FATIGUE OF SANDWICH CONSTRUCTIONS FOR AIRCRAFT

Fiberglas-laminate Facing and Paper Honeycomb Core Sandwich Material Tested in Shear

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In Cooperation with the University of Wisconsin

FATIGUE OF SANDWICH CONSTRUCTIONS FOR AIRCRAFT[1]

Fiberglas-laminate Facing and Paper Honeycomb Core Sandwich Material Tested in Shear[2]

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Summary and Conclusions

A limited number of tests have been made at the Forest Products Laboratory to determine the shear fatigue properties of an assembled sandwich panel with fiberglas-laminate facings and paper honeycomb core material. Repeated tests were made at a ratio of minimum to maximum loading of 0.1. The results of these tests and the S-N curve obtained from them are presented.

The study shows that, when this sandwich construction is subjected to repeated shear stresses, the failure may be (1) a diagonal tension failure of the core,

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[2] This is the seventh of a series of reports intended to offer a comparison of the shear fatigue properties of different sandwich materials. The following FPL reports discuss the shear fatigue properties of:
1559 "Cellular Cellulose Acetate Core Material"
1559-A "Aluminum Face and Paper Honeycomb Core Sandwich Material"
1559-B "Aluminum Face and End-grain Balsa Core Sandwich Material"
1559-C "Aluminum or Fiberglas-laminate Face and Fiberglas Honeycomb Core Sandwich Material"
1559-D "Fiberglas-laminate Face and End-grain Balsa Core Sandwich Material"
1559-E "Aluminum or Fiberglas-laminate Face and Cellular-hard-rubber Core Sandwich Material"
1559-F "Cellular Cellulose Acetate Core Material with Aluminum or Fiberglas-laminate Facings"

[3] Maintained at Madison 5, Wis., in cooperation with the University of Wisconsin.

(2) predominately diagonal tension failure of the core with some shear failure of the glue line, (3) predominately shear failure of the glue line with some diagonal tension failure of the core, or (4) complete shear failure of the glue line. Erratic results were obtained with tests wherein the failure was either of the latter two types, and these tests were therefore not used in determining the S-N curve. The results of tests having complete or predominately diagonal tension failure of the core material indicate a fatigue strength at 30 million cycles of approximately 54 percent of the static strength for the condition of loading used.

From the tests of this sandwich material, it is evident that an improved type or method of bonding the core and facings might be necessary under some conditions of loading to preclude shear failure of the glue line.

Introduction

If plates of sandwich constructions are designed so that their facings are elastically stable under the intended loads, the most critical stress to which the core is subjected is shear. The consideration of the effect of repeated shear stresses on the material of the cores and on the bonds between the core and facings is, therefore, important.

The general testing procedures and the nomenclature applied to these tests are similar to those used by the Forest Products Laboratory in testing aluminum facing and paper honeycomb core sandwich material.[2]

Description of Material and Specimens

The paper honeycomb core material was made at the Forest Products Laboratory. It was produced by impregnating 4.5-mil kraft paper of 12-inch width with about 10 percent of phenol resin and putting the dried paper through a B-flute corrugating machine. Node-to-node length and height of corrugations were approximately 0.230 and 0.097 inch, respectively (fig. 1). The corrugated paper was cut into sheets 40 inches long, and the individual sheets impregnated with resin B.[4] The sheets were then laid node to node to form a block about 2-5/8 inches thick. The over-all density of each block was about 6 pounds per cubic foot, with a resin content of approximately 55 percent.

The core material for each of the three panels was cut from three separate blocks. Each block was sawn perpendicular to the flutes with a band saw, to a thickness of 0.5 ± 0.005 inch, and the strips glued together to form the finished core. The core dimensions for panels 1, 2, and 3 were 25 by 25 inches, 18 by 18 inches, and 18 by 34 inches, respectively.

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[4]Additional information on the facings and adhesives referred to in this report is contained in appendix 1.

Facings for the sandwich panels were made of six plies of cross-laminated glass cloth[4] impregnated with 50 to 55 percent of resin A[4] by weight. A spread of 10 grams of resin per square foot was first applied to each face of the honeycomb core. The panels were then assembled and cured in a press at 225° F. and a pressure of 15 pounds per square inch for 1 hour, except that panel 1 was pressed at 25 pounds pressure per square inch.

Specimens were cut from the assembled panels with a high-speed, steel, circular saw to a width and length of 2 and 5.67 inches, respectively. The specimens were cut in two directions with respect to the core orientation; to produce shear deformation in (1) the LR plane and (2) the LT plane (fig. 1). They were glued to the 1/2-inch shear plates with adhesive M[4] primary and adhesive N[4] secondary, the latter being cured at 15 pounds of pressure per square inch and 220° F. for 1 hour.

The results of 48 fatigue tests and 34 control tests are presented in this report.

Testing

All tests were made similar to the methods described in Forest Products Laboratory Report No. 1559-A.

The specimens from panel 1 were cut and tested to produce shear deformation in the LR plane (fig. 1) and those of panel 2 to produce shear deformation in the LT plane. Both types of specimens were cut and tested from panel 3.

Failure of fatigue specimens was diagonal tension failure of the core, shear failure in the core-to-facing glue line, or a combination of the two. In all cases the failure was rapid and took place after a few cycles once it had begun.

Loading of control specimens increased at a uniform rate until the maximum load was reached, and then the specimen failed suddenly. The failures were of the same type as the fatigue failures except that generally there was more evidence of diagonal tension in the control failures.

There was no apparent difference between the failures of specimens tested in LR or LT direction. A typical diagonal tension failure is shown in figure 2, and a predominately shear failure, accompanied by some diagonal tension cracks, is shown in figure 3.

Presentation of Data

Table 1 presents the results of the individual fatigue and control tests. Values are calculated as in Forest Products Laboratory Report No. 1559-A. The fatigue specimens whose failures were completely or predominately a shear failure of the glue line, indicated as (1) glue shear or (2) glue shear and diagonal tension failures, are included in the table and plotted in figure 4, but were not used in determining the S-N curve.

There is considerable variation between groups of control specimens, but the specimens within each group are in reasonable agreement. A comparison of data from the control specimens of panel 3 (table 1) shows that, as an average, the strength in the LT direction is greater than the strength in the LR direction.

The S-N curve of figure 4 is drawn through the average of specimens whose failure was predominately in the core.

Analysis of Data

The scatter of points around the S-N curve from specimens whose failure was in the core (fig. 4) may be attributed principally to variation of the core material within a panel and to slight damage from fabrication. It is quite probable that the latter accounts for the three points that fall considerably below the curve.

Although most of the plotted points are based on results of tests in which the shear deformation was in the LR plane, the specimens tested in the LT plane produced similar values. In these tests the shear strength of the core in the LT direction is greater than the strength in the LR direction, but the shear fatigue strength, based on appropriate control strength, is approximately the same in each direction.

It should be emphasized that the S-N curve of figure 4 is drawn through points which represent specimens where the failure was completely or primarily a core failure. Thus the curve is indicative of the fatigue characteristics of paper honeycomb core material. The study shows, however, that 18 of the 48 shear fatigue specimens with fiberglas facings failed completely or predominately in the core-to-facing glue line, which indicates that an improved method of gluing must be employed to develop the full shear or shear fatigue strength of the core material. The results of tests whose failure was primarily in the glue line are scattered, largely because of the different percentages of glue-line failure, so no S-N curve was drawn through these values. Such a curve would fall below the curve drawn in figure 4 and, from these limited tests, would indicate a fatigue strength at 30 million cycles of approximately 45 percent of the static strength.

It is of interest to note that panel 2 was made by the same methods as panels 1 and 3, yet the specimens from this panel were particularly weak in the glue line. No explanation is suggested for this difference.

Prior to testing, it was agreed to discontinue testing any fatigue specimen that withstood 30 million cycles without failure. Eight such specimens were removed from the machine. It can be seen from the curve that the endurance limit cannot be accurately determined from these tests, but the curve may be as shown in figure 4. The curve obtained from these tests is similar to the curve drawn for aluminum facing-paper honeycomb sandwich materials except that it is higher beyond 1 million cycles.

Appendix 1

Description of Resins, Adhesives, and Facings

Resin A -- A high-temperature-setting, high-viscosity, contact-pressure, laminating resin of the polyester type.

Resin B -- A high-temperature-setting, low-viscosity, laminating resin of the styrene monomer, polyester type.

Adhesive M -- A high-temperature-setting mixture of thermosetting resin and synthetic rubber.

Adhesive N -- A high-temperature-setting, acid-catalyzed, phenolic resin.

Glass Cloth -- Heat-cleaned cloth chemically treated with a chrome-complex bath after the lubricant has been completely removed by exposure to high temperature.

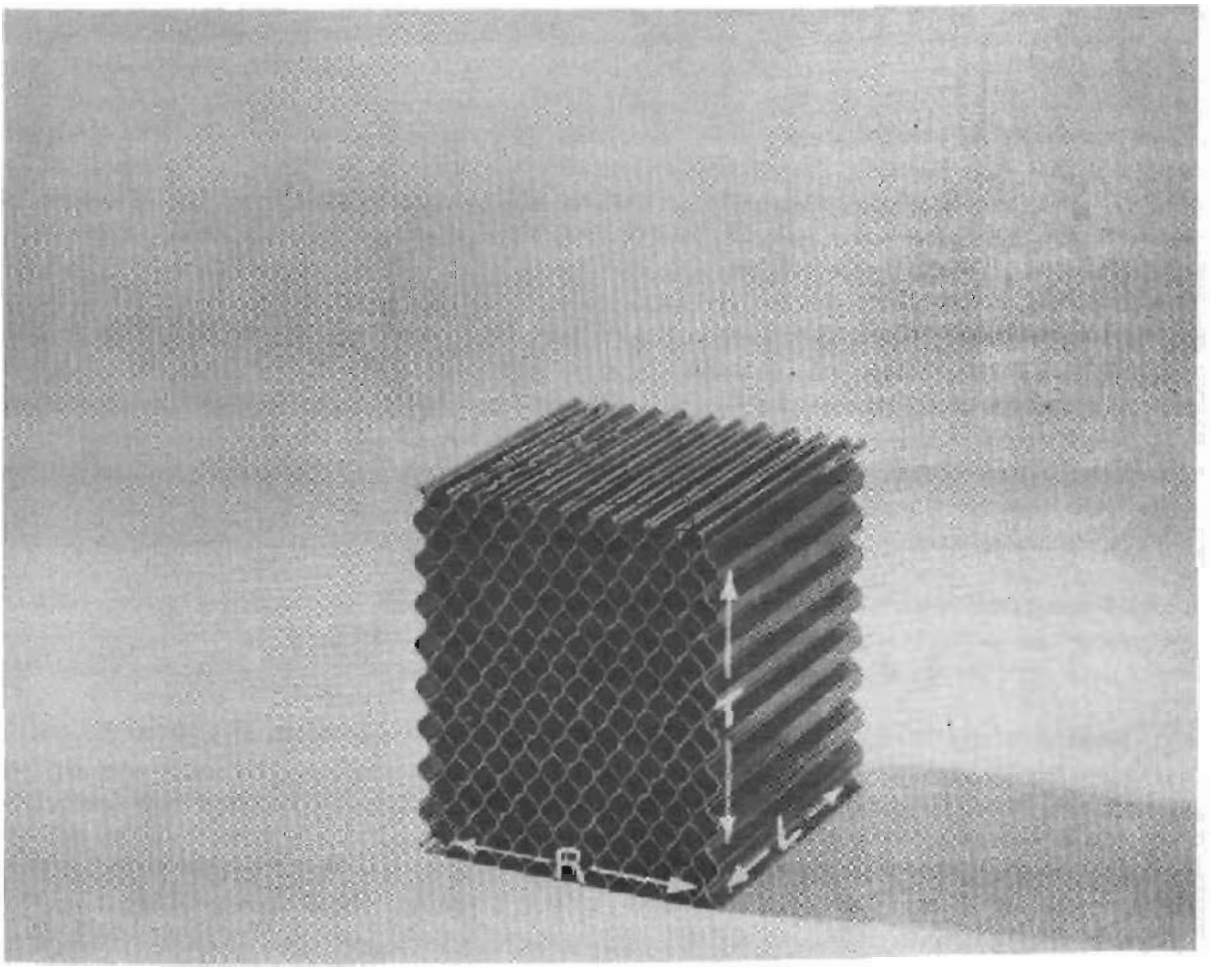
Table 1.--Shear fatigue strength of sandwich constructions having fiberglas-laminate facings and paper honeycomb cores[1]

Fatigue tests						Control tests	
Specimen No.	Maximum repeated shear stress	Control strength	Ratio of maximum repeated stress to control strength	Cycles to failure	Remarks on visible failure[2]	Specimen No.	Shear strength
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	P.s.i.	P.s.i.	Percent				P.s.i.
Panel 1 -- 24 by 24 inches -- Tested in LR direction							
F4-1-1	125.0	250.1	50.0	1,871,600	Diagonal tension and glue shear	F4-1-2	248.5
3	210.0	250.1	84.0	12,200	Diagonal tension	5	240.3
4	135.0	250.1	54.0	17,755,700	Diagonal tension	8	262.1
6	120.0	250.1	48.0	30,855,200+	No failure	11	256.2
7	225.0	250.1	90.0	4,600	Diagonal tension	14	270.2
9	190.0	250.1	76.0	6,400	Diagonal tension and glue shear	17	236.8
10	140.0	250.1	56.0	8,533,100	Diagonal tension	20	235.3
12	117.5	250.1	47.0	30,962,300+	No failure	23	267.9
13	230.0	250.1	92.0	0	Glue shear	26	250.4
16	200.0	250.1	80.0	13,600	Diagonal tension and glue shear	29	233.5
19	230.0	250.1	92.0	9,800	Diagonal tension		
21	155.0	250.1	62.0	57,700	Glue shear and diagonal tension	Average.	250.1
22	180.0	250.1	72.0	158,900	Diagonal tension and glue shear		
24	219.8	250.1	87.9	1,000	Glue shear and diagonal tension		
25	187.6	250.1	75.0	35,500	Glue shear		
27	160.0	250.1	64.0	1,124,300	Diagonal tension		
28	215.1	250.1	86.0	11,800	Diagonal tension		
30	150.0	250.1	60.0	213,600	Glue shear and diagonal tension		
31	147.5	250.1	59.0	10,179,900	Diagonal tension		
Panel 2 -- 18 by 18 inches -- Tested in LT direction							
F4-2-1	132.5	239.6	55.3	4,216,200	Glue shear and diagonal tension	F4-2-2	257.4
3	119.7	239.6	50.0	30,868,900+	No failure	5	239.8
4	191.5	239.6	79.9	7,900	Glue shear and diagonal tension	8	222.1
6	117.2	239.6	48.9	239,100	Glue shear and diagonal tension	11	221.2
7	167.4	239.6	69.9	20,700	Glue shear and diagonal tension	14	223.4
9	143.6	239.6	59.9	10,000	Glue shear and diagonal tension	17	230.1
13	177.3	239.6	74.0	19,000	Glue shear and diagonal tension	20	244.6
15	167.5	239.6	69.9	8,600	Glue shear and diagonal tension	23	277.8
16	112.5	239.6	47.0	1,037,000	Glue shear		
18	153.2	239.6	63.9	36,900	Glue shear and diagonal tension	Average.	239.6
19	124.5	239.6	52.0	427,700	Glue shear and diagonal tension		
22	167.9	239.6	70.1	86,000	Glue shear and diagonal tension		
24	112.5	239.6	47.0	9,264,100	Glue shear and diagonal tension		
Panel 3 -- 18 by 34 inches -- Tested in LR direction							
F4-3-2	102.9	209.7	49.0	31,204,300+	No failure	F4-3-1	185.2
4	156.5	209.7	74.6	331,000	Diagonal tension	3	223.3
6	121.6	209.7	58.0	8,114,800	Diagonal tension and glue shear	5	220.6
						Average.	209.7
F4-3-8	121.5	233.7	52.0	33,627,400+	No failure	F4-3-7	223.0
10	154.1	233.7	65.9	214,000	Diagonal tension	9	247.1
12	142.5	233.7	61.0	1,078,300	Diagonal tension and glue shear	11	231.0
						Average.	233.7
F4-3-14	168.9	219.6	77.0	127,700	Diagonal tension	F4-3-13	224.4
						15	214.7
						Average.	219.6
Panel 3 -- 18 by 34 inches -- Tested in LT direction							
F4-3-1a	111.2	232.0	47.9	11,363,400	Glue shear and diagonal tension	F4-3-2a	234.6
3a	190.1	232.0	81.9	22,500	Diagonal tension and glue shear	4a	230.1
5a	134.5	232.0	58.0	33,246,500+	No failure	6a	221.8
7a	120.6	232.0	52.0	30,214,800+	No failure	8a	241.7
9a	115.8	232.0	49.9	33,249,400+	No failure		
						Average.	232.0
F4-3-10a	188.0	272.3	69.0	6,600	Diagonal tension and glue shear	F4-3-11a	256.7
13a	149.7	272.3	55.0	11,796,500	Diagonal tension	12a	288.9
14a	187.6	272.3	68.9	291,900	Diagonal tension and glue shear	15a	277.6
17a	171.5	272.3	63.0	1,144,100	Diagonal tension	16a	266.0
						Average.	272.3

[1] Fatigue specimens loaded at a rate of 900 cycles per minute in direct-stress fatigue machine. Ratio of minimum to maximum load was 0.10. Control specimens tested in a testing machine at a head speed of 0.01 inch per minute.

[2] Diagonal tension failure is a failure of the core material, while glue shear failure is a failure of the glue line between core and facing. Specimens where failure is predominately glue shear are referred to as (1) glue shear or (2) glue shear and diagonal tension.

M 80085 F



ZM 74154 F

Figure 1.--Paper honeycomb block, with directional orientation referred to as L (longitudinal), R (radial), and T (tangential).

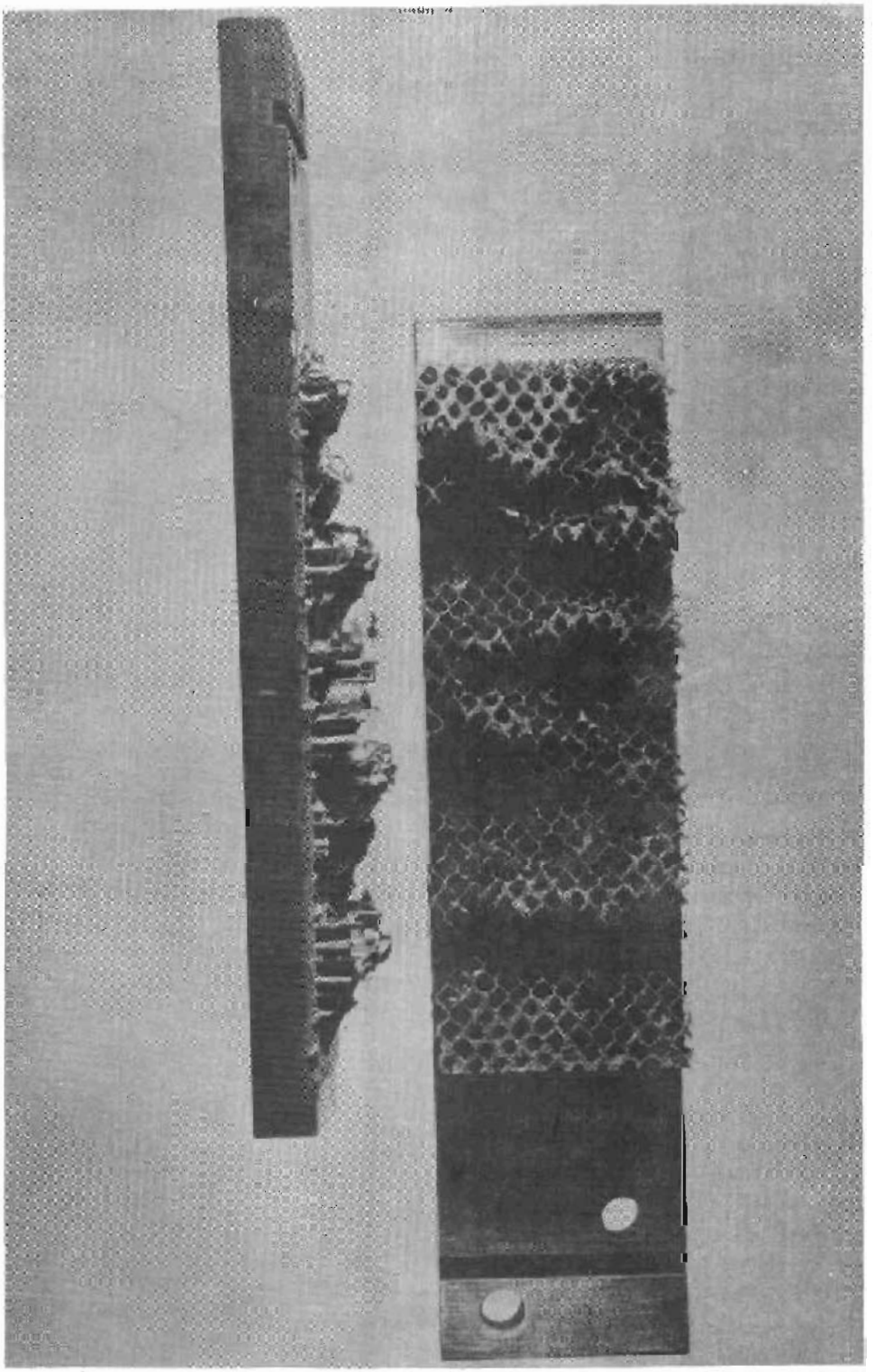


Figure 2.--Typical diagonal tension core failure of sandwich material with fiberglas-laminate facings and paper honeycomb core, after failure in shear fatigue.

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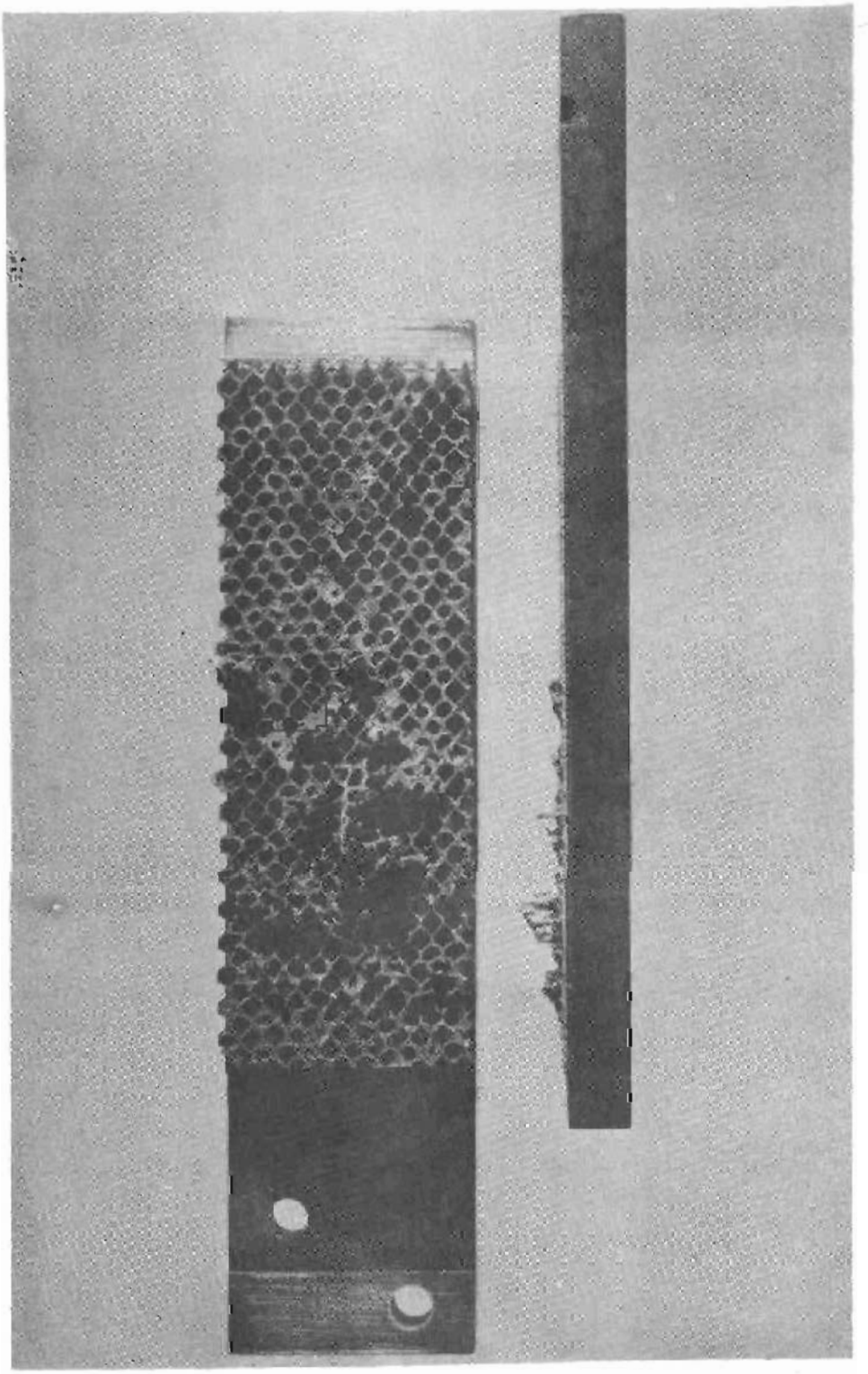

Figure 3.--A sandwich specimen with fiberglas-laminate facings and paper honeycomb core after failure in shear fatigue. Failure is primarily a shear failure of the core-to-facing glue line, with some diagonal tension failure of the core.

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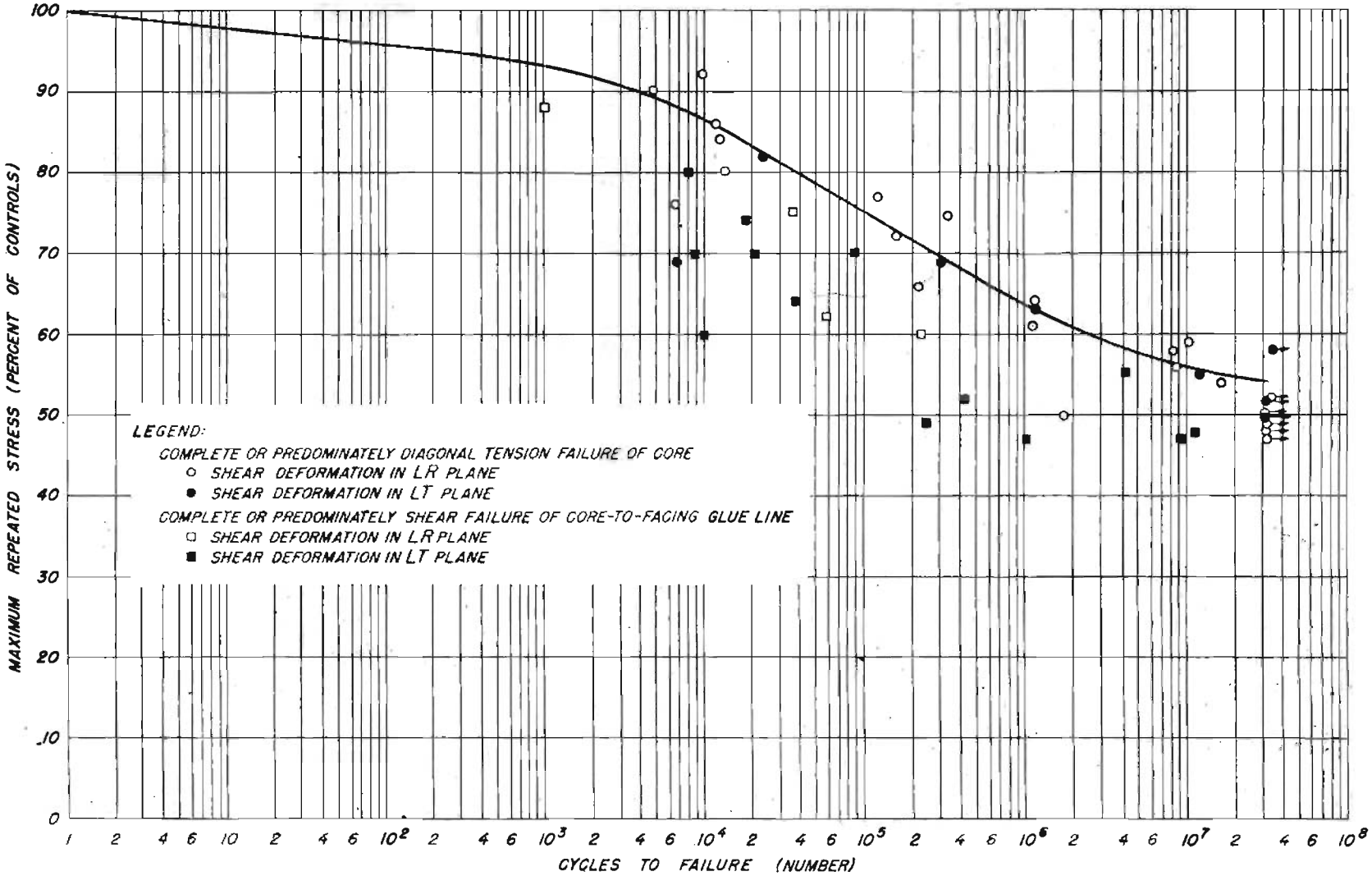

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Figure 4.--"S-N" curve for sandwich material with fiberglas-laminate facings and paper honeycomb core, tested in shear. Ratio of minimum to maximum loading (range ratio) was 0.10. Curve is drawn through points representing specimens which failed predominately in the core. Letter designations for planes refer to longitudinal, radial, and tangential directions for cores.