, C at +15°, D at 0°, E at -15°, F at -30°, and G at -45°.

Figures 35 and 36 illustrate, for each of the subgroups, the direction of the face grain with respect to a particular edge of the panel, also the direction in which load was applied by the testing machine.

The specimen number is a key to its classification, for example, the number of specimen 5-D-1 indicates:

<table>
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<th>Number of plies</th>
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<tr>
<td>Subgroup</td>
<td>D (face grain parallel to edge of panel)</td>
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<tr>
<td>Panel number</td>
<td>1 in subgroup D</td>
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</table>

The letters CP in the subgroup classification denote a control panel. No distinction was made for veneer thickness. Hence, one panel made of 1/16-inch veneer and another of 1/32-inch veneer have the same number.

All veneers making up the plywood tested in this series were conditioned at a relative humidity of 65 percent and at a temperature of 24° C. (75° F.) to bring the veneers to the moisture content necessary for hot pressing. Likewise, all the test specimens were subjected to the same conditions before and during test. The length of time that specimens were retained in the conditioning room depended upon their size and thickness.

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Series B and C

Veneers used in these series were rotary cut from a different yellow-poplar log from those of series A. The procedure for fabrication into panels, marking, and conditioning was the same as for veneers in series A.

Type of Specimen and Apparatus

Series A

Figure 37 illustrates the apparatus and type of specimen used in tests of series A. The method of test illustrated has been described elsewhere.4

Four hard maple blocks were glued to each face of the panel to be tested and thus formed a rectangular frame on each face. Four holes were drilled through the blocks and the plywood. Pins, with rollers, were then inserted in the holes. The location of such pinholes allowed a portion of the rollers to extend beyond the ends of the maple blocks, and thus provided clearance for contact between the rollers and V-shaped loading blocks mounted in the testing machine. The force exerted by the testing machine on the specimen was transmitted through the rollers and pins to the maple blocks which in turn exerted shearing forces on the plywood along the inner edges of the blocks.

Two extensometers of 1-inch gage length, one on each side of the panel, were used to measure deformations.

Series B

This series included three groups of tests.

In group 1 the type of specimen and apparatus was identical to those of series A. Group 2 was also identical to series A except that the pinholes were moved away from the inner edge of the blocks so that the vertical distance between holes was approximately equal to the length of the diagonal of the panel.


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In group 3, use of the revised apparatus (figs. 38 and 39 eliminated the need for holes in the specimen and located the centers of the rollers directly opposite the inner edges of the blocks.

The revised apparatus consisted of four pairs of steel plates with a solid steel roller attached to the outside face of each plate. Each plate also had two shoulders projecting out from the inside face. When the plates were clamped to the blocks on the panel, the shoulders extended over the ends and the inner edge of the blocks. Wood wedges were inserted between shoulders at the ends of the plates and the sides of the panel, to insure good contact between the shoulders on the plates and the inner edges of the blocks (fig. 38). Load applied by the testing machine passed through the rollers to the steel plates which in turn transmitted the load to the blocks and plywood by means of the shoulders on the plates.

This apparatus was designed primarily to eliminate holes through the panels. In series A, a majority of the failures had their inception at the pinholes, thus giving weight to the belief that the values of shear strengths obtained in this series are not accurate.

Series C

This series included two groups of tests, numbered 1 and 3. The apparatus used in each of these groups was the same as for groups 1 and 3 in series B, except that the extensometers were different.

The extensometers used in series C were designed especially for these tests. Calibration of these extensometers was made with an optimeter using a National Bureau of Standards extensometer comparator. The extensometers were found to be less than 2 percent in error.

Test Procedure

Series A

Figure 37 shows a specimen in the testing machine prior to test. The specimens in series A were tested in a mechanical screw-gear testing machine of 30,000 pounds capacity.

Prior to test, the approximate ultimate load was computed for each specimen and increments of load determined on this basis. Increments of load were chosen such that a sufficient number of points were obtained for a well defined load-deformation curve.
Load was applied continuously throughout the test with a uniform motion of the movable head of the testing machine equal to 0.005 inch per inch of length of the diagonal of the specimen per minute.4

The extensometers were attached to the specimen and centered both horizontally and vertically. Figure 37 shows how the gages were held in place.

The specimen was then placed in the testing machine and the movable head lowered until uniform contact was obtained on all eight rollers. An initial load was applied to the specimen and zero readings were taken on the extensometer. The initial load was equal to one-half of the load increments to be used during test. Load was then applied until failure occurred. Readings of deformation were taken for each increment of load up to the limit of the range of the gages.

In some tests, especially those in which the face grain of the specimen was parallel to one of its diagonals, it was necessary to remove the gages before maximum load was reached. Had this not been done, sudden failures of the specimens would have resulted in damage to the gages.

Series B and C

The specimens in series B and C were tested in a hydraulic testing machine of 10,000 pounds capacity. Testing procedure for these tests was the same as for series A, except that in series C the usual extensometers were replaced with an especially designed type of extensometer (fig. 38) having a much greater range.

Tables and Figures

Tables 18, 19, and 20 contain summaries of the test results of series A, B, and C, respectively. Columns with the same heading on each table have been given the same column number.

Table 1 identifies each specimen. Moisture content and specific gravity based on oven-dry weight and volume at time of test are in columns 2 and 3, respectively. Column 4 gives values of proportional limit in shear. In column 5 are the values of shear strength. Values of shear modulus of elasticity are in column 6.

Figures 35 and 36 are sketches showing the direction of the face grain in the different subgroups of series A. These sketches apply also to series B and C if the subgroup designations shown in the sketches are ignored.

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Figure 37 shows the type of specimen and apparatus used for the tests of series A, and for groups 1 and 2 of series B. Figure 38 illustrates the revised apparatus used for the tests of group 3 in series B and C.

Figure 39 shows the position of the rollers with respect to the inner edges of the blocks in the revised apparatus.

Figure 40 shows the type of specimen and apparatus used for the tests of group 1 in series C.

Figure 41 shows typical failures of specimens of identical construction obtained by the three different methods of test.

Graphs illustrating the variation in shear strength and in proportional limit in shear of yellow-poplar plywood subject to shearing forces applied at various angles to the face grain are shown in figures 42 and 43, respectively. The angles shown are those between the edge of the panel and the direction of face grain (figs. 35 and 36). The data plotted is for series A and was taken from table 18.

Figure 44 shows the effect of veneer thickness on the shear strength of yellow-poplar plywood subject to shearing forces applied at various angles to the face grain. These graphs were taken from figure 42 and plotted together for comparative purposes.

Figure 45 presents graphs illustrating the variations in shear strength obtained by three different methods of applying shear forces at various angles to the face grain of the plywood. The data plotted are for series B and C and were taken from tables 19 and 20. Values plotted in curve 1 are the averages of values from group 3 of series B and C. Curve 2 represents the averages of values from group 1 of series B and C. Average values plotted for curve 3 are from series B, group 2.

Figures 46 to 51, inclusive, contain stress-strain curves for the tests of series A. Because of the relatively short range of the type of extensometer used in these tests, the complete curves were not obtained. The shear strength for each specimen is labeled at the end of its curve.

Figure 52 contains stress-strain curves for the tests in group 3 of series B, and figure 53 stress-strain curves from tests of group 3 of series C. These two sets of curves are from those tests in which the revised apparatus was used.
Analysis of Results

Series A

The variation in shear strength of yellow-poplar plywood subject to shearing forces applied at various angles to the face grain is illustrated in figure 42, in which data from tests on plywood made of 1/16- and 1/32-inch veneers are plotted.

These graphs show that for the plywood tested, the shear strength decreases to a minimum as the angle between the face grain and the edge of the panel (figs. 35 and 36) varies from -45° to 0°. With a variation in angle from 0° to +45° the shear strength increases.

Examination of the failures of the specimens tested at angles of +45° and -45° reveals that 50 percent of the failures originated at the pinholes and, for the -45° specimens, followed the face grain of the specimen. Therefore the values of shear strength obtained at these angles may be low.

This type of failure was also present in some of the specimens tested at other angles. Here again there is reason to believe that the type of failure materially affected the results obtained. Measures taken to remedy this type of failure are discussed later under "series B."

Graphs of the variation in proportional limit in shear (fig. 43) show that the trend is analogous to that of variation in shear strength (fig. 42). Despite the similarity between the two sets of graphs, those for proportional limit in shear exhibit much more spread than those for shear strength. The apparent erratic pattern of the proportional-limit graphs may be better explained by referring to the stress-strain graphs in figures 46 through 51. For the angles +45°, +30°, -30°, and -45° practically all the stress-strain graphs turn upward instead of following the course of a normal stress-strain graph. The stress at which any one of these graphs turns upward may or may not be the proportional limit, but it is the point beyond which the ratio of stress to strain is no longer constant. The abnormal behavior of the stress-strain curves probably indicates that the specimens were not subjected to pure shear stresses throughout their volumes and that much reliance cannot be placed upon the values of the modulus of elasticity which were obtained in shear.

In the plots of these "proportional-limit" stresses (fig. 43) the values for angles of +45° and -45° are apparently not in line with the stress values at other angles.
The effect of veneer thickness upon the shearing strength of the plywood is best illustrated in figure 44. For five-ply plywood made of 1/16- and 1/32 inch veneers, the plywood made of the 1/32-inch veneers shows a shear strength approximately 25 percent higher than that for plywood made of 1/16-inch veneers, for all angles except +45° and -45°. For seven-ply plywood made of 1/16- and 1/32-inch veneers, the plywood made of the 1/32-inch veneers has a shearing strength approximately 25 percent higher than that for plywood made of 1/16-inch veneers for angles of +15°, 0°, and -15°. For +45°, +30°, -30°, and -45° the strengths are about the same. A further investigation of this difference is being made.

Series B

In the preceding discussion it was brought out that 50 percent of the failures in series A originated in the pinholes, such failures casting some doubt upon the accuracy of the results obtained. The purpose of the tests in series B was to devise some method, or to revise the apparatus, to circumvent these failures.

Tests in this series are divided into three groups. Group 1 tests were a repetition of the tests in series A using five-ply plywood made of 1/16-inch veneers and were used for comparison with groups 2 and 3 in this series. In group 2 the location of the pinholes was changed. Tests in group 3 were made with the revised apparatus.

In group 2 the pinholes were moved out from the inner edge of the blocks, on lines parallel to the ends of the blocks. Thus, the vertical distance between holes was made approximately equal to the length of the diagonal of the panel.

Moving the pinholes out proved to be a step in the wrong direction. For the angles +45°, +30°, -30°, and -45° (figs. 35 and 36), all specimens had the failures beginning in the pinholes. For angles +15° and -15°, half of the specimens failed at the pinholes; and at 0° none of the specimens had failures beginning at the holes. Furthermore, for all angles except +15° and -15°, the shear strengths in this group were lower than those for similar specimens in group 1.

Results of these tests pointed out the necessity for eliminating the pinholes. For this purpose the testing apparatus was revised. Figure 39 illustrates how the revised apparatus eliminates the need for holes through the panel, yet the location of the rollers permits application of the shearing forces along the glue line at the intersection of the inner edges of the blocks with the face of the plywood. Using this revised apparatus a series of tests (group 3) was conducted on specimens of yellow-poplar plywood matched to that tested in groups 1 and 2.
Data from the tests of group 3 indicate that favorable results were obtained. The type of failure exhibited in the tests was as desired in that it occurred in the plywood along a line parallel to and near the inner edge of one of the blocks.

Series C

Tests in this series were made to gather more data for a comparison of test methods used. Included in this series are two groups of tests on five-ply yellow-poplar plywood made of five thicknesses of 1/16-inch veneer. The groups in this series were numbered to correspond with like tests in series B.

In group 1 the original apparatus was used. Holes were drilled in the panels in the same location as for the specimens of group 1 in series B. In group 3 the revised apparatus was used, thus eliminating the holes.

In those panels which had drilled holes, a majority of the failures originated at the holes. Those specimens tested with the revised apparatus exhibited failures that were representative of the characteristics of the material.

Figure 45 illustrates the variation in shear strength obtained by the three different methods of test. The magnitude of the difference of stress between the different methods of test is greatest at +45° and -45°. At 0° this difference is comparatively small. From this it is quite evident that, with the original apparatus, failures beginning at the pin-holes had a marked effect on the maximum shear stress, especially for +45° and -45°. At 0° there is little to choose between the original and revised apparatus.

Figures 52 and 53 are stress-strain curves of those tests in series B and C in which the revised shear apparatus was used. In comparing these curves with those in figures 46 through 51, it is apparent that the revised apparatus produces better and more consistent results than the original apparatus.

Conclusions

From an analysis of the data of all tests, the following conclusions can be drawn:

1. The shear strength of the plywood tested, whether made of either 1/16-inch or 1/32-inch veneers, did not vary appreciably with the number of plies.
2. The plywood made of 1/32-inch veneers showed a higher shear strength than the corresponding plywood made of 1/16-inch veneers for all angles of the grain except +45° and -45°. The shear strengths at these angles were about equal.

3. Minimum shear strength values were obtained when the face grain of the plywood was parallel or perpendicular to the direction of shear stress.

4. The method of test affects the magnitude of the shear strength, especially when the direction of the face grain is +45° or -45° to the edge of the panel. The effect is negligible when the angle is 0°.

5. The revised apparatus yields stress-strain curves that are more normal in appearance than those obtained with the original apparatus.
Table 18.—Series a point shear tests on roller-pluged plywood loaded at various angles to the face grain.

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<th>Specifying</th>
<th>Proportional</th>
<th>Bearing</th>
<th>Sheer modulus</th>
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### Table

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### Notes

- **Flaminig**: 1.00
- **Beerlite**: 1.00

### Instructions

- Insert angle between the edge of panel and direction of face grain (Fig. 11 and 35).
- Select contact and specific gravity based on density weight and volume of test.
- Marked values indicate that the stress-strain curve turned upward at the indicated stress rather than in the normal manner.
- Values in parenthesis originated from phenolic.
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<td>1.140</td>
<td>21.260</td>
<td>700.0</td>
<td>556 x 10^3</td>
<td>7.1</td>
<td>3.7</td>
<td>1.060</td>
<td>1.050</td>
<td>21.300</td>
<td>715.0</td>
<td>556 x 10^3</td>
<td>7.1</td>
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<td>1.140</td>
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<td>700.0</td>
<td>556 x 10^3</td>
<td>7.1</td>
<td>3.7</td>
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<td>1.050</td>
<td>21.300</td>
<td>715.0</td>
<td>556 x 10^3</td>
<td>7.1</td>
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<tr>
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<td>6.0</td>
<td>1.150</td>
<td>1.140</td>
<td>21.260</td>
<td>700.0</td>
<td>556 x 10^3</td>
<td>7.1</td>
<td>3.7</td>
<td>1.060</td>
<td>1.050</td>
<td>21.300</td>
<td>715.0</td>
<td>556 x 10^3</td>
<td>7.1</td>
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<td>556 x 10^3</td>
<td>7.1</td>
<td>3.7</td>
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<td>1.050</td>
<td>21.300</td>
<td>715.0</td>
<td>556 x 10^3</td>
<td>7.1</td>
</tr>
</tbody>
</table>

**Note:** The table contains data on the shattering and proportional strength of different materials, with columns for history, matrix, proportional strength, and shattering. Each group contains three specimens, with averages calculated for each column. The data is presented in a table format, with columns labeled for specimen number, history, matrix, proportional strength, and shattering. The values are given in a format that allows for easy comparison and analysis.
Table 20.—Series C panel shear tests on 5/16-inch yellow-poplar plywood showing comparative results of two different methods of testing panels of identical construction

<table>
<thead>
<tr>
<th>Specimen No.</th>
<th>Moisture content</th>
<th>Specific gravity</th>
<th>Proportional limit</th>
<th>Shaving limit (in.)</th>
<th>Elastic modulus</th>
<th>Specimen No.</th>
<th>Moisture content</th>
<th>Specific gravity</th>
<th>Proportional limit</th>
<th>Shaving limit (in.)</th>
<th>Elastic modulus</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group A</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Group B</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>363(0°)</td>
<td></td>
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<td></td>
<td></td>
<td>363(0°)</td>
<td></td>
<td></td>
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<td>11-1</td>
<td>6.6</td>
<td>0.35</td>
<td>1.80</td>
<td>2.00</td>
<td>624.0</td>
<td>11-1</td>
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<td>1.80</td>
<td>2.00</td>
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<tr>
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<td>2.00</td>
<td>624.0</td>
<td>2-1</td>
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<td>1.80</td>
<td>2.00</td>
<td>624.0</td>
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<td>1.80</td>
<td>2.00</td>
<td>624.0</td>
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<tr>
<td>Average</td>
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<td>0.35</td>
<td>1.80</td>
<td>2.00</td>
<td>624.0</td>
<td>Average</td>
<td>6.8</td>
<td>0.35</td>
<td>1.80</td>
<td>2.00</td>
<td>624.0</td>
</tr>
</tbody>
</table>

- Moisture content and specific gravity based on oven-dry weight and volume at test.
- Underscored values indicate that the stress-strain curve turned upward at this stress rather than downward in the normal manner.
- Group 1 specimens tested with original apparatus—1/8-inch clearance between plies and inner edges of blocks.
- Group 3 specimens tested with revised apparatus.
- θ is the angle between the edge of panel and the direction of face grain (figs. 35 and 36).
- Failures in these specimens originated in plies.
Figure 35.—Sketch showing the direction of face grain in the panels of subgroups A to D inclusive.
Figure 36.—Sketch showing the direction of face grain in the panels of subgroups E, F, and G.
Figure 37.—Type of specimen, apparatus, and method of applying load for tests in series A and groups 1 and 2 of series B. Extensometers of 1-inch gage length are attached to both faces of the specimen.
Figure 38.--Type of specimen, revised apparatus, and method of applying load for tests in group 3 of series B and C.
Figure 39.--Revised apparatus, showing the position of the rollers with respect to the inner edges of the blocks. This apparatus was used for tests of group 3 in series B and C.
Figure 40.--Type of specimen, apparatus and method of applying load for tests of group 1 series C.
Figure 41.—Typical failures of specimens of identical construction but subjected to three different methods of test: a, original apparatus; b, original apparatus modified (holes moved away from inner edge of blocks); c, revised apparatus.
Figure 42.--Variation in shear strength (series A) of yellow-poplar plywood subjected to shearing forces applied at various angles to the face grain. Top, 1/16-inch veneers; bottom, 1/32-inch veneers.
Figure 43.--Variation of proportional limit in shear in tests (series A) on yellow-poplar plywood at various angles to the face grain. Top, 1/16-inch veneers; bottom, 1/32-inch veneers.
Figure 44.—Effect of veneer thickness on the shear strength of yellow-poplar plywood subjected to shearing forces applied at various angles to the face grain (Series A).

Figure 45.—Variations in shear strength obtained by three different methods of applying shearing forces at various angles to the face grain of the plywood. Plywood was made of five plies of 1/16-inch yellow-poplar veneer.
Figure 46.—Series $A$ panel shear tests on yellow-poplar plywood loaded at various angles to the face grain. Strains were measured on the principal axis of compression. Construction was three plies of $1/16$-inch veneer.
Figure 47.—Series A panel shear tests on yellow-poplar plywood loaded at various angles to the face grain. Strains were measured on the principal axis of compression. Construction was five plies of 1/16-inch veneer.
Figure 48.--Series A panel shear tests on yellow-poplar plywood loaded at various angles to the face grain. Strains were measured on the principal axis of compression. Construction was seven plies of 1/16-inch veneer.

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Figure 49.—Series A panel shear tests on yellow-poplar plywood loaded at various angles to the face grain. Strains were measured on the principal axis of compression. Construction was five plies of 1/32-inch veneer.

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Figure 50.—Series A panel shear tests on yellow-poplar plywood loaded at various angles to the face grain. Strains were measured on the principal axis of compression. Construction was seven plies of 1/32-inch veneer.
Figure 51.--Series A panel shear tests on yellow-poplar plywood loaded at various angles to the face grain. Strains were measured on the principal axis of compression. Construction was nine plies of 1/32-inch veneer.
Figure 52.--Series B, group 3, panel shear tests on yellow-poplar plywood loaded at various angles to the face grain. Strains were measured on the principal axis of compression. Construction was five plies of 1/16-inch veneer.
Figure 53.—Series C, group 3, panel shear tests on yellow-poplar plywood loaded at various angles to the face grain. Strains were measured on the principal axis of compression. Construction was five plies of 1/16-inch veneer.
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