FATIGUE OF SANDWICH CONSTRUCTIONS FOR AIRCRAFT

CELLULAR CELLULOSE ACETATE CORE MATERIAL IN SHEAR

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FATIGUE OF SANDWICH CONSTRUCTIONS FOR AIRCRAFT

Cellular Cellulose Acetate Core Material in Shear[1]

By

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Summary and Conclusions

A limited number of fatigue tests have been made at the Forest Products Laboratory in shear on cellular cellulose acetate, and the "S-N" curve has been determined for one condition of loading (ratio of minimum to maximum stress of 0.1). This curve is presented herein. The tests indicate an endurance limit of approximately 37 percent of the static strength for the condition of loading used.

Introduction

Sandwich construction is a combination of materials that holds considerable promise for use in structural parts of aircraft. In sandwich construction thin, relatively high-strength facings are glued or otherwise intimately fastened to low-density, low-strength cores, thus giving a rigid light-weight construction of adequate strength for monocoque or semi-monocoque structures. Among the core materials under consideration for sandwich construction are: cellular cellulose acetate, foamed synthetic rubber; end-grain balsa wood; and paper, glass cloth, and cotton cloth honeycomb. Facings proposed for use with these cores are aluminum alloys, resin-impregnated glass cloth, papreg, plywood, and stainless steel.

The fatigue characteristics of an aircraft material are as important as any of the other strength properties. The number of different materials that can be used for sandwich construction make a complete evaluation of the fatigue characteristics of the many combinations impractical. One condition of loading has been chosen and tests will be made in fatigue as far as possible on the more promising combinations using the different cores. This

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[1]This is one of a series of progress reports prepared by the Forest Products Laboratory relating to aircraft. Results here reported are preliminary and may be revised as additional data become available.

report is the first of a series which will offer comparisons of the abilities of the different core materials and sandwich constructions to withstand repeated loads. The range ratio (ratio of minimum to maximum stress) of 0.1 will be used in all tests.

Description of Specimens and Matching

The specimens for the fatigue tests in shear were made as shown in figure 1. The cellular cellulose acetate had a specific gravity of approximately 0.1 and was extruded with a cross section of about 5/8 by 2-3/4 inches in random lengths. The skin was removed and the core material finished in blocks each 1/2 inch thick, 2 inches wide, and 6 inches long. These blocks were glued to the steel side plates as shown in figure 1. The knife-edged steel end plates were glued to the ends of the block to complete the frame. The plates were glued to the cellular cellulose acetate by means of a special metal priming adhesive and a cold-setting resorcinol resin glue.

The fittings that transmitted the loads from the testing machine to the side plates were designed so that the plane of the load passed through the diagonally opposite corners of the core as shown by the dashed line in figure 1. Thus, the intensity of the shear stress was calculated by dividing the load by the product of the width and the distance between the diagonally opposite corners.

Specimens were prepared from five different pieces of the core material, generally in groups of three, with the middle one a control specimen and the other two fatigue specimens. There were 12 control specimens that were loaded statically to obtain the strengths of the acetate in shear and 23 specimens that were loaded repeatedly to various percentages of the control strengths to obtain the fatigue limits.

Method of Test

The fatigue specimens were tested in a direct-stress fatigue machine as shown in figure 2. Essential parts of the machine are indicated on this figure. When making a fatigue test with this type of machine the mean load is placed on the specimen by adjusting the upper loading screw (A), and the desired variation in load for each cycle is obtained by adjusting the throw of the eccentric (H). The adjustable eccentric applies the changes in deformation to the specimen by means of the cantilever loading arm (E) and the lower loading screw (C).

The magnitudes of the static loads are determined by means of the dial bar (F) because the deflection of the cantilever loading arm is directly proportional to the load. Dynamic loads are, however, different from the indicated static loads because of inertia effects. By using the

electric strain gages (D) mounted on the vertical flexure plates, and a Wheatstone bridge and cathode ray oscillograph it was found that the maximum load was increased and the minimum load was decreased an equal amount for any one condition of loading. This difference between the dynamic and static loads was found to be directly proportional to the amount of throw, in pounds, (difference between maximum and minimum loads) for any one machine speed; so the static dial readings were corrected to give the desired loads when the machine was in operation.

Loads were applied to the specimens at the rate of 900 cycles per minute. The fan was used to cool the specimens under test and to reduce the tendency of the specimen to heat from the work done on it during the repeated loading. Self-alining, pin-connected fittings were used to assure that the plane of the load passed through the diagonally opposite corners of the specimen.

The ratio of minimum to maximum loads (range ratio) was 0.1 for all tests. Tension loadings on the specimens produced the shear stresses. Each specimen was loaded so that the maximum repeated load was a certain percentage of the control strength, and the number of cycles the specimen withstood before failure was obtained by cycle counters that registered the number of repetitions of stress in hundreds of cycles. The magnitude of the loads was checked periodically during the progress of each test to insure that the specimens were being subjected to the desired stresses. The electronic shut-off mechanism (G) stopped the machine when the specimen failed or when the load "fell-off" more than a predetermined amount. The contact on the switch was set so that a reduction in load of approximately 25 pounds stopped the machine. Thus, essentially constant maximum loads were achieved for the tests.

Control specimens were loaded to failure in a hydraulic testing machine and the maximum loads determined. Tension loads were applied to the specimens at a rate of head travel of 0.01 inch per minute to produce the shear failures of the controls. The same fittings were used on the control specimens as were used for the fatigue tests.

All tests were made in a controlled room where the temperature was maintained at 75° F. and the relative humidity at 64 percent. The specimens were conditioned in this same room for 2 weeks before test to assure uniform conditions at time of test.

The width and thickness of the core material was measured to the nearest 0.001 inch and the length and diagonal to the nearest 0.01 inch.

Presentation of Data

The data from the individual fatigue tests are presented in table 1. The specimen numbers in column 1 show the origin, relative position, and the approximate percentage of the maximum repeated load. For example, the number "1A-6-40" indicates that this specimen was from piece number 1 of the acetate, that the specimen was number 6 in the length (specimen 7 was next to it, and 8 was two spaces away), and that it was subjected to maximum repeated loads of approximately 40 percent of the static strength. The maximum repeated stresses are given in column 2 and the average control strengths for each length of the core material in column 3. The maximum repeated shear stresses are expressed as percentages of the average control strengths in column 4, and the cycles of loading that each specimen withstood before rupture are listed in column 5. Column 6 gives a brief description of the visible failure for each specimen.

Table 2 presents the results of the static tests to determine the control strengths of the cellular cellulose acetate. The same type of specimen number was used for these tests as for the fatigue tests, except that the letter "C" was substituted for the percentage to indicate that the specimen was for a control test. It was found that the fatigue results were in slightly better agreement when the average control values for each piece were used instead of individual control strengths. The averages for each piece of core material are shown also in this table.

The results of the fatigue tests are plotted in figure 3, where the maximum repeated shear stresses, in percent of controls, (S) are plotted as ordinates on a rectangular scale and the number of cycles to failure (N) as abscissas to a logarithmic scale. The resulting S-N curve is drawn through the average of these points.

Modes of Failure

The visible failures of both the fatigue and the control specimens were either diagonal tension, shear, or a combination of the two. The specimens in the fatigue tests all carried the repetitions of load without any indication of failure until shortly before failure. Rupture in fatigue was accomplished within a few cycles once failure had started; so it was possible to determine the end point of test accurately. Similarly, the failures of the control specimens were sudden and had a clearly defined maximum load. The loads continued to increase as deformations were applied to the control specimens until the ultimate was reached, after which the load fell off and the specimen ruptured.

Figure 4 shows fatigue failure of specimen 4A-8-38 after 25,075,000 cycles of a maximum stress of 45 pounds per square inch. This failure was typical of the shear type of failure with diagonal tension failures at the ends of the specimen. Diagonal tension failures were visible on some

specimens about every 3/8 inch along the length. The diagonal tension failures were probably preceded by diagonal compression failures oriented at about 90° to them, but the compression failures were not visible. So far as could be determined there was no difference in the appearance between the fatigue and static failures.

Analysis of Data

The control strengths varied considerably among the different pieces, from 109 to 135 pounds per square inch, but not a significant amount among the tests from any one piece. When the results of the fatigue tests were plotted on semilogarithmic paper with the maximum repeated stress in pounds per square inch as ordinates and the cycles to failure on a logarithmic scale as abscissas the result was a scatter-band rather than a clearly defined curve. However, when the maximum repeated stresses were plotted as percentages of the control strengths the band became narrow, and it was possible to draw an S-N curve through the points.

Still slightly better agreement was had when the maximum repeated stresses were expressed as percentages of the average control values for each piece. The data in figure 4 were plotted on this basis. The resulting S-N curve is concave downward for the first 60,000 cycles, appears to be a straight line from 60,000 to 4 million cycles, and becomes concave upwards at that point. This lower portion of the curve indicates that, if the repeated stresses were less than about 37 percent of the ultimate, the tests would continue almost indefinitely without failure. This suggests an endurance limit for this material of about 37 percent of the ultimate shear strength.

Because all of the specimens, both fatigue and control, failed in the core material itself rather than at or near the glue line it is logical to assume that the glue bond between the core and the facings was adequate. This indicates that, if the gluing is well done, the core itself is critical as far as repeated loading is concerned rather than the glue line.

Table 1.--Summary of results of fatigue tests in shear of cellular cellulose acetate core material for sandwich construction[1]

Specimen number	Maximum repeated shear stress	Control strength	Maximum repeated shear stress to control strength	Cycles to failure	Remarks on visible failure
(1)	(2)	(3)	(4)	(5)	(6)
	Lb. per sq. in.	Lb. per sq. in.	Percent		
1A-6-40	52.2	131.0	39.9	9,450,700	Shear
1A-8-65	84.8	131.0	64.7	337,700	Shear
1A-13-80	108.8	131.0	83.1	29,700	Diagonal tension
1A-15-55	74.7	131.0	57.0	640,200	Diagonal tension
1A-18-38	51.1	131.0	39.0	22,632,000	Diagonal tension
2A-1-70	94.4	131.0	72.0	128,600	Diagonal tension
2A-3-45	60.6	131.0	46.2	3,775,400	Shear and diagonal tension
2A-4-60	86.6	131.0	66.1	363,600	Do.
2A-6-40	57.4	131.0	43.8	6,051,000	Do.
3A-7-80	96.4	114.0	84.5	65,400	Shear
3A-9-60	72.3	114.0	63.4	456,000	Shear and diagonal tension
3A-13-75	89.8	114.0	78.8	56,900	Shear
3A-15-55	65.5	114.0	57.4	1,171,000	Shear and diagonal tension
3A-16-70	81.1	114.0	71.1	127,800	Shear
3A-18-40	46.1	114.0	40.4	14,100,000	Shear
4A-5-50	59.6	118.8	50.2	2,721,300	Shear and diagonal tension
4A-7-45	53.7	118.8	45.2	3,716,000	Do.
4A-8-38	45.0	118.8	37.9	25,075,000	Do
4A-10-90	103.8	118.8	87.3	24,400	Shear
10A-1-85	113.5	127.1	89.3	8,300	Diagonal tension
10A-3-65	87.6	127.1	68.9	213,900	Shear and diagonal tension
10A-4-50	68.6	127.1	54.0	1,161,000	Do.
10A-6-75	102.1	127.1	80.3	51,000	Diagonal tension

[1]Specimens were loaded at the rate of 900 cycles per minute in a direct stress fatigue machine. Range ratio (ratio of minimum to maximum load) was 0.10 for all tests. See figure 1 for details of specimen.

Table 2.--Summary of control tests in shear of cellular cellulose acetate core material for sandwich construction[1]

Specimen number	Shear strength
(1)	(2)
	Lb. per sq. in.
1A-7-C	130.4
1A-14-C	128.0
1A-16-C	134.6
Average for piece 1A	131.0
2A-2-C	127.0
2A-5-C	135.1
Average for piece 2A	131.0
3A-8-C	120.5
3A-14-C	112.5
3A-17-C	109.1
Average for piece 3A	114.0
4A-6-C	119.3
4A-9-C	118.3
Average for piece 4A	118.8
10A-2-C	126.2
10A-5-C	128.0
Average for piece 10A	127.1

[1] Loads were applied to the specimens in the tension direction at a rated head travel of 0.01 inch per minute. See figure 1 for the details of the specimen.

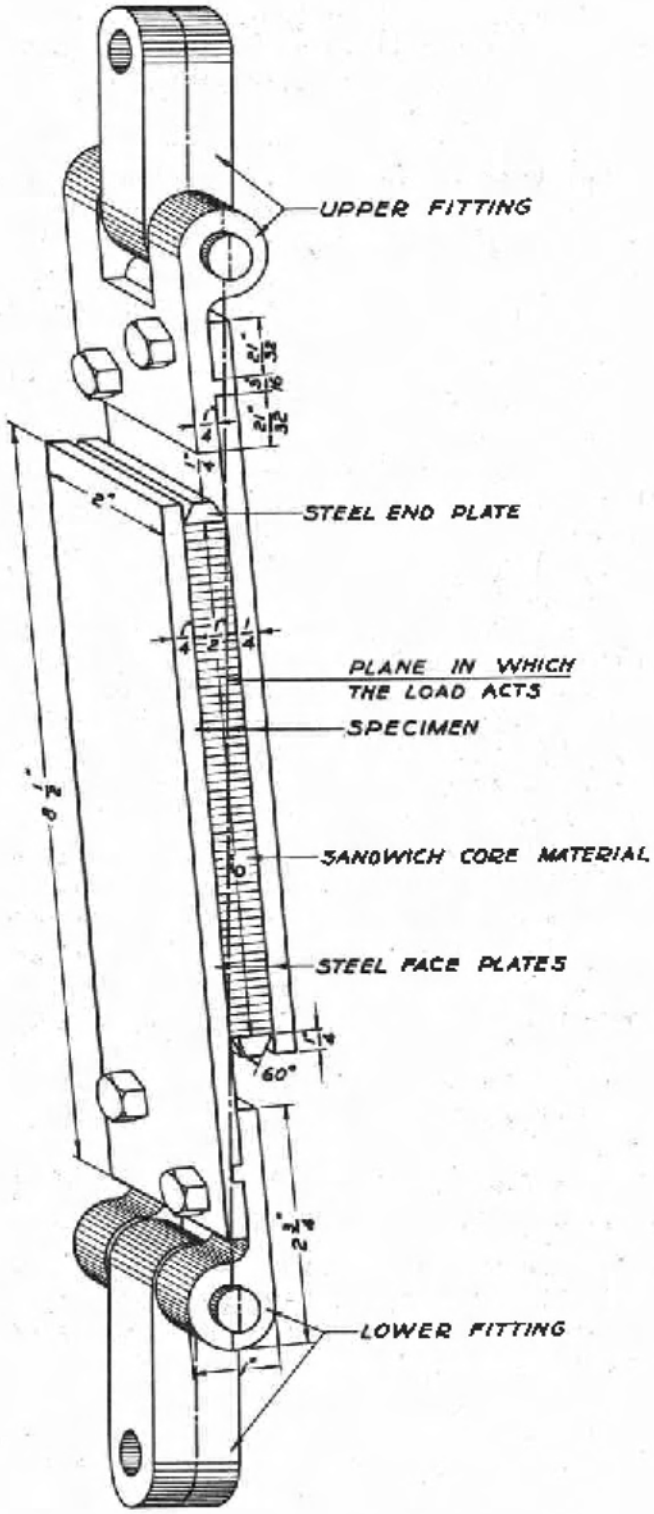

Figure 1.--Detail of specimen for fatigue test in shear of core material for sandwich construction.

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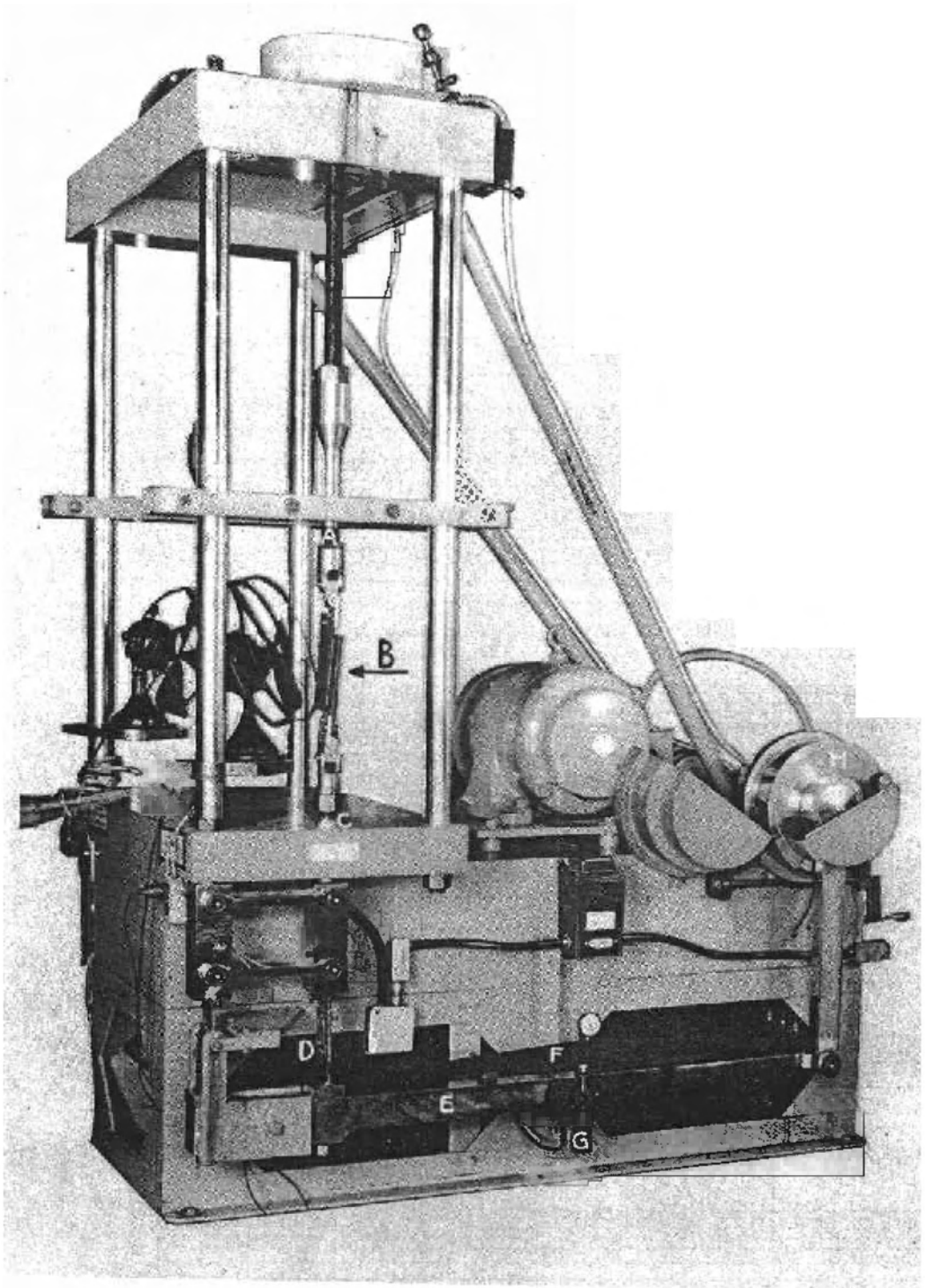

Figure 2.--Direct stress fatigue machine showing: (A) upper loading screw, (B) specimen, (C) lower loading screw, (D) electric strain gages for determining corrections for dynamic effects, (E) horizontal loading arm, (F) calibrated dial bar for determining static loads, (G) electronic cut-off switch for stopping machine, and (H) adjustable eccentric.

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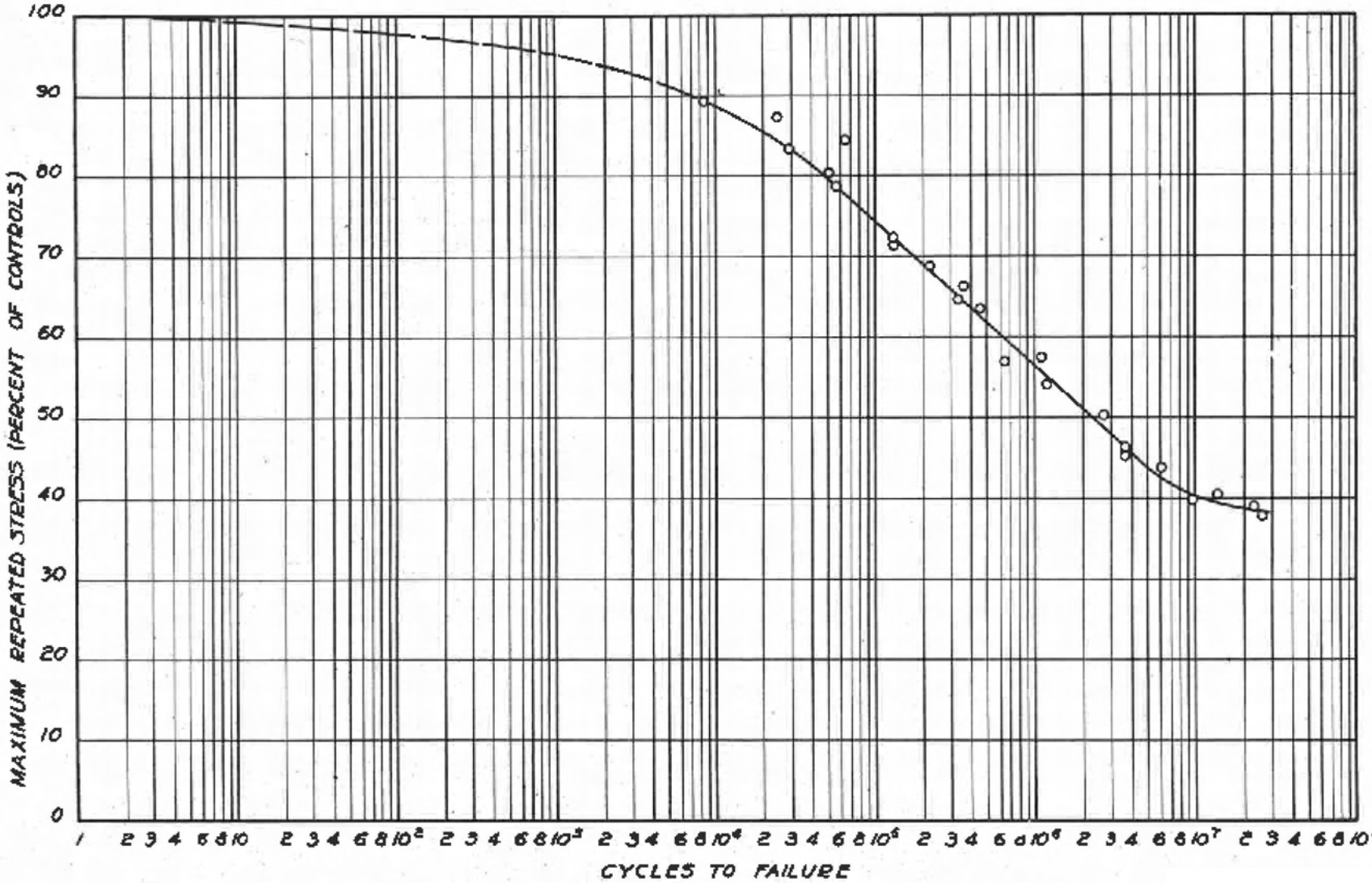

Figure 3.--"S-N" (stress-number of cycles to failure) curve for celluiar cellulose acetate in shear. Ratio of minimum to maximum stress (range ratio) was 0.10.

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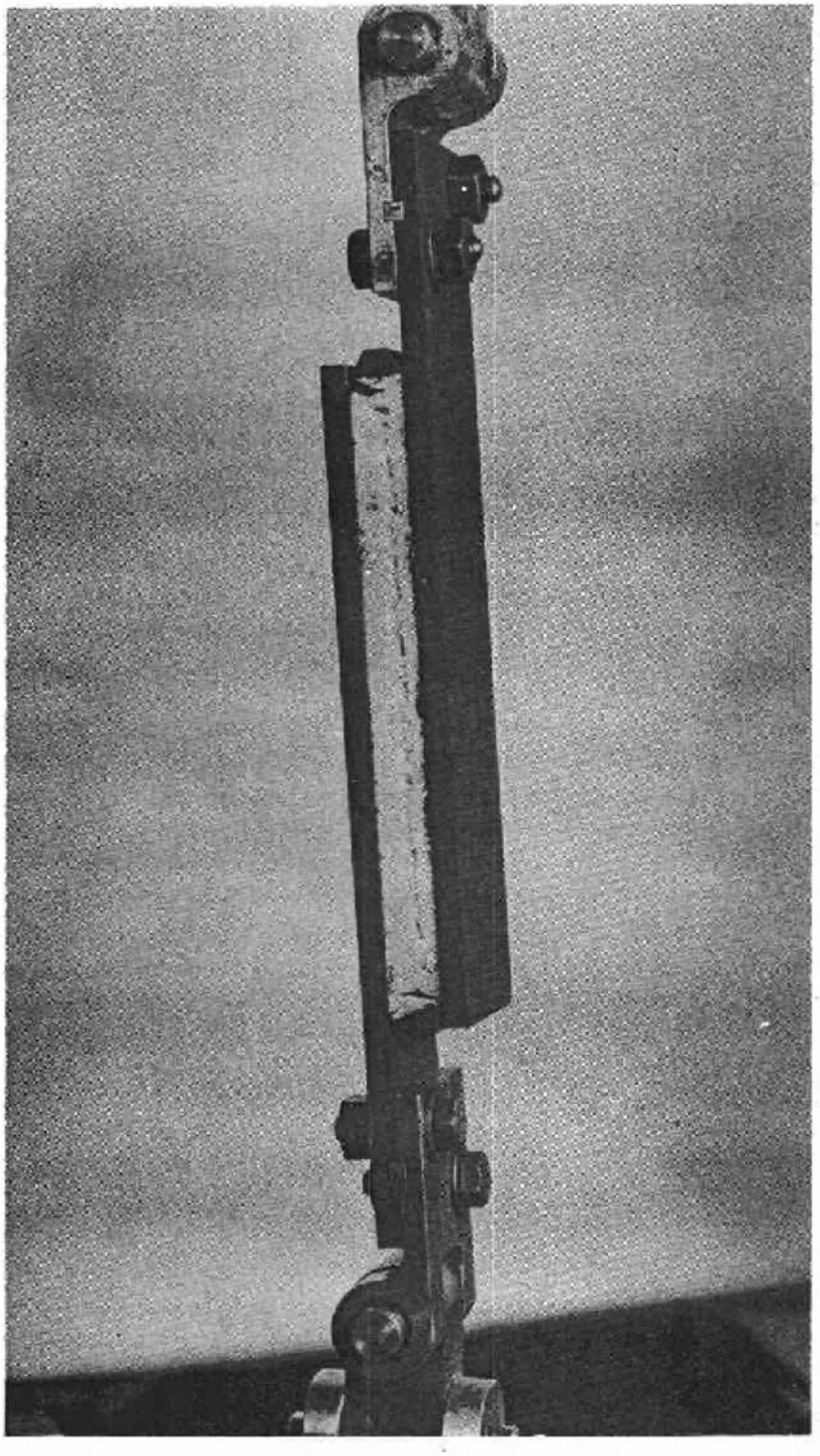

Figure 4.--Fatigue failure of cellular cellulose acetate shear specimen after 25,075,000 cycles of repeated stress to a maximum of 45 pounds per square inch (range ratio 0.1).

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