Supplement to
MECHANICAL PROPERTIES OF
CROSS-LAMINATED AND COMPOSITE
GLASS-FABRIC-BASE PLASTIC LAMINATES
March 1953

INFORMATION REVIEWED
AND REAFFIRMED
1959

This Report is One of a Series
issued in Cooperation with the
AIR FORCE-NAVY-CIVIL SUBCOMMITTEE
on
AIRCRAFT DESIGN CRITERIA
Under the Supervision of the
AIRCRAFT COMMITTEE
of the
MUNITIONS BOARD

No. 1821-A

UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE
FOREST PRODUCTS LABORATORY
Madison 5, Wisconsin
In Cooperation with the University of Wisconsin
SUPPLEMENT TO
MECHANICAL PROPERTIES OF CROSS-LAMINATED AND
COMPOSITE GLASS-FABRIC-BASE PLASTIC LAMINATES

By
ALAN D. FREAS, Engineer
and
FRED WERREN, Engineer
Forest Products Laboratory, Forest Service
U. S. Department of Agriculture

Abstract

Methods of predicting the properties of cross laminates and composite parallel laminates were presented in Forest Products Laboratory Report No. 1821. Reported herein are the results of tests on additional composite parallel laminates, together with the results of tests on the computation methods previously presented. The conclusions of the original report are reasonably confirmed by the results of the present study.

Introduction

It was the purpose of this study to supplement the data of the original report by tests on composite parallel laminates of a different type than that originally studied. In this study, facings of from 1 to 11 plies of a fine-weave fabric were applied to a core of a coarser-weave fabric. This type of construction might be employed where it was desired to impart a relatively smooth surface to a laminate made primarily of a coarse-weave fabric.
Material

One 1/4-inch-thick panel of each of three constructions was tested in this study. All panels were made with a core of 162-114 fabric with 1, 6, or 11 plies of 112-114 fabric on each face. The panels were laminated with resin 2, a laminating resin of the polyester (styrene-alkyd) type conforming with the requirements of types I, II, and III of U. S. Air Force Specification 12049. For all panels, the resin was catalyzed with 0.8 percent of benzoyl peroxide by weight.

Fabrication procedures were as described in the original report. Information on the make-up and physical properties of the various panels is given in table 11.

Before the composite panels were fabricated, an attempt was made to obtain 162-114 fabric from manufacturer A, who furnished the 162-114 fabric for the earlier panels. The manufacturer did not have the fabric available at that time, so the material was purchased from manufacturer B. Both manufacturers stated that the 114 finishes were identical and that the fabrics, as obtained from either source, were considered to be the same. Subsequent tests, however, showed that this was not so. Therefore, a 162-114 control laminate was fabricated by using fabric from the same roll as that used in the composite laminates. Fabrication procedures were the same as those used for the composite laminates.

Testing

All test procedures were the same as those described in the original report.

Presentation and Discussion of Results

Average miscellaneous data and test results are given in tables 11, 12, 13, 14, and 15. Control data for the 112-114 laminate and for the shear properties of the 162-114 laminate are from earlier tests of another study. Tension, compression, and bending properties of the 162-114 laminate are from the control laminate made of the same fabric used in the composite laminate. Comparisons of test results with computed results are shown in tables 16 through 20.

---


Report No. 1821-A

-2-
Methods of computing the various properties of the composite laminates from the properties of the components are described in the original report and will not be repeated herein except for the equations.

**Tension and Compression**

**Modulus of elasticity.** -- Modulus of elasticity of composite laminates may be computed from the equation:

\[
E_a = \frac{1}{A} \sum_{i=1}^{n} E_i A_i
\]

where \( E_a \) = modulus of elasticity of the composite laminate
\( A \) = cross-sectional area of the composite laminate
\( E_i \) = modulus of elasticity of the \( i \)th ply in the direction of stress
\( A_i \) = cross-sectional area of the \( i \)th ply.

Values of \( E_i \) were taken from the data for parallel laminates, tables 12 and 13. A comparison of computed and test results is shown in tables 16 and 17. Computed and test values for modulus of elasticity in tension and in compression generally agree within 10 percent.

**Strength properties.** -- Three possible procedures for computing the tensile and compressive strength properties of composite laminates from those of the component materials are represented by the equations:

**Method 1**

\[
S_a = \frac{S_1}{A} \left[ A_1 + \frac{E_2}{E_i} A_2 \right]
\]

**Method 2**

\[
S_a = \frac{S_2}{A} \left[ \frac{E_1}{E_2} A_1 + A_2 \right]
\]
Method 3

\[ S_a = \frac{1}{A} \sum_{i=1}^{n} S_i A_i \]  

where \( S_a \) = strength property of composite laminate

\( S_1 \) = strength property of type 1 layers parallel to direction of stress

\( S_2 \) = strength property of type 2 layers parallel to direction of stress

\( S_i \) = strength property of the \( i \)th ply parallel to stress

\( E_1 \) = modulus of elasticity of type 1 layers parallel to direction of stress

\( E_2 \) = modulus of elasticity of type 2 layers parallel to direction of stress

\( A_1 \) = total cross-sectional area of type 1 layers

\( A_2 \) = total cross-sectional area of type 2 layers

\( A_i \) = cross-sectional area of the \( i \)th ply

\( A \) = total cross-sectional area.

In method 1, the computations were based on the properties of the 112 laminate; that is, \( S_i \) equals the strength of the 112 laminate. In method 2, the computations were based on the strength of the 162 laminate.

Ratios of strength values computed by all three methods to strength values obtained by test are shown in tables 16 and 17.

As was to be expected from the results given in the original report, neither method 1 nor method 2 gives good correlation between computed and test values. By using method 3, there is reasonably good correlation between the tensile values. Compression values are also in reasonable agreement except for the composite laminate with facings of one ply of 112-114 fabric.

Properties in tension at a 45° angle. -- Two methods of predicting the tensile properties of composite laminates at an angle of 45° to the warp direction were discussed in the original report. The first involved the use of the formulas of
Forest Products Laboratory Reports Nos. 1803 and 1803-A, with the
tensile and shear properties of the composite laminates at angles of 0° and
90°. The second was based on using the weighted average of the 45° pro-
perties of the component parallel laminates. Parallel-laminate properties
were weighted according to the proportion of the area occupied in the com-
posite laminate. Results of both methods of computation are shown in table
20.

Both methods, except for stress at proportional limit, give reasonable
correlation between computed and test results in tension, with the second
method being somewhat better. The lack of correlation for stress at propor-
tional limit may be attributed largely to difficulties in accurately locating the
proportional limit.

Discussion of tensile properties. --Previous discussion has mentioned that a
new panel of 162-114 fabric, parallel-laminated, was made to furnish control
values for tension, compression, and bending tests. This was necessary
because the laminates made from the 162-114 fabric from manufacturer B were
appreciably lower in tensile properties than comparable laminates made with
similar fabric from manufacturer A. Other mechanical properties were
reasonably comparable.

In two other instances in tests of plastic laminates, laminates made with
fabric from manufacturer B were appreciably lower in tensile properties than
those made with fabric from manufacturer A. This may be seen by a com-
parison of items 1-3 and 1-13 (128-114 laminates) and items 1-8 and 1-20
(181-114 laminates) in Forest Products Laboratory Reports Nos. 1820-3 and
1820-A. Examination of the data will also show that laminates made with
fabric from manufacturer A were thinner, had a higher specific gravity, and
had a lower resin content.

Analysis of these data indicates that there is apparently some difference
between 114 finish fabrics furnished by the two manufacturers, even though
the materials are supposed to be identical. This difference or variation,
which might be in the finish, substantially affects the tensile properties of
the laminate. Some differences might also be noted in tensile tests of the
fabric, as are shown in the results of tests of 162-114 fabric, table 21.

Static Bending

Modulus of elasticity. -- The modulus of elasticity in static bending may be
computed from:

\[ E_a = \frac{1}{I} \sum_{i=1}^{i=n} E_i I_i \]  

where \( E_a \) = modulus of elasticity of the composite laminate 

\( E_i \) = modulus of elasticity of the \( i \)th ply parallel to span 

\( I_i \) = moment of inertia of the \( i \)th ply about the neutral plane of the laminate 

\( I \) = moment of inertia of the laminate about its neutral plane.

A comparison of computed with test values is shown in table 18.

Strength properties. -- Three possible methods of computing the static-bending-strength properties of the composite laminates from the strength properties of the component materials are represented by the equations:

**Method 1**

\[ f_a = \frac{f_2}{I} \left[ \frac{E_1}{E_2} I_1 + I_2 \right] \]  

**Method 2**

\[ f_a = \frac{f_1}{I} \left[ 1 - \frac{2t_f}{d} \right] \left[ I_1 + \frac{E_2}{E_1} I_2 \right] \]  

**Method 3**

\[ f_a = \frac{1}{I} \sum_{i=1}^{i=n} f_i I_i \]
where \( f_a \) = strength property of the composite laminate

\[ f_1 = \text{strength property of the type 1 layers parallel to span} \]

\[ f_2 = \text{strength property of the type 2 layers parallel to span} \]

\[ f_i = \text{strength property of the } i\text{th ply parallel to span} \]

\[ I_1 = \text{sum of moments of inertia of the layers of type 1 about the neutral plane of the laminate} \]

\[ I_2 = \text{sum of moments of inertia of the layers of type 2 about the neutral plane of the laminate} \]

\[ I_i = \text{moment of inertia of the } i\text{th ply about the neutral plane of the laminate} \]

\[ I = \text{moment of inertia of the composite laminate about its neutral plane} \]

\[ E_1 = \text{modulus of elasticity of the layers of type 1 parallel to span} \]

\[ E_2 = \text{modulus of elasticity of the layers of type 2 parallel to span} \]

\[ \frac{t_f}{d} = \text{ratio of thickness of surface layer to total thickness of laminate.} \]

In method 1, computations were based on the strength of the 112 laminate; that is, \( f_2 \) equals the strength of the 112 laminate. In method 2, computations were based on the strength of the 162 laminate. The value of \( t_f \) was taken as the total thickness of each 112 facing. Results of computations by these methods are shown in table 18.

As was found in the original report, methods 1 and 2 do not give consistently good correlation between computed and test results. Method 3, however, gives generally good correlation except for stress at proportional limit.

**Shear**

The original report showed that reasonably good correlation between computed and test results in shear could be expected by use of the following equation:

\[
F_a = \frac{1}{A} \sum_{i=1}^{i=n} F_i A_i
\]
where $F_a$ = property of composite laminate
\[ A = \text{total cross-sectional area of composite laminate} \]
\[ F_1 = \text{property of } \text{ith ply} \]
\[ A_1 = \text{cross-sectional area of } \text{ith ply}. \]

A comparison of computed and test results is given in table 19. In view of the small number of tests (two per laminate), the correlation is considered satisfactory.

Conclusions

The results of tests of three composite laminates made of 112-114 and 162-114 glass fabrics confirm reasonably well the conclusions of the original report.

The conclusions of the original report were:

(a) The properties of composite or cross laminates stressed in tension or compression parallel or perpendicular to the warp direction may be taken as the average of the properties of the component layers, parallel to stress, weighted according to the proportion of the area they occupy.

(b) The properties of cross laminates or composite laminates stressed in bending parallel or perpendicular to the warp direction may be taken as the average of the properties of the component layers, parallel to span, weighted according to the proportion they contribute to the moment of inertia of the laminate.

(c) The properties of cross laminates or composite laminates stressed in shear with the shear loads applied parallel and perpendicular to the warp direction may be taken as the average of the properties of the component plies when loaded in the same way, weighted according to the proportion of the area they occupy. For cross laminates, the properties are the same as for parallel laminates.

(d) The properties of cross laminates or composite laminates stressed in tension at 45° to the warp direction may be taken as the average of the properties of the component layers, parallel to stress, weighted according to the proportion of the area they occupy. For cross laminates, the properties are the same as for the parallel laminates.

(e) Since the laminates tested involve fabrics having a range of relative strength parallel and perpendicular to warp typical of the range used in aircraft applications, the relations developed should be applicable to any other glass fabrics now being used for aircraft laminates.

Report No. 1821-A
Table 11.--Miscellaneous data relative to composite parallel laminates made of 112-114 and 162-114 fabrics and resin

<table>
<thead>
<tr>
<th>Panel : Number of plies</th>
<th>Specific gravity</th>
<th>Resin content</th>
<th>Barcol hardness</th>
<th>Thickness (In.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>112-114 Control Laminates</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 : 84 : 284 :.........: 1.71 : 43.5 : 69 : 0.250</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 : 84 : 284 :.........: 1.70 : 43.4 : 69 : 0.250</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>162-114 Laminates--for Shear Controls</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>52 : 17 :.........: 217 : 1.76 : 37.7 : 62 : 0.252</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>53 : 17 :.........: 217 : 1.76 : 38.2 : 62 : 0.254</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>162-114 Laminate--for Tension, Compression, and Bending Controls</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>223 : 16 :.........: 216 : 1.72 : 41.0 : 63 : 0.257</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Composite Laminates</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>217 : 18 : 22 : 216 : 1.73 : 41.1 : 69 : 0.262</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>218 : 26 : 226 : 214 : 1.71 : 42.0 : 69 : 0.264</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>219 : 34 : 222 : 222 : 1.71 : 42.0 : 69 : 0.260</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1 Layers of 112-114 fabric formed a facing on a core of 162-114 fabric.
2 One-half the number of plies of 112-114 fabric shown above at each face.
3 Fabric from manufacturer A.
4 Fabric from manufacturer B.
Table 12.—Results of tension tests of parallel laminates made of 112-114 and 162-114 fabrics and resin 2

<table>
<thead>
<tr>
<th>Fabric:Layers of: Direction of: Modulus of elasticity: Stress at:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fabric at: test: Proportional limit: Ultimate:</td>
</tr>
<tr>
<td>each face: Initial:Secondary:</td>
</tr>
<tr>
<td>No.: Degrees: 1,000: 1,000: P.s.i.: P.s.i.: P.s.i.:</td>
</tr>
<tr>
<td>Controls - Parallel-laminated:</td>
</tr>
<tr>
<td>112-114: 0: 45: 90: 2,690: 1,540: 2,640: 2,760: 2,240: 2,290: 11,800: 9,800: 29,500: 27,050: 42,700:</td>
</tr>
<tr>
<td>162-114: 0: 45: 90: 2,760: 1,360: 1,960: 2,760: 1,520: 2,760: 2,440: 7,940: 4,560: 9,840: 5,520:</td>
</tr>
<tr>
<td>Composite Laminates - Parallel-laminated:</td>
</tr>
<tr>
<td>112-114: 1: 45: 90: 6: 0: 2,670: 1,350: 1,960: 2,670: 2,250: 8,120: 4,660: 8,490: 24,500: 12,850:</td>
</tr>
<tr>
<td>162-114: 1: 45: 90: 11: 0: 2,690: 1,530: 2,000: 2,690: 2,240: 8,490: 5,520: 8,490: 24,500: 14,750:</td>
</tr>
</tbody>
</table>

Report No. 1821-A
Table 13.--Results of compression tests of parallel laminates made of 112-114 and 162-114 fabrics and resin 2

<table>
<thead>
<tr>
<th>Fabric</th>
<th>Layers of</th>
<th>Direct-</th>
<th>Modulus of</th>
<th>Stress at --</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>:tion of:</td>
<td>elasticity</td>
<td>Proportional: 0.2 percent: Ultimate</td>
</tr>
<tr>
<td></td>
<td></td>
<td>fabric at:</td>
<td>test:</td>
<td>limit:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>each face:</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>No.:</td>
<td>Degrees</td>
<td>1,000</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>p.s.i.</td>
</tr>
<tr>
<td>Controls - Parallel-laminated</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>112-114</td>
<td>...........</td>
<td>0</td>
<td>2,820</td>
<td>23,250</td>
</tr>
<tr>
<td></td>
<td></td>
<td>90</td>
<td>2,630</td>
<td>21,600</td>
</tr>
<tr>
<td>162-114</td>
<td>...........</td>
<td>0</td>
<td>2,850</td>
<td>11,250</td>
</tr>
<tr>
<td></td>
<td></td>
<td>90</td>
<td>2,100</td>
<td>10,200</td>
</tr>
<tr>
<td>Composite Laminates - Parallel-laminated</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>112-114</td>
<td>...........</td>
<td>1</td>
<td>0</td>
<td>2,810</td>
</tr>
<tr>
<td>162-114</td>
<td>...........</td>
<td>90</td>
<td>1,900</td>
<td>15,700</td>
</tr>
<tr>
<td>112-114</td>
<td>...........</td>
<td>6</td>
<td>0</td>
<td>2,660</td>
</tr>
<tr>
<td>162-114</td>
<td>...........</td>
<td>90</td>
<td>2,020</td>
<td>17,300</td>
</tr>
<tr>
<td>112-114</td>
<td>...........</td>
<td>11</td>
<td>0</td>
<td>2,810</td>
</tr>
<tr>
<td>162-114</td>
<td>...........</td>
<td>90</td>
<td>2,050</td>
<td>17,800</td>
</tr>
</tbody>
</table>

Report No. 1821-A
Table 14.--Results of static-bending tests of parallel laminates made of 112-114 and 162-114 fabrics and resin 2

<table>
<thead>
<tr>
<th>Fabric :Layers of: Direc-</th>
<th>Modulus of : Stress at --</th>
<th>Modulus</th>
</tr>
</thead>
<tbody>
<tr>
<td>: 112-114 :tion of: elasticity :-----------------------------: of</td>
<td></td>
<td></td>
</tr>
<tr>
<td>:fabric at: test : :Proportional: 0.2 percent :rupture</td>
<td></td>
<td></td>
</tr>
<tr>
<td>:each face: : : :limit : offset</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>No.</td>
<td>Degrees</td>
</tr>
<tr>
<td></td>
<td>:</td>
<td>:</td>
</tr>
<tr>
<td>Controls - Parallel-laminated</td>
<td></td>
<td></td>
</tr>
<tr>
<td>112-114 :...........: 0 : 2,590 : 31,000 : 58,250 : 58,250</td>
<td></td>
<td></td>
</tr>
<tr>
<td>: 162-114 :...........: 0 : 2,470 : 17,200 : 32,550 : 35,000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>: : 90 : 1,720 : 11,300 : 22,850 : 26,900</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Composite Laminates - Parallel-laminated</td>
<td></td>
<td></td>
</tr>
<tr>
<td>112-114; : 1 : 0 : 2,690 : 24,550 : 38,600 : 38,800</td>
<td></td>
<td></td>
</tr>
<tr>
<td>162-114: : 90 : 2,000 : 12,200 : 26,250 : 28,800</td>
<td></td>
<td></td>
</tr>
<tr>
<td>112-114; : 6 : 0 : 2,680 : 24,050 : 43,750 : 43,750</td>
<td></td>
<td></td>
</tr>
<tr>
<td>162-114: : 90 : 2,110 : 15,250 : 33,750 : 33,750</td>
<td></td>
<td></td>
</tr>
<tr>
<td>112-114; : 11 : 0 : 2,730 : 28,200 : 54,650 : 55,050</td>
<td></td>
<td></td>
</tr>
<tr>
<td>162-114: : 90 : 2,270 : 14,950 : 36,800 : 37,800</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Report No. 1821-A
Table 15.—Results of panel shear tests of parallel laminates made of 112-114 and 162-114 fabrics and resin 2

<table>
<thead>
<tr>
<th>Fabric</th>
<th>Plies of</th>
<th>Modulus</th>
<th>Stress at --</th>
<th>Stress at --</th>
<th>Stress at --</th>
<th>Stress at --</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>112-114</td>
<td>of</td>
<td>fabric at:</td>
<td>rigidity:</td>
<td>Proportional:</td>
<td>0.2 percent:</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>of each face</td>
<td>limit:</td>
<td>offset:</td>
<td>Ultimate</td>
</tr>
<tr>
<td></td>
<td>No.</td>
<td>1,000 P.s.i.</td>
<td>P.s.i.</td>
<td>P.s.i.</td>
<td>P.s.i.</td>
<td></td>
</tr>
<tr>
<td>Controls - Parallel-laminated</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>112-114</td>
<td>............</td>
<td>660</td>
<td>1,920</td>
<td>4,070</td>
<td>13,600</td>
<td></td>
</tr>
<tr>
<td>162-114</td>
<td>............</td>
<td>580</td>
<td>2,220</td>
<td>4,810</td>
<td>11,700</td>
<td></td>
</tr>
<tr>
<td>Composite Laminates - Parallel-laminated</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>112-114</td>
<td>1</td>
<td>570</td>
<td>2,240</td>
<td>4,930</td>
<td>10,300</td>
<td></td>
</tr>
<tr>
<td>162-114</td>
<td>6</td>
<td>560</td>
<td>2,160</td>
<td>4,580</td>
<td>10,850</td>
<td></td>
</tr>
<tr>
<td>112-114</td>
<td>11</td>
<td>510</td>
<td>2,540</td>
<td>4,850</td>
<td>10,900</td>
<td></td>
</tr>
<tr>
<td>162-114</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 16.—Ratios of computed tensile properties to properties obtained in test

<table>
<thead>
<tr>
<th>Direction</th>
<th>Modulus of elasticity</th>
<th>Stress at proportional limit</th>
<th>Ultimate stress</th>
</tr>
</thead>
<tbody>
<tr>
<td>Degrees:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 Ply of 112-114 Fabric on Each Face</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>1.00 : 1.03 : 1.89 : 1.24 : 1.26 : 1.63 : 1.07 : 1.08 : 1.22 : 1.06 : 1.06</td>
<td></td>
<td></td>
</tr>
<tr>
<td>90</td>
<td>.97 : 1.12 : 1.69 : 1.06 : 1.08 : 1.58 : .87 : .90 : 1.34 : 1.05 : 1.06</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 Plies of 112-114 Fabric on Each Face</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>1.03 : 1.08 : 1.48 : .98 : 1.05 : 1.43 : .94 : 1.01 : 1.20 : 1.04 : 1.06</td>
<td></td>
<td></td>
</tr>
<tr>
<td>90</td>
<td>1.05 : 1.16 : 1.64 : 1.03 : 1.14 : 1.53 : .85 : .99 : 1.25 : .98 : 1.04</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11 Plies of 112-114 Fabric on Each Face</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>1.02 : 1.08 : 1.41 : .93 : 1.06 : 1.22 : .80 : .91 : 1.14 : .99 : 1.03</td>
<td></td>
<td></td>
</tr>
<tr>
<td>90</td>
<td>1.07 : 1.15 : 1.44 : .90 : 1.08 : 1.40 : .78 : 1.00 : 1.22 : .96 : 1.05</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 17.—Ratios of computed compressive properties to those obtained in test

<table>
<thead>
<tr>
<th>Direction</th>
<th>Ratios</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modulus of proportional limit</td>
<td>Stress at 0.2 percent offset</td>
</tr>
<tr>
<td>Method 1: Method 2: Method 3: Method 1: Method 2: Method 3</td>
<td></td>
</tr>
</tbody>
</table>

### Degrees

<table>
<thead>
<tr>
<th>1 Ply of 112-114 Fabric on Each Face</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
</tr>
<tr>
<td>90</td>
</tr>
</tbody>
</table>

### 6 Plies of 112-114 Fabric on Each Face

| 0 | 1.07 | 1.42 | 0.68 | 0.79 | 1.68 | 0.86 | 0.98 | 1.68 | 0.86 | 0.98 |
| 90 | 1.08 | 1.26 | 0.59 | 0.69 | 1.55 | 0.85 | 0.95 | 1.55 | 0.85 | 0.95 |

### 11 Plies of 112-114 Fabric on Each Face

| 0 | 1.01 | 1.40 | 0.67 | 0.86 | 1.59 | 0.81 | 1.02 | 1.59 | 0.81 | 1.02 |
| 90 | 1.10 | 1.22 | 0.57 | 0.75 | 1.43 | 0.78 | 0.96 | 1.43 | 0.78 | 0.96 |
Table 18.—Ratios of computed static-bending properties to properties obtained in test

<table>
<thead>
<tr>
<th>Direction:</th>
<th>Ratios</th>
<th>Modulus of rupture</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Method 1 : Method 2 : Method 3</td>
</tr>
<tr>
<td>Degrees</td>
<td></td>
<td>Method 1 : Method 2 : Method 3</td>
</tr>
</tbody>
</table>

1 Ply of 112-114 Fabric on Each Face

<p>| | | | | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.92</td>
<td>1.21</td>
<td>0.68</td>
<td>0.74</td>
<td>1.44</td>
<td>0.83</td>
<td>0.89</td>
</tr>
<tr>
<td>90</td>
<td>0.89</td>
<td>1.59</td>
<td>0.93</td>
<td>1.01</td>
<td>1.36</td>
<td>0.87</td>
<td>0.94</td>
</tr>
</tbody>
</table>

6 Plies of 112-114 Fabric on Each Face

<p>| | | | | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.94</td>
<td>1.25</td>
<td>0.62</td>
<td>0.93</td>
<td>1.29</td>
<td>0.65</td>
<td>0.97</td>
</tr>
<tr>
<td>90</td>
<td>0.94</td>
<td>1.42</td>
<td>0.73</td>
<td>1.11</td>
<td>1.18</td>
<td>0.66</td>
<td>0.96</td>
</tr>
</tbody>
</table>

11 Plies of 112-114 Fabric on Each Face

<p>| | | | | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.93</td>
<td>1.08</td>
<td>0.46</td>
<td>0.91</td>
<td>1.05</td>
<td>0.45</td>
<td>0.89</td>
</tr>
<tr>
<td>90</td>
<td>0.94</td>
<td>1.57</td>
<td>0.69</td>
<td>1.37</td>
<td>1.17</td>
<td>0.56</td>
<td>1.04</td>
</tr>
</tbody>
</table>
Table 19.--Ratios of computed shear properties to properties obtained from test

<table>
<thead>
<tr>
<th>Construction</th>
<th>Ratios</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>:Modulus : Stress at -- : Modulus : Stress at--</td>
</tr>
<tr>
<td></td>
<td>of : rigidity : Proportional : 0.2 percent : Ultimate</td>
</tr>
<tr>
<td>1 ply of 112-114 fabric on each face</td>
<td>: 1.02 : 0.99 : 0.97 : 1.14 : 1.05 : 1.01 : 1.03 : 1.10</td>
</tr>
<tr>
<td>6 plies of 112-114 fabric on each face</td>
<td>: 1.18 : .84 : .95 : 1.12</td>
</tr>
</tbody>
</table>

Table 20.--Ratios of computed tensile properties, at $45^\circ$ to warp, to properties obtained in test

<table>
<thead>
<tr>
<th>Construction</th>
<th>Modulus of : Stress at</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>elasticity : Proportional : Ultimate</td>
</tr>
<tr>
<td></td>
<td>: Method 1:Method 2 : Method 1:Method 2</td>
</tr>
<tr>
<td>1 ply of 112-114 fabric on each face</td>
<td>: 0.99 : 0.94 : 1.74 : 1.34 : 1.11 : 1.03</td>
</tr>
<tr>
<td>6 plies of 112-114 fabric on each face</td>
<td>: 1.06 : 1.03 : 1.67 : 1.36 : 1.15 : 1.03</td>
</tr>
</tbody>
</table>
Table 21.--Physical properties of 162-114 glass fabric from two different manufacturers

<table>
<thead>
<tr>
<th>Properties</th>
<th>Samples from</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Manufacturer A</td>
<td>Manufacturer B</td>
</tr>
<tr>
<td>Breaking strength (pounds per inch) (Grab method)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Warp</td>
<td>459</td>
<td>398</td>
</tr>
<tr>
<td>Fill</td>
<td>277</td>
<td>253.4</td>
</tr>
<tr>
<td>Elongation (percent)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Warp</td>
<td>8.0</td>
<td>7.3</td>
</tr>
<tr>
<td>Fill</td>
<td>4.0</td>
<td>4.5</td>
</tr>
<tr>
<td>Breaking strength of thread (pounds)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Warp</td>
<td>17.0</td>
<td>17.5</td>
</tr>
<tr>
<td>Fill</td>
<td>18.1</td>
<td>15.9</td>
</tr>
<tr>
<td>Elongation of thread (percent)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Warp</td>
<td>1.7</td>
<td>1.87</td>
</tr>
<tr>
<td>Fill</td>
<td>1.7</td>
<td>1.49</td>
</tr>
<tr>
<td>Thread count per inch</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Warp</td>
<td>28.5</td>
<td>28.5</td>
</tr>
<tr>
<td>Fill</td>
<td>16.5</td>
<td>16.5</td>
</tr>
<tr>
<td>Yarn ply</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Warp</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Fill</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Weave</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(2)</td>
<td>(2)</td>
</tr>
<tr>
<td>Twist per inch (yarn)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Warp</td>
<td>4.5</td>
<td>4.6</td>
</tr>
<tr>
<td>Fill</td>
<td>4.1</td>
<td>4.2</td>
</tr>
</tbody>
</table>

1-Properties based on tests at the Wright Air Development Center, Wright-Patterson Air Force Base, Ohio.
2-Plain, 1 up and 1 down.