FATIGUE OF SANDWICH CONSTRUCTIONS FOR AIRCRAFT

(Aluminum Facing and Aluminum Honeycomb Core Sandwich Material Tested in Shear)

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FATIGUE OF SANDWICH CONSTRUCTIONS FOR AIRCRAFT[1]

(Aluminum Facing and Aluminum Honeycomb Core Sandwich Material Tested in Shear)[2]

By FRED WERREN, Engineer

Forest Products Laboratory,[3] Forest Service
U. S. Department of Agriculture

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 aluminum facings and perforated-aluminum-foil honeycomb

[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 the ninth 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"
1559-G "Fiberglas-laminate Facing and Paper Honeycomb Core Sandwich Material"

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

core material. Repeated tests were made at a ratio of minimum to maximum loading of 0.1. The results of the tests and the S-N curves obtained from them are presented.

The shear and shear fatigue properties in the LT plane (fig. 1) are different from those in LR plane, and the results of tests in each direction are given. The shear strength in the LT plane is almost twice as great as the shear strength in the LR plane, but the fatigue properties are proportionately better in the LR plane. If equal repeated shear stresses were applied to a specimen in each plane, however, the specimen with deformation in the LR plane would be expected to fail first. The results of the series of tests in the LR plane indicate a fatigue strength at 30 million cycles of approximately 36 percent of the static strength for the condition of loading used. In the LT plane, the fatigue strength at 30 million cycles is about 23 percent of the static strength.

Introduction

If plates of sandwich construction are designed so that their facings are elastically stable, 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 bands between the core and facings is, therefore, important.

The general testing procedures and 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

Three panels of the sandwich material were furnished to the Laboratory by the manufacturer.[4] The honeycomb core material consisted of 0.004-inch perforated aluminum foil formed into 3/8-inch cells of hexagonal shape, and weighed about 5-1/2 pounds per cubic foot. The core was cut to a thickness of 0.500 ± 0.005 inch and was bonded to the 0.020-inch

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[4]Additional information on the panels and on the adhesives used in these tests is given in Appendix 1.

aluminum facings with an adhesive especially formulated for bending metals. The core and facings were assembled and cured in a press at 10 pounds per square inch at 300° F. for 20 minutes.

Specimens were cut from the panels with a metal-cutting band saw to a width and length of 2.00 and 5.67 inches, respectively. The specimens were cut in two directions with respect to the core orientation to permit application of shear deformation in (1) the LR plane and (2) the LT plane (fig. 1). The specimens were glued to the 1/2-inch shear plates with Adhesive Y,[4] with a final cure at 10 pounds per square inch and 300° F. for 1 hour.

The results of 33 fatigue tests and 24 control tests are presented in this report.

Testing

All tests were made in accordance with the methods described in Forest Products Laboratory Report No. 1559-A.[2]

The failure of fatigue specimens tested to produce shear deformation in the LR plane was a combination of buckling of the cell walls and of diagonal tension (fig. 2). The diagonal-tension cracks originated relatively early in the test and always had their inception at one of the perforations in the cell wall. These early cracks almost always occurred in the cell wall of single thickness. Slight buckling of some of the cell walls was also evident almost from the beginning of the test. In spite of the early fractures and buckling, the load dropped off only slightly until shortly before the final failure. Usually the final failure was a progressive buckling and diagonal-tension failure of the cell walls, and the specimen would not hold the load. There was no sudden failure or drop off in load such as has been experienced with several other core materials.

The failure of the specimens that were tested to produce shear deformation in the LT plane was considerably different from that mentioned above. The final failure was a combination of (1) buckling of the cell walls, (2) diagonal-tension failure of the core originating at the perforations, and (3) glue-line failure between core and facings. It appeared that the glue-line failure occurred after the other two types, and the specimen failed more rapidly once the bond had begun to fail. As with the LR specimens, however, the failure was progressive until the specimen would no longer

hold the load. It was noted that the initial buckling appeared limited to the single cell walls but that the diagonal-tension cracks originated at the perforations in both the single and double walls.

The failure of the control specimens tested in the LR plane was due to buckling of the cell walls. If the load was carried on beyond the maximum, the result was a further collapse of the cell walls. In specimens tested in the LT plane, the failure was also due to buckling of the cell walls. The double cell walls buckled noticeably at the maximum load, and the buckling was followed by progressive buckling and a slow drop in load. In each case, the load appeared to increase at a uniform rate until the maximum load was reached.

Presentation of Data

The results of the individual fatigue and control tests are presented in table 1. Values are calculated as in Forest Products Laboratory Report No. 1559-A. It is evident that the shear strength in the LT plane is almost double that in the LR plane.

The results of the fatigue tests are plotted in figure 3, and an S-N curve is plotted through the points representing the two planes tested.

Analysis of Data

From an examination of the construction of the core material (fig. 1), it can be seen that the cell walls of double thickness are in an LT plane. Therefore it appears that the strength in the LT plane would be greater than that in the LR plane, provided the glue bond between core and facings is satisfactory. This was confirmed in static tests wherein the bond did not fail. Since the fatigue characteristics in the two planes might be completely different in such a construction, however, tests in both the weak and the strong direction seemed advisable.

The S-N curve associated with the weaker direction (LR plane) is an indication of the shear fatigue properties of the core in that direction, and the bond between core and facing appeared to be satisfactory. Failure was due to diagonal-tension cracks originating at the perforations in the cell walls and to buckling of the cell walls (fig. 2). Although no diagonal-

tension failures were visible in the static tests, the effect of repeated stresses resulted in the tension cracks at the perforations, where there is a zone of stress concentration. In specimen A6-2-13, one such diagonal-tension crack was observed at about 3 million cycles, and additional ones at about 13 million cycles. Nevertheless, the specimen withstood more than 30 million cycles without complete failure.

For specimens tested in the LT plane, the failure was different than that above, and the resultant S-N curve reflects a combination of failure of the core material and failure of the bond between core and facings.

A comparison of the data and the two S-N curves indicates that the LR plane, within the range tested, is still the critical plane as far as fatigue is concerned. Even though the curve for the LT plane is lower, these percentage values are based on a higher control strength. As an example, a specimen from panel 2 subjected to stresses in the LR plane at a maximum repeated shear stress of 100 pounds per square inch would be expected to withstand about 200,000 cycles before final failure. A similar specimen from the same panel but subjected to the same repeated shear stress in the LT plane would be expected to withstand almost 2 million cycles. The above comparison is of course limited to the type of loading used in these tests.

It is important to repeat here that the perforations in the cell walls are a point of stress concentration and that when the core material is subjected to repeated shear stresses, a few diagonal-tension cracks become evident long before the final failure takes place.

Prior to testing, it was agreed to discontinue testing any fatigue specimen that withstood 30 million cycles without complete failure. Four such specimens were removed from the machine. It can be seen from the plotted points and curves of figure 3 that the endurance limit cannot be accurately determined from these tests. For specimens tested in the LR plane, it appears that the endurance limit might be about 35 percent of the static strength for the condition of loading used; but for specimens tested in the LT plane, there does not appear to be a definite indication that the endurance limit is being approached, even at 30 million cycles.

Appendix 1

Description of Sandwich Panels

The following description of the sandwich panels was submitted to the Forest Products Laboratory by their manufacturer.

Facings	24 ST clad aluminum alloy
Facing thickness	0.020 inch
Core	3/8-0.004 PR (3/8-inch cells, perforated aluminum foil 0.004 inch thick)
Core thickness	0.500 ± 0.002 inch
Molded panel thickness	0.541 ± 0.002 inch
Number of panels submitted	3
Molding temperature	300° F.
Molding pressure	10 pounds per square inch
Preheat time: in press	3 minutes at zero pressure
Molding time	20 minutes in steam-heated pressure
Core weight	5.55 pounds per cubic foot
Adhesive	FM-45, composition unknown
Weight of panels	0.92 pound per square foot

Description of Adhesive

Adhesive Y, a modified polyvinyl butyral adhesive.

Table 1.--Shear fatigue strength of sandwich constructions of aluminum facings and aluminum honeycomb cores[1]

Fatigue tests					Control tests	
Specimen No.	Maximum repeated shear stress	Control strength	Ratio of maximum repeated shear stress to control strength	Cycles to failure	Specimen No.	Shear strength
(1)	(2)	(3)	(4)	(5)	(6)	(7)
	P.s.i.	P.s.i.	Percent			P.s.i.
PANEL 1 -- 18 by 24 INCHES -- TESTED IN LR DIRECTION						
A6-1-1	44.8	154.1	29.1	30,381,700+	A6-1-2	155.4
3	55.5	154.1	36.0	26,858,500	4	149.4
5	63.2	154.1	41.0	1,200,200	6	155.1
7	52.4	154.1	34.0	30,381,700+	8	160.8
9	58.6	154.1	38.0	13,305,700	10	154.5
11	134.1	154.1	87.0	6,600	12	149.4
					Average	154.1
PANEL 2 -- 18 by 28 INCHES -- TESTED IN LR DIRECTION						
A6-2-1	79.1	149.5	52.9	513,500	A6-2-2	148.5
3	73.8	149.5	49.4	1,650,400	4	145.4
5	68.5	149.5	45.9	2,162,300	6	148.1
7	64.2	149.5	42.9	3,319,800	8	152.9
9	114.3	149.5	76.4	50,100	10	145.9
11	87.0	149.5	58.2	723,500	12	146.3
13	60.6	149.5	40.5	30,493,100+	14	152.0
15	123.0	149.5	82.3	12,600	16	151.1
17	96.7	149.5	64.7	235,300	18	151.8
19	57.1	149.5	38.2	4,775,900	20	152.7
21	104.5	149.5	70.0	109,000		
					Average	149.5

Table 1.--Shear fatigue strength of sandwich constructions of aluminum facings and aluminum honeycomb cores[1] (Continued)

Fatigue tests					Control tests	
Specimen No.	Maximum repeated shear stress	Control strength	Ratio of maximum repeated shear stress to control strength	Cycles to failure	Specimen No.	Shear strength
(1)	(2)	(3)	(4)	(5)	(6)	(7)
	P.s.i.	P.s.i.	Percent			P.s.i.
PANEL 2 -- 18 by 28 INCHES -- TESTED IN LT DIRECTION						
A6-2-1a	123.0	286.0	43.0	356,700	A6-2-2a	270.6
3a	175.9	286.0	61.5	45,100	5a	306.2
4a	228.8	286.0	80.0	4,400	8a	289.1
6a	140.6	286.0	49.2	107,800	11a	275.9
7a	210.9	286.0	73.7	9,000	14a	288.2
9a	109.9	286.0	38.4	1,108,000		
10a	96.7	286.0	33.8	3,126,900	Average	286.0
12a	191.6	286.0	67.0	27,000		
13a	103.3	286.0	36.1	1,339,300		
15a	116.4	286.0	40.7	455,000		
16a	158.2	286.0	55.3	78,100		
PANEL 3 -- 18 by 28 INCHES -- TESTED IN LT DIRECTION						
A6-3-1a	81.7	283.3	28.8	9,381,500	A6-3-2a	277.9
3a	70.8	283.3	25.0	21,801,900	5a	279.4
4a	76.5	283.3	27.0	5,190,900	8a	292.6
6a	87.3	283.3	30.8	4,065,900		
7a	65.2	283.3	23.0	31,242,500+	Average	283.3

[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 at a head speed of 0.01 inch per minute.

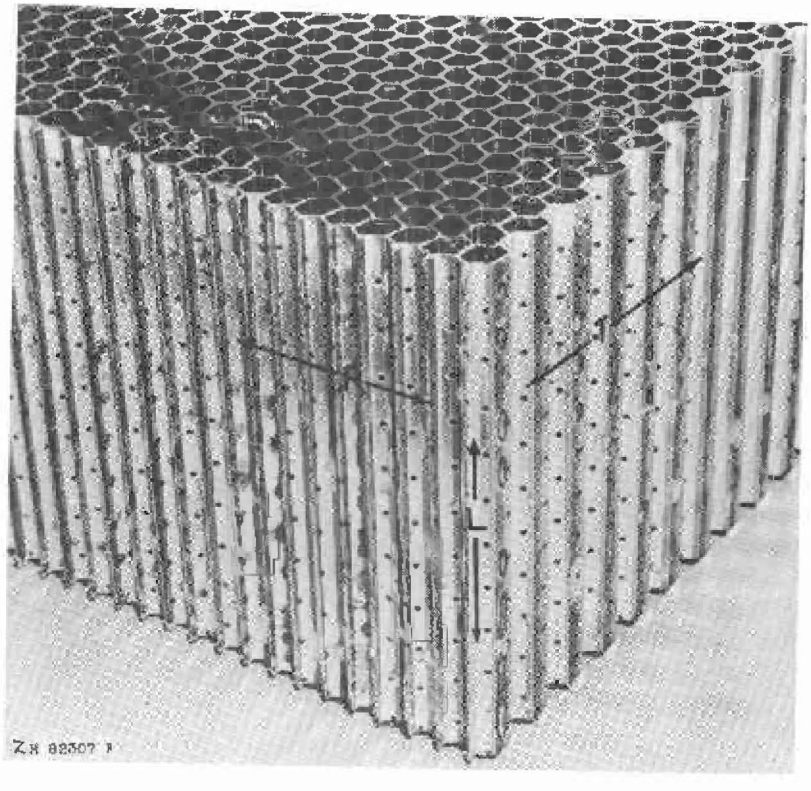

Figure 1. --Section of a block of aluminum honeycomb core material made from perforated aluminum foil. Directional orientation referred to as L (longitudinal), R (radial), and T (tangential)

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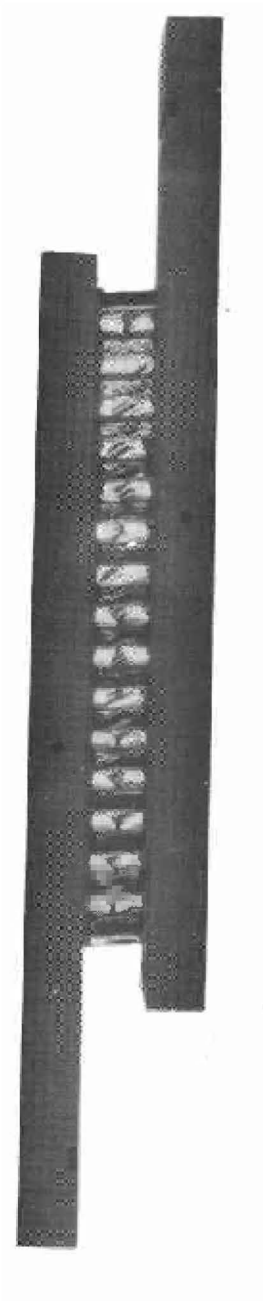

Figure 2. --Sandwich material with aluminum facings and aluminum honeycomb core after failure in shear fatigue test. Specimen was tested to produce shear deformation in the LR plane.

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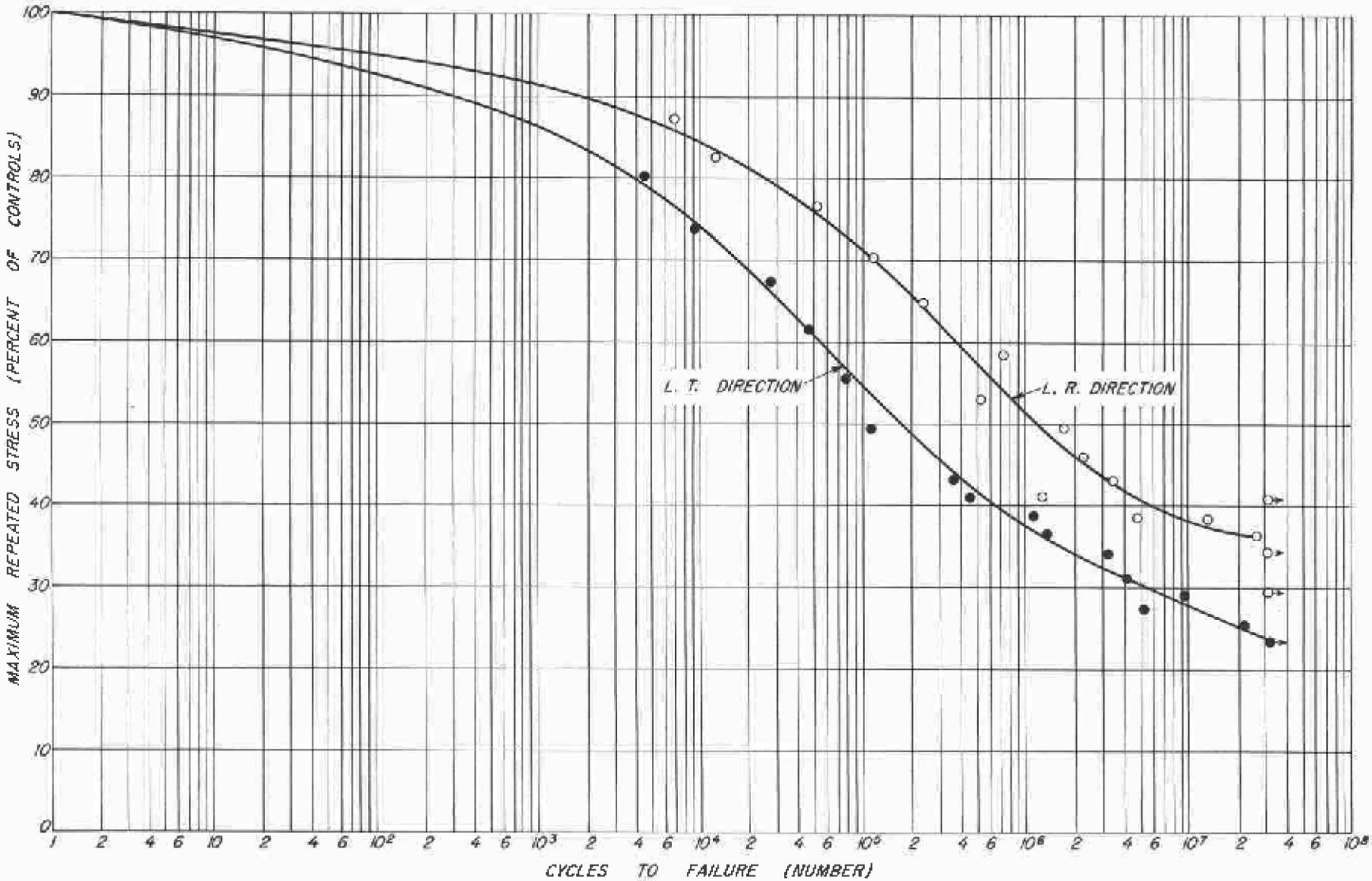

Figure 3. --"S-N" curve for sandwich material with aluminum facings and perforated-aluminum-foil honeycomb core, tested in shear. Ratio of minimum to maximum loading (range ratio) was 0 10

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