EFFECT OF SPAN-DEPTH RATIO AND THICKNESS ON THE MECHANICAL PROPERTIES OF A TYPICAL GLASS-FABRIC-BASE PLASTIC LAMINATE AS DETERMINED BY BENDING TESTS

~~Information Reviewed and Reaffirmed~~

~~July 1955~~

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. 1807

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

EFFECT OF SPAN-DEPTH RATIO AND THICKNESS ON THE MECHANICAL PROPERTIES OF A TYPICAL GLASS-FABRIC-BASE PLASTIC LAMINATE AS DETERMINED BY BENDING TESTS[1]

By

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Summary

A limited number of bending tests of a typical glass-fabric-base plastic laminate were made to determine the effect of span-depth ratio and thickness on the mechanical properties obtained from test. Three thicknesses of laminate, 1/16, 1/4, and 1/2 inch, were tested at span-depth ratios between 12 and 38. A few tensile and compressive tests were included for each thickness of laminate.

The results of the tests show that the modulus of rupture decreases with an increase in span-depth ratio or with an increase in thickness of the laminate, and the modulus of elasticity increases slightly with an increase in span-depth ratio. For any given span-depth ratio, the modulus of rupture was markedly lower the thicker the material, even though the tensile and compressive properties, Barcol hardness, resin content, and specific gravity were closely comparable for all three thicknesses. At a span-depth ratio of 16 to 1, the moduli of rupture were about 67,000, 59,000, and 52,000 pounds per square inch for approximately 0.074, 0.27, and 0.53 inch thicknesses, respectively.

Introduction

The proper structural application of glass-fabric-base plastic laminates often requires a knowledge of the mechanical properties of the material when subjected to bending. Specifications[2] that outline the test procedures for this material usually designate a minimum ratio of length of span to depth of specimen (span-depth ratio) to be used in the bending tests.

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[1]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 Amend. No. 1 and U.S. Air Force No. USAF-PO-33-038 (49-241E). Results here reported are preliminary and may be revised as additional data become available.

[2]An example of such a specification is found in Federal Specification L-P-406a, Method No. 1032. This specification was followed in the bending tests for this report, except as mentioned under the heading of "Testing."

Preliminary tests of these laminates have, however, indicated that a change of span-depth ratio for a given thickness of laminate or a change in thickness of laminate for a given span-depth ratio may appreciably change the values of the results obtained from the bending tests. It is the purpose of this report to summarize the results of tests made to determine the effect of the span-depth ratio and of the thickness of the laminate on the mechanical properties obtained from bending tests of a typical glass-fabric-base plastic laminate. Three thicknesses of laminate were tested in bending, each at varying span-depth ratios, and a few tension and compression tests were included for each thickness of laminate.

Description of Material

Three 18- by 18-inch glass-fabric-laminate panels were made of 181-114 fabric, to a nominal thickness of 1/16 inch (7 plies), 1/4 inch (25 plies), and 1/2 inch (50 plies). The fabric was parallel-laminated with a high-temperature-setting, low-viscosity, laminating resin of the alkyd-styrene polyester type, with 0.8 percent benzoyl peroxide catalyst by weight. The laminates were laid up by hand and pressed between aluminum cauls, with the laminate separated from each caul by a sheet of cellophane. A pressure of 14 pounds per square inch was applied to the laminate in a press by controlling the pressure in an oil-filled bladder on the bottom platen of the press. The temperature was then raised slowly. After the exothermic reaction had taken place and the temperature of the laminate had become stabilized to that of the press, the panel was pressed for 1 hour at 250° F. The temperature of the panel was obtained by use of a thermocouple placed adjacent to the center lamination about 4 inches in from the edge of the panel. Periodic temperature readings were made with a potentiometer.

Upon completion of pressing, each panel was trimmed to size with a metal-cutting band saw. The panel was carefully measured and weighed, and the over-all average resin content and specific gravity were calculated. Barcol hardness readings were also made at various positions on each face of the panel (fig. 1). Following is a summary of general information on each panel.

	Panel 1	Panel 2	Panel 4
Number of plies	7	25	50
Average thickness (inch)	.074	.268	.530
Average Barcol hardness	67	67	67
Resin content (percent by weight)	37.0	37.4	36.7
Specific gravity	1.79	1.77	1.77
Total time in press (minutes)	115	100	105
Maximum temperature due to exothermic reaction (°F.)	No reaction noted	273	325

Testing

Bending Tests

Bending specimens were tested flatwise in a mechanical testing machine in accordance with Federal Specification L-P-406a, Method No. 1031,[2] except that the width of the 1/16-inch laminate specimens was usually less than the specified minimum width of 1/2 inch. The contact edges of the supports were of 1/8-inch radius, and the center loading piece had a radius of twice the nominal thickness of the specimen. The rate of head travel varied for each group of specimens, but was such that the unit rate of fiber strain, Z, was about 0.004 inch per inch of outer fiber length per minute. The load was applied at the center of the specimen, and the deflection was measured with a dial gage reading to either 0.001 or 0.0001 inch and having its spindle in contact with the bottom of the specimen at its center (fig. 2). Simultaneous readings of load and deflection were taken until the specimen failed. A typical load-deflection curve is shown in figure 3.

The 1/16-inch laminate was tested at span-depth ratios of 16, 20, and 32, the 1/4-inch laminate at span-depth ratios of 12, 16, 20, 26, 32, and 38, and the 1/2-inch laminate at span-depth ratios of 12, 16, and 30. The ratio of width to depth of each specimen was approximately 2, except for one series of 1/16-inch laminate specimens, which were 1/2 inch wide.

The first evidence of failure was on the compressive face near the point of loading. This failure sometimes was evident just before the maximum load was reached, even though it may have been nothing more than a slight spalling off of resin. The load dropped suddenly when the maximum load was reached, and then there was evidence of both compression and tension failures. There was no evidence of shear failure in the horizontal (interlaminar) plane, except that due to the local compressive or tensile failure at the center of the specimen.

Tension Tests

The tensile specimens used in these tests were 16 inches long and of the thickness of the laminate. 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 for the 1/16- and 1/4-inch laminates, and 0.5 inch wide and 2-1/2 inches long for the 1/2 inch laminate. The maximum and minimum sections were connected by circular arcs of 20-inch radius tangent to the minimum section. This type of specimen was selected because it has a long tapered section which greatly reduces the stress concentration at the test section as compared with those in Federal Specification L-P-406a where the transition is more abrupt. Experience has shown that the failure is not appreciably influenced by restraint at the ends of the specimen and occurs at or near the minimum section of the specimen.

The specimens were tested in a hydraulic testing machine equipped with templin tension grips (fig. 4). Load was applied at a head speed of 0.035 inch per minute, and load-deformation readings were taken to failure. The strains were measured parallel to the applied load across a 2-inch gage length with a pair of Marten's mirrors reading to 0.00001 inch. The specimens failed suddenly when the maximum load was reached, and failure was primarily a tension failure.

Compression Tests

The compression specimens used in these tests were 1 inch wide, 4 inches long, and of the thickness of the laminate. The specimens were loaded at their ends and the 1/16- and the 1/4-inch specimens were restrained from buckling by means of the apparatus illustrated in figure 5. The 1/2-inch specimens were tested without the restraining apparatus and did not buckle before failure.

The specimens were tested in a hydraulic testing machine, equipped with a spherical head, at a head speed of 0.012 inch per minute. Strains were measured parallel to the applied load across a 2-inch gage length with a pair of Marten's mirrors reading to 0.00001 inch, mounted on opposite sides of the specimen. The load increased steadily to maximum load, and then the specimen failed suddenly. The failure was generally a crushing of the fibers combined with transverse-shear failure.

Presentation of Data

Table 1 presents the results of bending tests of the three thicknesses of laminate at various span-depth ratios. Values are calculated from the equations given in Federal Specifications L-P-406a.[2] It may be noted that the width-to-depth ratio is approximately 2 for all specimens except those of the first group of 1/16-inch-laminate specimens whose width-to-depth ratio is about 7. Table 2 presents the results of tension tests. The initial and secondary values of proportional limit and modulus of elasticity in tension are as discussed in Forest Products Laboratory Report No. 1803.[3] The results of compression tests are given in table 3.

The effect of the span-depth ratio and of the thickness of the specimen upon the modulus of rupture and the modulus of elasticity in bending is shown in figure 6, in which the plotted points represent the average values of table 1.

Analysis of Data

The three glass-fabric-base plastic laminate panels made for these tests were made as nearly alike as possible in that the same fabrication conditions were employed for all. The similarity of the values for Barcol hardness,

[3]Werren, F. and Norris, C. B. "Directional Properties of Glass-fabric-base Plastic Laminate Panels of Sizes that Do Not Buckle," Forest Products Laboratory Report No. 1803, January 1949.

resin content, and specific gravity indicates that conditions of fabrication were essentially the same among the three panels. The only evident difference lies in the marked difference in maximum temperature resulting from differences in exothermic reaction for the three different thicknesses.

Although the specifications[2] state that the minimum width of a bending specimen shall be 1/2 inch, this requirement was not adhered to in most of the tests of the 1/16-inch laminate. Since specimens that are wide with respect to their depth, exhibit properties approaching those of a plate, and because the 1/16-, 1/4-, and 1/2-inch laminates are to be compared as beams in bending, the ratio of width to depth of approximately 2 was adhered to in all but one case. This exception is the first group of table 1, wherein the specimens were 1/2 inch wide and were tested over the same span as the specimens of the second group. These wider specimens, on the average, exhibited slightly higher values of stress at proportional limit and of modulus of rupture, and a slightly lower value of modulus of elasticity. More tests would be required, however, to establish an empirical relationship on the effect of width. The results from this group of 1/16-inch laminates has not been used in analysis of the data.

The effect of span-depth ratio and of thickness of specimens on modulus of rupture and on modulus of elasticity in bending is seen most readily in figure 6, as plotted from the average values of table 1. The curves show that an increase in span-depth ratio for any thickness of laminate tested decreases the resulting modulus of rupture. The rate of decrease is, however, less as the thickness of the laminate is increased. The curves indicate also that as the thickness of the laminate increases, the modulus of rupture at a given span-depth ratio decreases. Modulus of elasticity appears to be independent of the thickness of the laminate and increases slightly with an increase in span-depth ratio, probably due to decreasing effects of shear. Values of proportional limit were not plotted because they were somewhat erratic, but an examination of the values from table 1 indicates that for each laminate an increase in span-depth ratio, on the average, results in a lower value of stress at proportional limit. The results of tension tests (table 2) and compression tests (table 3) have likewise not been plotted, but they may be compared by an examination of the values given in the tables. The maximum stress in tension of the 1/16-inch laminate is about 9 percent less than the maximum stress of the other two laminates. In compression, the maximum stress of the 1/4-inch laminate is roughly 15 percent greater than the average of the other laminates. These differences in average tensile and compressive strengths are small in comparison to the differences in the average moduli of rupture; the values do not correlate directly with thickness as the moduli of rupture values do; and the differences fall within the range of variation which is normally obtained for different panels of the same thickness, even when made under closely comparable conditions, such as is shown in a previous report.[3]

The preceding discussion indicates that further study might be desirable to determine the reasons for the trends and variations of the mechanical properties of the laminates. Since fabrication methods were essentially identical, and values of Barcol hardness, resin content, and specific gravity were essentially the same for all panels, there appears to be no obvious reason for the difference in properties. There remains the possibility that the apparent effect of thickness on bending properties is not merely a matter of testing technique, but may be due to variations in properties through the thickness of the panel.

Conclusions

From analysis of the limited data resulting from bending tests of three thicknesses of one type of glass-fabric-base plastic laminate, the following conclusions may be drawn.

1. As the span-depth ratio for a given thickness of laminate is increased, the resultant value of modulus of rupture is decreased.

2. The rate of decrease of modulus of rupture resulting from an increase in span-depth ratio appears to become less as the thickness of the laminate is increased.

3. For a given span-depth ratio, a thin laminate has a higher modulus of rupture than a thick one. Additional studies are needed to investigate the cause of the variation of mechanical properties of laminates with thickness.

4. The modulus of elasticity appears to be independent of the thickness of the laminate and increases slightly with an increase in span-depth ratio, probably due to decreasing effects of shear.

5. On the average, the fiber stress at proportional limit for a given thickness of laminate decreases with an increase in span-depth ratio.

Table 1.--Results of static-bending tests of three thicknesses of glass-fabric base plastic laminate at various span-depth ratios

1/16-inch laminate -- 7 plies

Specimen No.	Width	Depth	Span/depth ratio	Proportional-limit stress	Modulus of rupture	Modulus of elasticity
(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Inch	Inch		P.s.i.	P.s.i.	1,000 p.s.i.
Span 1.18 inches						
FBO-10-1-1	0.498	0.076	15.5	59,100	65,250	2,458
2	.501	.075	15.7	65,300	68,550	2,468
3	.502	.073	16.2	63,350	70,100	2,542
4	.499	.075	15.7	65,650	68,300	2,500
5	.498	.073	16.2	69,400	70,000	2,565
6	.497	.073	16.2	56,200	70,850	2,535
Av.	.499	.074	15.9	63,200	68,850	2,511
Span 1.18 inches						
FBO-10-1-1a	.147	.073	16.2	47,420	70,900	2,521
2a	.145	.074	15.9	66,900	68,000	2,464
3a	.146	.072	16.4	35,090	61,500	2,864
4a	.145	.074	15.9	60,200	65,100	2,545
5a	.145	.075	15.7	43,420	65,100	2,690
6a	.145	.076	15.5	61,000	69,600	2,616
Av.	.146	.074	15.9	52,340	66,700	2,617
Span 1.47 inches						
FBO-10-1-1b	.150	.073	20.1	46,900	63,200	2,758
2b	.144	.075	19.6	35,400	59,900	2,745
3b	.152	.073	20.1	62,650	70,800	2,711
4b	.150	.074	19.9	42,950	64,400	2,681
5b	.150	.073	20.1	41,380	63,400	2,723
6b	.149	.073	20.1	50,000	67,200	2,774
Av.	.149	.074	20.0	46,550	64,820	2,732
Span 2.34 inches						
FBO-10-1-1c	.149	.073	32.1	42,000	58,350	2,809
2c	.148	.073	32.1	37,850	63,600	2,735
3c	.148	.072	32.5	36,600	59,500	2,862
4c	.146	.074	31.6	....	57,550	2,960
5c	.148	.073	32.1	33,390	56,100	3,001
6c	.144	.073	32.1	29,740	55,400	2,839
Av.	.147	.073	32.1	29,930	58,420	2,868

1/4-inch laminate -- 25 plies

Specimen No.	Width	Depth	Span/depth ratio	Proportional-limit stress	Modulus of rupture	Modulus of elasticity
(8)	(9)	(10)	(11)	(12)	(13)	(14)
	Inch	Inch		P.s.i.	P.s.i.	1,000 p.s.i.
Span 3.28 inches						
FBO-10-2-1a	0.502	0.275	11.9	....	65,200	2,790
2a	.499	.271	12.1	50,350	60,450	2,688
3a	.496	.272	12.1	50,300	61,600	2,652
4a	.498	.275	11.9	47,030	60,600	2,621
5a	.496	.271	12.1	48,600	61,300	2,750
6a	.496	.274	12.0	45,600	58,000	2,678
Av.	.498	.273	12.0	48,380	61,190	2,696
Span 4.30 inches						
FBO-10-2-1	.492	.268	16.0	42,000	56,200	2,730
2	.494	.267	16.1	53,100	59,200	2,675
3	.489	.269	16.0	49,250	59,300	2,676
4	.492	.268	16.1	51,100	58,600	2,711
5	.496	.270	15.9	49,950	59,600	2,666
6	.498	.269	16.0	50,150	58,600	2,710
Av.	.494	.268	16.0	49,260	58,580	2,695
Span 5.50 inches						
FBO-10-2-1c	.497	.277	19.9	47,600	60,250	2,727
2c	.502	.277	19.9	42,880	60,000	2,748
3c	.501	.274	20.1	52,650	60,650	2,782
4c	.496	.271	20.3	47,580	58,700	2,730
5c	.498	.274	20.1	46,380	57,600	2,709
Av.	.499	.275	20.1	47,420	59,440	2,739
Span 7.18 inches						
FBO-10-2-1d	.501	.275	26.1	42,650	56,900	2,760
2d	.497	.273	26.3	40,740	53,400	2,740
3d	.501	.278	25.8	44,500	58,600	2,740
4d	.500	.277	25.9	42,120	58,200	2,786
5d	.497	.277	25.9	48,020	57,900	2,692
Av.	.499	.276	26.0	43,600	57,000	2,744
Span 8.51 inches						
FBO-10-2-1e	.489	.270	31.5	28,670	54,800	2,742
2e	.493	.270	31.5	24,870	57,550	2,957
3e	.487	.269	31.6	27,180	55,050	3,055
4e	.491	.269	31.6	28,720	55,300	2,962
Av.	.490	.270	31.6	27,360	55,680	2,929
Span 10.34 inches						
FBO-10-2-1f	.495	.271	38.2	34,150	54,400	2,974
2f	.500	.276	37.4	32,600	55,800	2,828
3f	.494	.270	38.3	36,600	54,250	2,715
4f	.498	.273	37.9	27,190	53,950	2,840
5f	.493	.271	38.2	27,880	53,400	2,821
6f	.497	.274	37.7	33,290	53,600	2,774
Av.	.496	.272	38.0	31,950	54,230	2,825

1/2-inch laminate -- 50 plies

Specimen No.	Width	Depth	Span/depth ratio	Proportional-limit stress	Modulus of rupture	Modulus of elasticity
(15)	(16)	(17)	(18)	(19)	(20)	(21)
	Inch	Inch		P.s.i.	P.s.i.	1,000 p.s.i.
Span 6.38 inches						
FBO-10-4-1b	0.988	0.532	12.0	41,090	47,150	2,480
2b	.985	.533	12.0	35,900	47,200	2,525
Av.	.986	.532	12.0	38,500	47,180	2,502
Span 8.51 inches						
FBO-10-4-1	.992	.530	16.1	29,800	51,150	2,735
2	.982	.530	16.1	31,480	53,700	2,715
3	.992	.531	16.0	29,210	51,600	2,743
4	.995	.532	16.0	29,020	50,800	2,710
5	.991	.534	15.9	32,500	51,500	2,701
6	.990	.535	15.9	30,600	50,800	2,678
Av.	.990	.532	16.0	30,440	51,590	2,714
Span 16.10 inches						
FBO-10-4-1a	1.004	.540	29.8	35,050	49,900	2,804
2a	1.004	.535	30.1	26,900	48,100	2,838
3a	.998	.537	30.0	30,200	49,500	2,778
4a	.998	.538	29.9	....	51,850	2,820
Av.	1.001	.538	30.0	30,720	49,840	2,810

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Table 2.--Results of tension tests of three thicknesses of glass-fabric-base plastic laminate

Specimen No.	Thickness	Initial proportional limit	Secondary proportional limit	Initial modulus of elasticity	Secondary modulus of elasticity	Maximum stress
	Inch	P.s.i.	P.s.i.	1,000 p.s.i.	1,000 p.s.i.	P.s.i.
1/16-inch laminate -- 7 plies						
TBO-10-1-1	0.078	7,100	26,100	2,750	2,360	42,800
2	.077	7,200	27,200	2,710	2,340	43,100
3	.076	6,500	28,500	2,760	2,420	45,000
4	.075	6,500	28,700	2,810	2,410	41,400
Average	.076	6,800	27,600	2,760	2,380	43,100
1/4-inch laminate -- 25 plies						
TBO-10-2-1	.263	7,600	36,000	2,870	2,480	47,300
2	.264	6,600	31,200	2,980	2,500	45,600
3	.264	7,700	27,800	2,770	2,380	46,800
4	.264	7,600	34,200	2,860	2,470	47,600
Average	.264	7,400	32,300	2,870	2,460	46,800
1/2-inch laminate -- 50 plies						
TBO-10-4-1	.524	11,500	....	2,580	2,490	46,000
2	.526	6,800	28,100	2,740	2,410	47,400
3	.527	13,000	26,800	2,550	2,400	47,900
4	.528	12,500	27,300	2,520	2,400	46,900
Average	.526	11,000	27,400	2,600	2,430	47,000

Table 3.--Results of compression tests of three thicknesses of glass-fabric-base plastic laminate

Specimen No.	Thickness	Proportional limit	Modulus of elasticity	Maximum stress
	Inch	P.s.i.	1,000 p.s.i.	P.s.i.
1/16-inch laminate -- 7 plies				
CBO-10-1-1	0.075	28,000	2,960	37,100
2	.073	27,400	3,070	38,700
3	.074	....	2,800	32,100
4	.075	32,100	2,990	40,100
5	.073	32,900	3,060	34,800
6	.072	22,300	3,070	29,600
7	.074	....	2,710	31,300
8	.074	29,800	2,990	35,200
Average	.074	28,800	2,960	34,900
1/4-inch laminate -- 25 plies				
CBO-10-2-1	.272	19,200	2,890	41,400
2	.267	27,100	2,750	38,100
3	.267	34,000	2,780	40,600
4	.268	28,600	2,880	38,400
Average	.268	27,200	2,830	39,600
1/2-inch laminate -- 50 plies				
CBO-10-4-1	.529	17,300	2,830	32,600
2	.530	13,100	2,760	34,300
3	.532	22,100	2,630	32,800
4	.532	16,000	2,800	35,200
Average	.531	17,100	2,760	33,700

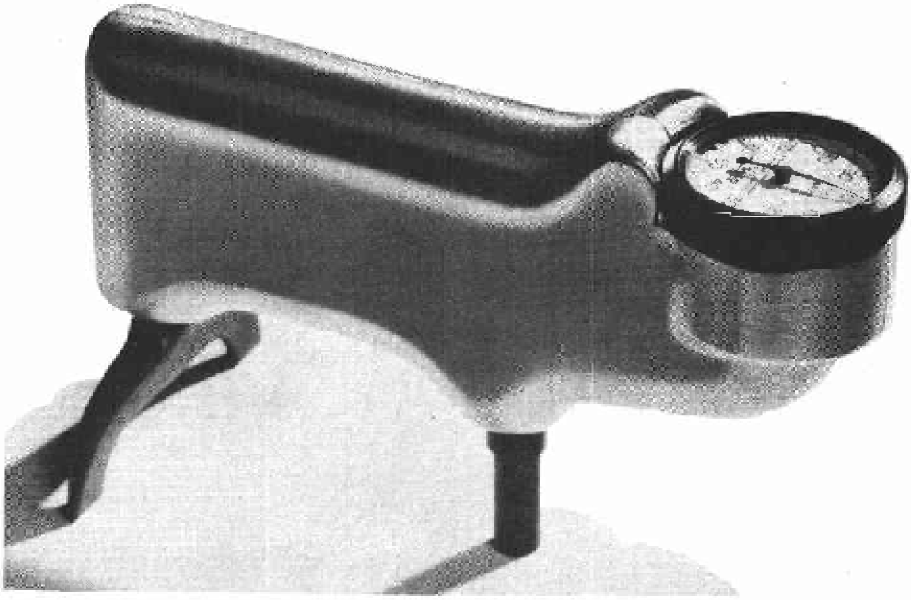

Figure 1.--Barcol hardness tester used for comparing the surface hardness of three thicknesses of glass-fabric-base plastic laminate.

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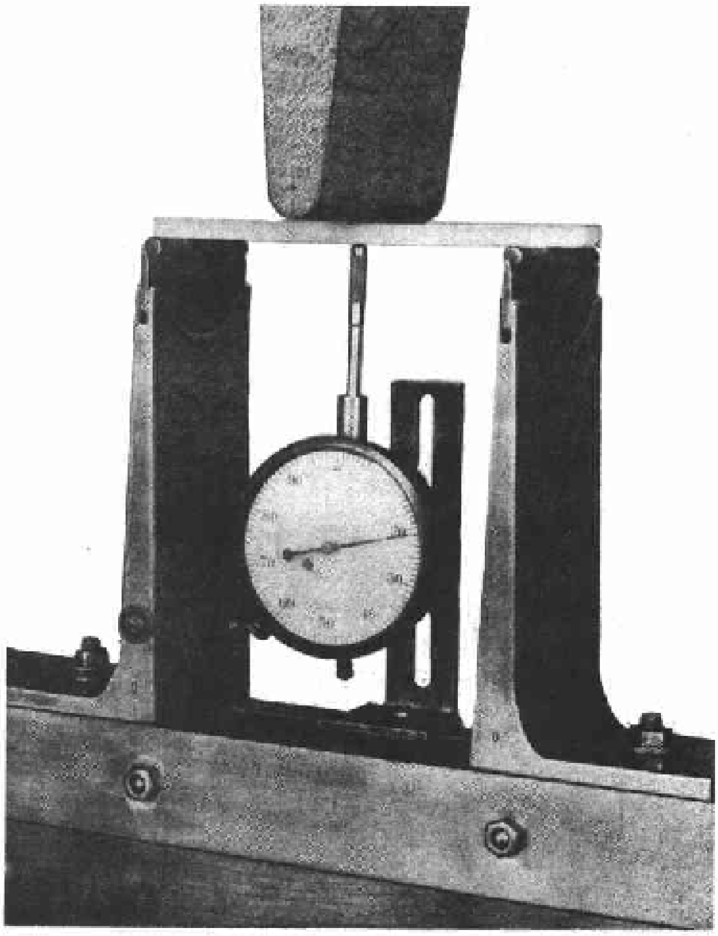

Figure 2.--Static-bending set-up used in testing glass-fabric-base plastic laminate specimens.

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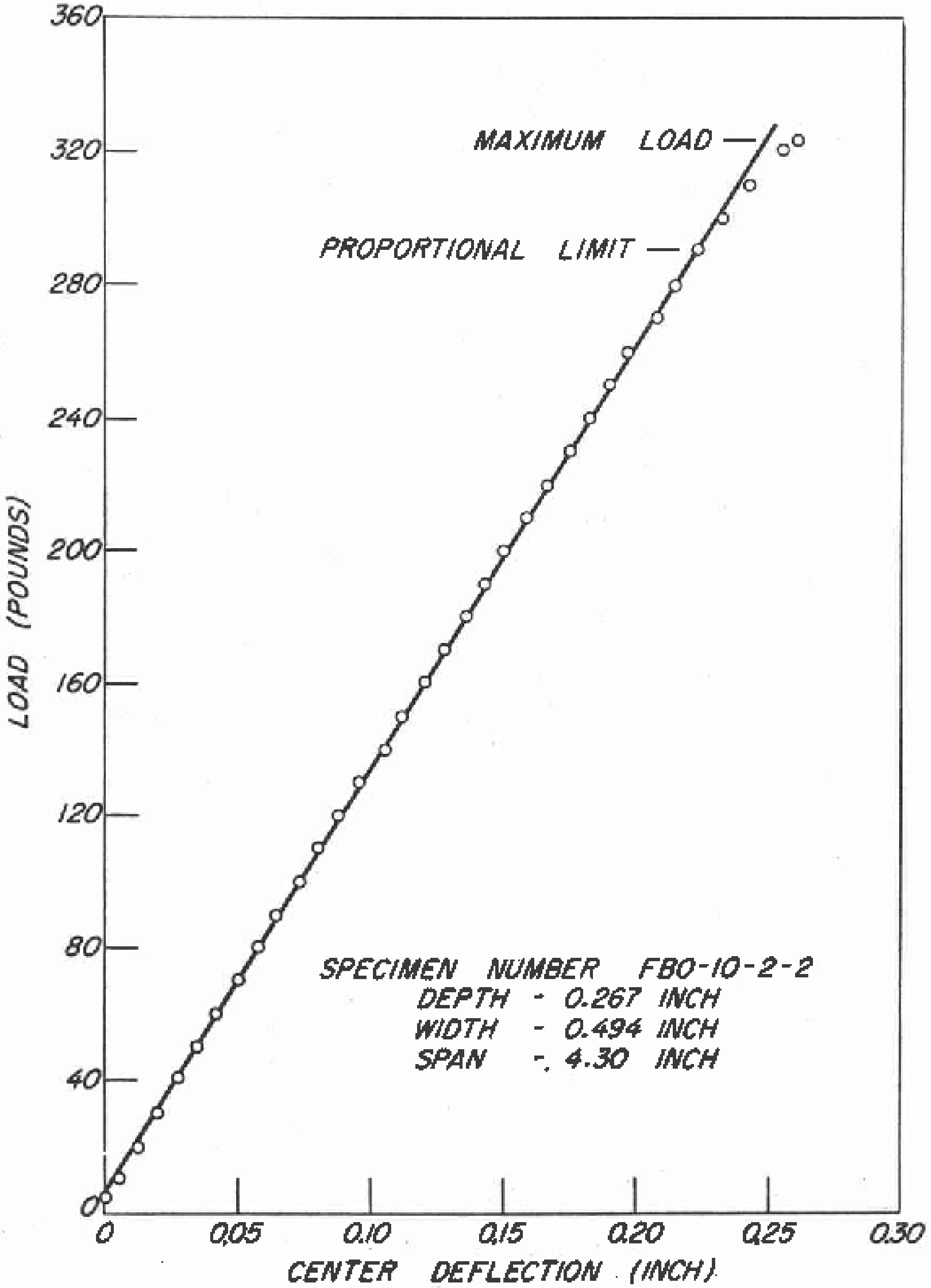

Figure 3.--Typical load-deflection curve for glass-fabric-base plastic laminate specimen tested in static bending.

2M 81220 F

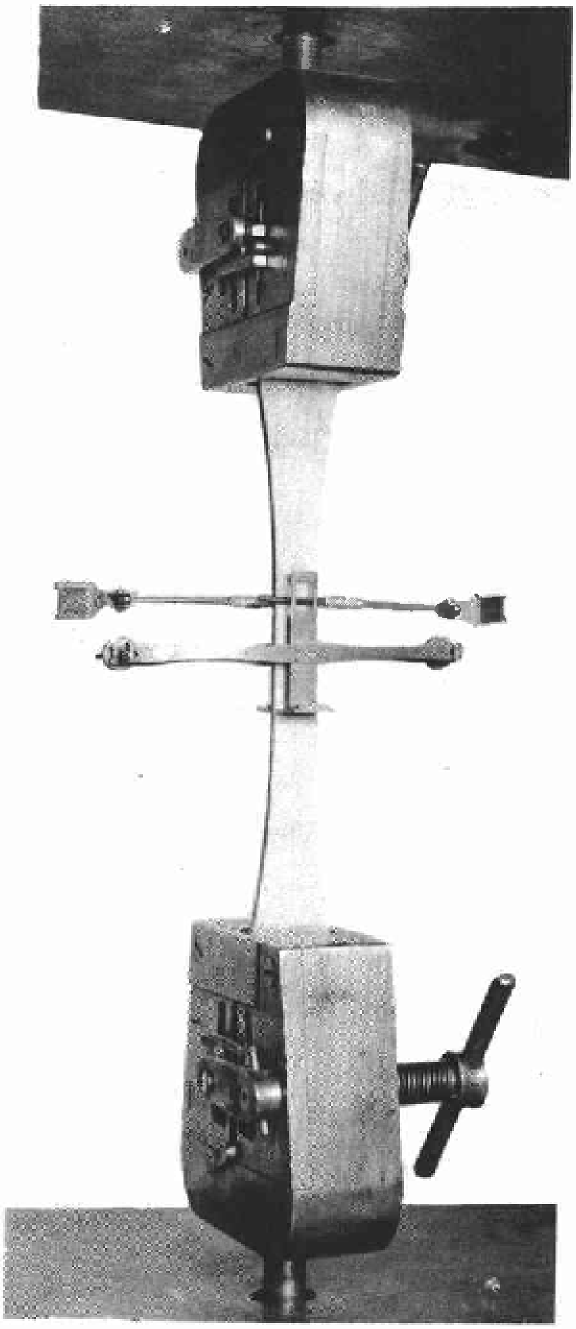

Figure 4.--Tensile-test set-up used in testing glass-fabric-base plastic laminate specimens.

ZM 78989 F

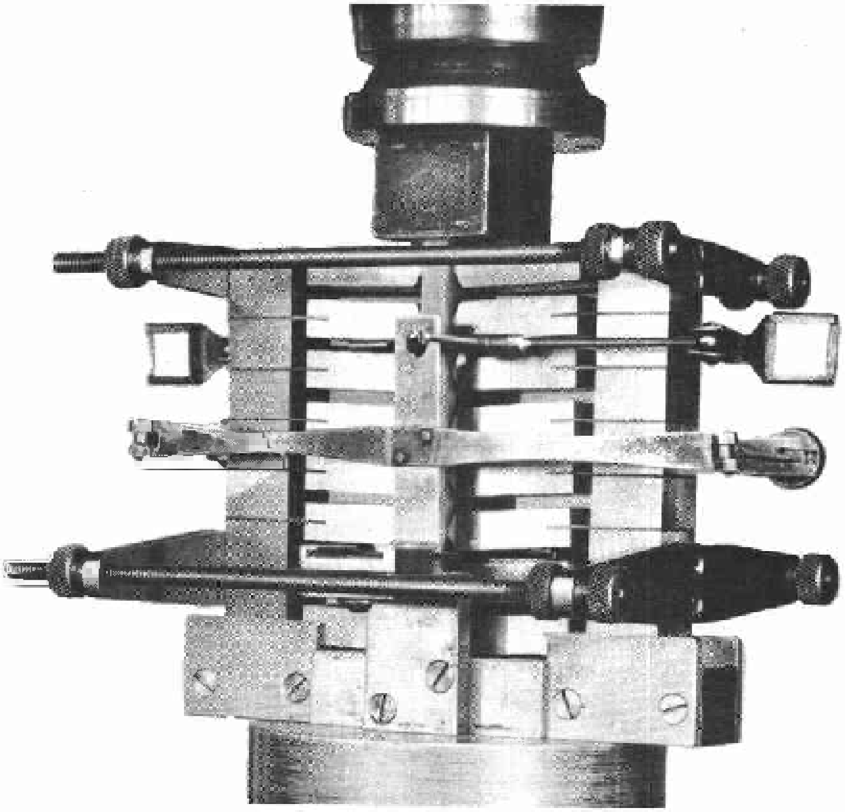

Figure 5.--Compression pack test used in testing glass-fabric-base plastic laminate specimens.

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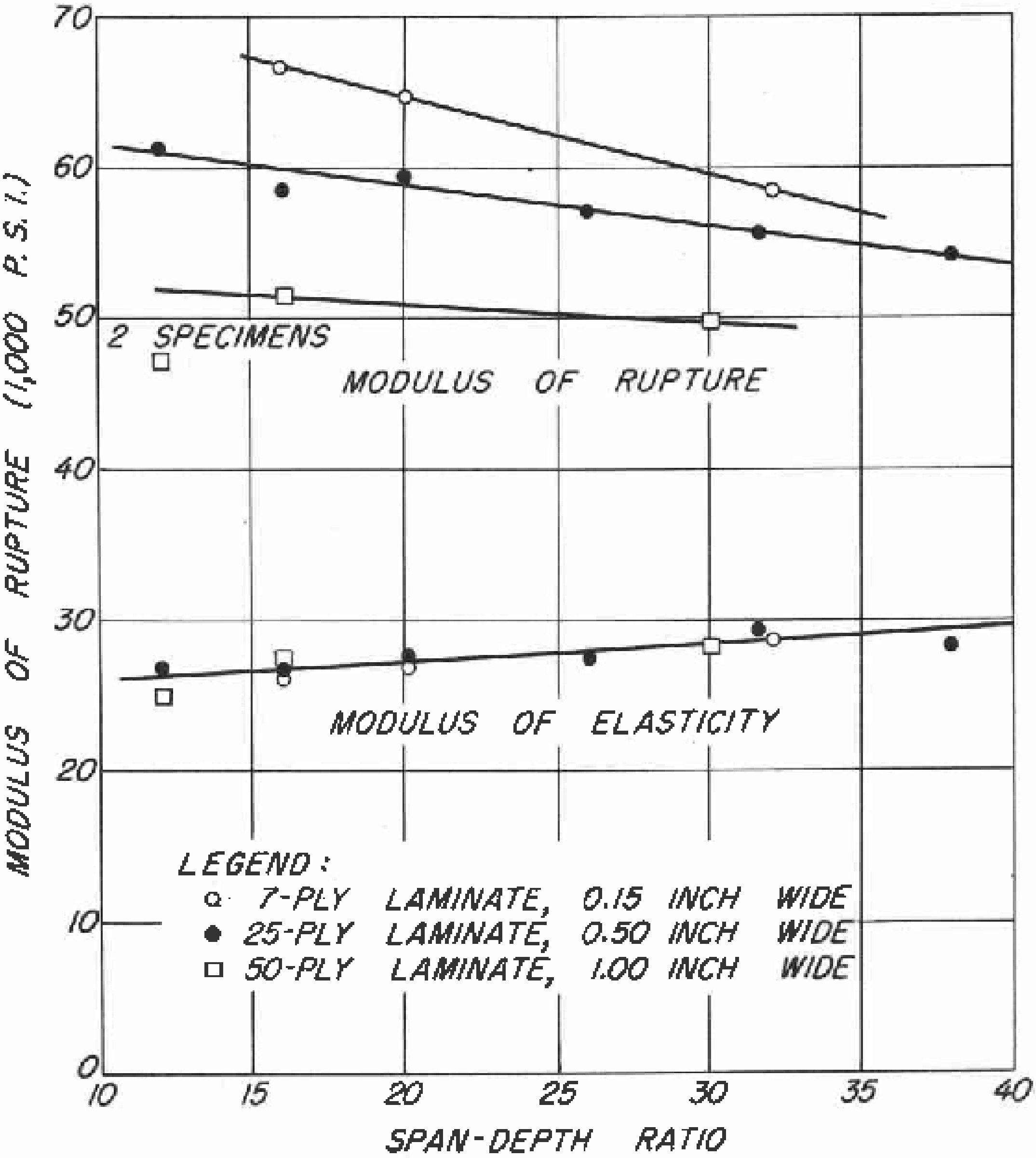

Figure 6.--Effect of span-depth ratio and thickness of laminate of a typical glass-fabric-base plastic laminate upon the modulus of rupture and modulus of elasticity in static bending.

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