FATIGUE OF SANDWICH CONSTRUCTIONS FOR AIRCRAFT

Aluminum Face and End-Grain Balsa Core Sandwich Material Tested in Shear

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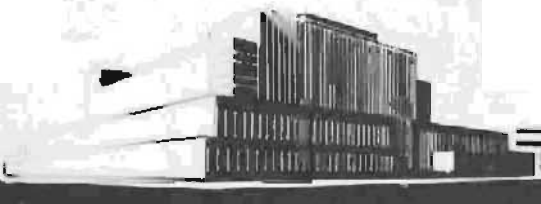

FOREST PRODUCTS LABORATORY
MADISON 5, WISCONSIN

UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE
In Cooperation with the University of Wisconsin

FATIGUE OF SANDWICH CONSTRUCTIONS FOR AIRCRAFT[1]

Aluminum Face and End-Grain Balsa Core Sandwich Material Tested in Shear[2]

By

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Summary and Conclusions

A limited number of tests (30) have been made at the Forest Products Laboratory to determine the shear fatigue properties of an assembled sandwich panel with aluminum facings and end-grain balsa core. These 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 curves are presented. The results of the tests indicate a fatigue strength at 30 million cycles of approximately 52 percent of the static strength for the condition of loading used.

Introduction

If plates of sandwich construction are designed so that their facings are elastically stable under the intended loads, the only important stresses to which the cores are subjected are shear stresses. Consideration of the effect of repeated shear stresses on the material of the cores and on the bonds between the cores and facings is, therefore, important.

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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 the third of a series of reports intended to offer a comparison of the shear fatigue properties of different sandwich materials. Original report issued April 1948. Forest Products Laboratory Report No. 1559 discusses cellular cellulose acetate core material tested in shear and Report No. 1559-A discusses aluminum face and paper honeycomb sandwich material tested in shear.

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

It was the purpose of the experiments conducted for this report to determine the shear fatigue characteristics of a typical assembled sandwich panel.

The facing material employed was 0.020-inch aluminum, the core material was 1/2-inch end-grain balsa, and facing and core were bonded together with a high-temperature-setting phenol resin, N.[4]

Description of Material and Specimens

The balsa used as the core material in these specimens was selected from rough balsa lumber having an over-all density range of 5 to 8 pounds per cubic foot. The core material for each panel was cut from a single length of material so that the core density of each panel would be fairly uniform throughout. Because of the great variation in shear strength of balsa, an effort was made to match the core material of each panel. A discussion of this method follows.

Figure 1A, shows a typical balsa block accurately jointed and planed to a rectangular shape. The block was then cut into end-grain slabs 0.500 ± 0.003 inch in thickness with a circular saw. Each slab was consecutively numbered as shown and weighed to the nearest tenth gram so that the core density of each specimen could be approximated. The slabs were assembled into a core panel, figure 1B, with the use of a high-frequency edge-gluing machine using a phenolic adhesive. After assembly, the core panel was sanded lightly to remove glue squeeze-out and other minor surface imperfections. (Additional information on the selection and assembly of balsa core material is contained in a previous report.[5])

Facings for the sandwich panels were made of 0.020-inch 24ST aluminum. After cleaning and etching, both sides of each facing were sprayed with a gluable metal-priming adhesive, M.[3]

The facings were bonded to the balsa core with a high-temperature-setting phenolic resin (adhesive N[4]) in a press at 230° F. and a pressure of 75 pounds per square inch for 1 hour. Three panels were assembled to provide specimens for the tests.

The specimens were cut from the assembled sandwich panels (fig. 1C) with a metal-cutting band saw to a width and length of 2 and 5.67 inches, respectively. The sandwich blocks were then glued to 1/2-inch steel shear plates with a high-temperature-setting adhesive, W,[4], and cured at 150 pounds pressure per square inch at 320° F. for 30 minutes. Some difficulty was experienced in obtaining a good glue bond between the aluminum and steel, and several fatigue

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

[5] Forest Products Laboratory Report No. 1574, "Fabrication of Lightweight Sandwich Panels of the Aircraft Type," June 1947.

specimens were culled because this glue-line failure preceded the core failure. The specimens were of such length that the load passed through diagonally opposite corners of the core, as indicated by the dotted line of figure 2. Self-alining, pin-connected fittings were used to prevent eccentricity of loading and to insure that the load passed through the indicated plane.

The results of 30 fatigure tests and 31 control tests are presented in this report.

Testing

Both fatigue and control specimens were tested in an atmosphere at a temperature of 75° F. and a relative humidity of 64 percent. Specimens were conditioned in this atmosphere for at least 7 days before testing, which brought the core to approximately 12 percent moisture content.

Fatigue specimens (fig. 2) were tested in a direct-stress fatigue machine of either 4,000- or 10,000-pound capacity. The 10,000-pound machine is shown in figure 3, and the smaller machine is fundamentally the same.

The mean load is placed on the specimen by adjusting the upper loading screw (A), and the cyclic variation is obtained by adjusting the eccentric (H). It will be noted that the horizontal loading arm is supported on the end opposite the eccentric, and the deformation applied by the lower loading screw (C) will, therefore, vary with the setting of the eccentric. The magnitude of the static load is measured by the dial on the bar (F), which measures the deflection in the horizontal loading bar. The load is directly proportional to the deflection of this calibrated loading bar.

As would be expected the dynamic load varies from the static load because of inertia effects. The increase of dynamic load over the static load was measured by using the metalectric strain gages (fig. 3,D) mounted on the lower flexure plate, and a wheatstone bridge and cathode ray oscillograph. The dynamic load was compared with the corresponding static load measured by the dial bar. For any static load, the maximum dynamic load is increased by the same amount as that by which the minimum dynamic load is decreased. This increase or decrease due to the dynamic throw is proportional to the load at any specified machine speed. The static load was corrected and applied so that the dynamic effects would provide the desired load.

The ratio of minimum to maximum load (stress ratio) was 0.1 for all of the fatigue tests. Loads were applied at a rate of 900 cycles per minute, and the maximum repeated load on the specimen was kept nearly constant throughout the test. The loads were checked periodically and adjusted as necessary. When the specimen failed or the load decreased more than about 50 pounds, the machine was stopped by means of an electronic shut-off mechanism (fig. 3,G). The number of repetitions of stress were obtained from cycle counters.

In general, the failure of the fatigue specimens was rapid. In some cases, shear failure of the core along the glue line was preceded by a partial shear failure parallel to the grain of the core. In this case, the load would drop off and the machine shut off. The load was reset and the machine started, and usually complete failure along the glue line would take place after a few cycles.

Static shear tests of control specimens (fig. 2) were made in a hydraulic testing machine at a head speed of 0.01 inch per minute. The load increased steadily until a maximum value was reached, and then the specimen failed suddenly.

The failures of the fatigue shear specimens are of the type shown in figure 4. In most cases, the failure was a combination of shear failure in the core adjacent to the glue line and partial failure parallel to the grain of the core. A typical failure of this nature is shown in figure 5, where the specimen failed after 42,300 cycles of repeated shear stress at 81.8 percent of control strength. In several instances, there was no evidence of failure parallel to the grain, all failure being shear failure along the glue line.

Failures resulting from static shear tests were similar to the above-described fatigue shear failures.

Presentation of Data

A summary of the data on the individual fatigue tests is presented in table 1. The specimen number is given in column 1. Column 2 gives the approximate density of the balsa core in each specimen in pounds per cubic foot. This value is based on the average density of the two slabs making up the core of the specimen (fig. 1). The maximum repeated shear stress, column 3, is obtained by dividing the component of the maximum repeated load, parallel to the steel face plates, by the width (measured to 0.001 inch) and the length of the core (measured to 0.01 inch). In column 4 are given the values of the appropriate control strength for each specimen, from column 10, based on an average of several controls. Column 5 gives the ratio of maximum repeated shear stress to the corresponding control strength, column 6 gives the cycles to failure, and column 7 expresses the type of visible failure.

Table 1 also presents the results of the individual control tests. The approximate density of the core, column 9, is obtained as in column 2. The shear strength, column 10, is obtained by dividing the maximum load by the shear area, as for the fatigue specimens.

The results of the fatigue tests are plotted in figure 6 and the S-N curve is drawn through the average values. The maximum repeated cyclic stress, expressed as a percentage of the control load, is plotted as the ordinate on rectangular coordinates. The number of cycles to failure is plotted as the abscissa on logarithmic coordinates.

Analysis of Data

It may be noted that specimens have been tested with cores varying from 5.1 pounds per cubic foot (in panel 1) to 8.3 pounds per cubic foot (in panel 3), with a variation in control strength between 235 and 395 pounds per square inch. The low-density material had considerable evidence of short-fiber material, commonly referred to as corcho. However, an examination of the data and figure 6 shows that the individual fatigue test results fall reasonably well around the curve despite the variation in core density. Although no complete data for analysis are available, it appears that the fatigue characteristics of sandwich panels made from core material within the above limits are similar.

With a core material as variable as balsa, considerable scatter of results are to be expected even when the materials are carefully matched. The scatter of points around the S-N curve may be attributed to this variation.

It had been previously agreed to discontinue any specimen that withstood 30 million cycles without failure. Six specimens with maximum stress varying from 48.8 to 56.9 percent of the control strength, withstood over 30 million cycles without failure. Because of the scatter of data, the endurance limit cannot be accurately determined. It does appear, however, that the S-N curve tends to level out beyond 8 million cycles and may be similar to the dotted portion of figure 6.

When a lightweight core material, such as balsa, is glued to a rigid face and the unit 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. The core failed a short distance from the glue line, so that many small particles of core material remained rigidly adhered to the face. Therefore, it may be concluded that the adhesion between the facing and the core was satisfactory.

APPENDIX 1

Description of Resins and Adhesives

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

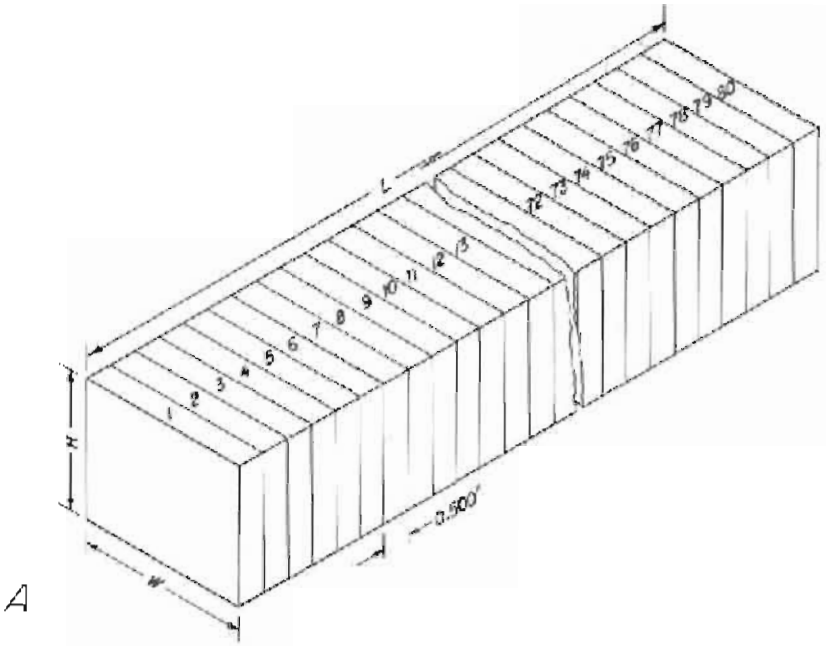
Adhesive N. A high-temperature-setting, acid-catalyzed, phenol resin.

Adhesive W. A high-temperature-setting adhesive used for metal-to-metal gluing.

Table 1.--Summary of results of fatigue and control tests in shear of aluminum face and end-grain balsa core sandwich material[1]

Results of fatigue tests							Results of control tests		
Specimen No.	Approximate density of balsa core	Maximum repeated shear stress	Control strength	Ratio of maximum repeated shear stress to control strength	Cycles to failure	Remarks on visible failure in core	Specimen No.	Approximate density of balsa core	Shear strength
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	Lb. per cu. ft.	P.s.i.	P.s.i.	Percent				Lb. per cu. ft.	P.s.i.
				PANEL 1				PANEL 1	
A3-5-1	5.1	162.9	235.6	69.2	31,300	Along glue line and grain direction	A3-5-2	5.1	239.0
-5	5.2	119.8	235.6	50.8	28,180,700	Along glue line	-4	5.2	227.0
-9	5.3	115.0	235.6	48.8	30,287,200+	No failure	-6	5.2	234.4
							-8	5.3	241.8
							Average		235.6
A3-5-14	5.8	160.0	281.0	56.9	30,315,000+	No failure	A3-5-11	5.7	275.8
-16	5.9	177.9	281.0	63.3	12,582,400	Along glue line and grain direction	-13	5.8	261.8
							-15	5.9	290.0
							-17	6.0	296.3
							Average		281.0
				PANEL 2				PANEL 2	
A3-6-1	7.5	208.8	329.3	63.4	1,308,300	Along glue line and grain direction	A3-6-2	7.5	324.0
-3	7.4	240.3	329.3	73.0	159,500	Along glue line and grain direction	-4	7.4	322.5
-5	7.4	182.1	329.3	55.3	31,018,500+	No failure	-6	7.3	328.8
-7	7.3	260.0	329.3	78.9	3,000	Along glue line and grain direction	-8	7.2	341.9
							Average		329.3
A3-6-11	7.2	163.2	320.7	50.9	30,093,900+	No failure	A3-6-12	7.1	325.4
-13	7.1	174.0	320.7	54.3	6,964,600	Along glue line	-14	7.1	319.2
-15	7.1	246.0	320.7	76.7	2,300	Along glue line	-16	7.1	319.9
-17	7.2	189.7	320.7	59.2	2,454,300	Along glue line and grain direction	-18	7.2	318.2
-19	7.2	162.0	320.7	50.6	12,104,100	Along glue line and grain direction			
							Average		320.7
A3-6-21	7.2	205.0	296.1	69.2	316,300	Along glue line and grain direction	A3-6-22	7.2	302.3
-23	7.1	214.0	296.1	72.2	93,800	Along glue line	-24	7.0	293.7
-25	7.0	260.9	296.1	88.1	58	Along glue line	-26	7.1	307.0
-27	7.1	220.1	296.1	74.4	12,300	Along glue line and grain direction	-28	7.1	281.5
-29	7.1	230.9	296.1	78.0	13,800	Along glue line			
							Average		296.1
A3-6-31	7.0	284.5	286.0	99.5	28	Along glue line and grain direction	A3-6-32	7.1	281.0
-33	7.1	142.0	286.0	49.6	33,829,000+	No failure	-34	7.1	295.3
-35	7.1	235.0	286.0	82.2	24,200	Along glue line	-36	7.1	283.1
-37	7.0	152.0	286.0	53.1	31,303,600+	No failure	-38	6.9	284.7
							Average		286.0
				PANEL 3				PANEL 3	
A3-7-5	8.1	239.9	369.0	65.0	100,600	Along glue line and grain direction	A3-7-2	7.9	365.7
-6	8.1	302.0	369.0	81.8	42,300	Along glue line and grain direction	-4	8.0	386.5
-8	8.0	250.0	369.0	67.8	39,100	Along glue line and grain direction	-7	8.0	349.2
-10	8.0	314.0	369.0	85.1	16	Along glue line	-9	8.0	374.7
							Average		369.0
A3-7-12	8.3	328.0	393.3	83.4	10,700	Along glue line and grain direction	A3-7-11	8.3	433.4
-15	8.0	344.0	393.3	87.4	53	Along glue line and grain direction	-14	8.1	387.6
-18	8.2	330.0	393.3	83.9	4,000	Along glue line and grain direction	-17	8.1	359.0
							Average		393.3

[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. See figure 2 for details of specimen.



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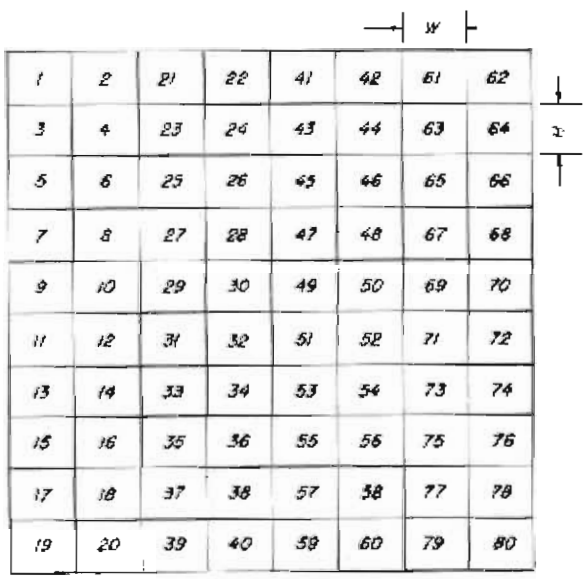

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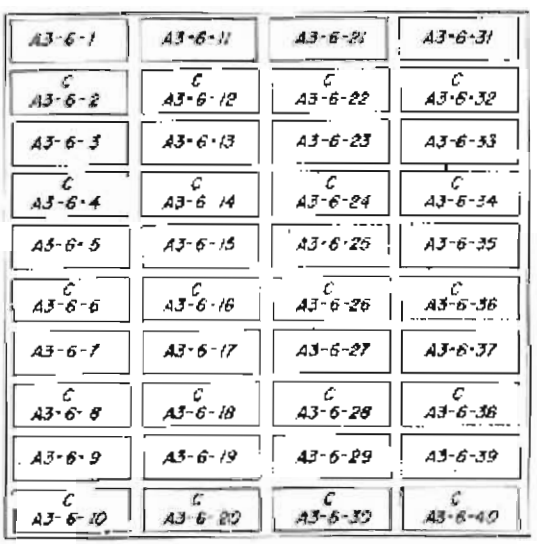

C

Figure 1.--Method of cutting and distribution of core material in a typical aluminum face and end-grain balsa core sandwich panel to be tested in shear fatigue. A. Method of numbering slabs cut from a balsa block; B. Distribution of slabs in the assembled core; C. Selection and numbering of specimens, 2 by 3.87 inches, cut from an assembled sandwich panel, with "c" designating control specimens.

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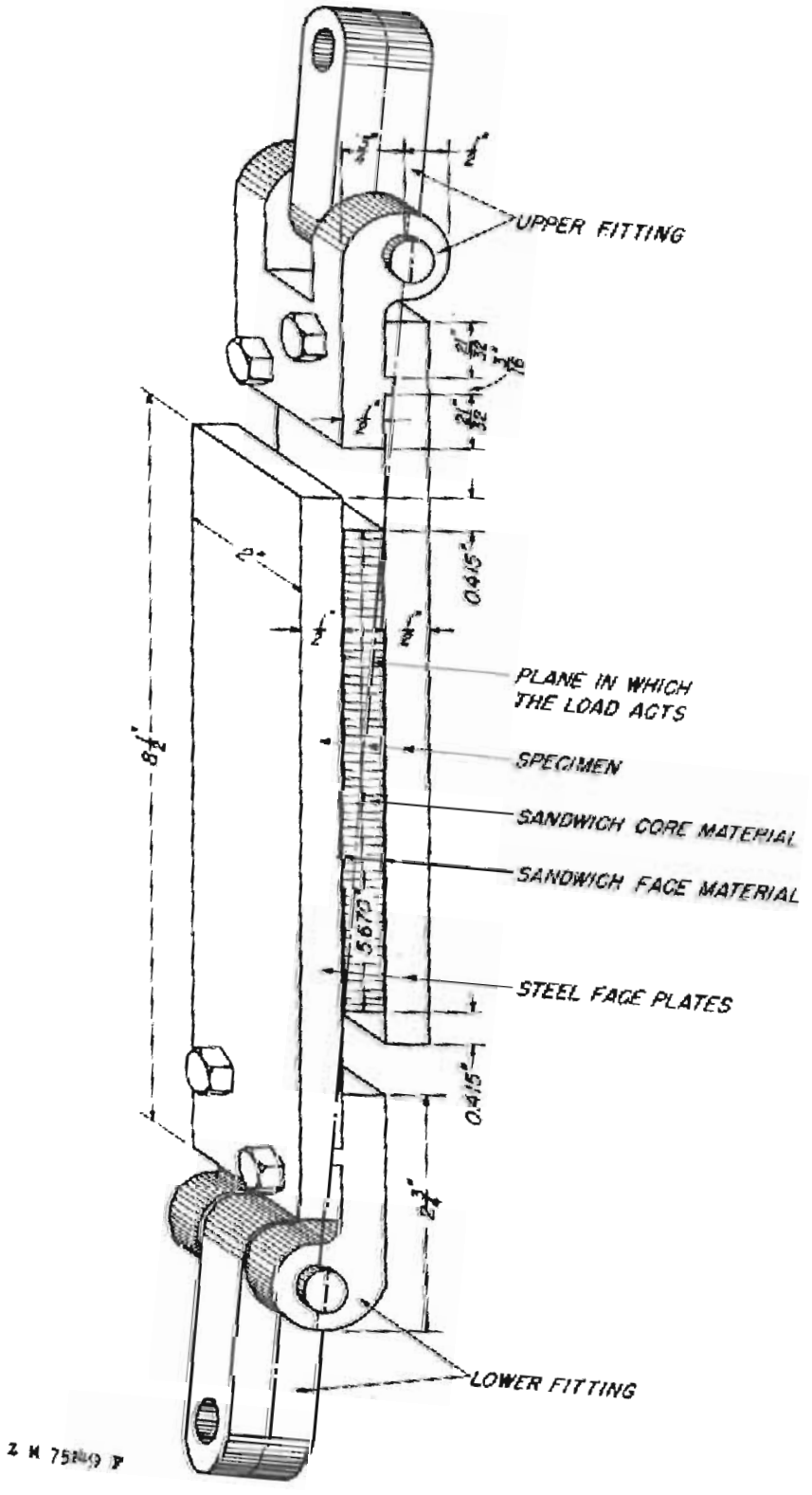

Figure 2.--Detail of frame shear specimen used for control and fatigue shear tests of sandwich material.

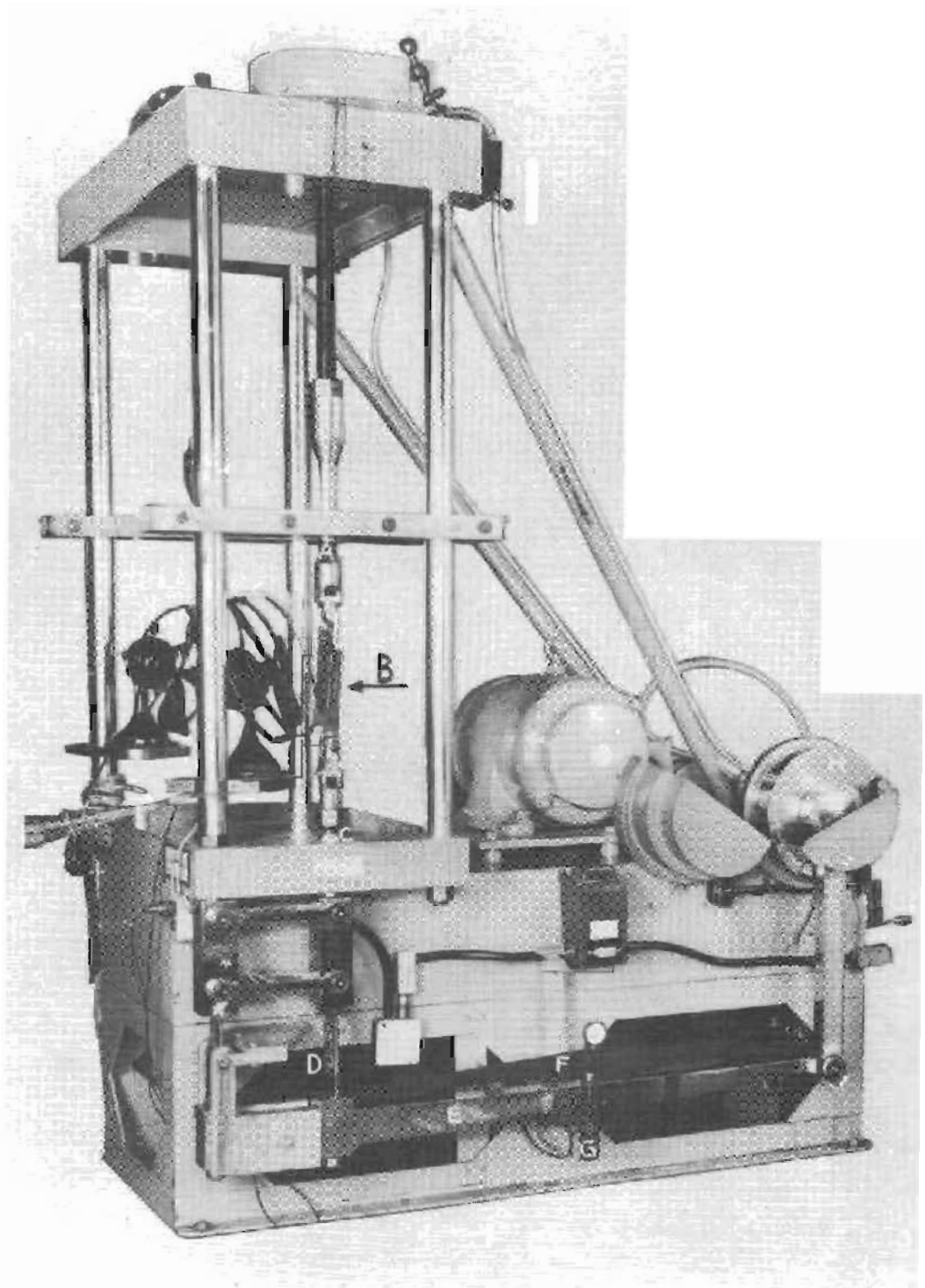

Figure 3.--Direct-stress fatigue machine showing: (A) upper loading screw, (B) specimen, (C) lower loading screw, (D) electric strain gages for determining corrections for dynamic effects, (E) horizontal loading arm, (F) calibrated dial bar for determining static loads, (G) electronic cut-off switch for stopping machine, and (H) adjustable eccentric.

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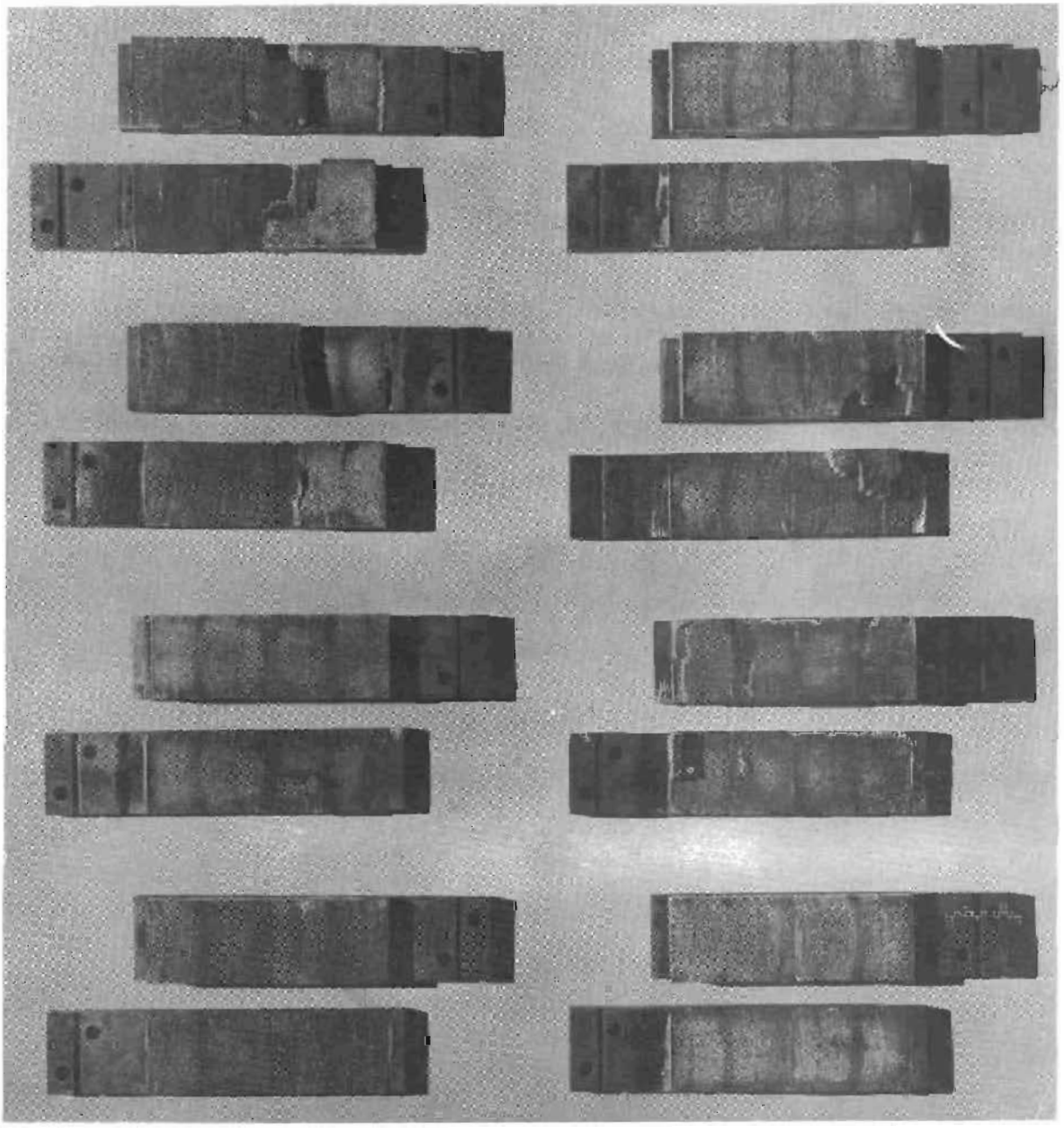

Figure 4.--Typical failures of fatigue shear specimens from aluminum face and end-grain balsa core sandwich panels.

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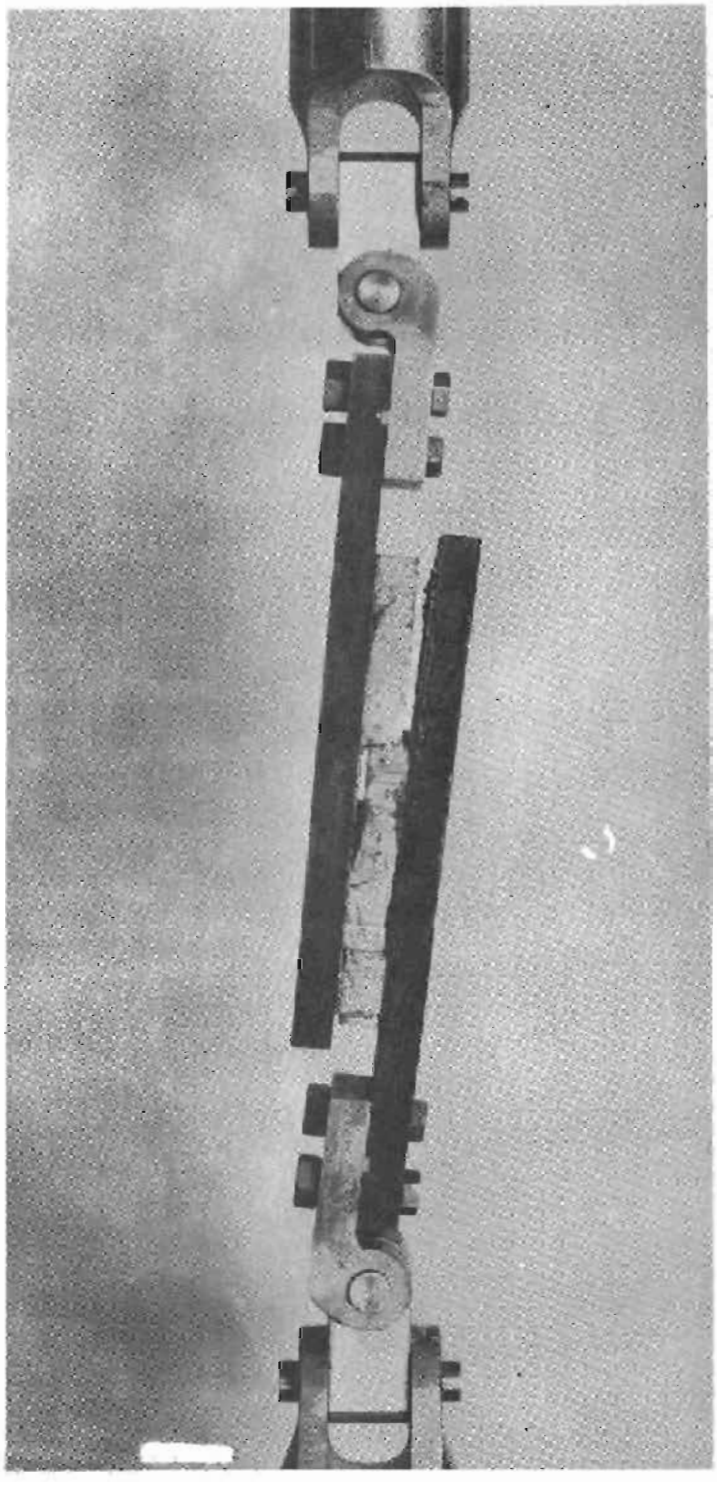

Figure 5.--Typical failure of a fatigue shear sandwich specimen with aluminum faces and end-grain balsa core. Core failure is a combination of shear failure along the glue line and shear failure parallel to the grain.

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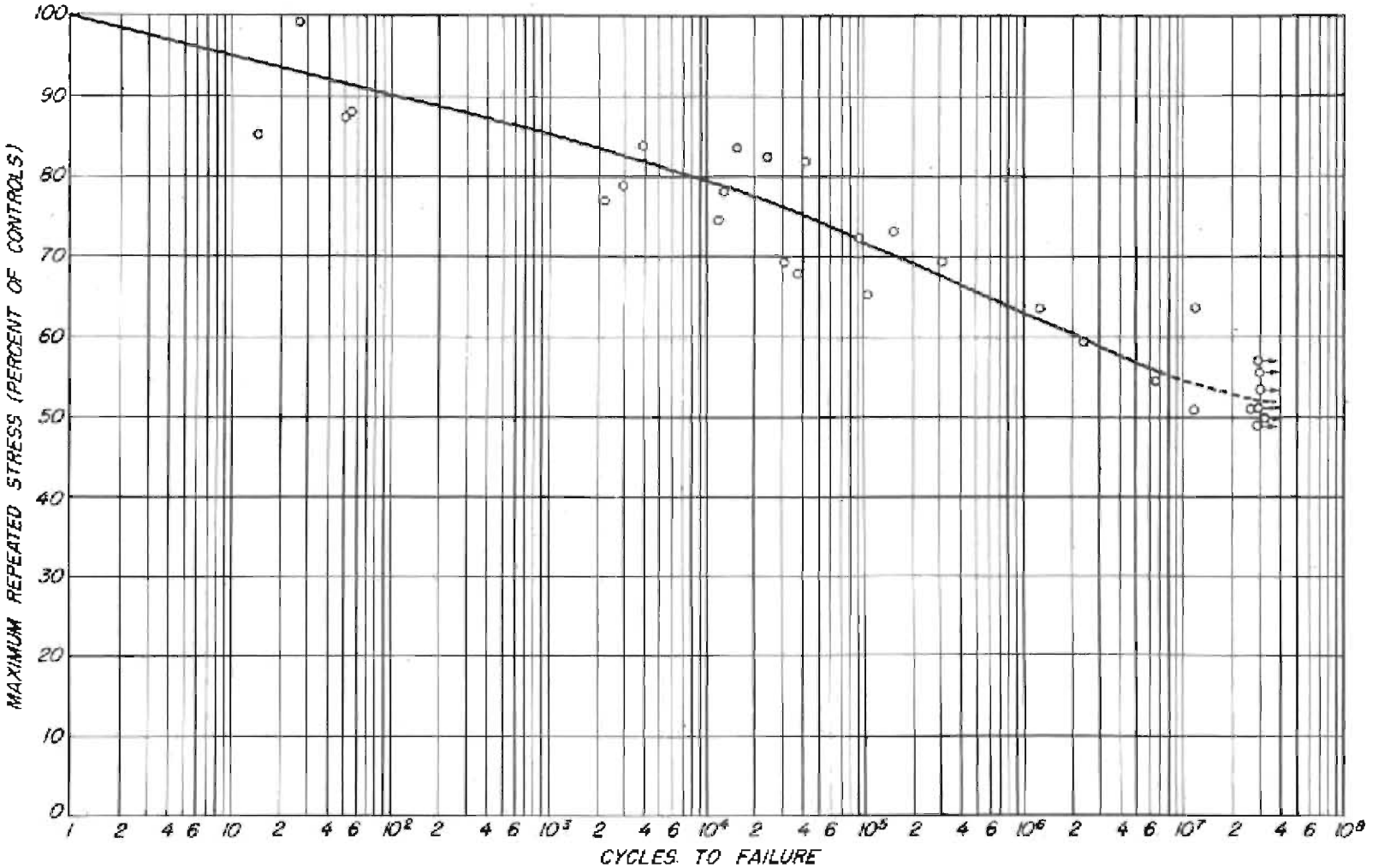

Figure 6.--"S-N": (stress-number of cycles to failure) curve for aluminum face and end-grain balsa core sandwich material in shear. Ratio of minimum to maximum stress (range ratio) was 0.10.