FATIGUE OF SANDWICH CONSTRUCTIONS FOR AIRCRAFT

Cellular-hard-rubber Core Material with Aluminum or Fiberglas-laminate Facings, Tested in Shear

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FATIGUE OF SANDWICH CONSTRUCTIONS FOR AIRCRAFT[1]

(Cellular-hard-rubber Core Material with Aluminum or Fiberglas-laminate Facings, Tested in Shear)[2]

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Summary and Conclusions

A limited number of tests (46) have been made at the Forest Products Laboratory to determine the shear fatigue properties of an assembled sandwich panel of cellular-hard-rubber core material and aluminum or fiberglas-laminate facings. The tests have been made at a ratio of minimum to maximum loading of 0.1. The results of these tests and the corresponding S-N curve are presented. The results of the tests indicate a fatigue strength at 30 million cycles of approximately 44 percent of the static strength for the condition of loading used.

Introduction

Experiments were conducted at the Forest Products Laboratory to determine the shear fatigue characteristics of typical sandwich panels having cellular-hard-rubber core material. The facing materials employed were

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[2] This is the sixth of a series of reports intended to offer a comparison of the shear fatigue properties of different sandwich materials. The following Forest Products Laboratory reports have been completed:

- 1559 - "Cellular Cellulose Acetate Tested in Shear"
- 1559-A - "Aluminum Face and Paper Honeycomb Core Sandwich Material Tested in Shear"
- 1559-B - "Aluminum Face and End-grain Balsa Core Sandwich Material Tested in Shear"
- 1559-C - "Fiberglas Honeycomb Core Material with Fiberglas-laminate or Aluminum Facings Tested in Shear"
- 1559-D - "Fiberglas-laminate Face and End-grain Balsa Core Sandwich Material Tested in Shear"

(1) 0.020-inch aluminum bonded to the core with a room-temperature-setting resorcinol resin, adhesive V,[3] and (2) six-ply fiberglas laminate impregnated with a high-temperature-setting laminating resin, resin A.

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

Description of Material and Specimens

The cellular hard rubber was received from a commercial manufacturer in blocks approximately 1-1/2 by 20 by 36 inches. The blocks were sawn parallel to the longest side into strips about 5 inches wide. These strips were further finished by sawing into strips 0.500 ± 0.005 inch thick as described elsewhere.[4] Five 1/2- by 5- by 25-inch strips were edge glued together to form a finished core.

Two panels with aluminum facings were prepared and bonded in a press as described in method 2 of aluminum-to-cellular-hard-rubber assembly techniques, Forest Products Laboratory Report No. 1574.[4] One panel with fiberglas facings was made in a press by the methods described in the same report. The facings were made of six plies of cross-laminated glass cloth impregnated with 45 to 50 percent of resin A by weight.

The 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. With the exception of specimens designated with an "a," the specimens were cut parallel to the direction of the core strips so that no part of the core-to-core glue line was included in the specimen. Some specimens from panel A2-7 were cut perpendicular to the core-to-core glue lines and thus include at least one such glue line. These specimens were lettered with an "a."

The specimens with aluminum facings were glued to the 1/2-inch shear plates as described in Forest Products Laboratory Report 1559-A, except that the secondary adhesive was adhesive N, cured at 15-pounds-per-square-inch pressure at 180° F. for 1 hour. Specimens with fiberglas-laminate facings were glued with adhesive M primary and adhesive N secondary and cured as above.

The results of 46 fatigue tests and 30 control tests are presented in this report.

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[3]The resins, adhesives, and core material referred to in this report are described further in appendix 1.

[4]Forest Products Laboratory Report No. 1574, "Fabrication of Lightweight Sandwich Panels of the Aircraft Type," by B. G. Heebink, June 1947.

Testing

All tests were made by methods similar to those described in Forest Products Laboratory Report No. 1559-A.[2]

On the basis of the method of manufacturing the cellular hard rubber, it would seem likely that the shear properties of the sandwich panels would be similar in the planes parallel to the facings. This probability was confirmed by a few tests on panel A2-7, where the properties of a few specimens taken at right angles to the others appeared to be very nearly the same.

Tests of sandwich specimens with cellular-hard-rubber core presented many difficulties in fabrication, cutting, and testing. The brittle nature of the material, the variation in density, and the low proportional limit in compression at elevated temperatures[4] were among the factors complicating the experiments. The wide scatter of test results, both in static and fatigue tests, was in part due to these factors. It is difficult to detect minute fractures caused by fabrication or to observe and correct for variations of density, and since even the low pressures at elevated temperatures used in gluing the specimens probably exceed the compressive proportional limit, it is impractical to make corrections for the possible damage incurred.

Failure of control and fatigue specimens was rapid once failure had begun. In all cases, the failure occurred in the core near the glue line. Typical control failures are shown in figure 1. The left specimen is representative of shear failure in the core with one diagonal tension break. The right specimen similarly represents a shear failure of the core, but the ridges indicate a greater tendency toward diagonal tension failure. There was no discernible difference between the failures of the control and fatigue specimens.

Presentation of Data

Table 1 presents the results of the individual control and fatigue tests. Values are calculated as in Forest Products Laboratory Report No. 1559-A.[2] The control strengths varied from 84.6 to 159.7 pounds per square inch, and individual control strengths within a group varied as much as 26 percent from the average.

The results of the fatigue tests are plotted in figure 2, and the S-N curve is drawn through the average values.

Analysis of Data

The scatter of points around the S-N curve may be attributed principally to the variation of the core material. With the large differences of control values within a group, as shown in table 1, a considerable scatter of fatigue data must be expected.

It had been previously agreed to discontinue any specimen that withstood 30 million cycles without failure, so that this discontinuance, combined with the large variation in test results, makes it difficult to predict the endurance limit. However, a curve has been drawn through the plotted data (fig. 2) and shows the trend of the fatigue characteristics of these sandwich materials.

When a lightweight core material, such as cellular hard rubber, is glued to a rigid face and then is subjected to shear stresses, a zone of stress concentration must be expected near the glue line. The primary failure of all fatigue and control specimens tested for this report was a shear failure of the core near and parallel to the glue line. In some cases there was additional evidence of diagonal tension failure. Since there was no failure of the glue line itself, it may be concluded that the adhesion between the facings and core was satisfactory.

APPENDIX 1

Description of Resins, Adhesives, and Core Material

Adhesive V. A room-temperature-setting resorcinol resin.

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

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

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

Cellular hard rubber. A core material, black in color, of approximately 8-pounds-per-cubic-foot density (including skin).

Table 1.--Shear fatigue strength of sandwich constructions having cellular-hard-rubber cores and aluminum or fiberglas-laminate facings[1]

Fatigue tests						Control tests	
Specimen No.	Maximum repeated shear stress	Control strength	Ratio of maximum repeated stress to control strength	Cycles to failure	Visible failure in core	Specimen No.	Shear strength
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	P.s.i.	P.s.i.	Percent				P.s.i.
Sandwich Material of Cellular-hard-rubber Core and Aluminum Facings							
A2-6-1	58.2	132.2	44.0	15,914,400	Shear	A2-6-2	127.2
3	90.0	132.2	68.1	50,700	....do............	5	159.7
4	112.0	132.2	84.8	4,400	....do............	8	140.2
6	96.0	132.2	72.6	17,600	Shear and diagonal tension	11	110.3
7	73.0	132.2	55.2	1,390,800	Shear	14	123.6
9	76.0	132.2	57.5	22,000	....do............		
12	99.0	132.2	74.9	6,300	Shear and diagonal tension	Average...	132.2
13	59.5	132.2	45.0	6,966,000	....do............		
15	93.9	132.2	71.0	5,500	Shear		
16	86.0	132.2	65.0	23,400	Shear and diagonal tension		
A2-6-18	57.3	102.2	56.1	979,100	Shear	A2-6-17	99.9
19	83.9	102.2	82.1	15,200	Shear and diagonal tension	20	106.1
21	79.8	102.2	78.1	1,700	Shear	23	100.6
						Average...	102.2
A2-7-1	51.0	107.8	47.3	1,804,600	Shear	A2-7-2	112.8
3	81.0	107.8	75.2	900	Shear and diagonal tension	5	110.5
4	52.5	107.8	48.7	602,400	Shear	8	99.0
6	46.5	107.8	43.2	18,840,500	....do............	11	101.7
7	60.0	107.8	55.6	22,900	....do............	14	135.6
9	49.5	107.8	46.0	912,000	Shear and diagonal tension	17	99.2
10	54.0	107.8	50.1	60,200	Shear	19	96.0
12	48.4	107.8	44.9	2,727,900	....do............		
13	48.0	107.8	44.5	30,164,300+	No failure	Average...	107.8
15	57.0	107.8	52.8	258,600	Shear and diagonal tension		
16	75.0	107.8	69.5	174,200	....do............		
A2-7-4a	56.0	105.4	53.1	1,300,900	Shear	A2-7-2a	95.5
6a	41.3	105.4	38.9	33,118,300+	No failure	5a	94.1
7a	47.0	105.4	44.6	30,681,400+	....do............	8a	103.7
9a	50.0	105.4	47.4	1,132,100	Shear and diagonal tension	11a	111.5
10a	62.0	105.4	58.8	94,600	Shear	14a	101.2
12a	68.0	105.4	64.5	248,200	....do............	17a	108.1
13a	80.0	105.4	75.9	56,700	Shear and diagonal tension	20a	114.6
15a	53.0	105.4	50.3	2,495,500	Shear	23a	114.2
16a	74.0	105.4	70.2	371,700	Shear and diagonal tension	Average...	105.4
19a	98.8	105.4	93.7	4,300	....do............		
21a	100.0	105.4	94.9	20	....do............		
Sandwich Material of Cellular-hard-rubber Core and Fiberglas-Laminate Facings							
F2-1-1	44.5	106.0	42.0	1,791,700	Shear and diagonal tension	F2-1-2	110.5
3	47.2	106.0	44.5	33,765,400+	No failure	5	84.6
6	53.0	106.0	50.0	9,742,500	Shear	8	125.2
7	65.7	106.0	62.0	2,588,700	....do............	11	95.5
9	74.2	106.0	70.0	1,500	....do............	14	100.9
10	48.8	106.0	46.0	6,186,900	Shear and diagonal tension	17	109.9
12	45.6	106.0	43.0	38,808,900+	No failure	20	115.3
13	63.6	106.0	60.0	31,800	Shear		
15	78.5	106.0	74.0	16,200	Shear and diagonal tension	Average...	106.0
16	61.5	106.0	58.0	618,600	....do............		
21	70.0	106.0	66.0	43,000	Shear		

[1] Fatigue specimens loaded at 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 hydraulic testing machine at a head speed of 0.01 inch per minute.

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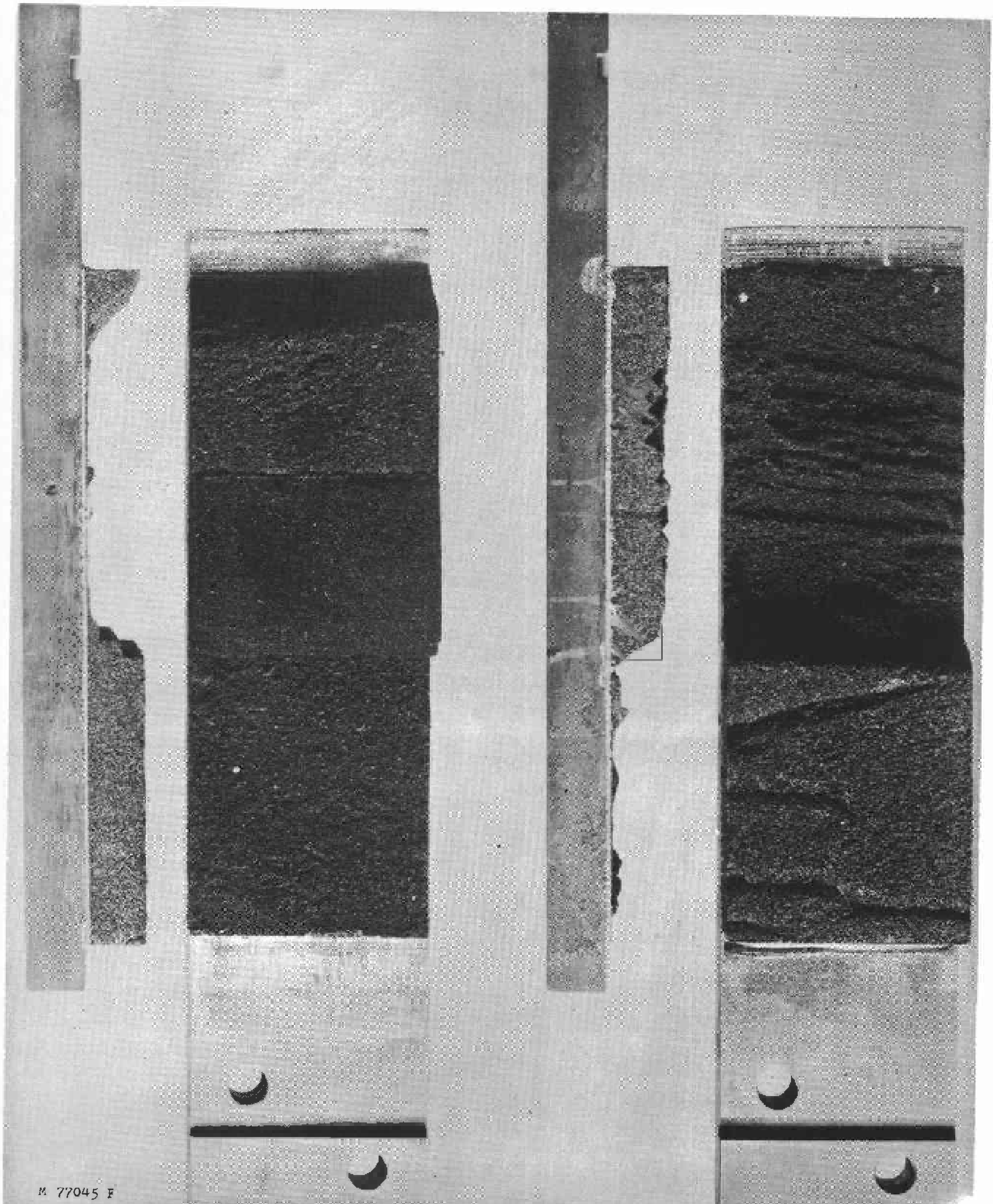

Figure 1.--Typical failures of control specimens from aluminum-face and cellular-hard-rubber-core sandwich panels.

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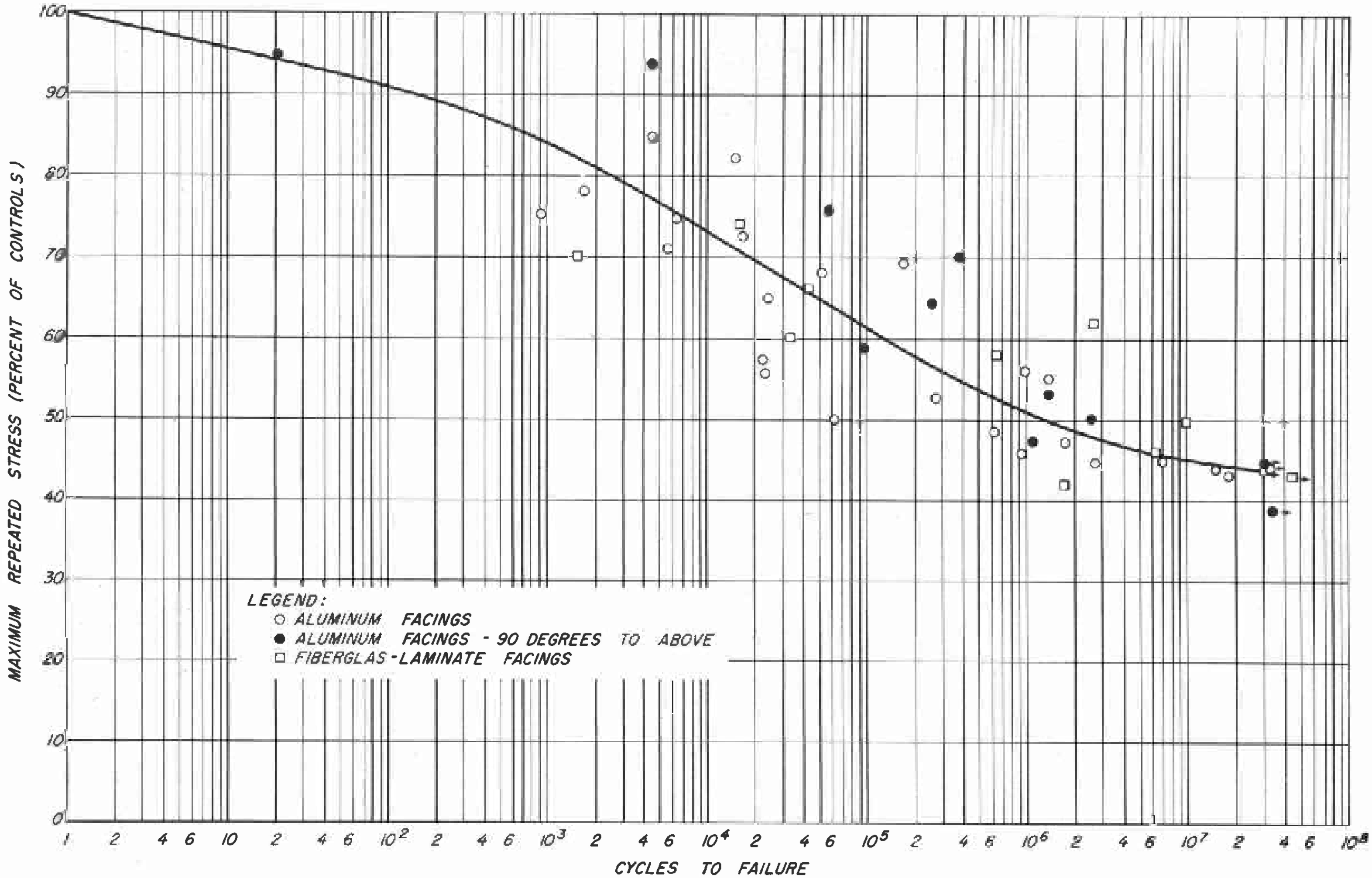

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Figure 2.--S-N curve for sandwich constructions tested in shear. Cellular-hard-rubber cores and fiberglas-laminate facings. Ratio of minimum to maximum stress (range ratio) was 0.10.