

FATIGUE OF SANDWICH CONSTRUCTIONS FOR AIRCRAFT

Aluminum Face and Paper Honeycomb Core Sandwich Material Tested in Shear

December 1947



**This Report is One of a Series
Issued In Cooperation with the
ARMY-NAVY-CIVIL COMMITTEE
on
AIRCRAFT DESIGN CRITERIA
Under the Supervision of the
AERONAUTICAL BOARD**

No. 1559-A

**UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE
FOREST PRODUCTS LABORATORY
Madison, Wisconsin**

In Cooperation with the University of Wisconsin

FATIGUE OF SANDWICH CONSTRUCTIONS FOR AIRCRAFT¹

(Aluminum Face and Paper Honeycomb Core Sandwich Material
Tested in Shear)²

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Summary and Conclusions

A limited number of tests (25) have been made at the Forest Products Laboratory to determine the shear fatigue properties of an assembled sandwich panel with aluminum facings and paper honeycomb 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 curve are presented herein. The tests indicate on the curve a fatigue strength at 30 million cycles of approximately 48 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. The 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.

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 24ST aluminum, the core material was 1/2-inch B-flute resin-impregnated paper honeycomb, and facing and core were bonded together with a high-temperature-setting phenol resin, N.³

¹This 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.

²This is the second of a series of reports intended to offer a comparison of the shear fatigue properties of different sandwich materials. FPL Report No. 1559, "Fatigue of Sandwich Constructions in Aircraft. Cellular Cellulose Acetate Core Material in Shear," by W. C. Lewis, 1946.

³Additional information on the adhesives referred to in this report is contained in appendix I.

Description of Material and Specimens

The paper honeycomb material used as the core material in these specimens was made at the Forest Products Laboratory. The material was produced by impregnating 4.5 mil kraft paper of 12-inch width with about 10 percent 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 a hot-setting polyester resin, B.³ The sheets were then laid node to node to form a block about 2-5/8 inches thick. Thus the final dimensions of the block were approximately 2-5/8 by 12 by 40 inches with the flutes parallel to the 12-inch direction. The cured block had an over-all density of 5.90 pounds per cubic foot, and a resin content of approximately 55 percent.

The block was sawn perpendicular to the flutes with a band saw, to a thickness of 0.500 ± 0.005 inch. The pieces were then glued together with adhesive N to form two finished cores 26 by 26 inches.

Facings for the sandwich panel 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

Core and facing materials were assembled with adhesive N. The technique employed in assembly is described under method 5 of aluminum to paper honeycomb panel-assembly techniques, Forest Products Laboratory Report No. 1574.⁴ This report also presents a complete description of the method used in preparing cores and facings for sandwich assembly.

The specimens were cut from two 26- by 26-inch panels with a metal-cutting band saw to a width and length of 2 and 5.67 inches, respectively. Considerable difficulty was encountered in cutting the specimens from the panels because the sawing often fractured the core. The undamaged sandwich blocks were then glued to 1/2-inch steel shear plates with a high-temperature-setting adhesive, W.³ and cured at 15 pounds pressure per square inch at 320° F. for 30 minutes. It was necessary to replace the 1/4-inch steel plates used in previous tests² with 1/2-inch plates. The paper honeycomb core was about 60 percent stronger in shear than the cellular cellulose acetate and at high loads introduced excessive bending deflection in the lighter plates. 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-aligning, pin-connected fittings were used to prevent eccentricity of loading and to insure that the load passed through the above-indicated plane.

⁴B. G. Heebink, "Manufacture of Lightweight Sandwich Panels of the Aircraft Type," 1947.

The specimens were cut so that the plane of the paper extended across the 2-inch direction of the specimen. Thus, the core material was tested in such a way as to produce shear deformation in the plane designated as LR² of figure 1.

The results of 25 fatigue tests and 15 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 10 days before testing.

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 of the lower loading screw will therefore vary with the setting of the eccentric. The magnitude of the static load is measured by the dial 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 metaelectric strain gages (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 that 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 (range 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 (G). The number of repetitions of stress were obtained from cycle counters.

5 Exploratory tests showed that the shear strength in the LR plane was lower than in the LT plane, and that fatigue failure at a given shear stress would take place in the LR plane at a lower number of cycles than in the LT plane.

Failure of fatigue specimens was rapid and took place after a few cycles once failure had begun.

Static 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.

There was no discernible difference between the type of failure of fatigue and control specimens. The failure was generally a diagonal-tension failure, sometimes accompanied by shear failure adjacent to the facing. A typical control failure is shown in figure 4. A failed fatigue specimen is shown in figure 5, after 1,602,100 cycles of repeated shear stress at 65 per cent of the control strength. The tension cracks are not clearly visible from the figure but occur at approximately 1/2-inch intervals along the core and are at an angle of 45° with the facing.

Presentation of Data

A summary of the data on the individual fatigue tests is presented in table 1. The maximum repeated shear stress 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).

Table 1 also presents the results of the individual control tests. Shear strength, as in the fatigue specimens, is obtained by dividing the maximum load by the shear area. Variations in the core material account for slightly different strength properties in the specimens. Control strengths varied from 183 to 217 pounds per square inch. A few control specimens tested were of much lower strength than these. They have not been incorporated in this report because it was apparent that the low strength was due to damage resulting from sawing and fabrication. Even though all specimens were carefully inspected for damage due to sawing, small fractures may not have been visible. An average of all acceptable control specimens was used to determine the average control strength.

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

The scatter of points around the S-N curve (fig. 6) may be attributed to core variation and to slight damage resulting from fabrication. The curve may be considered as being on the conservative side because low

control values were not used in determining the average control-strength value, and some of the low points plotted on the curve may be from specimens that had minute fractures prior to test.

It had been previously agreed to discontinue testing any specimen that withstood 30 million cycles without failure. Three specimens continued beyond 30 million cycles without failure, and another was removed unfailed after 25 million cycles. It can be seen from the curve that the endurance limit cannot be accurately determined from the tests made. It appears, however, that the curve tends to become horizontal beyond 10 million cycles and may be similar to the dotted portion of figure 6.

Failure of specimens was predominately a diagonal-tension failure, sometimes accompanied by shear failure along the glue line. From these tests it appears that the glue bond between the facing and core is satisfactory.

APPENDIX I

Description of Resins and Adhesives

- Note 1. Resin B. A high-temperature-setting, low-viscosity, laminating resin of the styrene monomer, 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-catalyzed, phenol resin.
- Note 4. 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 paper honeycomb core sandwich material¹

Fatigue-test results					: Control results	
Specimen No.	Maximum : repeated : shear stress :	Maximum : repeated : shear stress : to control : strength :	Cycles : to : failure :	Remarks on : visible failure :	Specimen No.	Shear strength
	: P.s.i. :	: Percent :				: P.s.i.
Panel 1 :	:	:	:	:	Panel 1 :	
A-4-1-2 :	120.2 :	60.1 :	1,250,800 :	Diagonal tension :	A-4-1-4 :	183.1
:	:	:	:	and shear :	1-5 :	205.0
A-4-1-3 :	145.4 :	72.7 :	317,900 :	Diagonal tension :	1-10 :	191.6
1-6 :	125.2 :	62.6 :	2,041,100 :	Diagonal tension :	1-13 :	206.8
1-8 :	115.4 :	57.7 :	1,664,000 :	Diagonal tension :	1-18 :	216.9
1-11 :	159.8 :	79.9 :	60,700 :	Diagonal tension :	:	
:	:	:	:	and shear :	:	
1-12 :	149.9 :	75.0 :	42,700 :	Diagonal tension :	:	
1-14 :	131.2 :	65.6 :	326,200 :	Diagonal tension :	:	
:	:	:	:	and shear :	:	
1-16 :	124.6 :	62.3 :	1,383,100 :	Diagonal tension :	:	
1-19 :	105.6 :	52.8 :	3,933,700 :	Shear :	Average	200.7
:	:	:	:	:	:	
Panel 2 :	:	:	:	:	Panel 2 :	
A-4-2-2 :	189.7 :	94.8 :	7,100 :	Diagonal tension :	A-4-2-1 :	195.1
2-3 :	179.4 :	89.7 :	6,400 :	Diagonal tension :	2-4 :	204.6
2-5 :	170.1 :	85.0 :	38,300 :	Diagonal tension :	2-7 :	200.9
2-6 :	100.1 :	50.0 :	8,322,200 :	Diagonal tension :	2-10 :	202.8
:	:	:	:	and shear :	2-13 :	192.6
2-8 :	175.1 :	87.6 :	5,600 :	Diagonal tension :	2-19 :	193.0
2-9 :	130.2 :	65.1 :	1,602,100 :	Diagonal tension :	2-22 :	212.0
2-11 :	110.1 :	55.0 :	14,127,000 :	Diagonal tension :	2-23 :	196.4
2-12 :	184.6 :	92.3 :	1,600 :	Diagonal tension :	2-26 :	193.2
:	:	:	:	and shear :	2-32 :	206.0
2-14 :	165.4 :	82.7 :	20,500 :	Diagonal tension :	:	
2-15 :	167.7 :	83.8 :	1,600 :	Diagonal tension :	:	
2-20 :	137.9 :	69.0 :	172,400 :	Diagonal tension :	:	
2-21 :	90.1 :	45.0 :	30,705,200+ :	No failure :	:	
2-25 :	80.0 :	40.0 :	35,710,400+ :	No failure :	:	
2-27 :	85.0 :	42.5 :	30,094,100+ :	No failure :	:	
2-30 :	104.9 :	52.4 :	17,822,000 :	Diagonal tension :	:	
2-31 :	95.1 :	47.6 :	25,147,900+ :	No failure :	Average	199.7
					Average control strength for all specimens = 200.0 p.s.i.	

¹Fatigue 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,

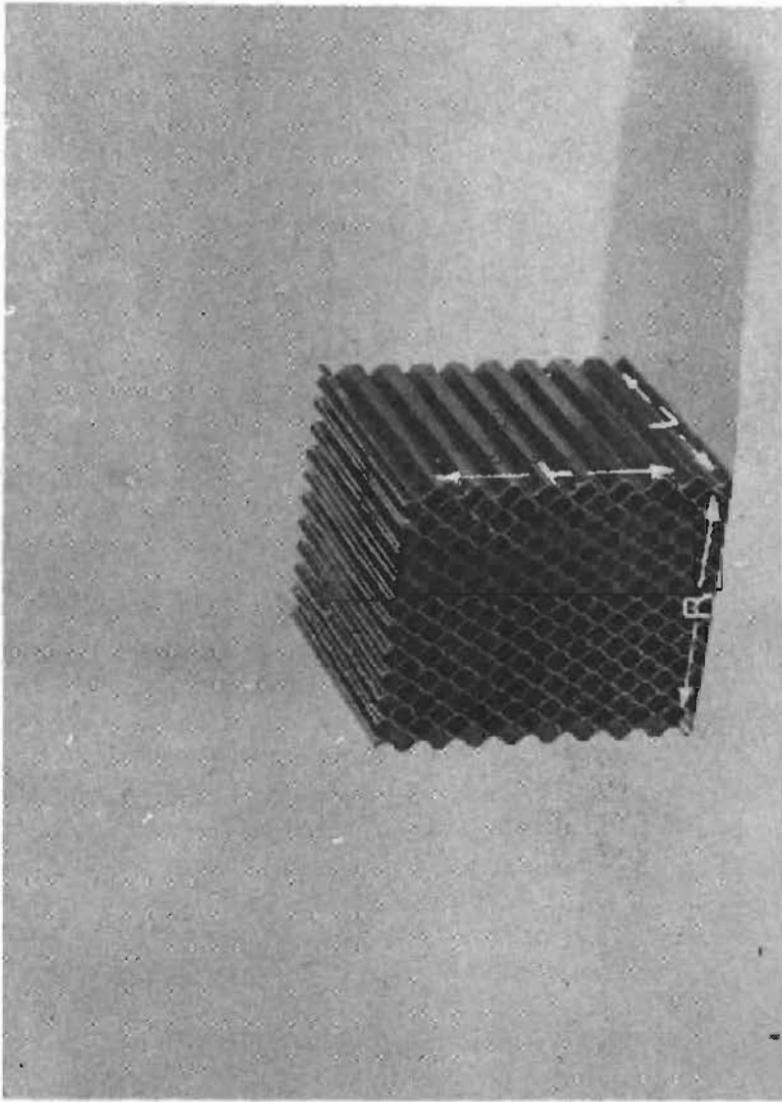


Figure 1.--Paper honeycomb block showing directional orientation, referred to as L (longitudinal), R (radial), and T (tangential).

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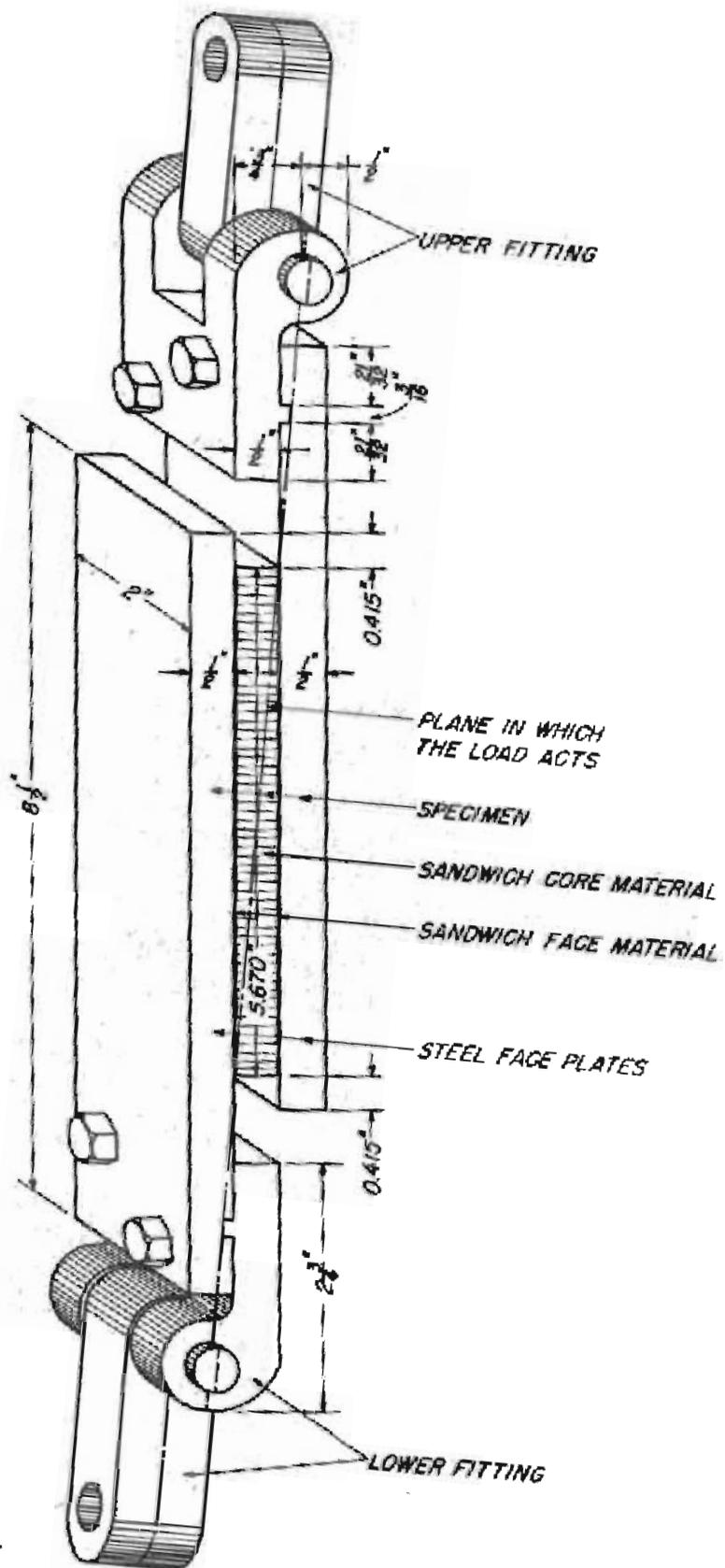


Figure 2.--Detail of frame shear specimen used for control and fatigue shear tests of sandwich material.

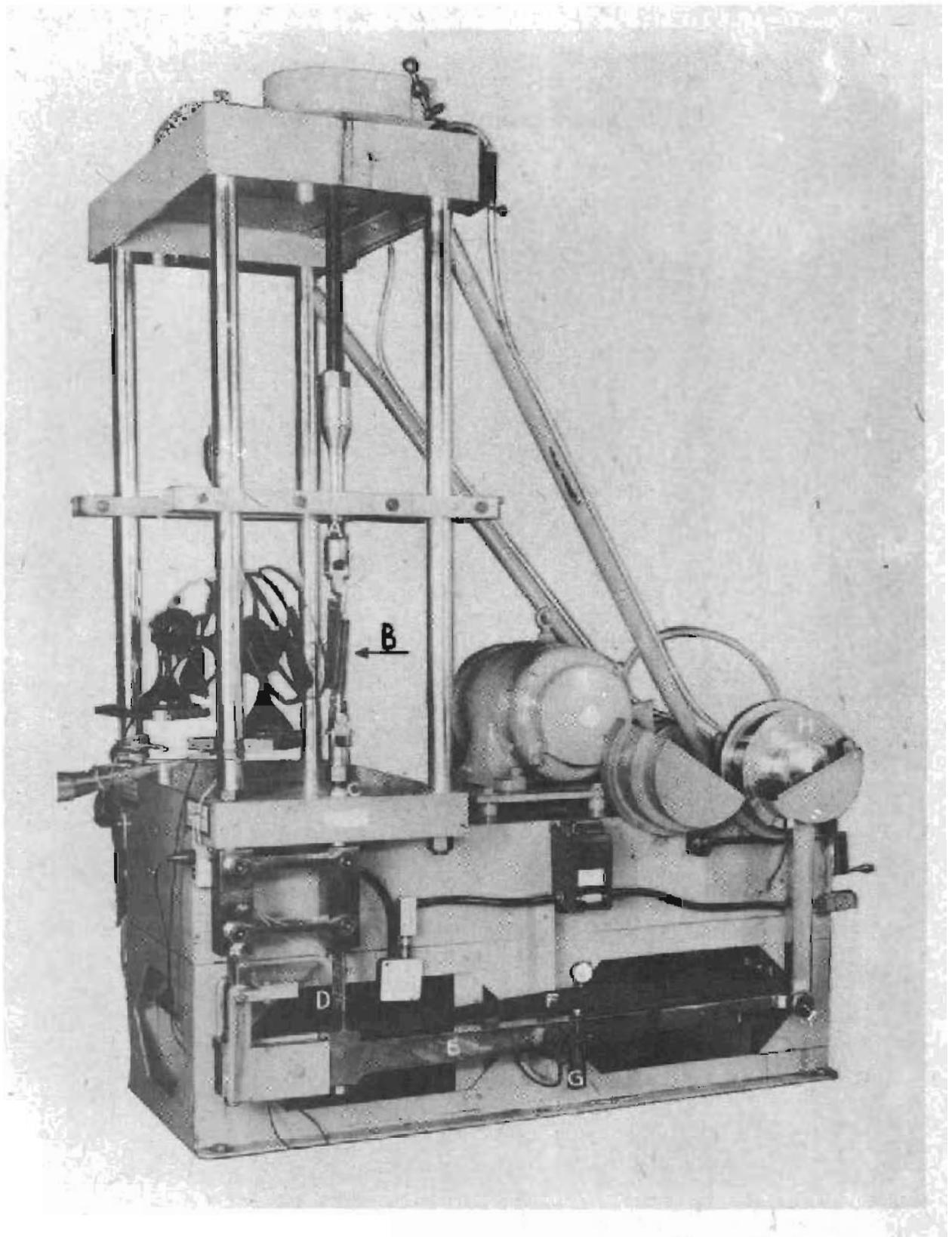


Figure 3.--Direct-stress fatigue machine showing: (A) upper loading screw, (B) specimen, (C) lower loading screw, (D) electric strain gages for determining corrections for dynamic effects, (E) horizontal loading arm, (F) calibrated dial bar for determining static loads, (G) electronic cut-off switch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

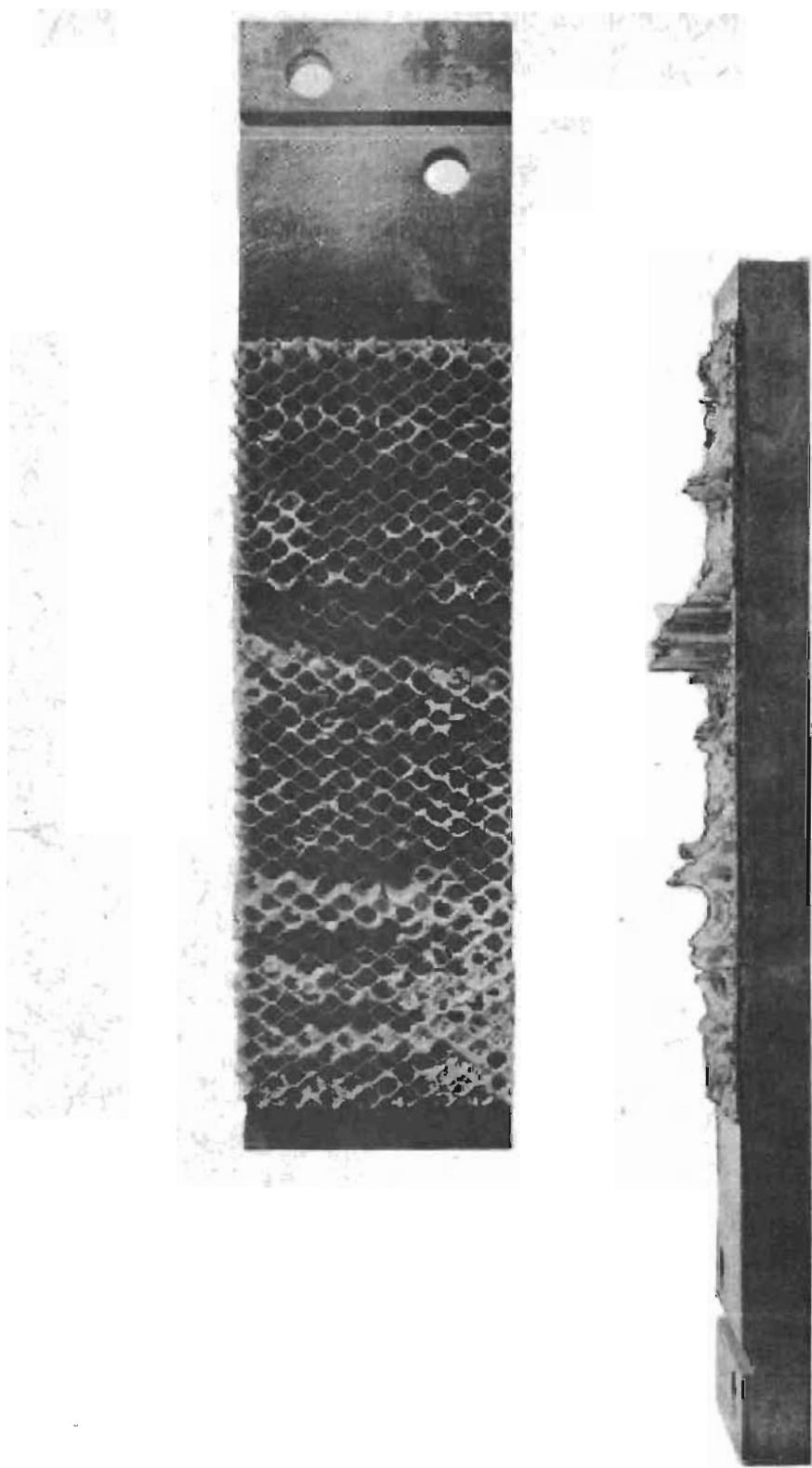


Figure 4.--Typical failure of control specimen of aluminum face and paper honeycomb core sandwich panel.

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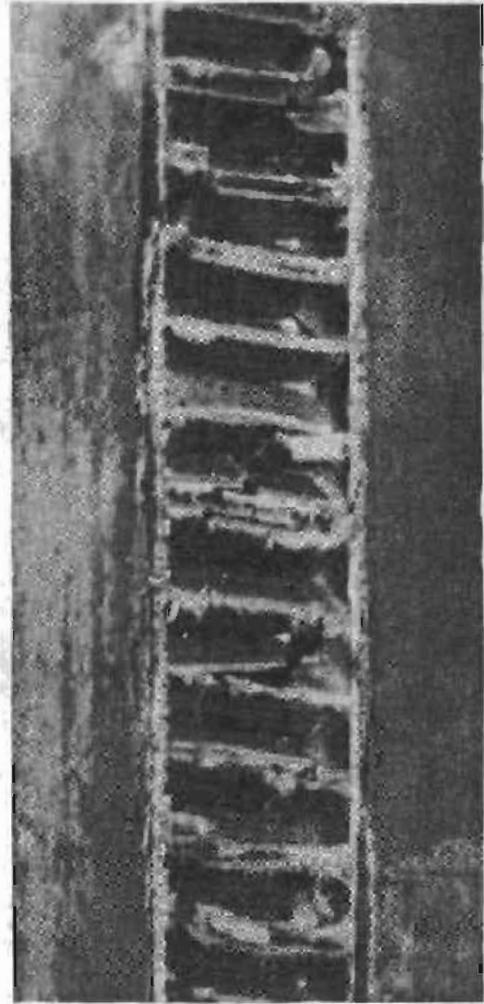
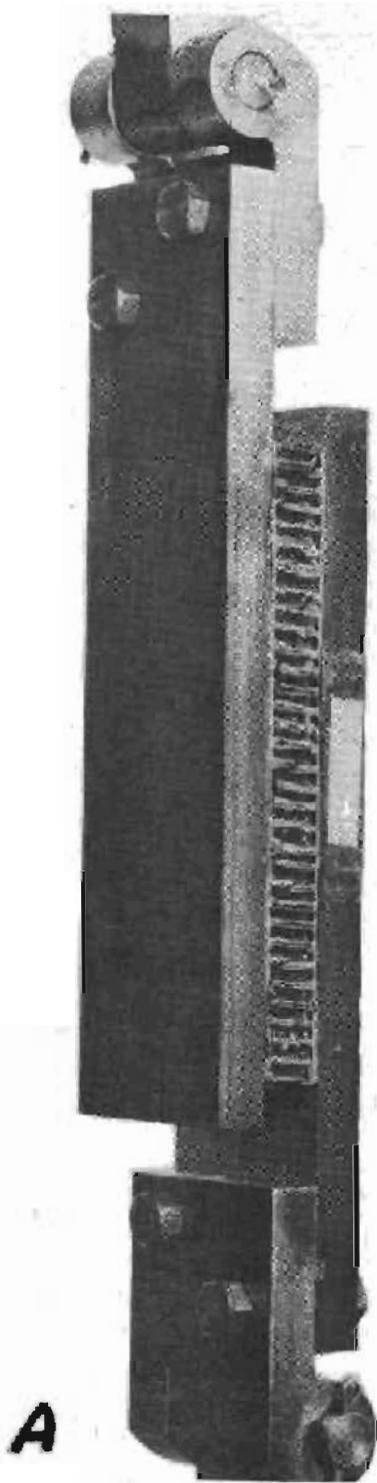
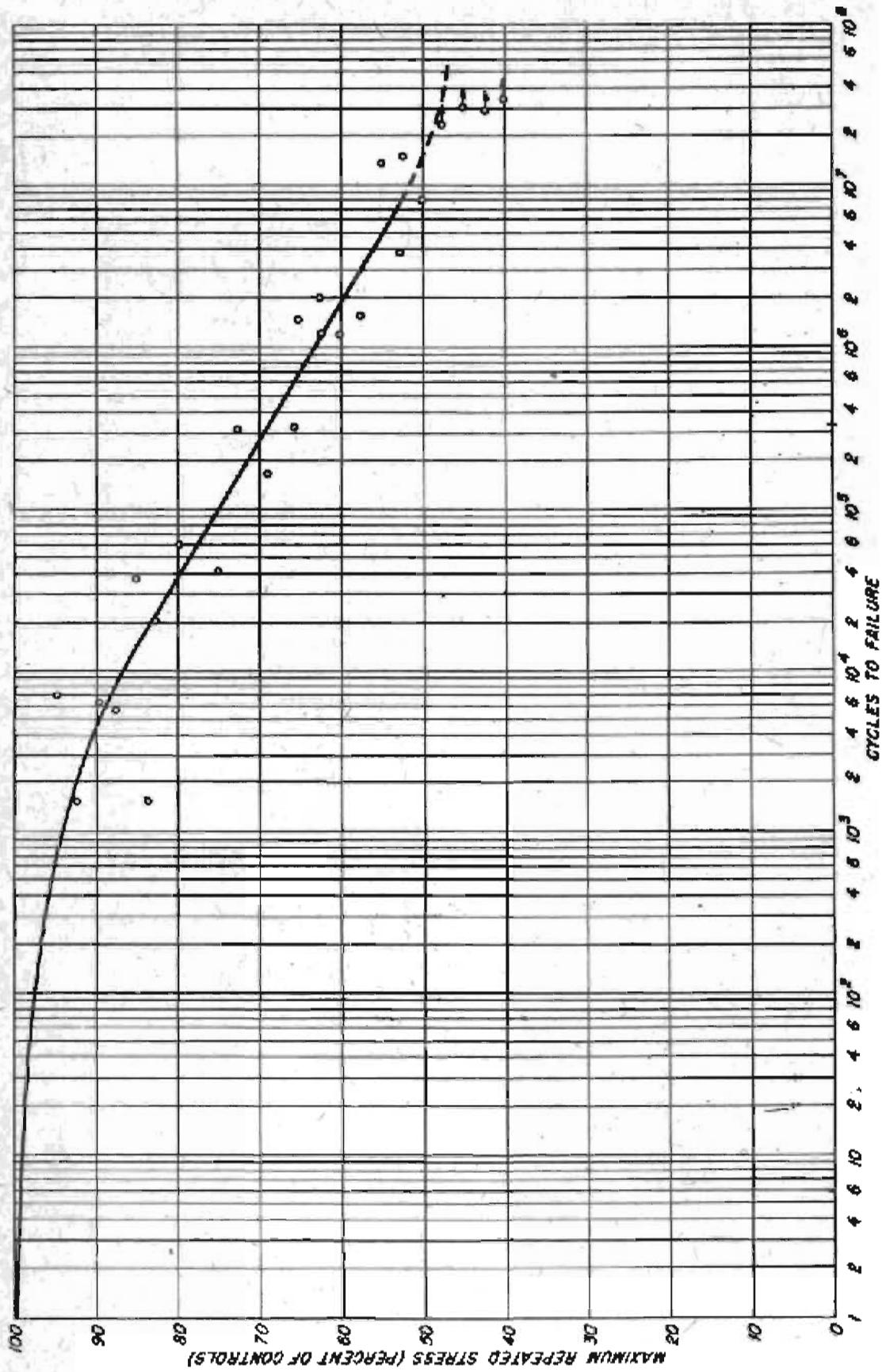


Figure 5.--An aluminum face and paper honeycomb core sandwich specimen after failure in shear fatigue test. **A**, failed specimen in testing machine; **B**, enlargement showing diagonal tension failures at 45° to the face of the specimen.



Z N 75250 F

Figure 5.--S-N* (stress-number of cycles to failure) curve for aluminum face and paper honeycomb core sandwich material in shear. Ratio of minimum to maximum stress (range ratio) was 0.10.