

# **EFFECT OF DEFECTS ON THE TENSILE AND COMPRESSIVE PROPERTIES OF A GLASS-FABRIC-BASE PLASTIC LAMINATE**

**Information Reviewed and Reaffirmed**

**March 1955**

INFORMATION REVIEWED  
AND REAFFIRMED  
1960



**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. 1814**

**UNITED STATES DEPARTMENT OF AGRICULTURE  
FOREST SERVICE  
FOREST PRODUCTS LABORATORY  
Madison 5, Wisconsin  
In Cooperation with the University of Wisconsin**

EFFECT OF DEFECTS ON THE TENSILE AND COMPRESSIVE PROPERTIES  
OF A GLASS-FABRIC-BASE PLASTIC LAMINATE<sup>1</sup>

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Summary and Conclusions

This report presents results of 52 tension and 52 compression tests made to determine the effect of defects on the mechanical properties of a glass-fabric-base plastic laminate. Because even carefully controlled fabricating procedures result in occasional defects, some indication of these defects on the strength of the laminate is desirable.

Seven laminated panels were fabricated for these tests: one control panel, one with high resin content, two with low resin content, one with surface wrinkles, one with butt joints, and one with lap joints.

An increase in resin content resulted in lower values of modulus of elasticity, proportional limit, and ultimate stress in tension, and a lower modulus of elasticity in compression. The ultimate stress in compression, however, increased with increased resin content within the range of resin content tested.

Surface wrinkles lower the strength in tension and compression, and the deeper the wrinkle the greater is the reduction.

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<sup>1</sup>This progress report is one of a series prepared and distributed by the Forest Products Laboratory under U. S. Navy, Bureau of Aeronautics No. NAer Order 00793, Amendment No. 1, and U. S. Air Force No. USAF-PO-33-038(50-1078-E). Results here reported were obtained during 1950.

<sup>2</sup>Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

Butt joints lower the tensile strength of the laminate but the compressive strength (within limits) is not appreciably affected. If a single butt joint occurred in a six-ply laminate, the tensile strength at the joint would be about five-sixths of the tensile strength where the plies were continuous.

Lap joints, in general, would be expected to lower the tensile strength of the laminate, and the reduction would depend upon the efficiency of the particular joint. An increase in length of lap would be expected to raise the efficiency. The compressive strength (within limits) does not appear to be appreciably affected.

### Introduction

An increasing number and variety of parts in modern aircraft are being fabricated from glass-fabric-base plastic laminates. Some of these are fairings and are lightly stressed; many, however, may be considered as part of the primary structure, and therefore must possess high and uniform strength. Limitations on width of glass fabric, and sometimes the complex shape of the part itself, necessitate joints in the individual plies. Furthermore, fabricating procedures, even when carefully controlled, will result in (1) some local variations in resin content, (2) nonuniformity, such as in thickness, or (3) a discontinuity in the surface due to wrinkles in the fabric, parting film, or blanket (used for fluid pressure molding). All of these imperfections may be considered defects; and, because defects are normally not allowed in test specimens, their effect on strength is seldom evaluated in investigations of the strength properties of laminates.

This report presents results of tension and compression tests on a limited number of defects considered to be typical of current production. The data presented may serve as a guide in developing inspection procedures or process specifications for plastic parts, or as a basis for further, more extensive studies on the subject. A previous report presents limited results obtained from tests of defective sandwich panels.<sup>2</sup>

### Fabrication of Test Specimens

Seven 18- by 18-inch panels approximately 1/8 inch thick were fabricated to supply the material required for the test specimens. Each panel was

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<sup>2</sup>B. G. Heebink and A. A. Mohaupt. "Effect of Defects on Strength of Aircraft-type Sandwich Panels," U. S. Forest Products Laboratory Report No. 1809, September 1949.

laid up of 12 plies of 181-114 glass cloth, parallel laminated. A typical low-viscosity polyester-type laminating resin was used throughout. Each panel was laid up and pressed in a hot press between cellophane-covered aluminum cauls. The curing cycle was 1 hour and 40 minutes in the press at a temperature gradually increasing from 220° to 250° F. The pressure for all but two panels (Nos. 41 and 44) was 14 pounds per square inch.

The panels contained five types of defects: high resin content, low resin content, wrinkles, butt joints, or lap joints. Table 1 is a summary of the fabrication details pertinent to each defect, and figure 1 presents the details of wrinkles and joint fabrication.

### High Resin Content

It was found that for the low-viscosity resin used in this study a pronounced relation existed between pressure during curing and final resin content of the panel. High resin content therefore could only be obtained by a reduction in pressure. The panel made for tests of the effect of high resin content was cured at a pressure of 4 pounds per square inch, which resulted in a final resin content of about 43 percent.

### Low Resin Content

Two panels were made to test the effect of a reduction in resin content. The low resin content in one resulted from the use of a reduced amount of impregnating resin, while in the other increased pressure (50 pounds per square inch) increased the amount of squeeze-out during pressing. The final resin content of these two panels was 31 and 28 percent, respectively.

### Wrinkles

One panel was fabricated to include on the center of one side a wrinkle of two different depths, one formed around a 0.015-inch wire and the other around a 0.030-inch wire. In both cases the wires were stretched to produce a straight line and were placed between the cellophane and the mold so as to result in grooves that were similar in cross section to that shown in figure 1, A.

### Butt Joints

To test the effect of one combination of butt joints, a panel was made to include a butt joint in alternate plies, as shown in figure 1, B. Each joint included a gap up to approximately 1/16 inch wide.

## Lap Joints

Figure 1, C shows the arrangement of laps in individual plies fabricated for this study. Each lap was about  $1/4$  inch long, with laps in alternate plies, so that the over-all length of the lapped area was about  $1-1/2$  inches.

## Cutting of Specimens

The cutting diagram for each of the seven laminated panels is shown in figure 2. The specimens were cut with the long dimension parallel to the warp of the laminations with a  $1/8$ -inch emery wheel rotating at 1,770 revolutions per minute on the arbor of a variable-speed table saw. This method of cutting provided square and smooth surfaces for the compression specimens. The tensile specimens were finished to the desired shape and curvature by use of an emery wheel mounted on a shaper head.

## Testing

All specimens were conditioned in an atmosphere at a temperature of  $73^{\circ}$  F. and at a relative humidity of 50 percent for at least 2 weeks prior to testing.

## Tension Tests

The tension specimens used in these tests were 16 inches long and the thickness of the laminate, with a reduced cross section at the center (fig. 3). The maximum sections at the ends were  $1-1/2$  inches wide and  $2-7/8$  inches long. The minimum section at the center was 0.8 inch wide and  $2-1/2$  inches long. The maximum and minimum sections were connected by circular arcs of 20-inch radius tangential to the minimum section. Experience has shown that this type of specimen is reasonably free from stress concentrations at the minimum section and from the influence of end restraint.

The specimens were tested in a 30,000-pound-capacity mechanical testing machine operated at a head speed of 0.035 inch per minute, and load-deformation readings were taken at regular increments of load. The strains were measured parallel to the applied load across a 2-inch gage length at the center of the specimen with a pair of Marten's mirrors reading to 0.00001 inch. The load increased steadily to the maximum value, at which point the specimen failed suddenly.

The specimens from panels Nos. 34, 41, 43, and 44 (control and panels with varying resin contents) failed primarily in tension with some evidence of shear failure. There was often slight delamination of the specimen near the failure, but this probably occurred after the primary failures. Specimens with wrinkles (panel No. 45) generally failed in tension at the wrinkle. In a few specimens, the laminate failed in tension on the side with the defect and in tension and shear on the other side, with these failures being accompanied by some interlaminar failure. The specimens with butt joints (panel No. 46) failed in tension across the joint. The specimens with lap joints at the center section (panel No. 47) failed in shear between the laps, and the continuous plies failed in tension. There was much delamination in the joint area.

### Compression Tests

The compression specimens used in these tests were 1 inch wide, 4 inches long, and of the thickness of the laminate. They were loaded on the 1-inch end and restrained from buckling by means of the apparatus used in testing veneer and plywood (fig. 4), which is described elsewhere.<sup>4</sup>

The specimens were tested in a 10,000-pound-capacity hydraulic testing machine, employing a spherical head, at a head speed of 0.012 inch per minute. The strains were measured across a 2-inch gage length on opposite edges, with a pair of Marten's mirrors reading to 0.00001 inch. The load increased steadily until the maximum load was reached, at which point the specimen failed suddenly.

Failures of all specimens were generally similar, except as noted below. The specimens from panels Nos. 34, 41, 43, and 44 (control and panels with varying resin contents) failed by a combination of crushing of fibers and transverse shear. Specimens from panel No. 45 failed at the wrinkle, primarily in shear but with some crushing of fibers. Two specimens from panel No. 46 failed at the section containing butt joints, and four failed outside of the joint area, with all failures being a combination of crushing of fibers and transverse shear. The specimens from panel No. 47 failed outside of the lap-joint area, and also by crushing of fibers and transverse shear.

### Discussion of Data

#### General

The data reported herein are intended to give some approximation of the effect of several types of defects on the mechanical properties of the

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<sup>4</sup>ASTM Standard Designation D805-47, "Methods of Testing Plywood, Veneer, and Wood-base Materials." 1947.

laminate. Although these defects will not be duplicated exactly in service conditions, the effect of similar defects may be estimated from the results of these laboratory tests.

Average values obtained from tension and compression tests of the various laminated panels are given in table 2. Barcol hardness values should be, and are, reasonably similar between panels Nos. 34, 45, 46, and 47 because the same fabrication procedures were employed except for the local defective areas. The values from panels with high or low resin content (Nos. 41, 43, and 44) are, however, inconsistent; and no conclusion can be drawn from these data as to what effect resin content has on the hardness.

All panels for this study were made from 12 plies of 181-114 fabric. It can be seen from table 2 that as the resin content is increased (panel No. 41), the thickness increases and specific gravity decreases. A reduction in the resin content results in a thinner laminate of higher specific gravity (panels Nos. 43 and 44).

### Tension

Previous studies of glass-fabric-base plastic laminates have, in general, indicated the presence of an initial and of a secondary straight line in the ordinary tensile stress-strain curve. The significance of this dual characteristic, which results in initial and secondary values of modulus of elasticity and of proportional limit, has been questioned in considering which values are to be used for design purposes. A series of tests at the Forest Products Laboratory<sup>2</sup> shows the effect of prestressing on the mechanical properties of two laminates. One of the laminates reported on was made of the same materials and by the same methods as panel No. 34 of this study. The general conclusion to be drawn from the results of the tests is that once the laminate has been prestressed beyond the initial proportional limit, the properties of the material are changed and the values obtained from ordinary stress-strain data no longer truly represent the properties of the laminate. It is suggested that the results of the tension tests given in this report be considered in light of this information.<sup>2</sup>

In view of the above, the average tensile stress-strain curve (fig. 5) is given for each panel. The initial proportional limit of each panel, and the variation of these values between panels, do not appear to be important in view of the previous data mentioned,<sup>2</sup> and are not discussed further, although the values are given in table 2.

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<sup>2</sup>Werren, Fred. "Effect of Prestressing in Tension or Compression on the Mechanical Properties of Two Glass-fabric-base Plastic Laminates."  
U. S. Forest Products Laboratory Report No. 1811. 1950.



The effect of resin content on the mechanical properties may be seen by an examination of the values given in table 2. As the resin content is increased (panel No. 41), the initial and secondary moduli of elasticity, the secondary proportional limit, and the ultimate stress fall below the control values. Conversely, a decrease in resin content results in higher mechanical properties. Panel No. 44 had a resin content of 28 percent, and its strength properties are higher than those of panel No. 43, which had a resin content of 31 percent.

A surface wrinkle (panel No. 45) results in lower strength properties, as expected, and the deeper the wrinkle the lower the value.

The tensile strength across a butt joint (panel No. 46) appears to be negligible. In other words, it appears that the tensile strength is dependent almost entirely upon the number of continuous plies. The particular construction used in these tests had six continuous plies and six plies with butt joints. It can be seen from table 2 that the value of the ultimate tensile stress is only about one-half that of the control, wherein all 12 plies are continuous. The value of the secondary proportional-limit stress is, however, greater than one-half that of the control.

The lap joints, as made for these tests, result in lower values of secondary proportional-limit and of ultimate stress. The length of each lap joint and the corresponding efficiency of the joint would determine the strength properties. For this construction, the strength of each joint is calculated to be about three-fourths that of a continuous ply.

Values of modulus of elasticity for panels with local defects, such as wrinkles, butt joints, and lap joints, have not been discussed above because they cannot be readily compared with the control values. The values calculated for the defective areas would vary with the gage length over which strains are measured.

It may be noted that the maximum tensile load of a laminate is largely dependent upon the number of continuous plies of glass fabric in the laminate. Such a comparison is made by multiplying the ultimate tensile stress by the thickness to obtain a value of ultimate load per unit width (col. 11, table 2). These values, for the control panels and for three panels of varied resin content, are within 10 percent of each other, whereas the ultimate stress of the panel with the least resin is about 35 percent higher than the panel with high resin content. Further, the panel with butt joints, having six continuous plies, has a load per unit width of about one-half those with 12 plies, as expected. Thus, it becomes apparent that the tensile strength per unit width is largely a function of the number of continuous plies and not nearly as susceptible to resin variations as the ultimate tensile stress. Surface defects and lap joints are difficult to analyze in this respect because the type of defect and the efficiency of lap joints enter into the calculation.



## Compression

There was considerably greater variation, within a group, in the results of compression tests than in those of tension tests. Therefore the effect of defects may not be as clearly marked in the compression as in the tension results. General tendencies are indicated, however, and are discussed below.

The proportional-limit values for all of the panels tested vary within 12 percent of the average. In view of the difficulty in selecting a proportional limit from materials such as these, where this value is not well defined, considerable variation must be expected. From these data no conclusion can be drawn as to what effect resin content has on the proportional-limit stress in compression. It appears that surface wrinkles do slightly lower the value, as would be expected. However, the laminates with butt joints and those with lap joints would be expected to have proportional-limit values near the control value because failure generally occurred outside of the joint area.

As the resin content is increased, the modulus of elasticity decreases. While the differences in ultimate stress due to variation of resin content are small, there appears to be a trend toward increased ultimate stress with an increase of resin content. Thus the effect of resin appears to be opposite to that observed on the ultimate tensile stress, within the range tested.

The ultimate compressive stress is not greatly lowered by a shallow wrinkle, but deeper wrinkles result in a pronounced reduction of strength. Since the specimens with butt and lap joints generally failed outside of the joint area, it appears that the ultimate stress is not greatly affected by defects similar to these.

The effect of local defects on the modulus of elasticity depends upon the gage length over which the strains are measured, and the values, as in tension, are difficult to compare with the control values.

The effect of resin content, wrinkles, and lap joints on the ultimate compressive strength of a solid laminate are similar to those previously reported for glass-cloth facings of sandwich materials.<sup>2</sup> For both materials, an increase in resin content, within the range tested, resulted in a higher compressive strength. However, it is expected that a further increase would eventually result in a decrease in compressive strength. The effect of a wrinkle on a solid laminate or sandwich facing would, of course, depend upon the depth of the wrinkle and the thickness of the material. The results of these tests show that the strength may be substantially reduced by the presence of a surface wrinkle. Lap joints, of the type used in the solid laminate or in the sandwich panel facing, do not appear to appreciably lower the edgewise compressive strength.

Table 1.--Types of defects and fabrication details of panels tested

Panel No.	Type of defect	Fabrication procedure
34	No defect. 38 per- cent resin content (control panel)	Normal molding pressure (14 p.s.i.). Cloth impregnated to 50 percent resin content.
41	High resin content (43 percent)	Low molding pressure (4 p.s.i.).
43	Low resin content (31 percent)	Small amount of resin applied. Normal molding pressure.
44	Low resin content (28 percent)	High molding pressure (50 p.s.i.). Normal amount of resin applied.
45(a)	Shallow wrinkle in one surface	Normal molding procedure. Wrinkle produced by 0.015-inch wire laid on one surface before molding. See figure 1, A.
45(b)	Deep wrinkle in one surface	Normal molding procedure. Wrinkle produced by 0.030-inch wire laid on one surface before molding. See figure 1, A.
46	Butt joints	Normal molding procedure. Alternate plies of cloth have butt joints all in one plane. See figure 1, B.
47	Lap joints	Normal molding procedure. Alternate plies incorporate a 1/4-inch lap joint staggered as shown in figure 1, C.

Table 2.--Average results of tension and compression tests of glass-fabric-base plastic laminates indicating the effect of defects on the mechanical properties

Panel No.	Barrel height	Specific gravity	Tension						Compression <sup>2</sup>						
			Number of specimens	Thickness	Modulus of elasticity <sup>1</sup>	Proportional-limit stress	Ultimate stress	Ultimate stress times thickness	Number of specimens	Thickness	Modulus of elasticity <sup>1</sup>	Proportional-limit stress	Ultimate stress		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
			Inch	P.S.I.	P.S.I.	P.S.I.	P.S.I.	P.S.I.	P.S.I.	Lb. per inch		Inch	P.S.I.	P.S.I.	P.S.I.
34	69	1.77	8	0.129	3,330	2,810	7,650	33,310	50,050	6,460	8	0.128	3,295	21,660	31,930
41	64	1.71	8	.146	3,090	2,520	6,500	28,560	41,510	6,060	8	.145	2,974	22,840	33,810
43	59	1.80	8	.114	3,700	3,140	6,760	33,440	53,100	6,050	8	.113	3,594	23,270	29,040
44	69	1.90	8	.104	4,000	3,340	8,110	37,050	56,180	5,840	8	.104	3,790	18,880	28,200
45 (a)	66	1.77	4	.127	3,140	2,840	9,110	27,200	40,100	5,090	4	.131	3,234	19,360	31,830
45 (b)	66	1.77	4	.131	2,920	2,660	7,280	26,200	34,700	4,550	4	.131	3,130	19,300	23,250
46	67	1.77	6	.126	3,070	2,730	6,250	19,330	23,810	3,000	6	.128	3,114	23,970	33,790
47	67	1.77	6	.123	3,390	2,970	7,280	28,620	43,960	5,410	6	.123	3,604	21,820	31,550

- 34 -- Control. No defect.
- 41 -- High resin content (43 percent).
- 43 -- Low resin content (31 percent).
- 44 -- Low resin content (28 percent).
- 45 (a) -- Shallow wrinkle in one surface.
- 45 (b) -- Deep wrinkle in one surface.
- 46 -- Butt joints.
- 47 -- Lap joints.

<sup>1</sup>50.2 percent offset stress equals ultimate stress.

<sup>2</sup>Strains measured over a 2-inch gage length.



A SURFACE WRINKLE



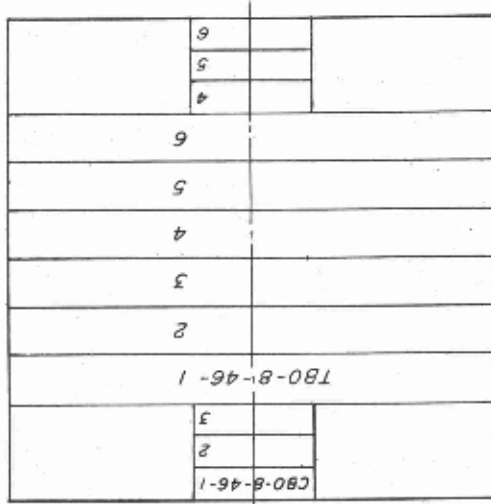
B BUTT JOINTS



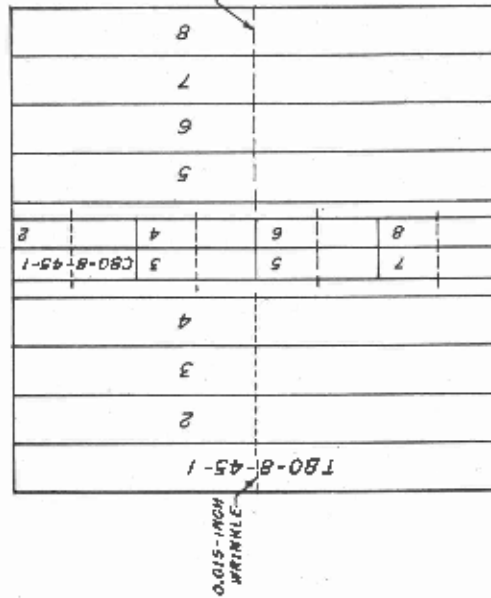
C LAP JOINTS

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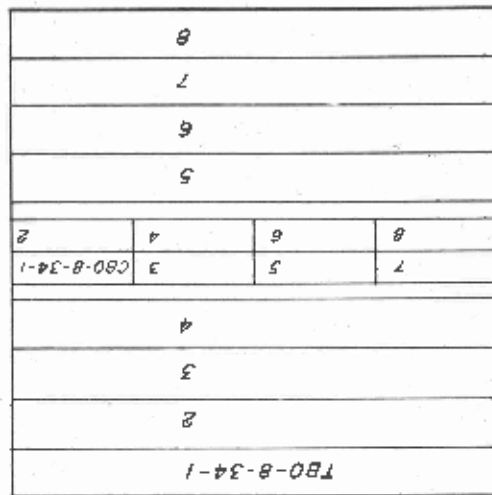
Figure 1.--Details of surface wrinkles, butt joints, and lap joints in defective laminated panels.



PANEL 46 (PANEL 47 SIMILAR)



PANEL 45



PANEL 34 (PANELS 41, 43 AND 44 SIMILAR)

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Figure 2.--Cutting diagrams for glass-fabric-base plastic laminate panels.

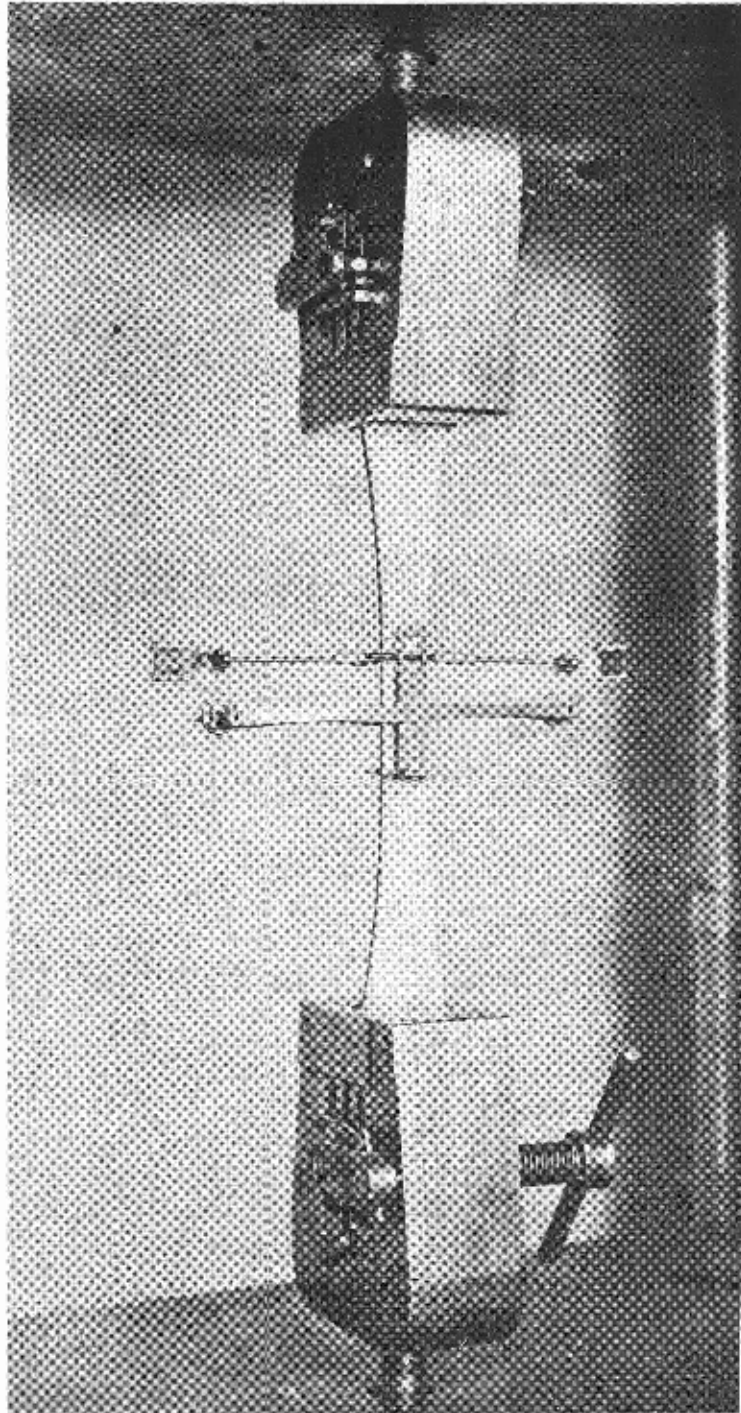


Figure 3.--Tensile test used in testing glass-fabric-base plastic laminate specimens.

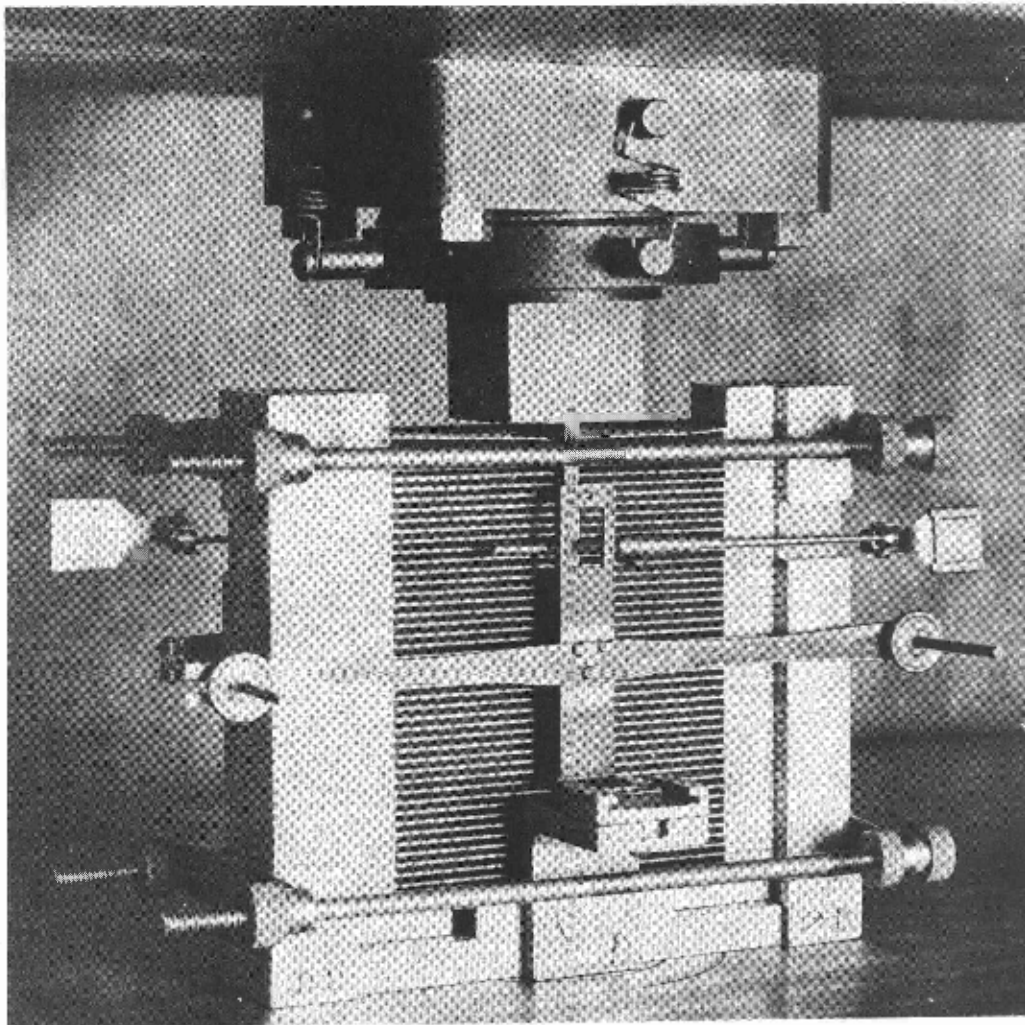


Figure 4.--Compression test used in testing glass-fabric-base plastic laminate specimens.

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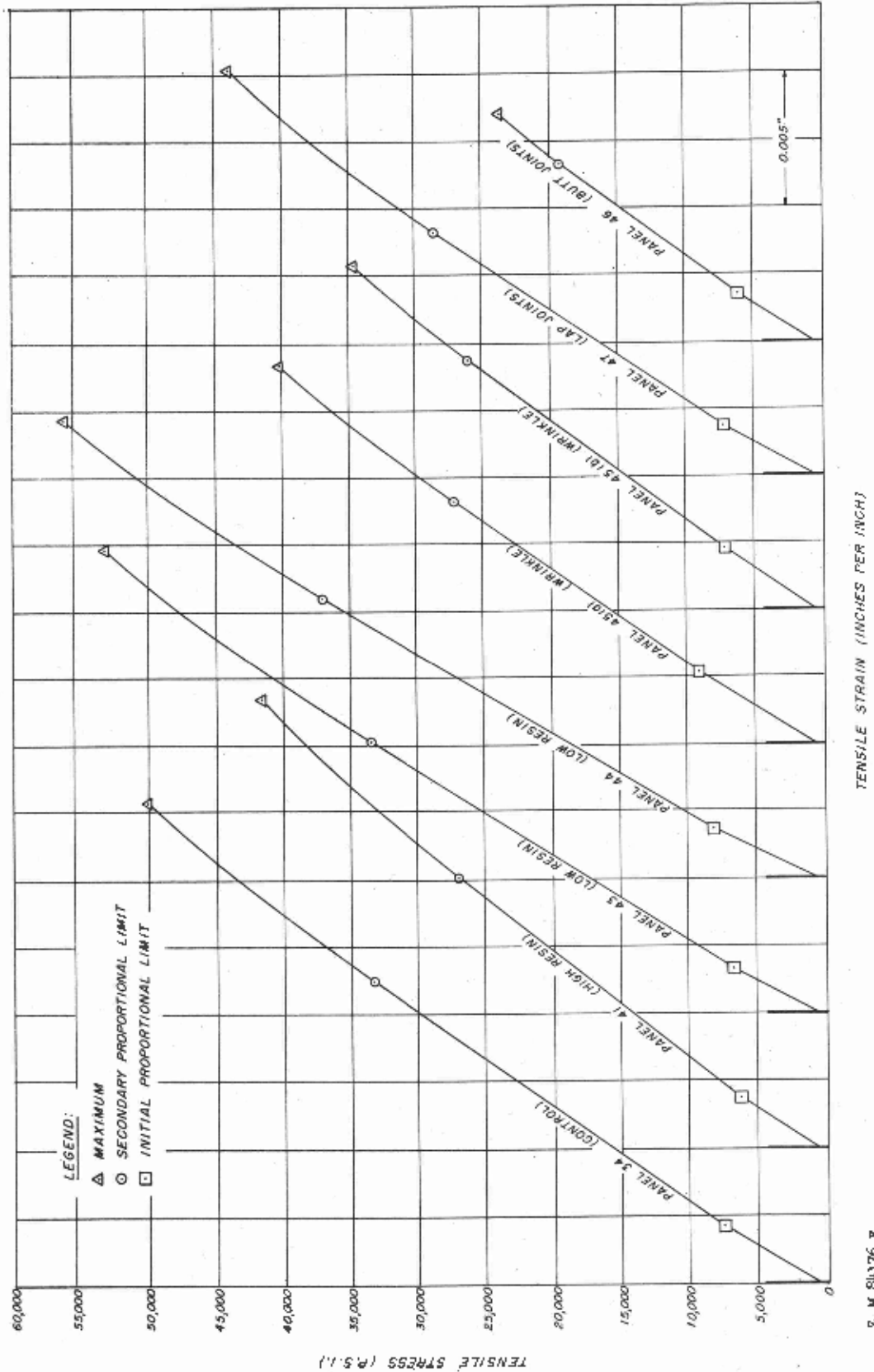


Figure 5.--Average stress-strain curves for defective glass-fabric-base plastic laminate tensile specimens.