FATIGUE OF SANDWICH CONSTRUCTIONS FOR AIRCRAFT

Cellular Cellulose Acetate Core Material with Aluminum or Fiberglas-laminate Facings, Tested in Shear

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In Cooperation with the University of Wisconsin

FATIGUE OF SANDWICH CONSTRUCTIONS FOR AIRCRAFT[1]

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

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Summary and Conclusions

A limited number of tests (49) have been made at the Forest Products Laboratory to determine the shear fatigue properties of an assembled sandwich panel of cellular cellulose acetate core material and aluminum or fiberglas-laminate facings. 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 results of the tests indicate a fatigue strength at 30 million cycles of approximately 36 percent of the static strength for the condition of loading used.

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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. NBA-PO-NAer 00619, Amendment No. 1, and U. S. Air Force No. USAF-PO-(33-038)48-41E. Results here reported are preliminary and may be revised as additional data become available.

[2]This is another 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 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"

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

Introduction

If plates of sandwich construction 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 bond between the core and facings is, therefore, important. The Forest Products Laboratory has completed a number of studies[2] to determine the effect of repeated shear stresses on sandwich constructions.

A previous study[2] was made to determine the shear fatigue properties of cellular cellulose acetate as a material. The experiments presented in this report were made to determine the shear fatigue properties of two types of typical sandwich constructions having cellular cellulose acetate cores. Therefore, not only the core material was tested, but the bond between core and facings as well. The facing materials employed were (1) 0.020-inch 24ST aluminum and (2) six-ply fiberglas-laminate. The aluminum was bonded to the 1/2-inch core material with a room-temperature-setting resorcinol resin, adhesive, V,[4] and the glass cloth was impregnated with a high-temperature setting laminating resin, resin A, prior to the sandwich assembly.

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

The cellular cellulose acetate was received in the form of continuously extruded bars, approximately 5/8 by 5 inches in cross section. The outer skins were removed and the bars cut into strips 0.500 ± 0.005 inch thick and 24 inches long. Five strips were edge glued to form a finished core approximately 24 by 24 inches.

Prior to assembly, both sides of each aluminum facing were cleaned and etched and then sprayed with a gluable metal-priming adhesive, M. Two panels with aluminum facings were assembled in a press according to method 4 of aluminum-to-cellulose acetate assembly techniques, Forest Products Laboratory Report No. 1574,[5] except that adhesive V was used instead of adhesive P. Two panels with glass-cloth facings were assembled in a press as described in method 1 of glass cloth-to-cellulose acetate assembly techniques in the above report. The facings were made of six plies of cross-laminated glass cloth impregnated with 45 to 50 percent of resin A by weight.

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[4]The resins and adhesives referred to here are described further in appendix 1.

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

Specimens were cut from the assembled sandwich panel 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: (1) parallel to the direction of the core extrusion, and (2) perpendicular to the direction of the core extrusion. In the former, cutting was done to eliminate any of the glue lines resulting from edge gluing of the core strips, and any effect such a glue line might have was thereby avoided. In the other specimens this glue line could not be eliminated because the core strips were narrower than the length of specimen.

The sandwich specimens with aluminum facings were glued to the 1/2-inch shear plates with adhesive N, a high-temperature-setting, acid-catalyzed phenolic resin. The resin was cured at 15 pounds pressure per square inch at 220° F. for 1 hour. Specimens with fiberglas-laminate facings were glued as above except that the shear plates were first sprayed with a primary adhesive, M.

The results of 49 fatigue tests and 28 control tests are presented in this report.

Testing

All fatigue and control tests were made similar to the methods described in Forest Products Laboratory Report No. 1559-A.[2]

In all tests, there was no noticeable difference between the failures of specimens with aluminum facings or fiberglas-laminate facings. The failure was primarily a failure of the core.

There was a noticeable difference in the type of fracture between specimens cut parallel or perpendicular to the core extrusion. Fatigue failure of the former was primarily a combination of many diagonal tension failures and shear failure near the center of the core, as typified in figure 1. Fatigue failure of specimens cut perpendicular to the core extrusion generally had only a few diagonal tension fractures and shear failure near the glue line (fig. 2). In both types of specimens, however, it appeared that diagonal tension failure occurred first and then the specimen failed suddenly with the final failure, as indicated above.

Loading of control specimens increased at a uniform rate until the maximum load was reached, and then the specimen failed suddenly. Diagonal tension failures were apparent in all control specimens, as well as shear failure of the core. In a few cases the shear failure occurred at the center of the core, but generally it was near the glue line.

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.[2] There is considerable variation in control strengths between panels, but specimens within a group are in close agreement. In specimens with core material tested parallel to extrusion, the average shear strength of the groups varies from 99 to 160 pounds per square inch. In specimens with core material perpendicular to the extrusion, the average shear strengths are 158 and 189 pounds per square inch.

The results of the fatigue tests are plotted in figure 3, and the S-N curve is drawn through the average values.

Analysis of Data

The scatter of points around the S-N curve (fig. 3) may be attributed principally to variations in the core material within a panel, but may also be due in part to minute fractures caused during fabrication of specimens. It is quite probable that the latter accounts for the three points that fall considerably below the curve. The fatigue characteristics of the weakest core material appear to be similar to those of the strongest material.

A cellular or foamy material that is extruded under pressure would be expected to have air inclusions that are not spherical. Further, these inclusions would be flattened in the extruded direction. Exploratory tests, including the use of microphotographs, were made at the Laboratory on typical commercial cellular cellulose acetate. These limited tests showed the length of the air cell in the extruded direction to be about one-half the diameter perpendicular to the extruded direction. It would then seem apparent that the shear strength in the parallel and perpendicular planes would not be equal. This is verified by control tests, where the perpendicular strength is about 50 percent greater than the parallel strength. Nevertheless, a few fatigue tests in the stronger direction were considered necessary in the event the particular cellular orientations might have entirely different fatigue properties. However, figure 3 shows that the fatigue characteristics in both planes, based on percentage of control strength, are approximately the same.

The difference in core failures, parallel or perpendicular to the core extrusion, can probably be attributed to this variation in size of the included cells. It has been noted that the failure of fatigue and control specimens was due to failure of the core material, an indication that the bond between core and facings was satisfactory.

Prior to testing, it was agreed to discontinue testing any fatigue specimen that withstood 30 million cycles without failure. Two 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 that the curve starts to flatten beyond 4 million cycles and may be as shown in figure 3. This is in close agreement with the fatigue strength at 30 million cycles obtained in previous tests of cellular cellulose acetate core material.[2] The curve obtained from tests reported herein is similar to but slightly lower than the curve obtained for the core material alone. From the tests, it is apparent that the fatigue curve of these sandwich constructions is based upon the fatigue properties of the core material.

APPENDIX 1

Description of Resins and Adhesives

Note 1. Resin A. A high-temperature-setting, high-viscosity, contact-pressure, laminating resin of the polyester type.

Note 2. Adhesive M. A high-temperature-setting mixture of thermosetting resin and synthetic rubber.

Note 3. Adhesive N. A high-temperature-setting, acid-catlyzed, phenolic resin.

Note 4. Adhesive P. A room temperature-setting resorcinol resin.

Note 5. Adhesive V. A room temperature-setting resorcinol resin

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

Fatigue tests					Control tests	
Specimen number	Maximum repeated shear stress	Control strength	Ratio of maximum repeated stress to control strength	Cycles to failure	Specimen number	Shear strength
(1)	(2)	(3)	(4)	(5)	(6)	(7)
	P.s.i.	P.s.i.	Percent			P.s.i.
			Sandwich Material with Aluminum Facings			
			Panel 1 -- Core material tested parallel to extrusion			
Al-1-2a	55.3	136.4	40.6	4,035,500	Al-1-1a	135.0
3a	63.9	136.4	46.9	1,971,700	4a	144.3
6a	59.0	136.4	43.2	2,968,200	5a	140.9
7a	52.0	136.4	38.1	6,944,400	8a	131.5
10a	66.6	136.4	48.8	2,401,700	9a	139.2
11a	56.9	136.4	41.8	3,587,400	12a	127.5
					Average.....	136.4
			Panel 2 -- Core material tested parallel to extrusion			
Al-5-1a	39.7	99.2	40.0	30,645,700+	Al-5-2a	111.3
4a	49.5	99.2	49.9	2,606,000	5a	89.1
6a	63.2	99.2	63.7	258,500	8a	94.4
7a	59.5	99.2	60.0	193,100	11a	92.8
9a	79.4	99.2	80.0	24,600	14a	108.6
10a	54.5	99.2	54.9	535,100		
12a	59.5	99.2	60.0	27,500	Average.....	99.2
13a	36.7	99.2	37.0	31,103,000+		
15a	63.3	99.2	63.8	924,600		
16a	69.4	99.2	70.0	148,900		
			Panel 2 -- Core material tested perpendicular to extrusion			
Al-5-1	71.1	158.0	45.0	255,400	Al-5-2	153.7
3	134.1	158.0	84.9	4,200	5	159.4
4	60.1	158.0	38.0	13,793,200	8	161.0
7	66.4	158.0	42.0	2,990,300	11	158.6
9	118.5	158.0	75.0	59,700	14	157.2
10	87.0	158.0	55.1	862,600		
12	71.1	158.0	45.0	2,950,400	Average.....	158.0
13	102.7	158.0	65.0	200,400		
15	63.3	158.0	40.1	9,053,300		

(continued) Sheet 1 of 2 sheets

Table 1.--Shear fatigue strength of sandwich construction, etc., (continued)

Fatigue tests					Control tests	
Specimen number	Maximum repeated shear stress	Control strength	Ratio of maximum repeated stress to control strength	Cycles to failure	Specimen number	Shear strength
(1)	(2)	(3)	(4)	(5)	(6)	(7)
	P.s.i.	P.s.i.	Percent			P.s.i.
Sandwich Material with Fiberglas Facings						
Panel 1 -- Core material tested parallel to extrusion						
F1-1-1a	70.0	159.7	43.9	6,167,500	F1-1-2a	165.1
3a	63.9	159.7	40.0	2,214,800	5a	154.3
4a	85.0	159.7	53.3	39,600		
6a	58.9	159.7	36.9	22,549,300	Average	159.7
Panel 2 -- Core material tested parallel to extrusion						
F1-2-1a	48.1	129.9	37.0	6,668,100	F1-2-2a	123.5
3a	70.0	129.9	53.9	620,000	5a	136.6
4a	109.9	129.9	84.6	4,700	8a	132.1
6a	51.8	129.9	39.9	8,252,300	11a	130.9
7a	90.0	129.9	69.3	156,200	14a	126.2
9a	58.2	129.9	44.8	1,816,100		
10a	46.7	129.9	36.0	18,733,300	Average	129.9
12a	80.1	129.9	61.6	360,900		
13a	100.0	129.9	77.0	20,200		
15a	113.0	129.9	87.0	1,500		
Panel 2 -- Core material tested perpendicular to extrusion						
F1-2-3	70.1	189.4	37.0	6,221,300	F1-2-4	179.9
5	126.9	189.4	67.0	83,200	7	194.9
6	91.6	189.4	48.4	2,245,400	10	189.8
8	79.6	189.4	42.0	3,547,400	13	197.0
9	69.0	189.4	36.4	10,848,400	16	185.6
11	67.2	189.4	35.5	11,057,100		
12	154.9	189.4	81.8	650	Average	189.4
14	142.0	189.4	75.0	38,100		
15	97.0	189.4	51.2	2,155,700		
17	167.0	189.4	88.2	400		

[1]Fatigue specimens loaded at the 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.

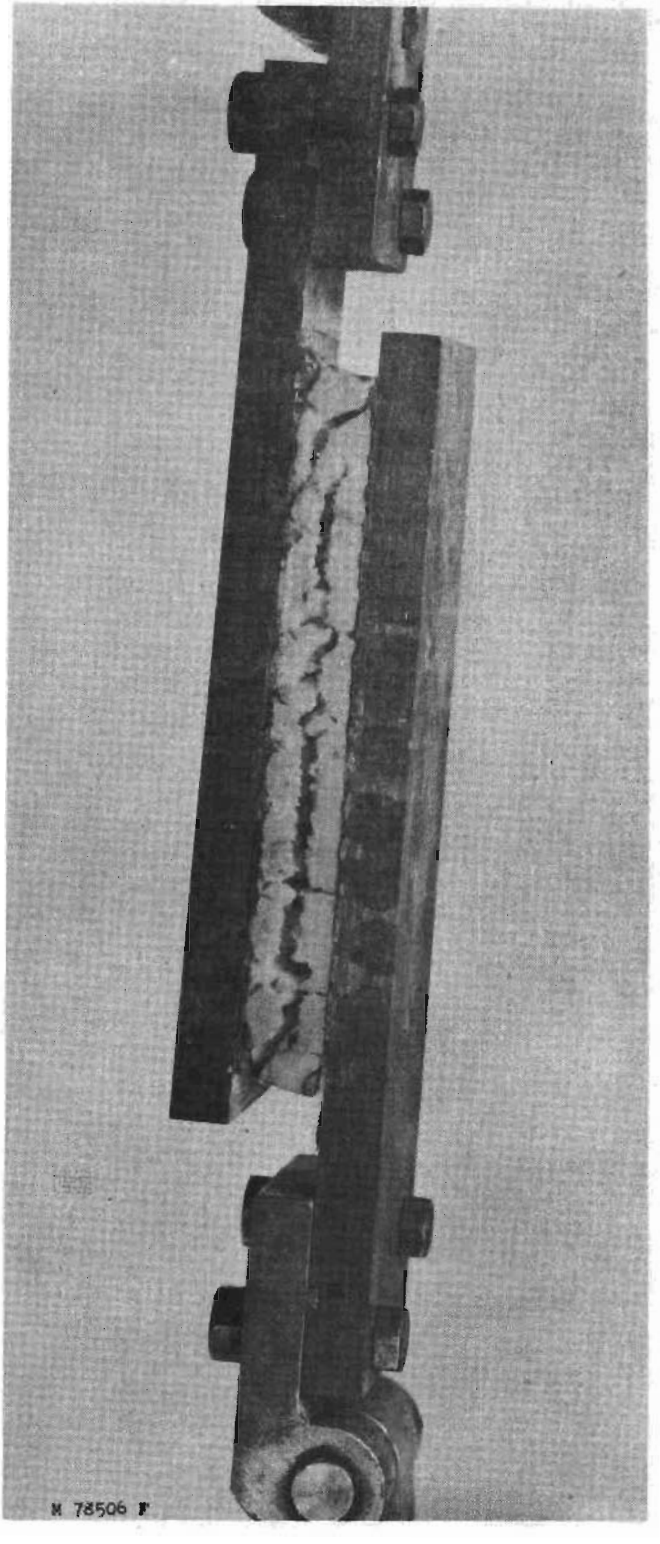

Figure 1.--A fiberglas-laminate face and cellular cellulose acetate core sandwich specimen after failure in shear fatigue test. Core orientation is such that the applied load is parallel to the extruded direction.
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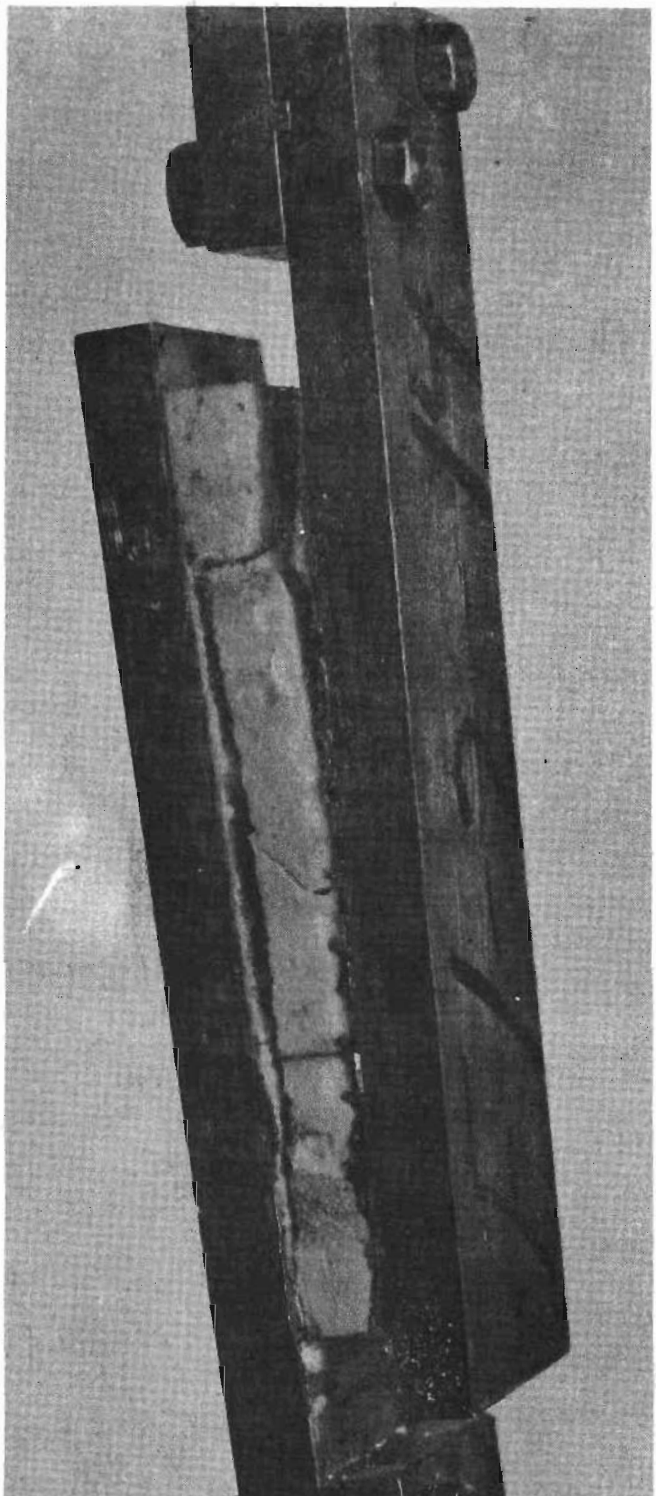

Figure 2.--A fiberglas-laminate face and cellular cellulose acetate core sandwich specimen after failure in shear fatigue test. Core orientation is such that the applied load is perpendicular to the extruded direction.

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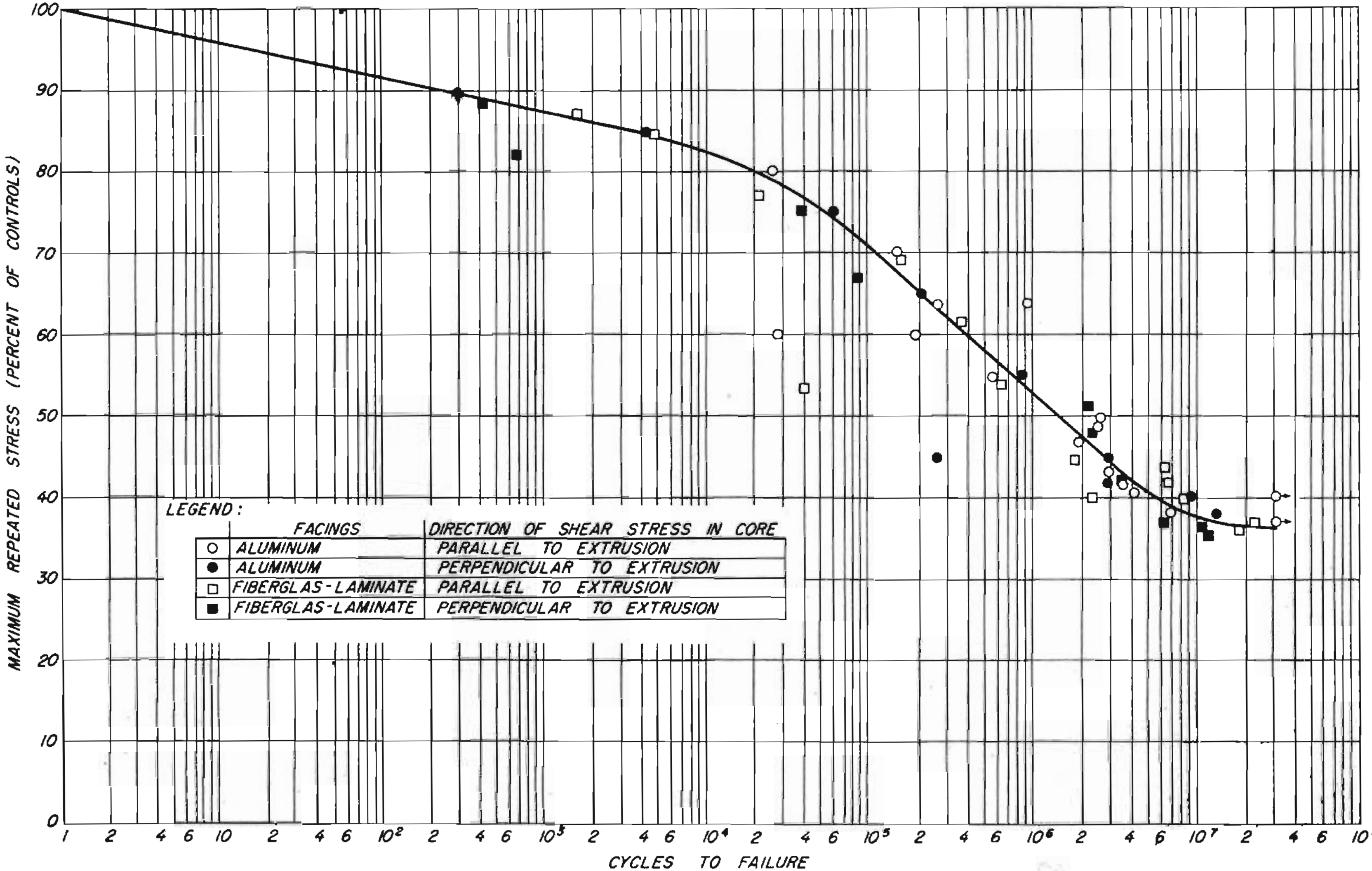

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Figure 3.--"S-N" curve for sandwich material with cellular cellulose acetate core and aluminum or fiberglas-laminate facings. Ratio of minimum to maximum stress (range ratio) was 0.10.