ARR No. 4E30

W-63

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WARTIME REPORT

ORIGINALLY ISSUED

May 1944 as
Advance Restricted Report 4E30

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Battelle Memorial Institute

NACA

WASHINGTON

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SUMMARY

This report includes tension fatigue test results on the following types of samples of 0.040-inch alclad 24S-T: (1) monoblock sheet samples as received and after a post-aging heat treatment, (2) "sheet efficiency" samples (two equally stressed sheets joined by a single transverse row of spot welds) both as received and after post-aging, (3) spot-welded lap-joint samples as received and after post-aging, and (4) roll-welded lap-joint samples.

Tests on the sheet material furnish base curves for the jointed samples and show the effect of post-aging on the sheet. Post-aging by heating 10 hours at 370° F raised the yield strength about 25 percent but raised the static ultimate only about 2.5 percent and did not, in general, measurably increase the fatigue strength values.

Sheet efficiency tests showed the two sheets joined by spot welds to have about 84 percent of the static ultimate strength of the sheet material. Samples post-aged after welding had 90 percent of the static strength of the (post-aged) sheet. On the other hand, samples tested in fatigue showed, for a range in lifetimes from 10^4 cycles to 10^7 cycles, about 80 percent of the strength of the sheet material. The fatigue strengths were not greatly affected by post-aging after spot-welding.

Neither post-aging after spot-welding nor post-aging before spot-welding, in general, increased the fatigue strength or the static shear strength of the spot-welded lap-joint samples. In fact, there appeared a slight

decrease in fatigue strength at a low (0.25) ratio of minimum load to maximum load owing to post-aging after spot-welding.

Roll-welded lap-joint samples appeared slightly weaker in fatigue (and, except for the 3/8-in. weld-spacing, in static tests) than similar spot-welded samples. The difference between the fatigue strengths of roll-welded and of spot-welded samples varied from 0 percent to 18 percent, but the maximum difference was not greater than the variation in fatigue strength among commercially spot-welded samples.

The variation in fatigue strength that might be expected in commercial practice is discussed briefly.

Testing procedures used to obtain the data given in this report are described in reference 1.

This investigation, conducted at the Battelle Memorial Institute, was sponsored by, and conducted with financial assistance from, the National Advisory Committee for Aeronautics.

Acknowledgment is due Mr. E. S. Jenkins of the Curtiss-Wright Corporation, Dr. Maurice Nelles of the Lockheed Aircraft Corporation, and Mr. T. E. Piper of Northrop Aircraft, Incorporated for advice and assistance in obtaining materials and jointed samples for this investigation.

I. FATIGUE TESTS OF SHEET MATERIAL

Material and Test Pieces

Tests have been made upon alclad 24S-T sheet to furnish base curves for the spot-welded samples and also to find the effect of post-aging upon the fatigue properties of the sheet. To date, fatigue tests have been made upon sheet in the 0.040-inch gage as received and after post-aging heat treatment of 10 hours at 370±5° F. A few samples were stretched 4.3 percent and then heat-treated in the same manner.

Preliminary tests with conventionally shaped specimens containing a section of uniform width gave considerable trouble with failures in the fillet section and with scatter of experimental fatigue data. Figure 1 shows the types of specimen finally adopted to overcome these difficulties. The specimen was inexpensively cut with a 12-inch fly-cutter and a vertical feed on a milling machine. Results in fatigue tests have been very consistent and reproducible.

Calculations indicate that, for the region (±1/4 in. from the center line) where all breaks have occurred, stress concentration factors are less than 1.03. Over this region, the cross-section area varies less than 0.2 percent. It, therefore, seems legitimate to compute the stress as load divided by cross-section area at the center (to within the estimated 3-percent precision in measuring and maintaining loads). Comparison of results of tests (both static tensile and fatigue) on the present specimens with results for conventional specimens shows good agreement. The chief difference in results is the reduced scatter in fatigue tests.

Table 1 gives the results of static tensile tests on samples of each group and figure 2 shows stress-strain curves from these tests. It may be noted in table 1 that aging samples at 370° F for 10 hours increased the yield strength* 25 percent but increased the static ultimate only 3 percent. Similarly, aging samples of sheet that had been stretched 4.3 percent raised the yield and the static ultimate the same amount as heat treatment without previous cold working.

The microstructures of the sheet as received and as post-aged are shown in figure 3.

Fatigue Test Results

Table 2 gives the results of fatigue tests on the sheet in the as-received condition, and figure 4 shows load-life curves plotted from these data. The small

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*All stress-strain data were taken with a 2-inch extensometer. For the samples with continuously varying section, a slight correction was made to give the average strain. Results agreed well with results on uniform width samples, as illustrated in fig. 2.

scatter of the experimental points about the mean curves is typical of results on monoblock samples (of the shape described) and is within the estimated experimental error of ±3 percent in load value. Table 3 gives fatigue test results for the sheet after post-aging.

Figure 5 shows load-life curves for sheet as received and for post-aged sheet. The small open circles are results for the few samples from sheet stretched 4.3 percent before the post-aging heat treatment. (See table 4.) Apparently the post-aging:

(1) Increased static yield 25 percent but static ultimate only 3 percent

(2) Slightly increased the fatigue strength (about 5 percent) at $R = 0.75$ (for which the static component of load is high)

(3) Did not, in general, increase the fatigue strength in tests at low load ratios (For $R = 0.25$ and at 2×10^5 cycles, the fatigue strength of the post-aged sheet appears actually 12 percent lower than that of sheet as received.)

It must be concluded that the post-aging treatments used on this 0.040-inch alclad 24S-T were not beneficial in fatigue.

II. SHEET EFFICIENCY FATIGUE TESTS

Test Pieces and Static Tests

Fatigue test results already have been reported in reference 2 for samples comprising unstressed (scab) sheets spot-welded to 0.040-inch 24S-T alclad sheets. These tests have been extended by using two equally stressed sheets of 0.040-inch alclad joined by a center row of spots spaced 3/4 inch apart.

A typical specimen is shown in figure 6. This shape of specimen is the same as that used for tests on monoblock samples. Tests were made on two sets of samples: (1) sheet spot-welded as received and given no post-aging, and (2) sheet spot-welded as received but samples heated for 10 hours at 370° F.

Static tensile results are shown in table 5. The stress-strain curves* for the sheet efficiency specimens, stressed and unstressed, aged and unaged, 12-inch R or parallel-sided sample, are the same as for sheet specimens. (See fig. 2.)

Spot welds from the stressed attachment sample are shown in figure 7.

Results of Fatigue Tests

Figure 8 shows load-life curves at a load ratio R = 0.25 for: (1) monoblock samples, (2) sheet samples with unstressed attachments, and (3) sheet samples with equally stressed attachments. In each case, sheet and attachment were of 0.040-inch 24S-T alclad and were joined by three spot welds 3/4 inch apart in a line across the center. The curve for the unstressed attachment samples was plotted from data previously reported (reference 1, table 23) supplemented by data on a few samples cut to the shape shown in figure 6. However, the unstressed attachment samples were from different sheet material than the stressed attachment samples. Data for figure 8 are given in tables 2, 7, and 8.

It is apparent that the spot welds have caused some strength reduction. The reduction appears much the same whether the attachment is unstressed or stressed as much as the sheet. It amounts to about 20 percent so that the sheet efficiency of the spot welded samples is about 80 percent for R = 0.25. At higher load ratios, the sheet efficiency is somewhat higher: namely, 85 percent at R = 0.50 and 90 percent at R = 0.75. The static sheet efficiency is about 85 percent.

Tables 6 and 7 give data for two sets of samples of sheets with stressed attachments: (1) as received, and (2) post-aged.

Figure 9 shows load-life curves for the two sets of samples of sheets with stressed attachments: (1) as-received, and (2) post-aged. Although the post-aging

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*Stress-strain curves were again taken with a 2-inch extensometer. The significance of "yield points" in sheet efficiency specimens is a question that may well deserve more attention in the future.

heat treatment increased the static failure strength about 11 percent, the sheet efficiency samples show no significant fatigue strength change. (Difficulties in loading the two sheets equally cause a possible error of 6 percent in each ordinate of each curve, so that differences in the curves of less than about 12 percent of any load value cannot be considered significant.)

Failure took place in stressed attachments along the periphery of the weld slug starting at the notch at the end of the spot (fig. 7(b)). This was the same type of fatigue break as that previously noted for welds in unstressed attachments (reference 1, fig. 34).

III. THE EFFECT OF POST-AGING ON SPOT-WELDED LAP JOINTS

Test Pieces and Static Tests

The effect of post-aging upon the fatigue strength of spot-welded lap-joint samples has been tested for 0.040-inch 24S-T alclad. Each sample was made by joining two pieces 9 inches long and 5 inches wide by a single row of spot welds (spaced 3/4 in. between centers) in a 1-inch overlap section.

Table 9 indicates the several sets of samples used. Sets 1 and 2 were used to study the effect of post-aging after welding. Not enough of the same sheet material was available to study the effect of post-aging before welding. Accordingly, set 3 was from a different lot of sheet, and a few samples of this different sheet were prepared as sets 4 and 5 to furnish data for intercomparison purposes.

Table 9 also gives the static breaking loads of the various samples. In general, the variation in static breaking load for samples as received was greater than variations noted due to aging.

Figures 10 to 13 show macrographs of typical welds. Micro-hardness tests showed little change in hardness in the various zones (see reference 2, fig. 16) because of any aging treatment.

Fatigue Test Results

Tables 10, 11, 12, and 13 show the results of fatigue tests on the various sets of spot-welded lap joints, and the load-life curves of figures 14, 15, and 16 summarize the main features of these results.

Figure 14 shows load-life curves for samples of the same sheet material both as received and after post-aging heat treatment. With one somewhat questionable exception ($R = 0.75$ for lifetimes greater than 10^6 cycles), the curves for the samples post-aged after spot-welding fall below the curves for the samples as received. In this instance, post-aging after welding appears to have lowered the fatigue strengths an average of about 8 percent.

Figure 15 shows load-life curves for lap-joint samples from sheet post-aged before spot-welding and for samples spot-welded without post-aging. The evidence in this case suggests strengthening at high loads and weakening at lower loads.

Finally, figure 16 shows results of tests on lap-joint samples: (1) as received, (2) post-aged after spot-welding, and (3) post-aged before spot-welding for a load ratio $R = 0.25$. Results for higher ratios are somewhat less definite because of an insufficient number of samples of the same sheet material; however, the curves for higher ratios do not seem to offer different results. It appears that post-aging before spot-welding is preferable to post-aging after spot-welding. Post-aging before welding may afford slight strengthening in fatigue for high loads.

Failure takes place in heat-treated spot welds and spot welds in aged sheet in the same manner as has been found for ordinary spot welds with cracks starting at the notch formed by the termination of the internal alclad at the weld slug and propagating outward toward the external alclad. (See figs. 10(b) to 13(b).)

IV. FATIGUE TESTS OF LAP JOINTS WITH ROLL WELDS

Test Pieces, Weld Properties, and Static Strengths

A few tests have been made to compare the fatigue strengths of lap joints made with roll welds to the strengths of similar joints made with spot welds. Three sets of roll-welded samples were tested. Each sample consisted of two pieces (5 by 9 in.) of 0.040-inch 24S-T alclad joined by a single row of welds along the center of a 1-inch overlap section. The spacings between weld centers were 3/8, 3/4, and $1\frac{1}{2}$ inches for the different groups.

The roll welds showed the same structural characteristics as conventional spot welds. In general, roller spots had considerably more indentation and showed a greater difference between longitudinal and transverse dimensions than conventional spot welds. In all cases, the greatest weld diameter was in the direction of rolling (peripheral rotation of welding wheel, table 14). The F1C-C set ($1\frac{1}{4}$-in. weld spacing) showed the greatest deviation in this respect. (See fig. 17(a).) Macrographs of welds from samples with 3/4- and 3/8-inch weld spacings are shown in figures 18(a) and 19(a).

Table 14 gives static shear strength values of the roll welds. The strength per spot decreased with decreasing spot spacing as for conventional welds. For spot welds (see reference 2, fig. 7), the static strength per inch of joint seemed to have a maximum for a spacing between 3/8 and 3/4 inch. On the contrary, the roll-welded joints withstood increasing loads with decreasing weld spacing to and including the 3/8-inch spacing.

Welds which failed in fatigue are shown in figures 17(b), 18(b), and 19(b). Fatigue cracks occurred in the same position and manner as for conventional spot welds. Cracks started at the notch formed by the internal alclad layer at the end of the weld button and propagated through the sheet toward the outer alclad surface. The cracks showed some tendencies to follow weld boundaries. Failure always took place along the least dimension of the weld, (transverse to the direction of rolling and in the direction of the applied stress). Exceptionally long and thin spots (e.g., fig. 17(b)) failed outside the weld slug; this was also a typical failure for conventional spot welds of similar dimensions.

Fatigue Test Results

Tables 15, 16, and 17 show load-life data for roll-welded lap joints.

Figure 20 shows load-life curves for lap joints with roll welds spaced 3/8 inch apart. For comparison, curves (taken from reference 2, fig. 6) for spot-welded lap joints are shown on the same figure. Figures 21 and 22 show similar sets of load-life curves for samples with weld spacings of 3/4 inch and of $1\frac{1}{4}$ inches, respectively.

Before drawing conclusions, it is well to note two points. First, the spot-welded samples and the roll-welded samples were from different lots of sheet material. Secondly, experimental points have been omitted from the curves. In general, the scatter was small (i.e., within the 3-percent precision of loading). There was, however, somewhat greater scatter for samples with roll welds $1\frac{1}{4}$ inches apart, possibly produced by variations in the weld dimensions. There was a further discrepancy in the roll-welded samples with 3/8-inch spaced welds; the number of welds varied from 11 to 14. The variation in number was due to different edge distances rather than varied spacings and did not so much affect the total strength of the joint as it did the strength per weld.

It will be observed that, in general, conventional spot welds appear stronger in fatigue than roll welds. This conclusion is questionable for the 3/8-inch weld spacing. For this spacing, roll welds were considerably stronger in static tests and were weaker in fatigue only for the 0.25-load ratio. It must be noted (see part V) that samples of different lots of sheet and spot-welded by different operators show considerable scatter. It seems possible, therefore, to conclude that roll welds are not necessarily weaker than spot welds but show sufficient promise to deserve further consideration.

V. VARIATIONS IN FATIGUE STRENGTHS IN COMMERCIAL WELDING

In a previous report (reference 2, pt. II), some comparisons of fatigue strengths of samples spot-welded by various operators were shown. Additional tests now give a total of six sets of samples which have been tested at a load ratio of R = 0.25. Figure 23 shows all the experimental points on a load-life diagram. Differences in weld dimensions, static shear strength of spots, and properties of sheet material are shown in table 16. (Tables 19 and 20 in appendix I and fig. 24 show the experimental data and macrographs of spot welds for one set of samples. All other points on fig. 23 are from previously reported data.) The 61 points in figure 23 fall within a reasonably well determined scatter band. The scatter in static ultimate values is 35 percent; while fatigue strength scatter varies from 21 percent at short lifetime to 45 percent at long lifetime. These results indicate the variation to be expected in commercial practice, owing to different operators using different machines, techniques, and lots of sheet material.

There are not enough data to estimate the relative importance of the two causes. Tests on any one set of samples show much less variation from a smooth curve than tests on samples from different sets show. The scatter is not reduced by plotting the ratios of fatigue strengths to static ultimate strengths. This emphasizes a previously stated conclusion (reference 2, p. 10) that, owing to differences in the nature of failure, high static strength of spot-welded lap joints does not imply correspondingly high values.

At the present time, the relation of weld structure and dimensions to fatigue strength is not sufficiently understood to interpret such scatter. As has been noted, the scatter in static results is about 35 percent, a value which seems large in view of the Rensselaer finding (reference 3) that the scatter for single spots is about 30 percent. Since the test pieces used here all involved at least 3 spots, it would be expected that the scatter would be less than for single spots. A part of the additional scatter is probably caused by different welding techniques and part by differences in material.

Battelle Memorial Institute,
Columbus, Ohio, March 1944.

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TABLE 1.- STATIC TENSILE STRENGTH OF MONOBLOCK FATIGUE SPECIMENS OF 0.40-INCH 24S-T ALCLAD

Type	Yield Strength* (p s i)	Ultimate Strength (p s i)	Elongation (% in 2 In.)
12" R sides - Unaged			
A1C - 29	50,300	67,300	19
A1C - 30	50,900	66,700	19
12" R sides - Aged			
A2C	62,400	69,400	4
A2C	62,400	68,700	4
Straight sides - Unaged			
A1C - 90	50,660	66,700	19
A1C - 91	49,700	66,000	19

*Taken with two-in. gage length extensometer. See footnote on page 3.

TABLE 2.- FATIGUE TEST RESULTS FOR ALUMINUM MONOBLOCK SAMPLES AS RECEIVED (1.000" x0.040")

Sample Number	Maximum Load (p s i)	Cycles to Failure
Ratio .25		
A1C 88	66,000	26,600
A1C 59	64,000	29,600
A1C 18	60,000	25,300
A1C 72	52,000	67,500
A1C 16	45,000	162,900
A1C 19	40,000	192,900
A1C 17	33,000	701,100
A1C 82	30,000	2,405,400
A1C 21	23,000	>10,417,200
A1C 28	37,000	308,900
A1C 32	28,000	1,564,400
A1C 35	26,000	>10,131,000
Ratio .50		
A1C 27	58,000	111,800
A1C 26	52,000	181,900
A1C 25	45,000	481,300
A1C 83	41,000	749,600
A1C 23	32,000	>9,173,100
A1C 23 reload	50,000	191,900
A1C 6	35,800	1,347,800
Ratio .60		
A1C 34	60,000	135,800
A1C 50	54,000	298,700
A1C 36	50,000	621,200
A1C 37	44,000	2,941,600
A1C 55	50,000	551,700
Ratio .75		
A1C 85	67,000	4,200
A1C 75	64,000	848,600
A1C 81	62,000	886,000
A1C 31	60,000	>9,637,000

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TABLE 3.- FATIGUE TEST RESULTS FOR ALUMINUM MONOBLOCK SAMPLES POST-AGED (1.000" x0.040")

Sample Number	Maximum Load (p s i)	Cycles to Failure
Ratio .25		
A2C 9	65,000	16,700
A2C 7	62,000	24,600
A2C 6	60,000	22,800
A2C 2	50,000	77,300
A2C 3	40,000	121,800
A2C 4	32,000	304,100
A2C 8	29,000	656,500
A2C 23	28,000	6,860,200
A2C 29	28,000	638,200
A2C 5	25,000	>10,011,200
Ratio .50		
A2C 15	65,000	78,100
A2C 24	65,000	22,100
A2C 14	60,000	79,300
A2C 12	50,000	119,700
A2C 17	47,000	335,400
A2C 13	44,000	310,300
A2C 11	40,000	2,927,600
A2C 18	36,000	6,343,200
Ratio .60		
A2C 22	64,000	194,600
A2C 16	56,000	545,800
A2C 20	50,000	748,100
A2C 25	45,000	3,765,200
Ratio .75		
A2C 21	60,000	> 5,779,500

TABLE 4.- FATIGUE TEST RESULTS FOR ALUMINUM MONOBLOCK SAMPLES PRE-STRETCHED 4% BEFORE POST-AGING (1.000" x0.040")

Sample Number	Maximum Load (p s i)	Cycles to Failure	Remarks
Ratio .25			
A4C 9	65,000	13,600	
A4C 5	50,000	57,500	
A4C 7	38,000	143,500	
A4C 14	34,000	232,300	
A4C 8	30,000	437,000	
A4C 10	28,000	3,039,400	
A4C 13	26,000	544,500	Possible flaw in machined edge; point not plotted on curve.

TABLE 5.- STATIC TENSILE STRENGTHS OF "SHEET EFFICIENCY" SPECIMENS

Type	Yield Strength* (p s i)	Ultimate Strength (p s i)	Elongation (% in 2 In.)
Stressed attachment (unaged)	52,200	55,550	4
Stressed attachment (aged)	59,100	62,400	2.5
Unstressed attachment (unaged)	52,000	58,350	5

*Taken with two-in. gage length extensometer. See footnote on page 5.

TABLE 6.- FATIGUE TEST RESULTS FOR SAMPLES OF 2 SHEETS 2.244" x 0.040" SPOT-WELDED ACROSS CENTER WITH 3/4" WELD SPACING.

Sample Number	(p s i) Maximum Load	Cycles to Failure
Ratio 0.25		
C1C 9D	52,000	7,100
C1C 27D	40,000	115,100
C1C 8D	33,000	87,300
C1C 10D	24,000	981,600
C1C 25D	23,000	1,285,000
Ratio 0.50		
C1C 15D	52,000	1,100
C1C 19D	52,000	3,000
C1C 17D	48,000	197,800
C1C 18D	34,000	730,100
C1C 23D	32,000	8,976,600
reload	50,000	30,300
Ratio 0.60		
C1C 21D	50,000	375,200
C1C 24D	45,000	762,300

TABLE 7.- FATIGUE TEST RESULTS FOR SAMPLES WITH 2 SHEETS 2.244" x 0.040" SPOTWELDED ACROSS CENTER WITH 3/4" WELD SPACING
(Post-aged After Welding)

Sample Number	Maximum Load (p s i)	Cycles to Failure
R 0.25		
C2C23D	54,000	22,300
C2C21D	50,000	51,000
C2C9D	46,000	50,800
C2C4D	40,000	3,400
C2C31D	39,000	90,000
C2C7D	37,000	190,800
C2C10D	36,000	179,500
C2C5D	34,000	173,800
C2C1D	30,000	232,400
C2C8D	26,000	500,500
C2C3D	24,000	255,600
C2C32D	23,000	641,000
C2C6D	22,000	1,504,300
C2C2D	22,000	
C2C2D	20,000	>10,724,800
Reload	40,000	114,300
R 0.50		
C2C16D	51,000	45,000
C2C21D	50,000	51,000
C2C13D	46,000	242,200
C2C11D	40,000	290,000
C2C12D	32,000	866,900
C2C15D	28,000	> 9,406,800
Reload	40,000	337,100
C2C14D	26,000	>10,239,200
Reload	40,000	504,500
R 0.60		
C2C25D	57,000	160,000
C2C22D	52,000	258,000
C2C20D	47,000	699,300
C2C24D	44,000	761,200
C2C19D	39,000	8,743,400

TABLE 8.- FATIGUE TEST FOR UNSTRESSED ATTACHMENT SAMPLES
2.244" x 0.040"

Sample Number	Maximum Load (p s i)	Cycles to Failure	Remarks
Ratio 0.25			
6A8	50,000	3,800	Failed through welds.
6A9	45,000	8,000	
6A10	44,000	45,300	" " "
6B6	40,000	85,800	" " "
6B5	34,000	246,700	" " "
6B14	28,000	501,700	" " "
6A7	22,000	787,900	" " "
6B1B	22,000	1,951,100	" " "
6A16	19,000	4,095,500	" " "

TABLE 9.- STATIC SHEAR STRENGTHS OF SPOTWELDED LAP-JOINT SAMPLES

Set Number	Sample Number	Sheet Material	Condition	Breaking Load Total Lb	Breaking Load Lb /Spot
1	B1C-10D	1	As-received.	3,800	633
	B1C-9D	1	" "	3,550	591
2	B2C-29D	1	Post aged after welding.	3,860	643
	B2C-30D	1	" " " "	3,620	603
3	2B3C-7D	2	Post aged before welding.	2,960	493*
4	2B2C-1D	2	Post aged after welding	3,120	520
	2B2C-9D	2	" " " "	3,450	575
5	2B1C-16D	2	As-received.	2,680	447
	2B1C-15D	2	" "	3,320	553

*Possibly slightly low due to one poor spot.

TABLE 10.- FATIGUE TEST RESULTS FOR LAP-JOINT SAMPLES POST-AGED AFTER WELDING

(Samples 5"x 0.040", spotwelds spaced 3/4" apart)

Sample Number	Maximum Load Total Lb	Maximum Load Lb /In.	Maximum Load Lb /Spot	Cycles to Failure	Remarks
Ratio 0.25					
B2C2D	2,000	400	333	6,500	Pulled buttons.
B2C6D	1,800	360	300	19,100	Fatigue crack.
B2C1D	1,500	300	250	58,900	" "
B2C3D	1,200	240	200	151,400	" "
B2C4D	875	175	146	525,000	" "
B2C5D	750	150	125	1,829,500	" "
B2C8D	700	140	116	4,000,000	" "
B2C7D	675	135	112	>9,421,400	Did not fail.
Reload	1,500	300	250	49,800	" " "
Ratio 0.50					
B2C19D	2,250	450	375	10,000	Pulled buttons.
B2C15D	2,000	400	333	39,300	Fatigue crack.
B2C14D	1,800	360	300	39,800	" "
B2C11D	1,500	300	250	114,300	" "
B2C12D	1,200	240	200	340,800	" "
B2C13D	1,000	200	166	715,600	" "
B2C17D	900	180	150	2,166,900	" "
B2C16D	825	165	138	3,882,000	" "
Ratio 0.75					
B2C24D	2,700	540	450	21,800	Pulled buttons.
B2C21D	2,500	500	416	113,900	" "
B2C18D	2,050	410	343	268,000	Fatigue cracks.
B2C22D	1,750	350	293	793,800	" "
B2C23D	1,500	300	250	3,856,600	" "
B2C25D	1,450	290	242	10,031,500	
Reload	2,500	500	416	54,300	Pulled buttons and fatigue crack.

TABLE 11.- FATIGUE TEST RESULTS FOR LAP JOINT SAMPLES AS RECEIVED (Samples 5" x 0.040", spots 3/4" apart)

Sample Number	Maximum Load Total Lb	Lb /In.	Lb /Spot	Cycles to Failure	Remarks
Ratio 0.25					
B1C 5D	2000	400	333	5,500	Pulled buttons
B1C 19D	1800	360	300	15,700	"
B1C 4D	1650	330	275	31,000	"
B1C 8D	1450	290	243	119,000	Fatigue cracks
B1C 7D	1300	260	216	384,900	"
B1C 1D	1200	240	200	289,700	"
B1C 2D	950	190	158	1,449,800	"
B1C 3D	875	175	146	1,712,600	"
B1C 6D	750	150	125	4,130,600	"
Ratio 0.50					
B1C 13D	2300	460	383	13,000	Pulled buttons
B1C 15D	2000	400	333	24,400	Fatigue cracks
B1C 18D	1850	370	308	78,800	"
B1C 12D	1750	350	292	92,000	"
B1C 16D	1550	310	258	173,500	"
B1C 11D	1250	250	208	525,400	"
B1C 14D	1000	200	166	1,625,000	"
B1C 17D	900	180	150	2,794,100	"
B1C 28D	850	170	142	>7,534,200	Did not fail
B1C 20D	800	160	133	>9,370,600	
Reload	1500	300	250	242,900	"
Ratio 0.75					
B1C 25D	3000	600	500	7,300	Shear and pulled buttons
B1C 23D	2700	540	450	71,600	Pulled buttons
B1C 22D	2125	425	354	282,700	Fatigue cracks
B1C 21D	1750	350	292	795,000	"
B1C 24D	1500	300	250	1,334,300	"
B1C 26D	1300	260	217	2,580,500	"
B1C 27D	1200	240	200	>9,731,800	
Reload	2000	400	333	234,800	"

TABLE 12.- FATIGUE TEST RESULTS FOR LAP JOINT SAMPLES FROM SHEET POST-AGED BEFORE WELDING (Samples 5" x 0.040", spots 3/4" apart)

Sample Number	Maximum Load Total Lb	Lb /In.	Lb /Spot	Cycles to Failure	Remarks
Ratio 0.25					
2B3C 3D	2300	460	383	7,500	Pulled buttons
2B3C 2D	2000	400	333	39,300	Fatigue crack
2B3C 1D	1500	300	250	152,500	"
2B3C 20D	1300	260	217	269,000	"
2B3C 4D	1200	240	200	426,600	"
2B3C 5D	1000	200	167	789,000	"
2B3C 6D	850	170	143	1,740,600	"
2B3C 8D	750	150	126	3,360,300	"
2B3C 9D	675	135	112	>7,533,000	Did not fail
Ratio 0.50					
2B3C 11D	2500	500	417	10,200	Pulled buttons and shear
2B3C 12D	2100	420	350	56,000	Fatigue crack & pulled buttons
2B3C 13D	1800	360	300	128,300	"
2B3C 14D	1500	300	250	205,900	"
2B3C 15D	1250	250	208	467,700	"
2B3C 16D	1050	210	175	1,014,400	"
2B3C 17D	925	185	154	3,618,400	"
2B3C 10D	850	170	142	3,791,600	"
Ratio 0.75					
2B3C 21D	3000	600	500	11,100	Shear
2B3C 26D	2750	550	458	91,300	Pulled buttons
2B3C 22D	2500	500	417	200,700	Fatigue cracks
2B3C 23D	2200	440	367	365,300	"
2B3C 24D	1800	360	300	625,400	"
2B3C 25D	1500	300	250	1,838,500	"
2B3C 27D	1350	270	225	3,006,500	"
2B3C 19D	1300	260	217	2,889,100	"

TABLE 13.- FATIGUE TEST RESULTS FOR LAP JOINT SAMPLES
(Samples 5" x 0.040", spots 3/4" apart)
AS RECEIVED

Sample Number	Maximum Load Total Lb	Lb /In.	Lb /Spot	Cycles to Failure	Remarks
Ratio 0.25					
2B1C 11D	2500	500	417	1,900	Shear
2B1C 1D	2000	400	333	6,200	Pulled buttons
2B1C 2D	1700	340	283	20,600	Pulled buttons & fatigue cracks
2B1C 3D	1400	280	233	88,600	Fatigue cracks
2B1C 5D	1150	230	192	339,200	"
2B1C 4D	1000	200	167	762,900	"
2B1C 6D	825	165	136	1,341,800	"
2B1C 8D	750	150	125	>9,520,500	Did not fail
Reload	1500	300	250	111,100	Fatigue crack
2B1C 7D	675	135	112	>10,856,000	Did not fail
Reload	1500	300	250	85,700	Fatigue crack
Ratio 0.75					
2B1C 13D	2300	460	383	127,100	Pulled buttons
2B1C 9D	2000	400	333	411,700	Fatigue cracks
2B1C 10D	1500	300	250	1,554,500	"
2B1C 12D	1400	280	233	2,710,400	"

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TABLE 14.- AVERAGE DIMENSIONS AND STATIC SHEAR STRENGTHS OF ROLLER SPOTWELDS

Specimen	Material Spacing	Gage		Static Breaking Load Lb - /Sample	Lb - /Spot	Weld Diameter (Inches)	Per Cent of Penetration	Remarks
F1C29C	3/8"	0.040"-0.040"		6,580	470	0.199±.010[1]	50±6%	Broke alongside spots.
F1C30C	"	"	"	6,140	440	0.220±.010[1]	50±12%	" " "
F1C29D	3/4"	"	"	3,380	565	0.180±.004[1]	50±5%	Sheared.
F1C30D	"	"	"	3,200	535	0.230±.004[2]	63±5%	"
F1C29E	1-1/4"	"	"	2,280	570	0.130±.0501 [1]	37±6%	"
F1C30E	"	"	"	2,280	570	0.230±.015[2]	40±6%	"

(1)Perpendicular to weld line.

(2)Parallel to weld line.

TABLE 15.- FATIGUE TEST RESULTS FOR LAP JOINT ROLL-WELDED SAMPLES
(Samples 5" x 0.040", welds 3/4" apart)

Sample Number	Maximum Load Total Lb	Lb /In.	Lb /Weld	Cycles to Failure	Remarks
Ratio 0.25					
F1C 2D	1750	350	292	4,900	Pulled buttons
F1C 22D	1550	310	258	17,600	"
F1C 5D	1500	300	250	19,400	"
F1C 1D	1250	250	208	55,800	Fatigue crack
F1C 3D	1000	200	166	109,500	"
F1C 27D	950	190	158	166,100	"
F1C 4D	750	150	125	509,100	"
F1C 6D	650	130	108	802,000	"
F1C 7D	600	120	100	1,310,700	"
F1C 8D	500	100	83	1,549,100	"
F1C 10D	475	95	79	3,405,300	"
F1C 9D	420	84	70	3,059,900	"
F1C 28D	400	80	67	5,586,800	"
Ratio 0.50					
F1C 14D	2050	410	342	9,300	Pulled buttons
F1C 13D	1800	360	300	30,100	"
F1C 11 D	1500	300	250	70,100	Fatigue crack
F1C 12D	1250	250	208	312,300	"
F1C 15D	1150	230	193	411,200	"
F1C 16D	1000	200	166	608,400	"
F1C 17D	850	170	141	724,500	"
F1C 18D	750	150	125	1,139,300	"
F1C 19D	650	130	108	2,242,100	"
F1C 20D	600	120	100	5,751,800	"
Ratio 0.75					
F1C 26D	2375	475	396	67,400	Shear and pulled buttons
F1C 21D	2000	400	333	181,400	Pulled buttons
F1C 23D	1550	310	258	593,800	"
F1C 24D	1375	275	230	860,500	Fatigue cracks
F1C 25D	1125	225	187	2,542,000	"
F1C 32D	1075	215	179	3,220,900	"
F1C 33D	1000	200	166	>11,136,900	Did not fail
Reload	1750	350	292	216,800	"

TABLE 16.- FATIGUE TEST RESULTS FOR LAP JOINT ROLL-WELDED SAMPLES
(Samples 5" x 0.040", welds 3/8" apart)

Sample Number*	Maximum Load Total Lb	Lb /In.	Lb /Weld	Cycles to Failure
Ratio 0.25				
F1C 10C (14)	2750	550	196	12,700
F1C 9C (13)	2500	500	192	14,300
F1C 6C (14)	2000	400	143	39,500
F1C 28C (14)	1750	350	125	22,400
F1C 4C (13)	1375	275	105	321,200
F1C 2C (13)	1200	240	92	302,200
F1C 1C (13)	1000	200	77	469,500
F1C 7C (14)	900	180	64	755,100
F1C 3C (13)	850	170	65	1,367,900
F1C 36C (14)	800	160	57	1,604,200
F1C 8C (13)	750	150	58	>10,247,600
Reload	2000	400	154	47,100
F1C 5C (14)	650	130	46	>9,173,100
Reload	1800	360	129	75,900
Ratio 0.50				
F1C 19C (12)	3000	600	250	58,700
F1C 13C (14)	2675	535	191	78,400
F1C 17C (12)	2200	440	183	151,000
F1C 11C (14)	2000	400	143	174,600
F1C 33C (14)	1850	370	142	117,110
F1C 18C (12)	1700	340	141	450,300
F1C 12C (14)	1500	300	107	557,200
F1C 14C (14)	1250	250	89	2,659,700
F1C 15C (12)	1150	230	96	1,327,600
F1C 20C (12)	1000	200	83	970,000
F1C 35C (14)	950	190	68	>10,516,600
Reload	2000	400	143	179,300
F1C 16C (12)	900	180	75	>9,008,000
Reload	2000	400	166	293,800
Ratio 0.75				
F1C 32C (14)	4000	800	286	74,600
F1C 34C (14)	3500	700	250	543,300
F1C 22C (14)	3000	600	214	559,900
F1C 21C (14)	2500	500	178	973,800
F1C 23C (14)	2200	440	157	1,473,700
F1C 24C (14)	1900	380	136	1,102,100
F1C 25C (14)	1750	350	125	2,103,300

*The number in parentheses gives the total number of welds for each sample. Variations are due to varied distances of outer welds from edges rather than to varied weld spacings.

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TABLE 17.- FATIGUE TEST RESULTS FOR LAP JOINT ROLL-WELDED SAMPLES
(Samples 5" x 0.040", welds 1¼" apart)

Sample Number	Maximum Load Total Lb	Lb /In.	Lb /Spot	Cycles to Failure	Remarks
Ratio 0.25					
F1C 5E	1300	260	325	8,700	Pulled buttons
F1C 1E	1200	240	300	13,500	"
F1C 4E	1100	220	275	20,000	"
F1C 2E	875	175	219	154,000	Fatigue cracks & pulled button
F1C 3E	625	125	156	892,200	"
F1C 6E	500	100	125	3,573,600	"
Ratio 0.50					
F1C 15E	1500	300	375	12,800	Pulled buttons
F1C 11E	1250	250	313	43,400	Shear & pulled buttons
F1C 12E	1000	200	250	239,200	Fatigue crack
F1C 13E	825	165	206	463,200	" " and pulled buttons
F1C 16E	650	130	163	2,731,000	
F1C 14E	600	120	150	9,230,300	
Reload	2000	400	500	300	Shear
Ratio 0.75					
F1C 25E	2000	400	500	37,900	Pulled buttons & shear
F1C 24E	1750	350	438	86,300	"
F1C 22E	1500	300	375	260,500	Fatigue crack and pulled button
F1C 21E	1250	250	313	647,700	"
F1C 23E	1000	200	250	1,156,400	"
F1C 26E	850	170	213	7,182,500	"

TABLE 18.- WELD DIMENSIONS, STATIC SHEAR STRENGTH, AND SHEET STRENGTH OF SPOTWELDED SAMPLES

Sample Designation	Description Spacing	Gage	Static Breaking Load, Lb /Spot	Weld Diameter (In)	Percentage Spot Penetration	Strength of Sheet Metal Yield p.s.i.	Ultimate p.s.i.	% Elong. in 2"	Remarks
Set 2	3/4"	0.040"	635*40	0.190-0.210	45-50	47,300	66,000	19	Sound, well dropped, little indentation.
Set 3	"	"	500*40	0.170-0.180	38-45	43,950	65,350	18	Sound, ends of weld taper, some indentation.
Set 6	"	"	595*5	0.215	35-50	52,500	67,000	17	Sound, well centered & shaped indentation.
Set 1	"	"	479*10	0.180-0.190	75-80	48,800	64,300	19	Heavy transverse cracking, some indentation.
Set 4	"	"	615*1	0.220-0.240	60-70	51,300	64,750	16	Welds off center, peanut shaped.
Set 5	"	"	520*7	0.170-0.180	55-60	54,700	68,500	19	Sound, some indentation, well shaped (even).

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APPENDIX I

ADDITIONAL TEST RESULTS ON SPOT-WELDED LAP JOINT SAMPLES

Tables 19 and 20 show load-life data for two sets of lap-joint samples spot-welded under different conditions (i.e., by a different operator and on a different machine) than any reported previously on this project. One set of these (that of 0.040-in. sheet) is included in the discussion in part V of this report. The other set of data has not been discussed, but, upon comparison with data for other samples of 0.032-inch sheet, shows signs of the same variation in fatigue strength as evidenced in the thicker gage sheet samples.

Figures 24 and 25 show photomacrographs of typical welds for samples listed in tables 19 and 20. These welds show no unusual feature.

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TABLE 19.- FATIGUE TEST FOR LAP JOINT SAMPLES 5", 0.040" - 0.040"
6 SPOT WELDS, 3/4" SPACED. MADE BY COMPANY C

Sample Number	Maximum Load Total Lb	Lb /In.	Lb /Spot	Cycles to Failure	Remarks
Ratio 0.25					
$B1^C_C$ 9D	2000	400	333	8,200	Pulled buttons
$B1^C_C$ 3D	1800	360	300	15,500	Fatigue crack
$B1^C_C$ 1D	1500	300	250	38,700	"
$B1^C_C$ 2D	1200	240	200	122,100	"
$B1^C_C$ 4D	1000	200	166	329,500	"
$B1^C_C$ 5D	850	170	142	705,000	"
$B1^C_C$ 6D	750	150	125	1,125,300	"
$B1^C_C$ 7D	650	130	108	1,044,100	"
$B1^C_C$ 10D	600	120	100	1,832,700	"
$B1^C_C$ 8D	550	110	92	9,028,200	Did not fail
$B1^C_C$ 19D	500	100	83	9,198,200	"
Reload	2000	400	333	18,000	Shear
Ratio 0.50					
$B1^C_C$ 11D	2000	400	333	14,400	Shear & pulled button.
$B1^C_C$ 18D	1700	340	283	76,500	Fatigue crack
$B1^C_C$ 12D	1500	300	250	141,000	"
$B1^C_C$ 13D	1200	240	200	284,800	"
$B1^C_C$ 14D	1000	200	166	621,500	"
$B1^C_C$ 15D	850	170	143	1,013,900	"
$B1^C_C$ 16D	750	150	125	1,044,600	"
$B1^C_C$ 17D	625	125	104	4,338,000	"
Ratio 0.75					
$B1^C_C$ 25D	2375	475	396	72,900	Pulled buttons
$B1^C_C$ 22D	2000	400	333	178,200	Fatigue crack
$B1^C_C$ 24D	1750	350	292	435,400	"
$B1^C_C$ 21D	1500	300	250	1,011,800	"
$B1^C_C$ 23D	1250	250	208	2,764,600	"
$B1^C_C$ 27D	1200	240	200	3,535,400	"
$B1^C_C$ 26D	1175	235	196	4,050,200	"

TABLE 20.- FATIGUE TEST FOR LAP JOINT SAMPLES 5",
.032" - .032" 6 SPOT WELDS, 3/4" SPACED
MADE BY COMPANY C

Sample Number	Maximum Load Total Lb	Lb /In.	Lb /Spot	Cycles to Failure	Remarks
Ratio 0.25					
B^1_CB 1D	1500	300	250	2,500	Shear
B^1_CB 5D	1250	250	208	6,600	"
B^1_CB 2D	1000	200	167	45,000	Fatigue cracks
B^1_CB 4D	800	160	133	220,500	"
B^1_CB 3D	675	135	112	1,095,500	"
B^1_CB 6D	550	110	92	1,204,800	"
B^1_CB 10D	500	100	83	1,546,000	"
Ratio 0.75					
B^1_CB 12D	1500	300	250	123,800	Fatigue cracks
B^1_CB 11D	1250	250	208	361,200	"
B^1_CB 7D	1000	200	167	1,103,600	"
B^1_CB 8D	850	170	142	2,107,800	"
B^1_CB 9D	750	150	125	10,843,200	Did not fail
Reload	1250	250	208	302,900	Fatigue crack

APPENDIX II

METHODS OF OBTAINING AND PLOTTING TEST RESULTS

Introduction

In previous reports, fatigue data have been presented in terms of maximum load-life curves at constant ratios of minimum load to maximum load. While families of curves of this kind can present all the information that can be obtained from direct stress fatigue tests, it is worth while periodically to reopen the question as to whether the data are being presented in the most usable form. There are two viewpoints to be considered:

(1) The viewpoint of the fatigue laboratory where the interest is in getting a maximum amount of information about a material from a given number of test pieces

(2) The viewpoint of the designer who wishes to have the data in the form most convenient for use

That method of plotting which satisfies the first viewpoint may not necessarily satisfy the second. However if a sufficiently complete pattern of data is obtained from one viewpoint, it can always be presented in terms of the second.

Figure 26 shows a sinusoidal loading curve for tension-tension fatigue testing. Two quantities must be specified to determine completely the loading condition, and three quantities are necessary to represent the load life. Because of the practical difficulties of representation of three-dimensional surfaces, it is convenient to use families of two-dimensional curves. Such curves may be considered to represent contours of the three-dimensional surface.

The two quantities necessary for specifying the loading condition can be selected in a large number of ways. The obvious quantities expressible in stress units are the following:

S_{min} minimum stress

S_{mean} mean stress

S_{max} maximum stress

S_{alt} amplitude of alternating stress

These 4 variables allow for consideration 12 types of load-life curves: (1) 3 types of constant S_{min} curves (with S_{mean}, S_{max}, or S_{alt} plotted against the number of cycles to failure); (2) 3 of constant S_{mean}; (3) 3 of constant S_{max}; and (4) 3 of constant S_{alt}.

Other load-life curves may be drawn by holding the ratio

$$R \equiv \frac{S_{min}}{S_{max}}$$

or the ratio

$$r \equiv \frac{S_{alt}}{S_{mean}} = \frac{1 - R}{1 + R}$$

constant and plotting any one of the four load values listed above against lifetime.

The fatigue tests made at Battelle Memorial Institute on monoblock samples of 24S-T alclad aluminum cover the tension-tension load range and a lifetime range from 10^4 to 10^7 cycles fairly completely. The load-life curves also show satisfactorily small scatter. Consequently, these data furnish excellent illustrations of the general appearances of the several possible types of load-life diagrams.

In the following section, there are shown 13 types of load-life diagrams drawn from the data on aluminum sheet samples. It is not believed that all these diagrams will be of common use.

As will be brought out later, it seems probable that, from the standpoint of the fatigue test laboratory, the most useful method of obtaining data on aluminum alloys appears to be the one of obtaining S-N curves at constant mean load; however, the advantages are not yet well enough established to warrant a change in method of taking data. The other types of curves illustrated in figures 27 to 39 have been drawn with the idea that an aircraft designer might find one method of presentation more useful than another. It is hoped that there will be comments from the aircraft companies that will aid in settling on the most useful method of presenting data.

Load-Life Diagrams

Figures 27 through 39 show various load-life diagrams. Most of the data were taken at constant load ratio, and all of these curves (fig. 2) except those for $R = 0.35$ and $R = 0.55$ were completely determined by direct experiment. The curves in the other figures were computed from the constant R curves. In a few instances, the assumption that the desired curves would have been easily obtained experimentally was checked by loading samples appropriately and obtaining the predicted lifetimes.

It should be noted that all diagrams are plotted on a log-log scale and all stress values are in units of 1000 psi. In general, certain limiting values appear on each diagram owing either to the fact that the maximum load is limited by the static ultimate S_u or the fact that the minimum load is limited (for these tension-tension tests) to a value just greater than zero. Such limitations are noted upon the individual graphs.

It might be noted that, of these load-life diagrams, figure 36 (curves at constant mean load) is perhaps most directly comparable to the diagrams commonly shown for reversed stress tests.

Constant Life Diagrams

It also is possible to represent the results by plotting various pairs of the variables against each other for a constant lifetime. Figures 40 through 46 show such diagrams. These representations have two valuable features: (1) They contribute to an understanding of the behavior of materials, and (2) they furnish useful means of interpolation between experimentally obtained curves. In each figure, the limiting values for tension-tension tests are indicated. Of these constant life diagrams, figure 45 (amplitude of alternating load against mean load) is a type of representation which often has been used.

Concluding Remarks

The most important criterion in choosing a method of plotting the test results is the use to be made of these results. It has already been suggested, however, that the same criterion does not necessarily apply to choosing the method of taking the data. It is quite possible to use one set of working curves in taking the data and to compute from these the desired set of curves for application of the results to practice. A reasonable criterion for choosing the working curves is to select those curves which, because of simplicity and uniformity of shape, afford the simplest interpolation between observed test points.

This may be illustrated by considering a specific example. Suppose that it is desired to obtain the complete family of constant ratio curves (such as fig. 27). It is quite possible to take a set of constant mean load curves (fig. 36) and to compute from these the constant ratio curves, and this procedure offers some advantages. Individual constant mean load curves are somewhat simpler in shape than individual constant ratio curves (particularly for short lifetimes), and thus it may be possible to determine a single constant mean load curve with fewer samples. Also, the constant mean load curves preserve more nearly the same shape throughout the family; this allows determination of the complete family from fewer curves than in the case of the constant ratio method. The relative simplicity of interpolation is also illustrated by a comparison of the constant life diagrams in figures 40 and 45. It appears that the constant mean load method might prove economical of test specimens and testing time for the purpose of covering the field of tension-tension loading.

It should be pointed out, however, that this choice of a method of obtaining data cannot be made in the absence of any knowledge of the behavior of the material. In another material, it might well be that the curve shapes for constant ratio would be the most simple. Furthermore, the present argument has been based on the assumption that it is desired to obtain enough information to plot an entire family of curves. If only enough samples are available to obtain a single curve, it is quite probable that some other type of curve would be the most informative.

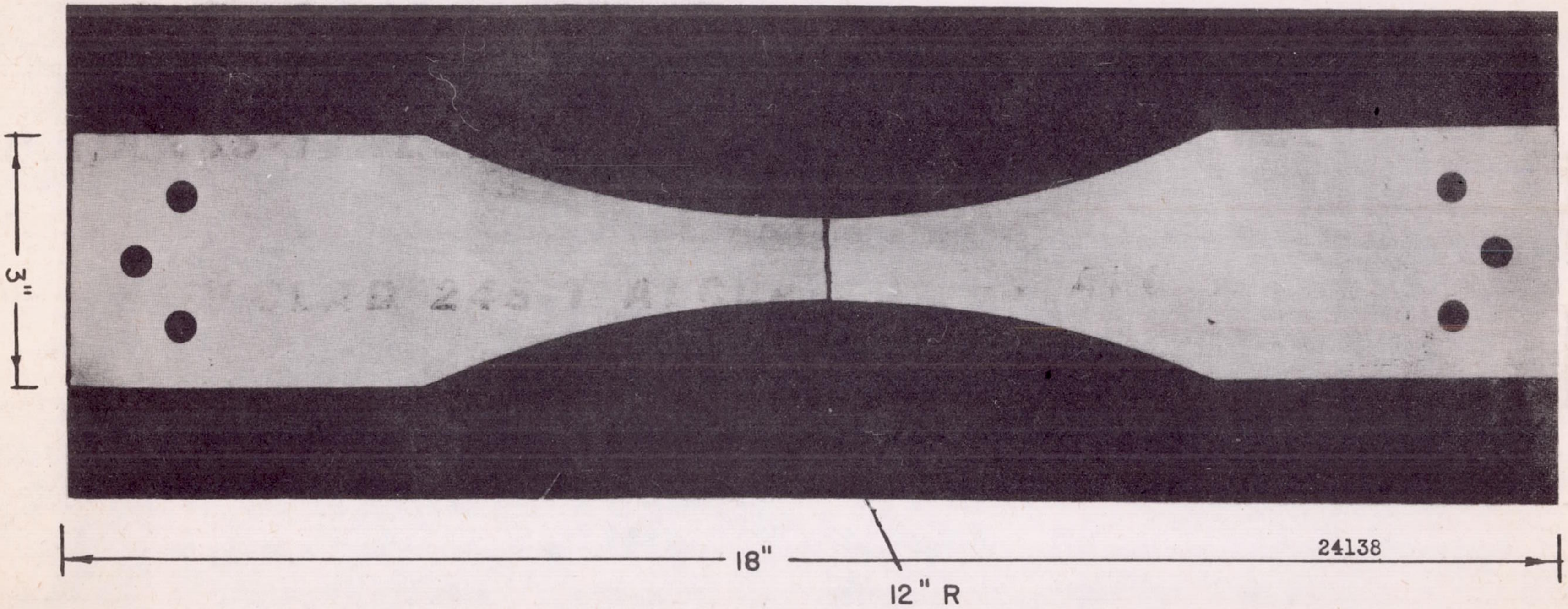

Figure 1. Photograph of a Typical (failed) Test Piece Used in Fatigue Tests.
(0.040" Alclad 24S-T Sheet)

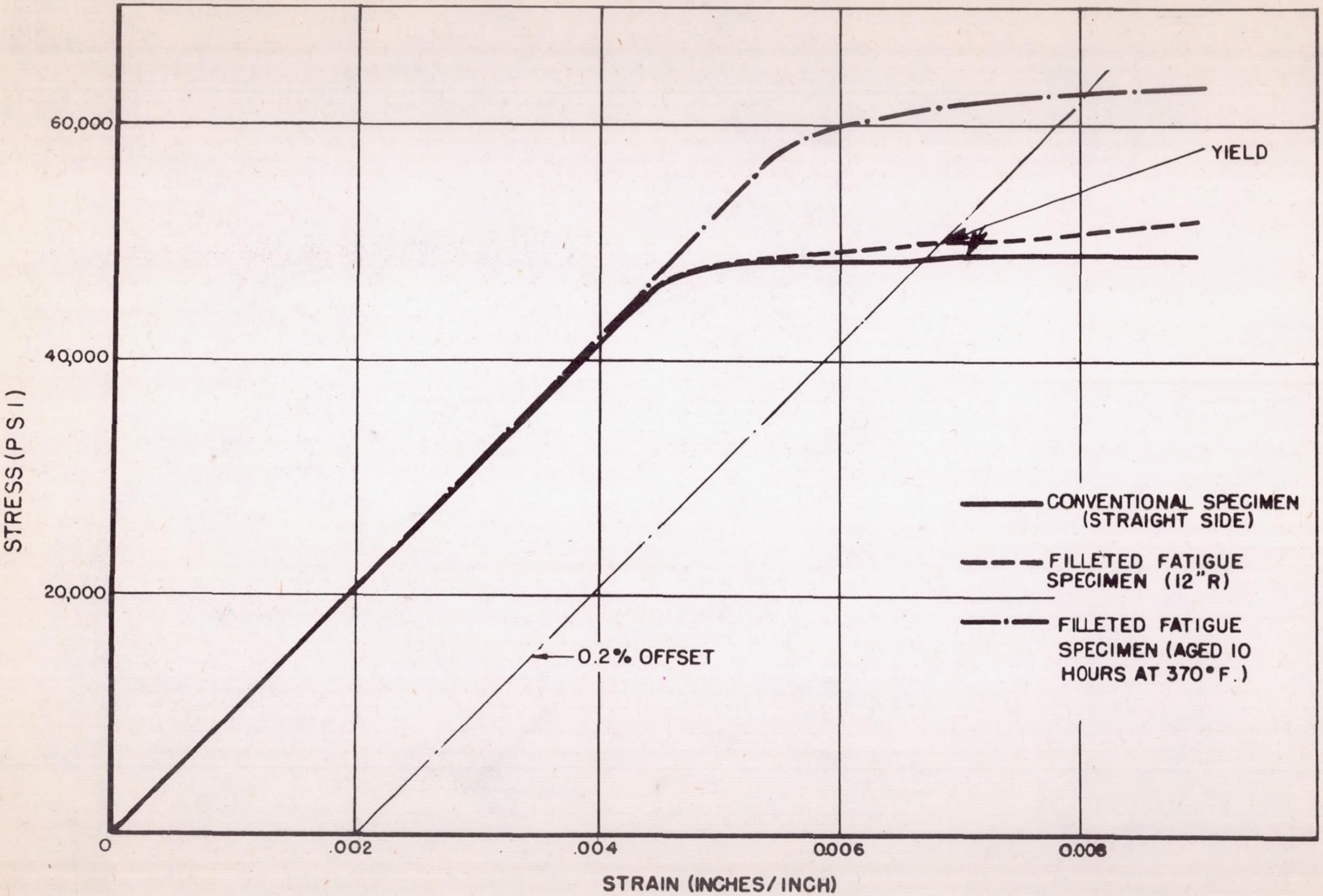

FIG. 2.- STATIC STRESS-STRAIN CURVE FOR ALCLAD 24 S-T SHEET 1.000" X 0.40".

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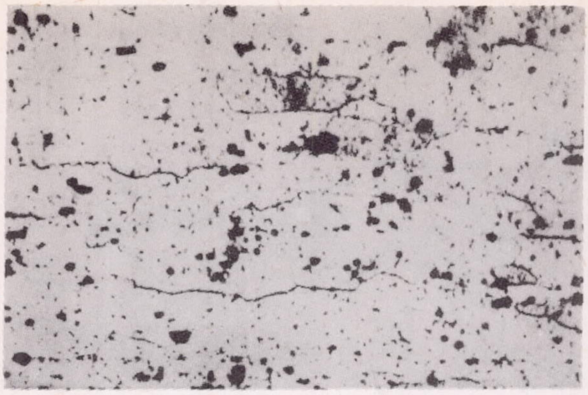
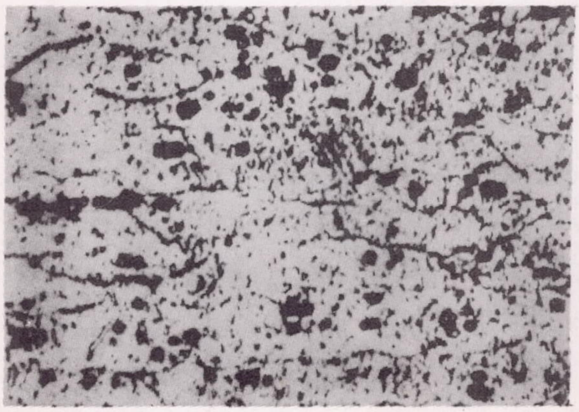


Keller's Etch 24432
500X

(a)

Microstructure of 24S-T Alclad.



Keller's Etch 24433
500X

(b)

Microstructure of 24S-T Alclad after
10 hours at 370°F.

Figure 3.

Metallographic Structure of Monoblock Fatigue Specimens.

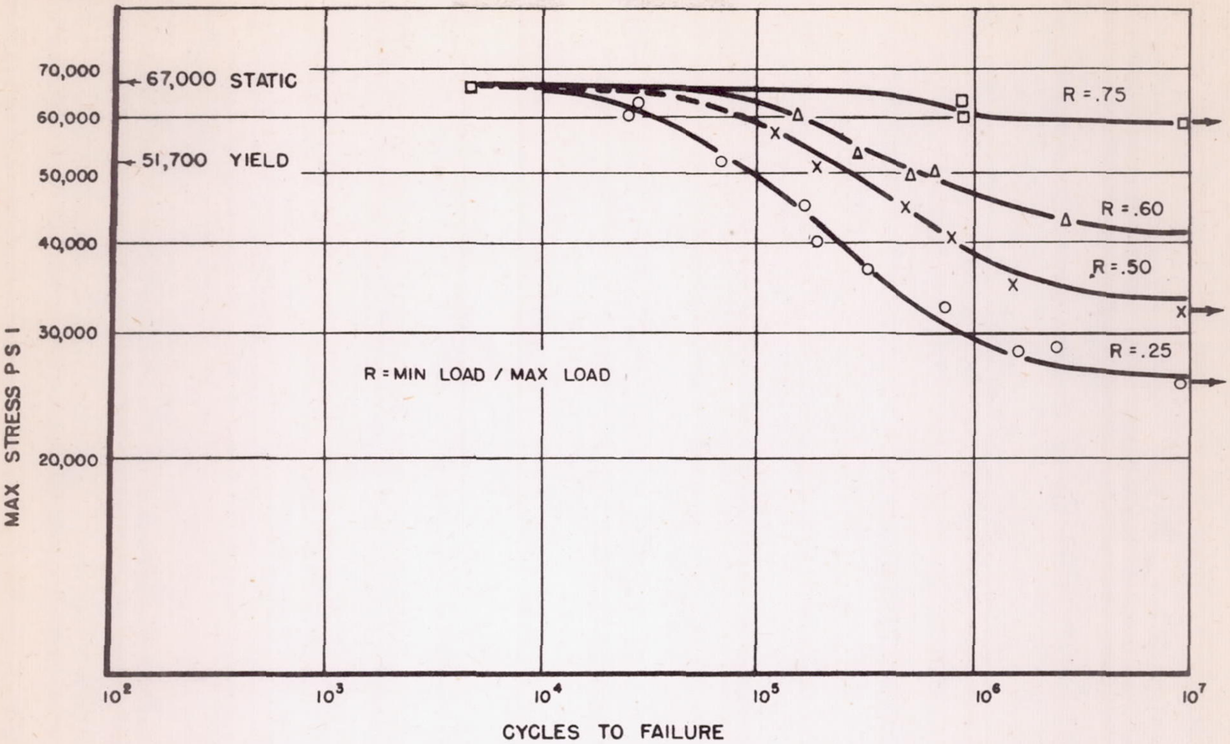


FIG. 4.- FATIGUE CURVES FOR ALUMINUM MONOBLOCK SAMPLES AS RECEIVED.

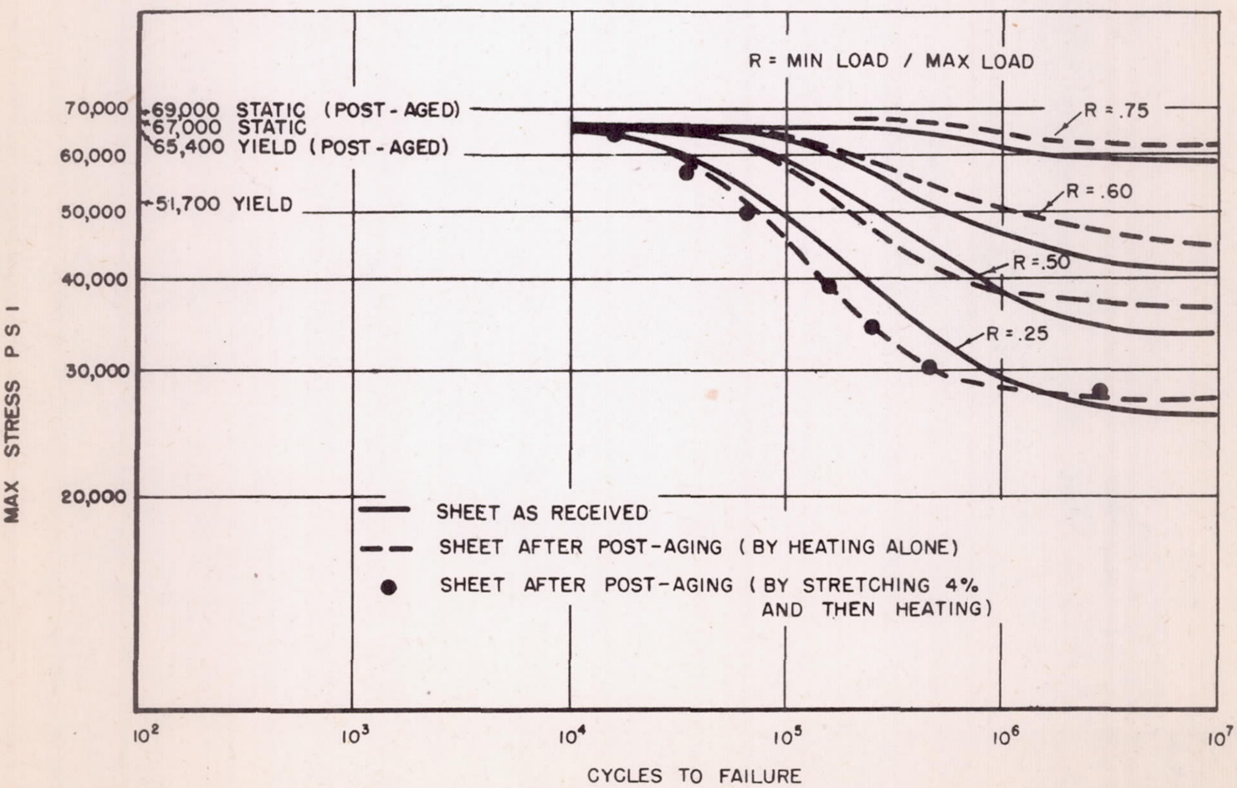


FIG. 5.- FATIGUE CURVES FOR 0.040" ALCLAD 24S-T AS RECEIVED AND AFTER POST-AGING AT 375° F FOR 10 HRS.

W-63

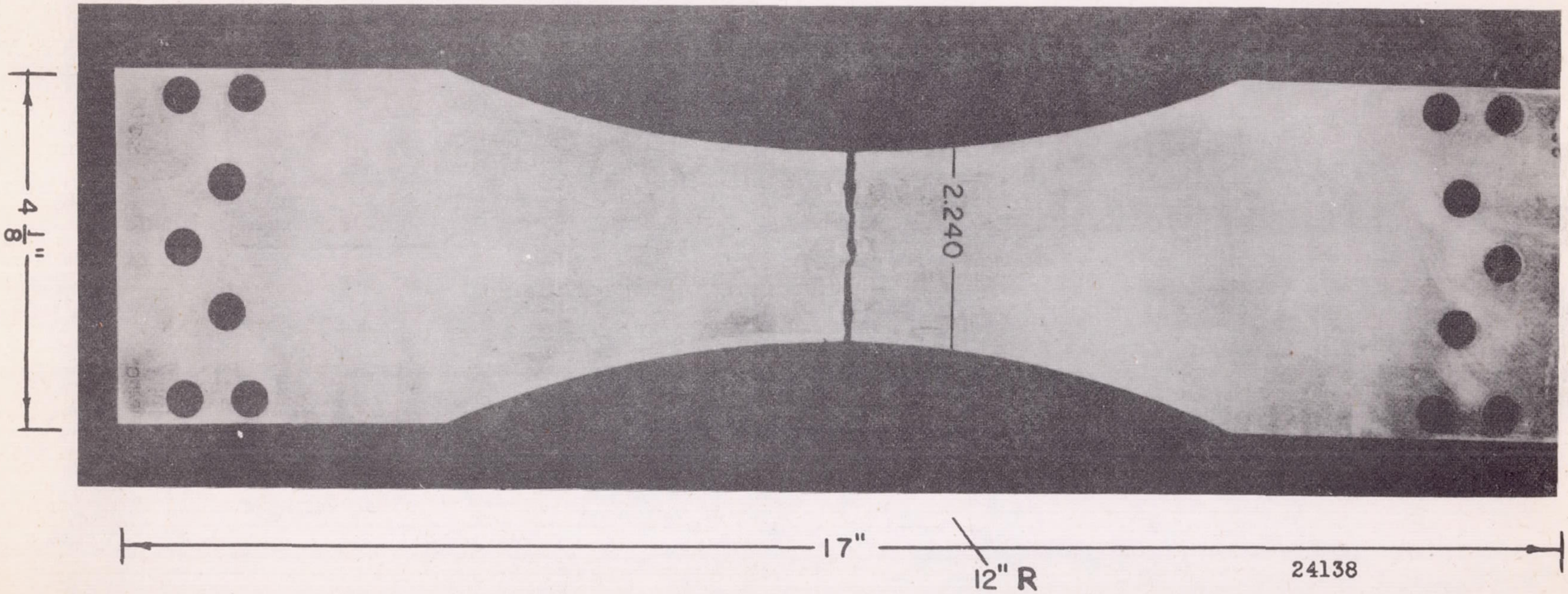
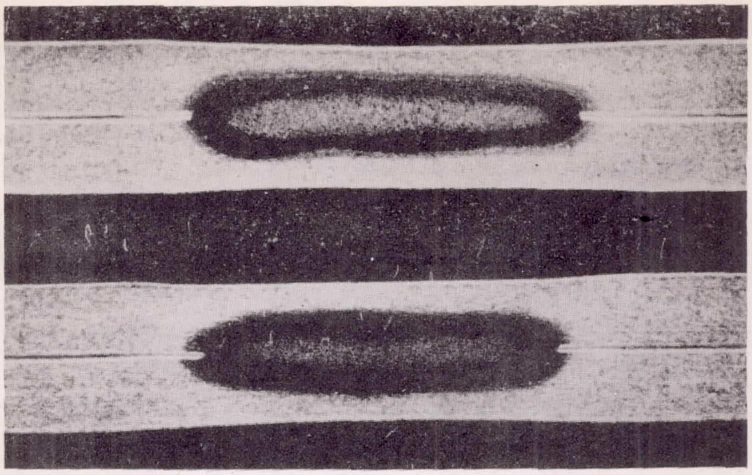


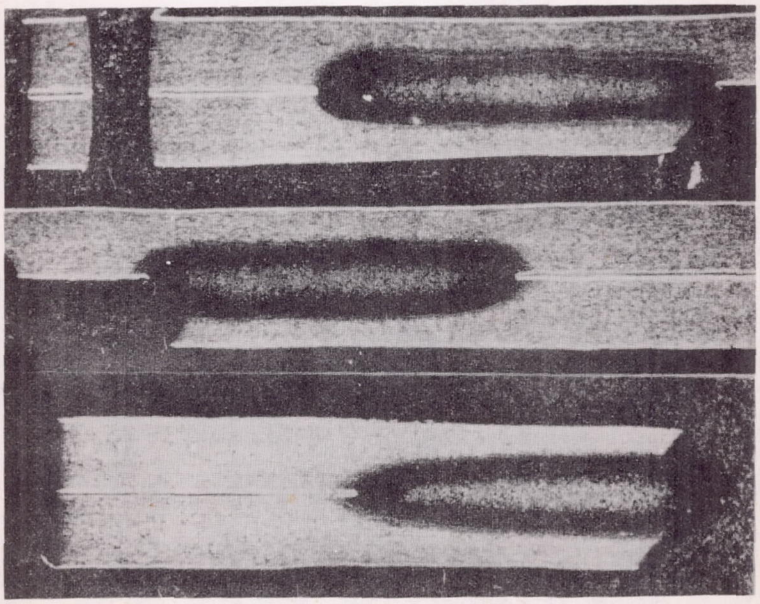
Figure 6. Photograph of a Typical (failed) Sheet Efficiency Test Piece Used in Fatigue Tests. (0.040" Alclad 24S-T, 3/4" Spot Spacing.)



Keller's Etch 24434
10X

(a)

As received.



Keller's Etch 24435
10X

(b)

Fatigued.

Figure 7.

Spotwelds From Stressed Attachments (0.040" - 0.040" Sheet).

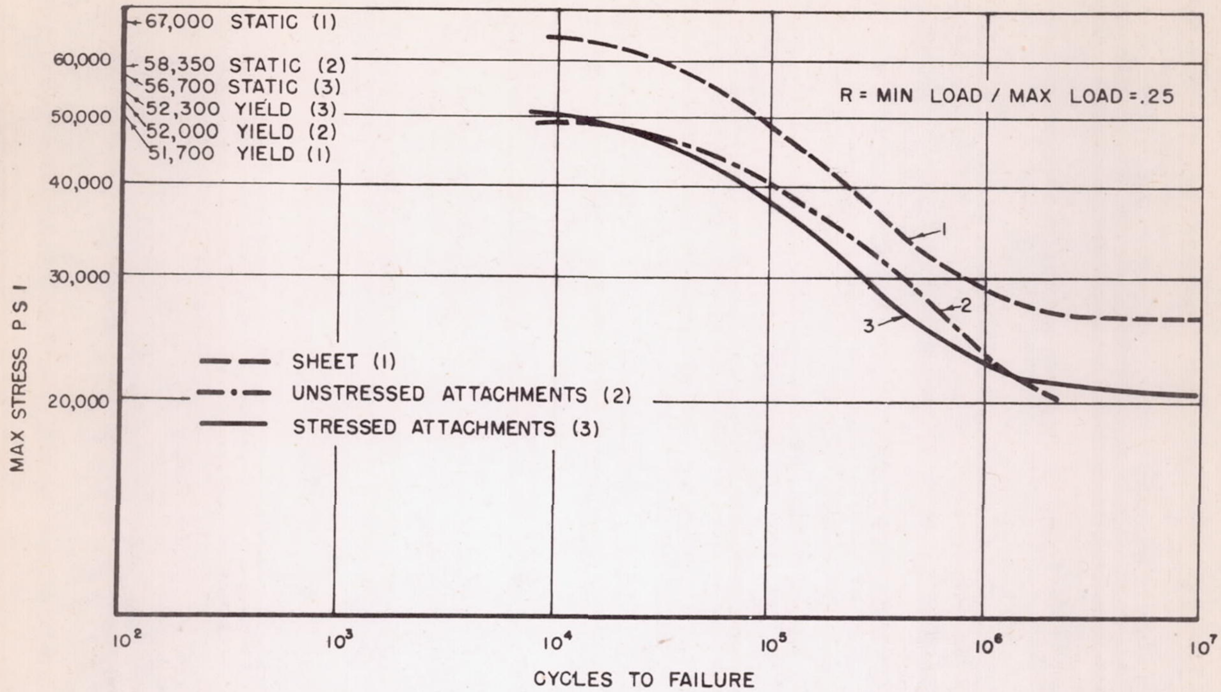


FIG. 8.- FATIGUE CURVES FOR SAMPLES OF 0.040" ALCLAD 24S-T WITH STRESSED AND UNSTRESSED ATTACHMENTS.

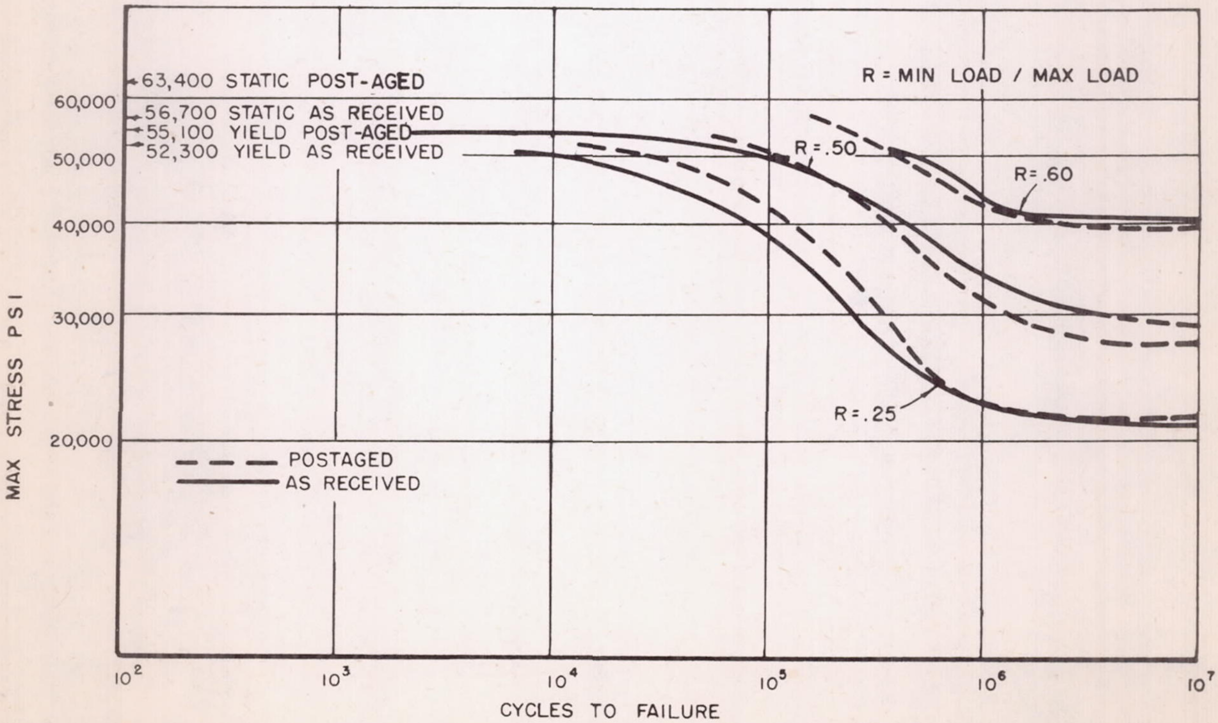
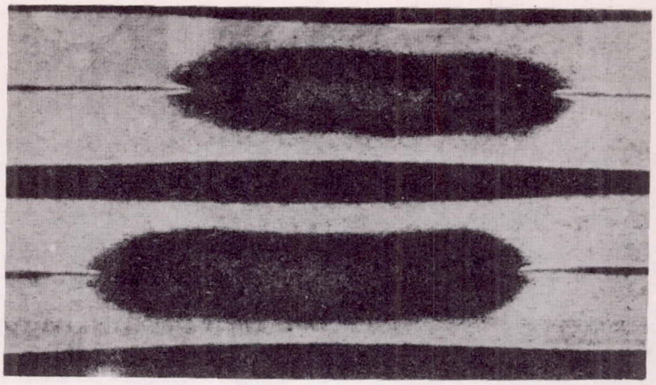


FIG. 9.- FATIGUE CURVES FOR SHEET EFFICIENCY SAMPLES 0.040" AS RECEIVED AND POST-AGED.

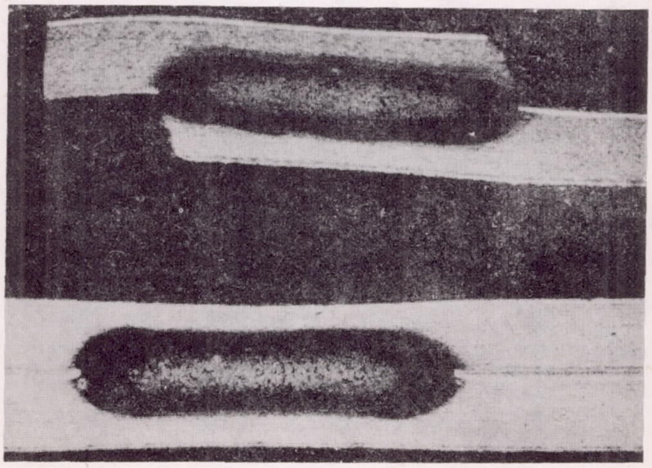
W-63



Keller's Etch 24436
10X

(a)

As-received.



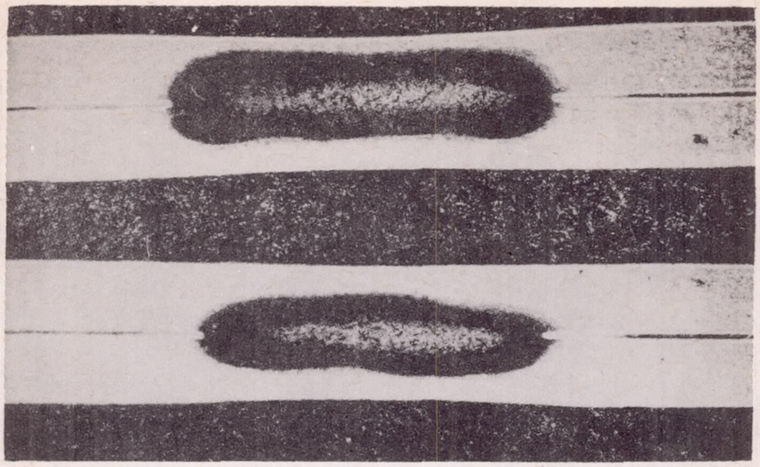
Keller's Etch 24437
10X

(b)

Fatigued.

Figure 10.

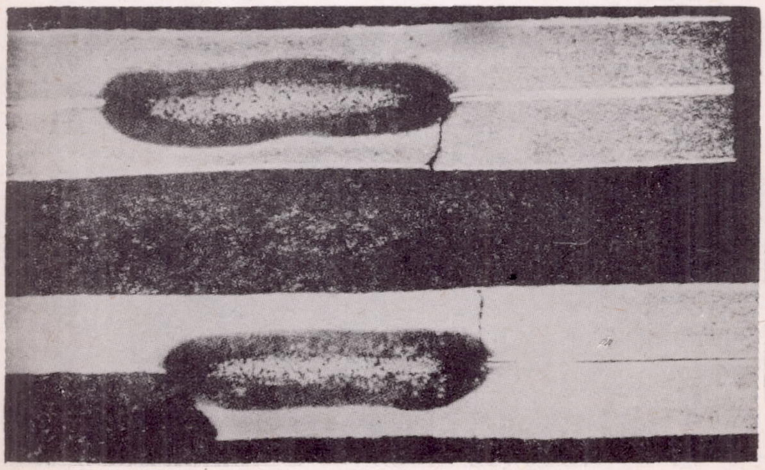
B1C Type Spotwelds (0.040" - 0.040" Sheet).



Keller's Etch 24438
10X

(a)

As received.



Keller's Etch 24439
10X

(b)

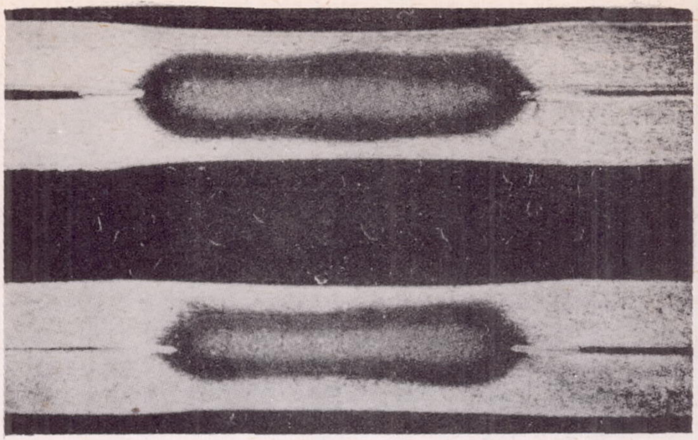
Fatigued.

Figure 11.

B2C Type Spotwelds Heat Treated at 370°F After Welding (0.040"-0.040" Sheet).

W-63

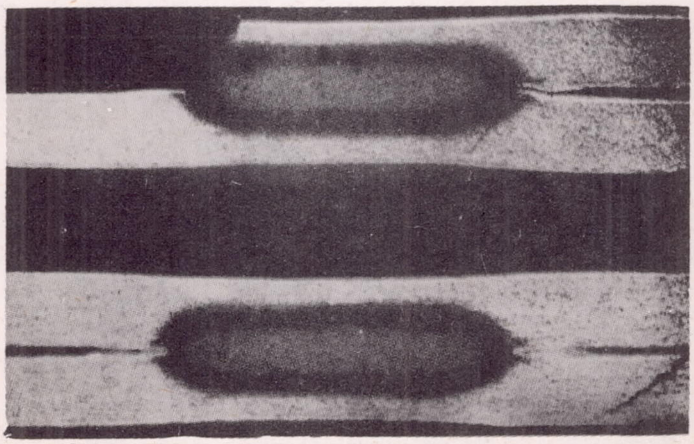
W-63



Keller's Etch 24440
10X

(a)

As received.



Keller's Etch 24441
10X

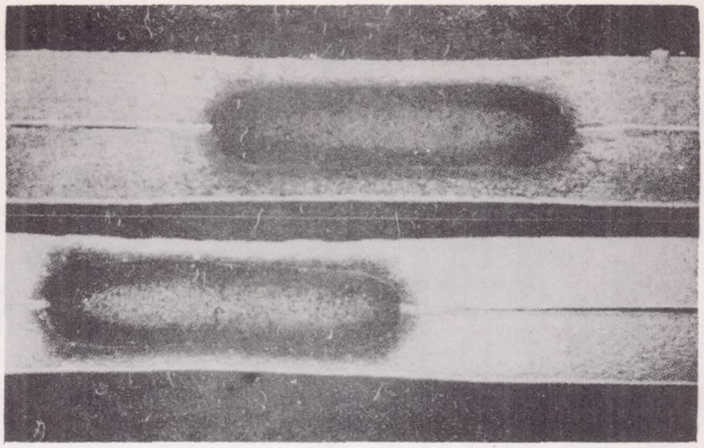
(b)

Fatigued.

Figure 12.

2B1C Type Spotwelds (0.040" - 0.040" Sheet).

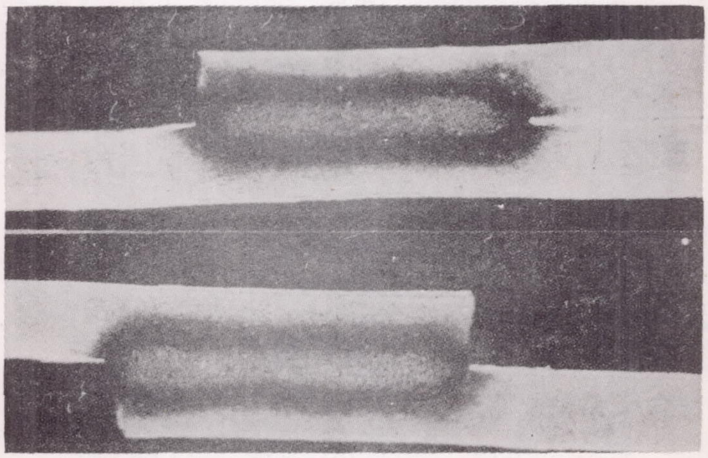
W-63



Keller's Etch 24442
10X

(a)

As received.



Keller's Etch 24443
10X

(b)

Fatigued.

Figure 13.

2B3C Type Spotwelds, Sheet Heat Treated at 370°F Before Welding (0.040" - 0.040" Sheet).

W-63

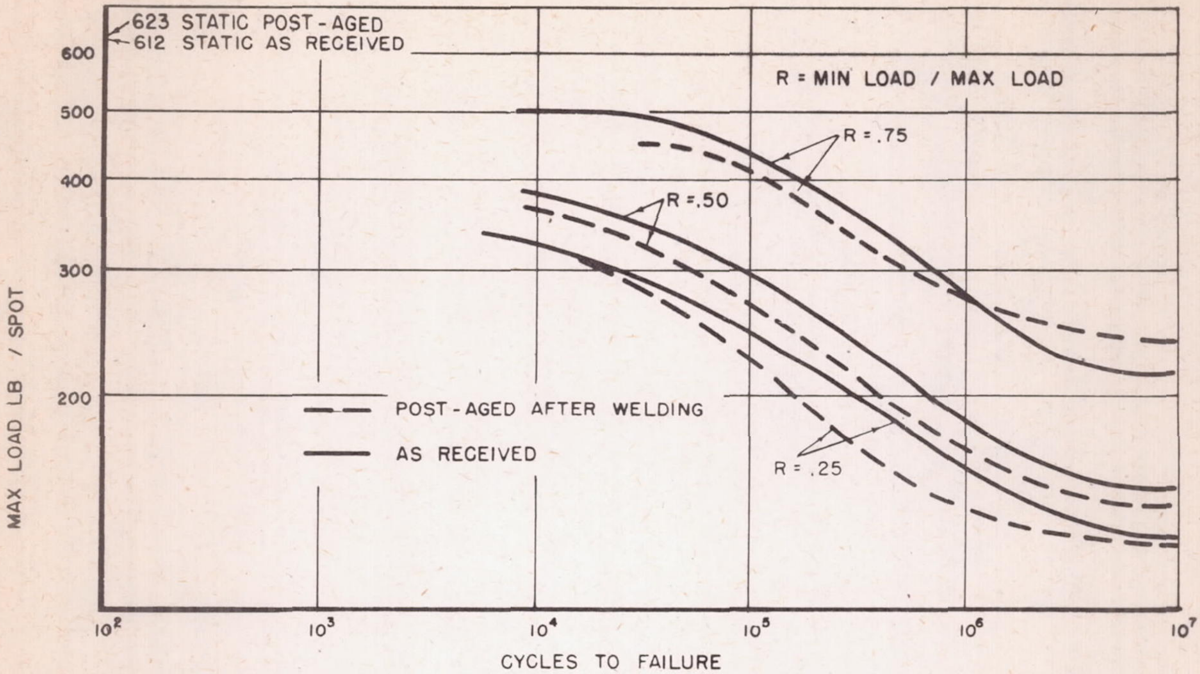


FIG. 14.- FATIGUE CURVES FOR LAP JOINT SAMPLES SPACED AS RECEIVED AND POST-AGED AFTER WELDING. (SAMPLES 5" X 0.040", SPOTS 3/4" APART.)

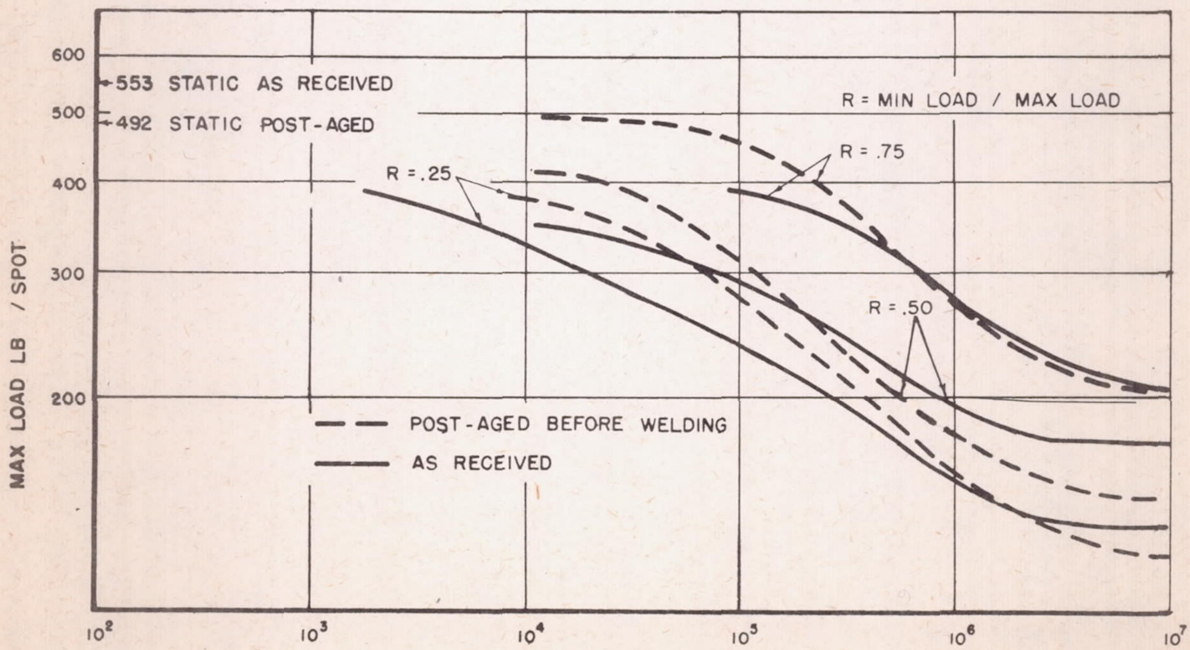


FIG. 15.- FATIGUE CURVES FOR LAP JOINT SAMPLES AS RECEIVED AND POST-AGED BEFORE WELDING (SAMPLES 5" X 0.040" SPOTS 3/4" APART.)

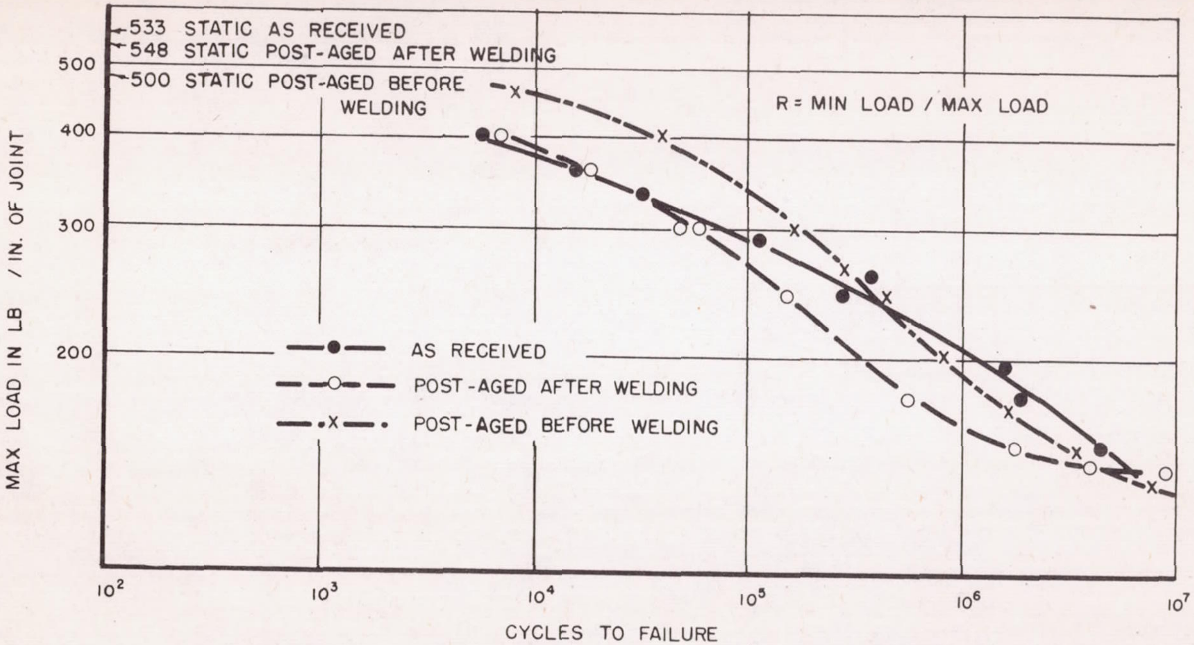
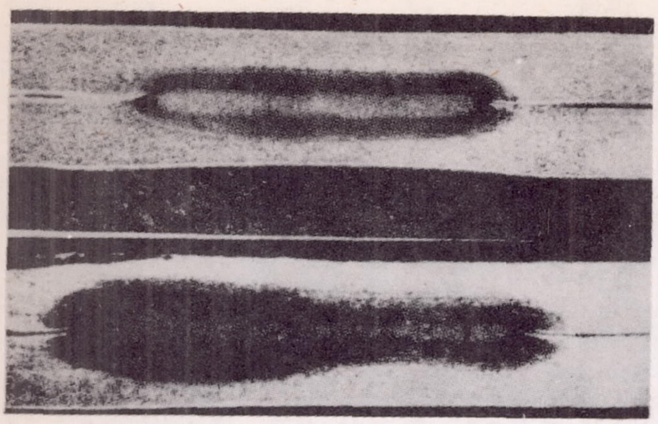


FIG. 16.- FATIGUE CURVES FOR LAP JOINT SAMPLES AS RECEIVED, POST-AGED BEFORE WELDING, AND POST-AGED AFTER WELDING (SAMPLES 5" X 0.040", SPOTS 3/4" APART).

W-63



24444

Sectioned transverse to rolling.

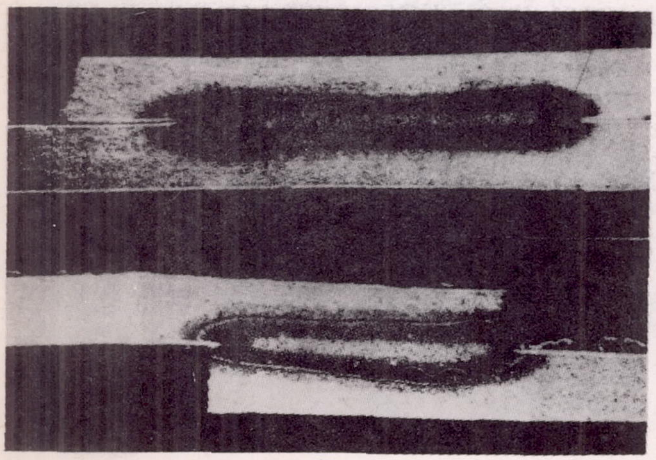
24445

Longitudinal to rolling.

Keller's Etch 10X

(a)

As received.



Sectioned in direction of testing-- transverse to rolling.

Keller's Etch 24444 10X

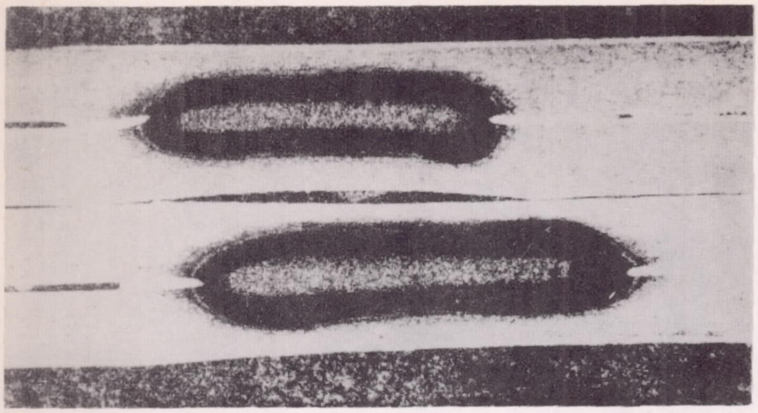
(b)

Fatigued.

Figure 17.

Roller Spotwelds, 1-1/4" Spacing.

W-63



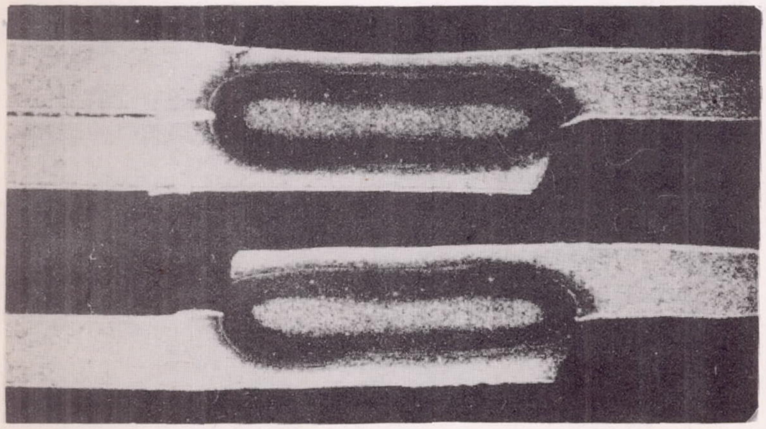
Transverse to rolling.

Longitudinal to rolling.

Keller's Etch 24446
10X

(a)

As received.



Keller's Etch 24447
10X

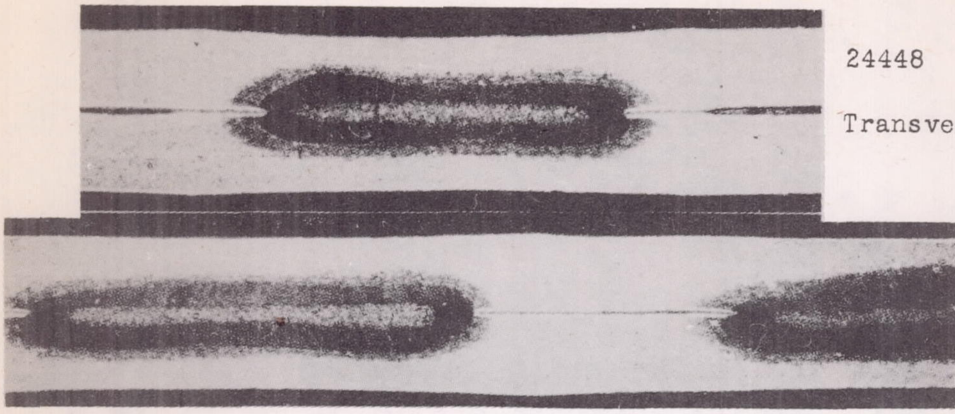
(b)

Fatigued.

Figure 18.

Roller Spotwelds, 3/4" Spacing.

W-63



24448

Transverse to rolling.

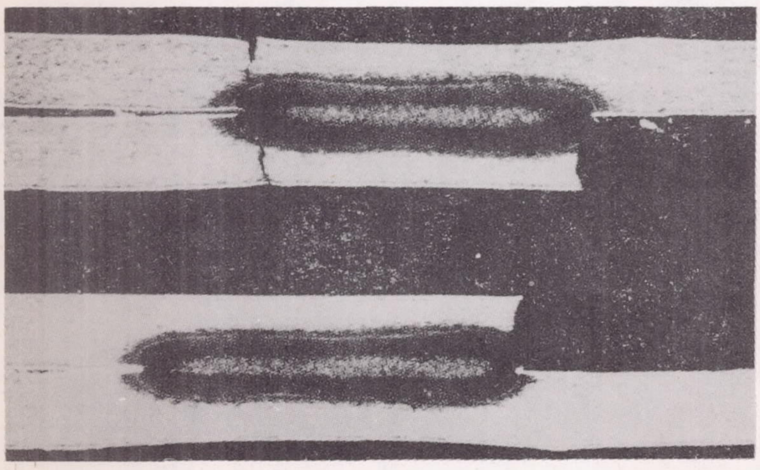
22254

Longitudinal to rolling.

Keller's Etch 10X

(a)

As received.



Keller's Etch 24449
10X

(b)

Figure 19.

Roller Spotwelds, 3/8" Spacing.

W-63

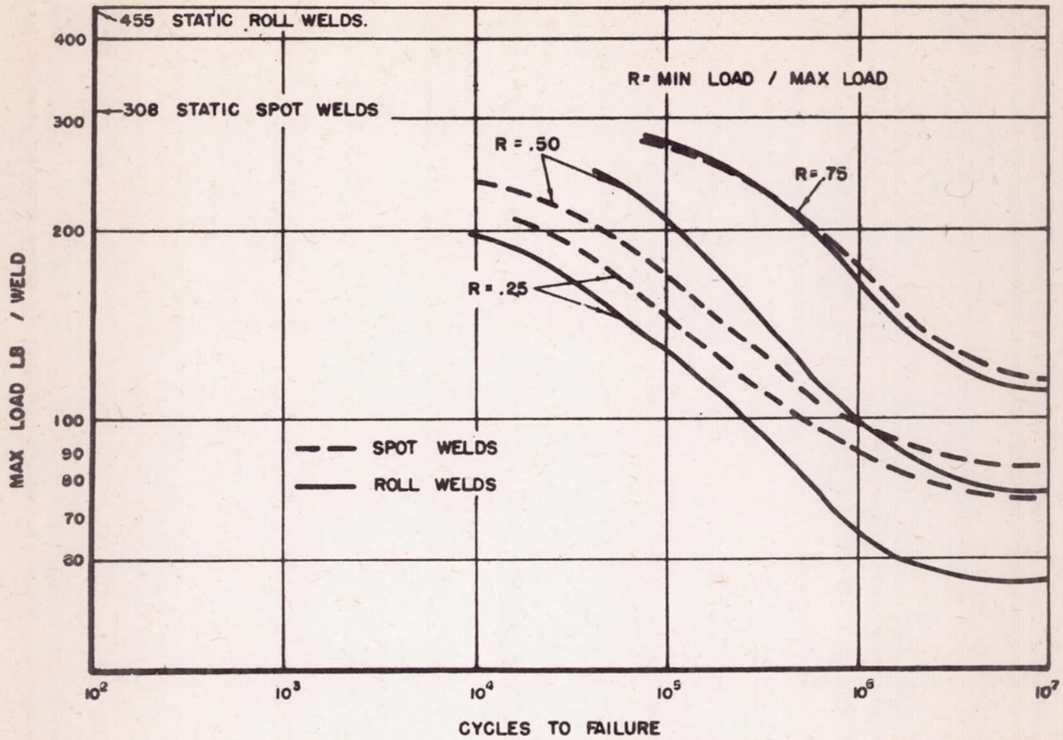


FIG. 20.- FATIGUE CURVES FOR ROLL-WELDED AND SPOT-WELDED SAMPLES.
(SAMPLES 5" X 0.040" WELDS 3/8" APART.)

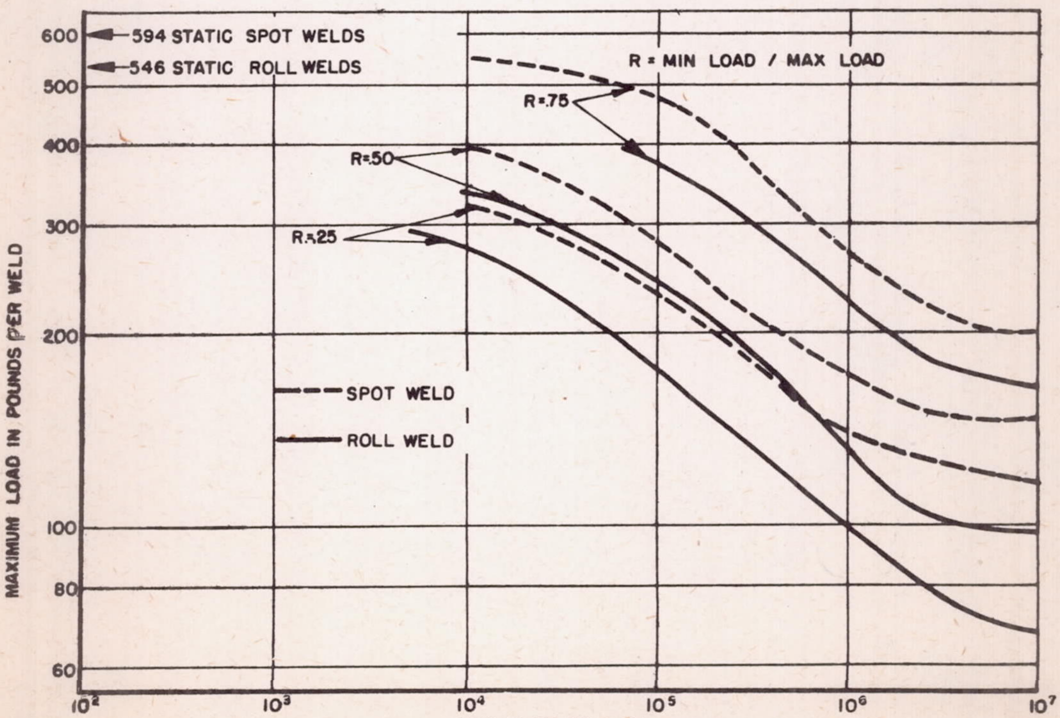


FIG. 21.- FATIGUE CURVES FOR ROLL-WELDED AND SPOT-WELDED SAMPLES. (SAMPLES 5" X 0.040". WELDS $\frac{3}{4}$" APART.)

W-63

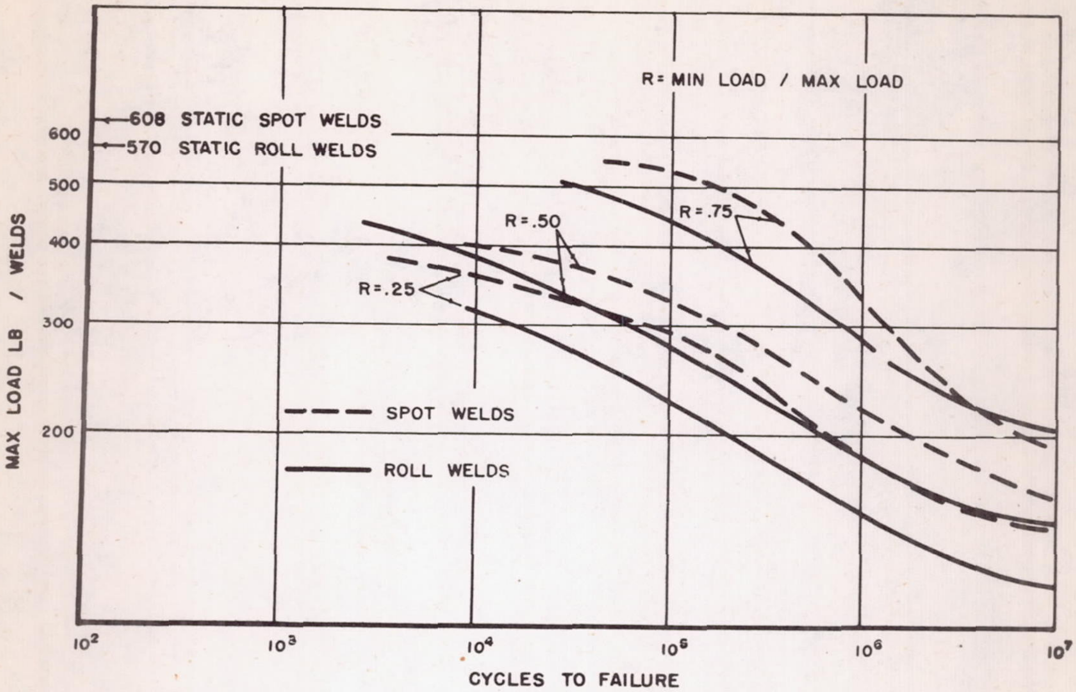


FIG. 22.- FATIGUE CURVES FOR ROLL-WELDED AND SPOT-WELDED SAMPLES. (SAMPLES 5" X 0.040", SPOTS 1-1/4" APART.)

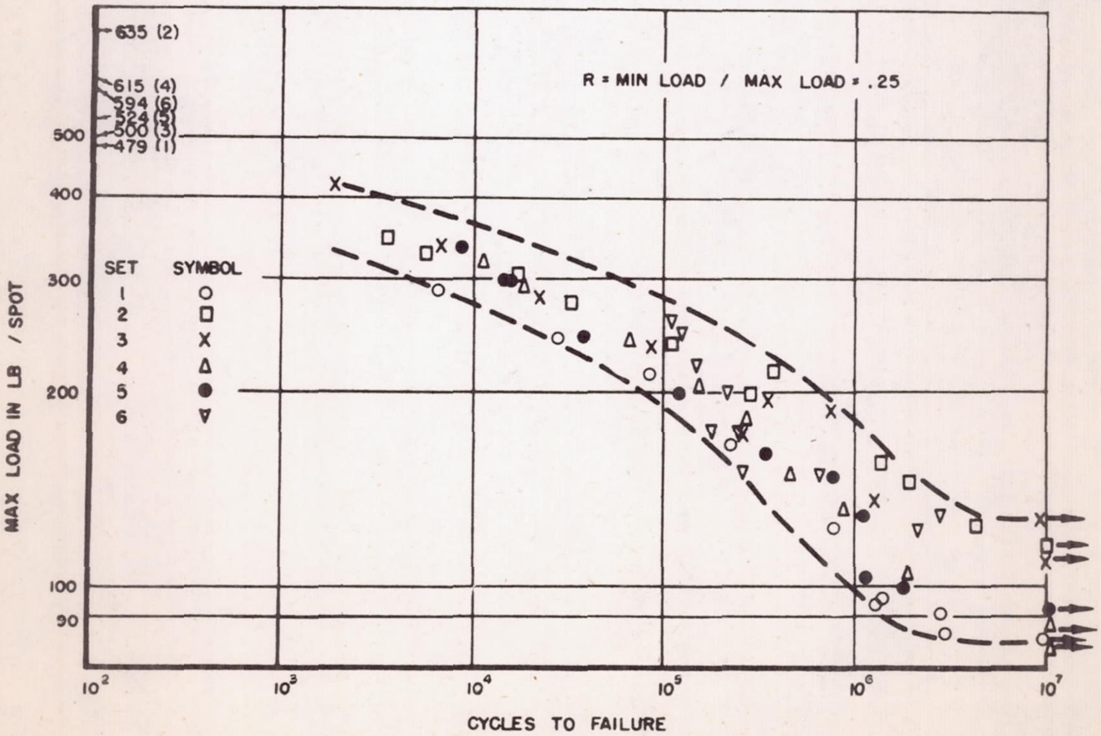
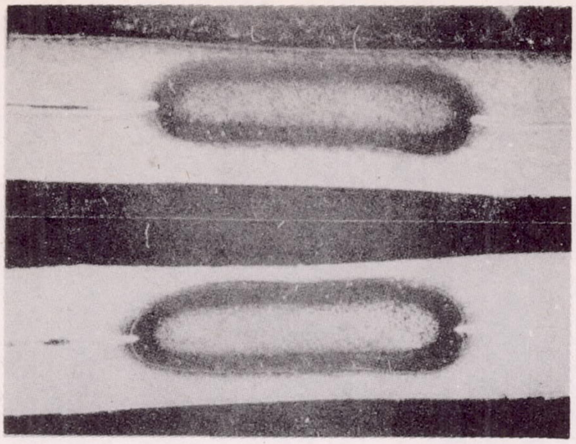


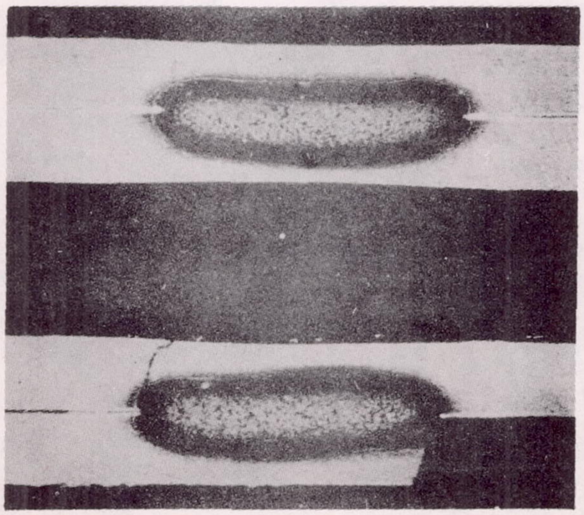
FIG. 23.- FATIGUE CURVES FOR LAP JOINT SAMPLES MADE WITH VARIOUS WELDING CONDITIONS FROM SHEET OF DIFFERENT HEATS (SAMPLES 5" X 0.040", 6 SPOT WELDS SPACED 3/4" APART.)



Keller's Etch 24450
10X

(a)

As received.



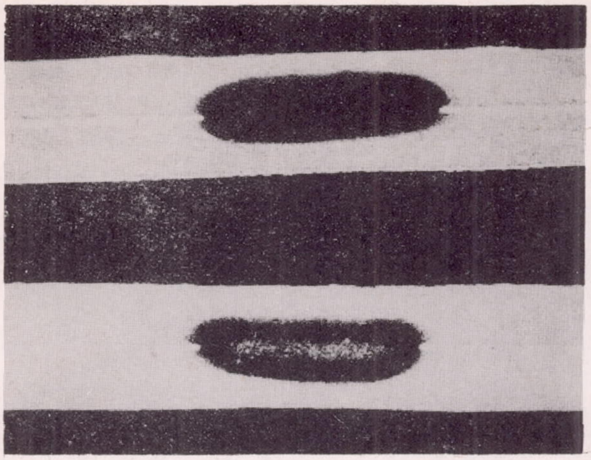
Keller's Etch 24451
10X

(b)

Fatigued.

Figure 24.

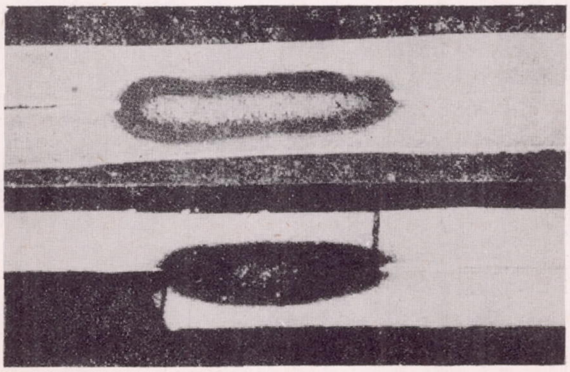
BlCC Type Spotwelds (0.040" - 0.040" Sheet).



Keller's Etch 22452
10X

(a)

As received.



Keller's Etch 22453
10X

(b)

Fatigued.

Figure 25.

B1BC Type Spotwelds (0.032" - 0.032" Sheet).

W-63

W-63

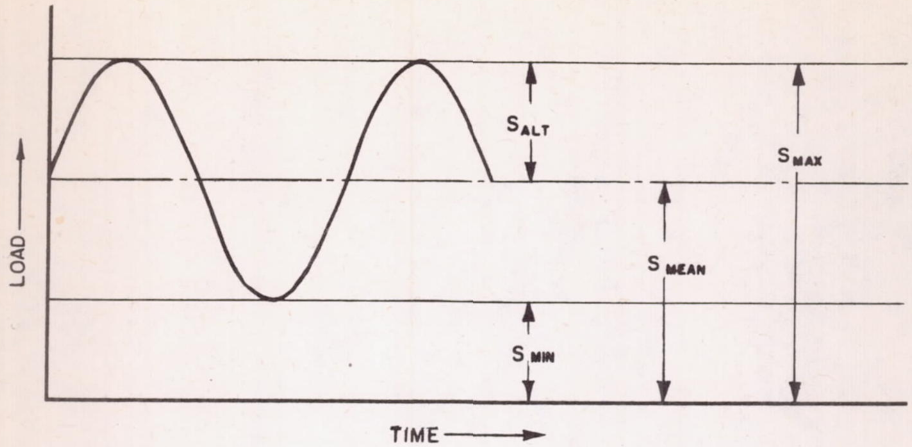


FIG. 26.- LOAD COMPONENTS OF TENSION-TENSION FATIGUE TESTING.

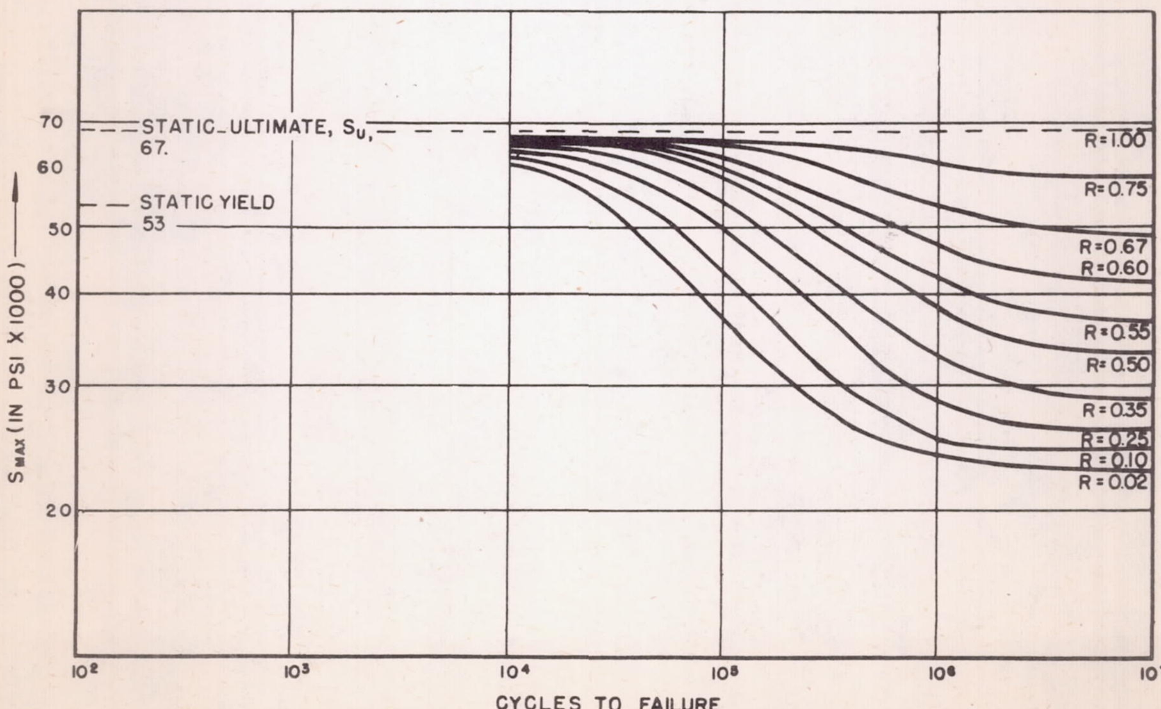


FIG. 27.- CONSTANT RATIO CURVES, MAXIMUM LOAD VS. LIFETIME.

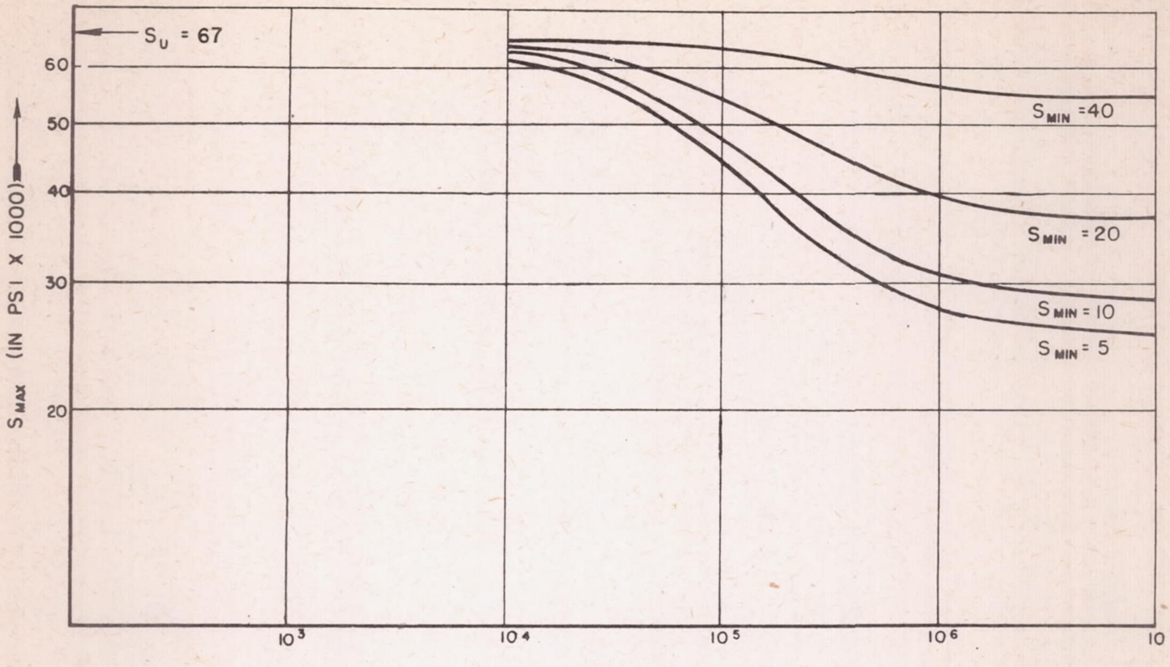


FIG. 28.-CONSTANT MINIMUM LOAD CURVES, MAXIMUM LOAD VS. LIFETIME.

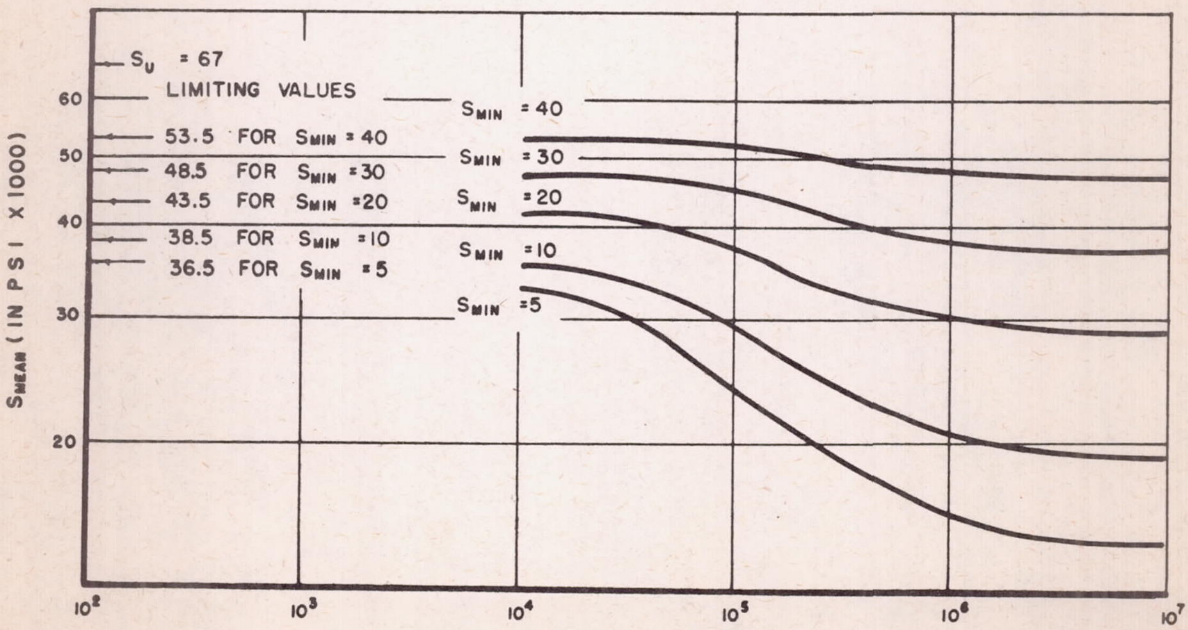


FIG. 29.-CONSTANT MINIMUM LOAD CURVES, MEAN LOAD VS. LIFETIME.

W-63

W-63

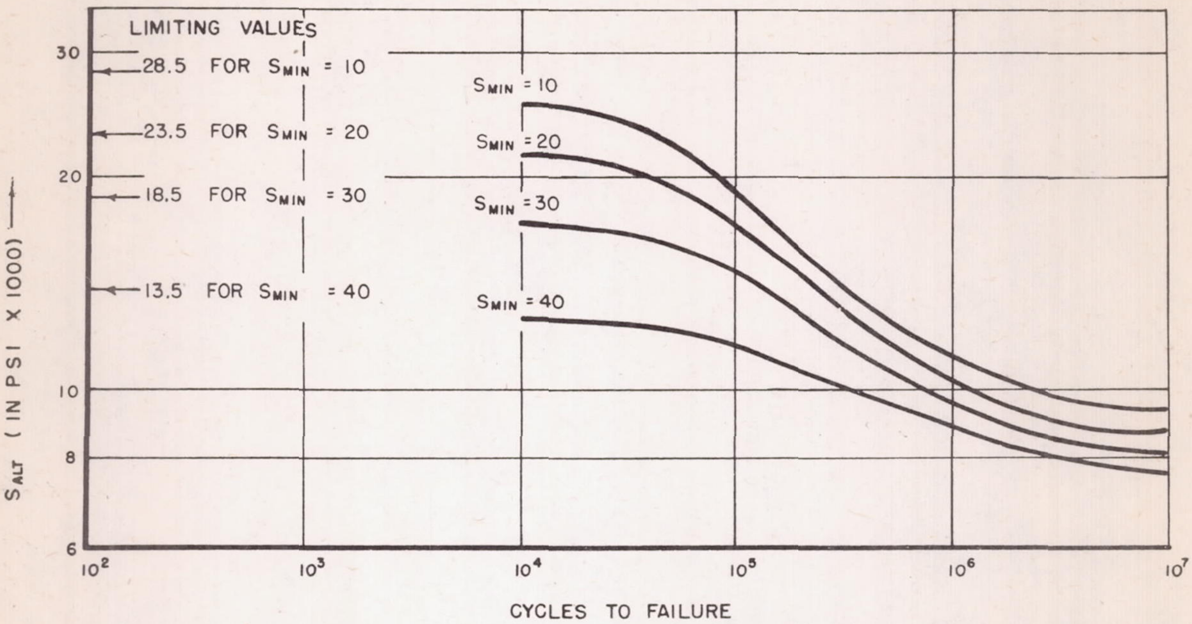


FIG. 30.-CONSTANT MINIMUM LOAD CURVES, ALTERNATING LOAD VS. LIFETIME.

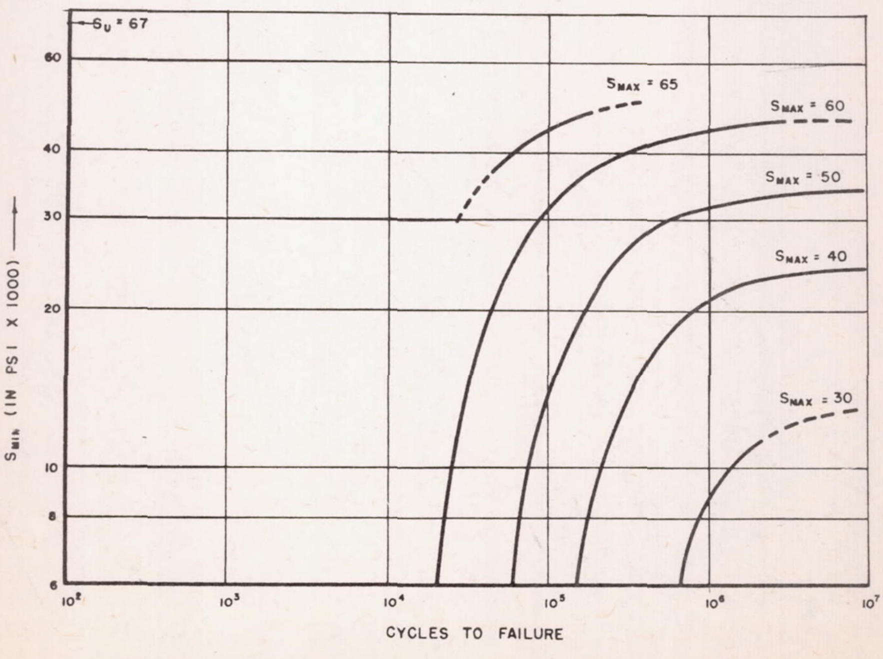


FIG. 31. - CONSTANT MAXIMUM LOAD CURVES, MINIMUM LOAD VS. LIFETIME.

W-63

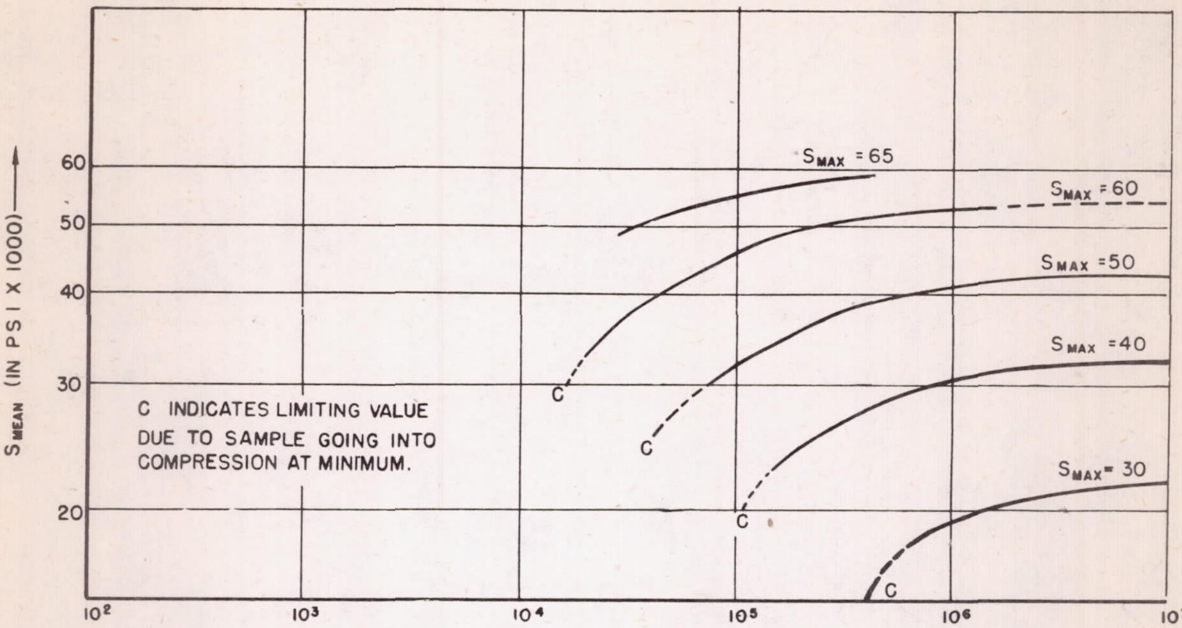


FIG. 32 CONSTANT MAXIMUM LOAD CURVES, MEAN LOAD VS. LIFETIME

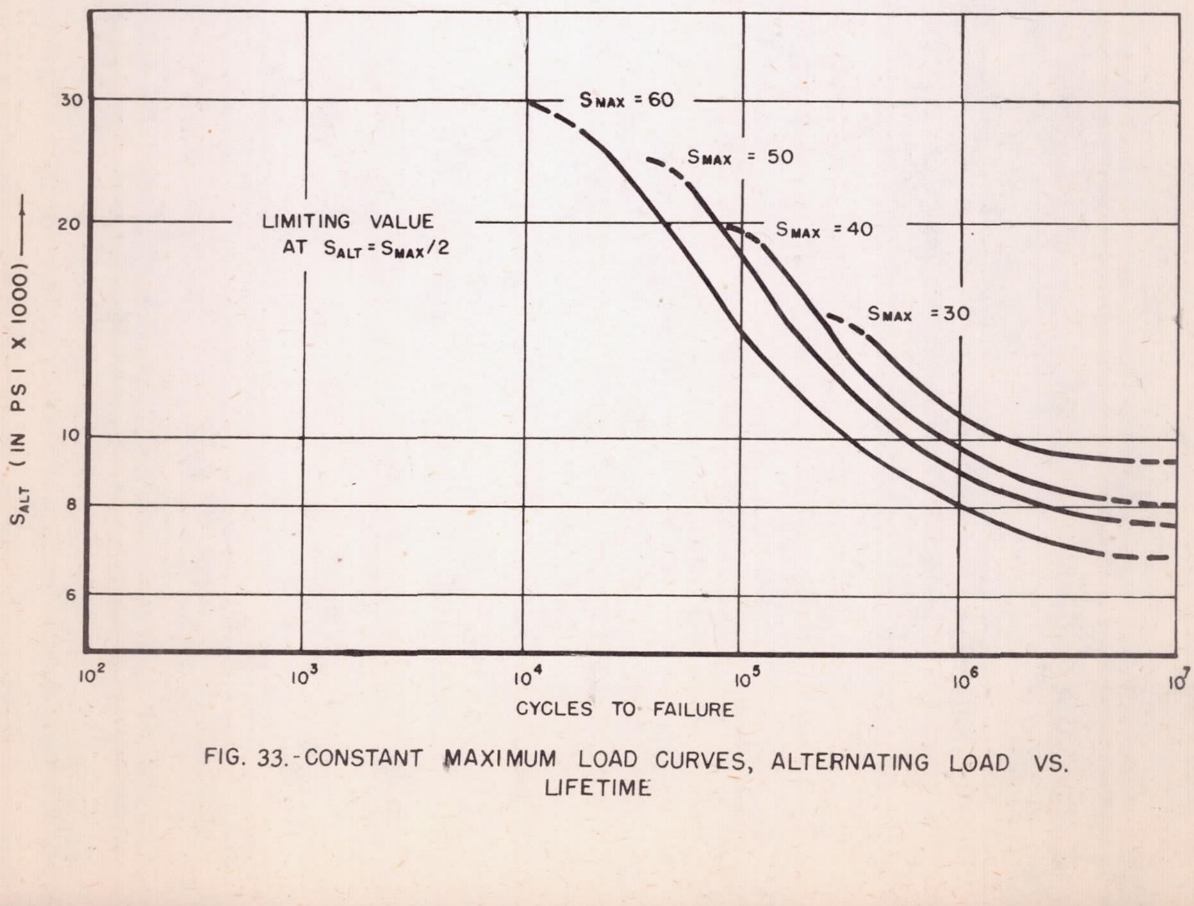


FIG. 33.-CONSTANT MAXIMUM LOAD CURVES, ALTERNATING LOAD VS. LIFETIME

W-63

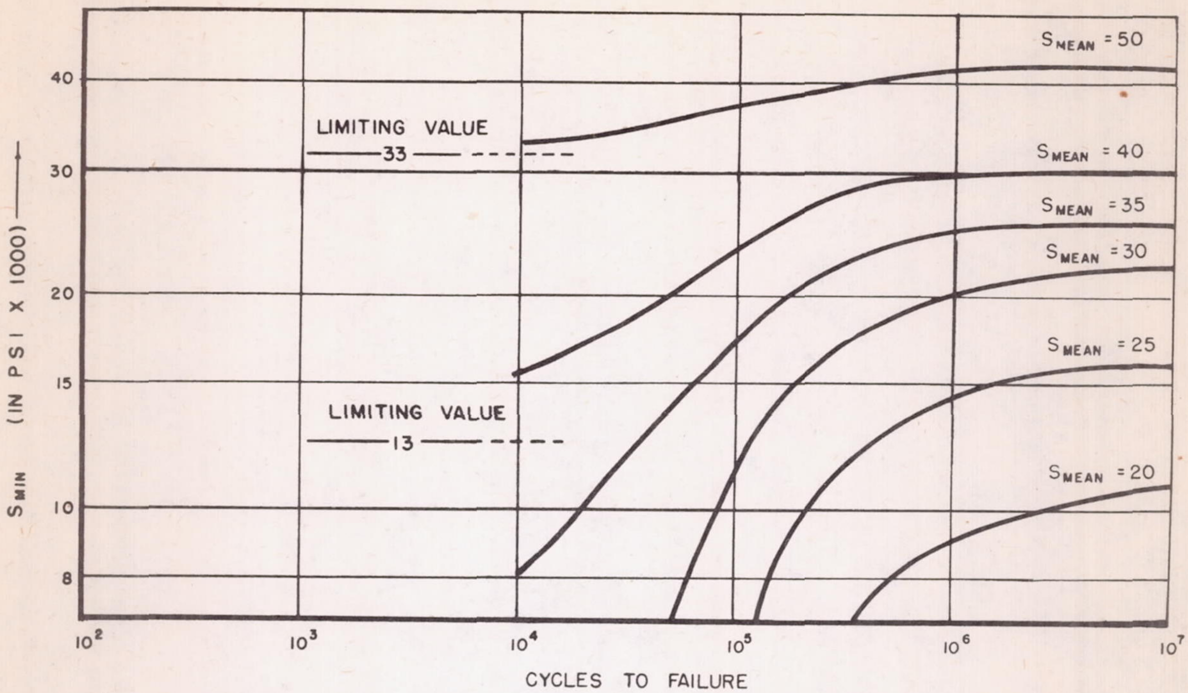


FIG. 34.- CONSTANT MEAN LOAD CURVES, MINIMUM LOAD VS. LIFETIME.

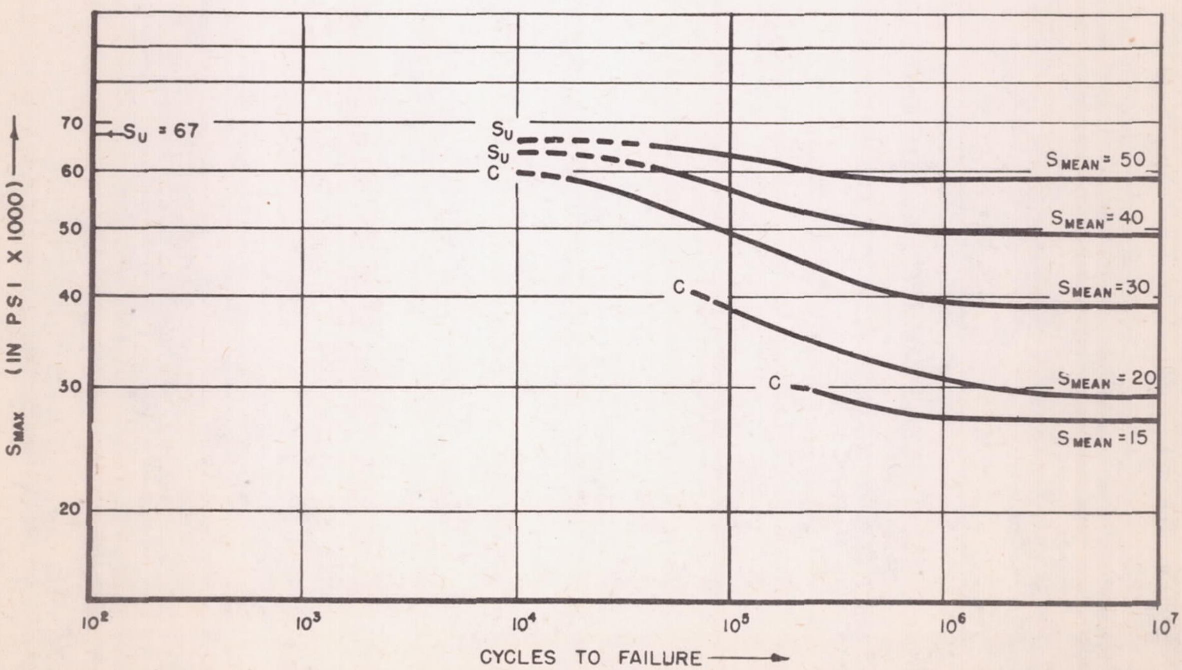


FIG. 35.- CONSTANT MEAN LOAD CURVES, MAXIMUM LOAD VS. LIFETIME.

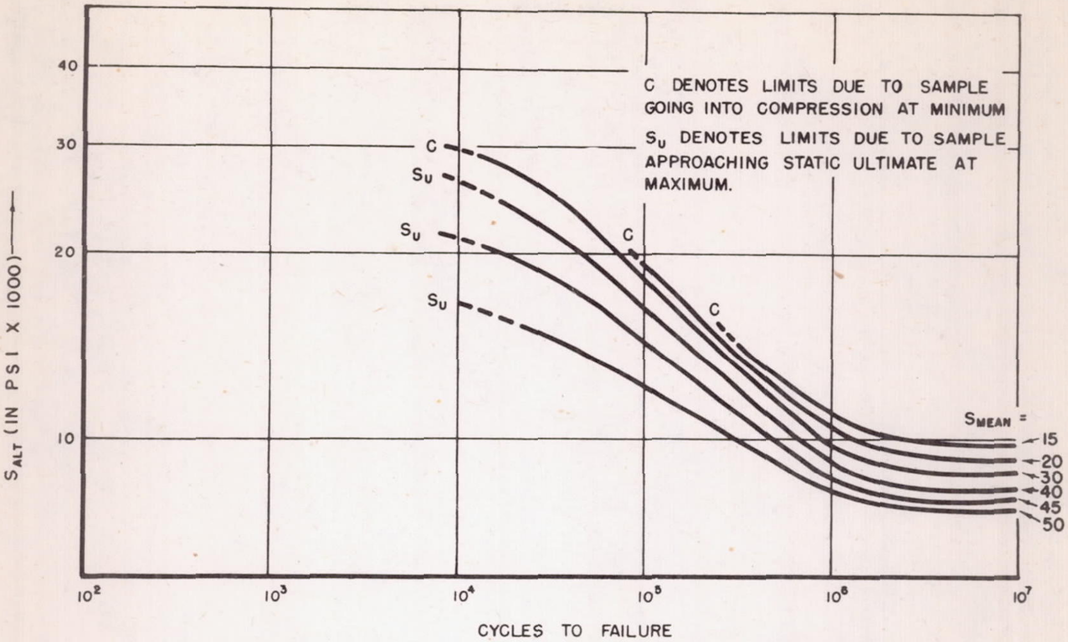


FIG. 36.-CONSTANT MEAN LOAD CURVES, ALTERNATING LOAD VS. LIFETIME.

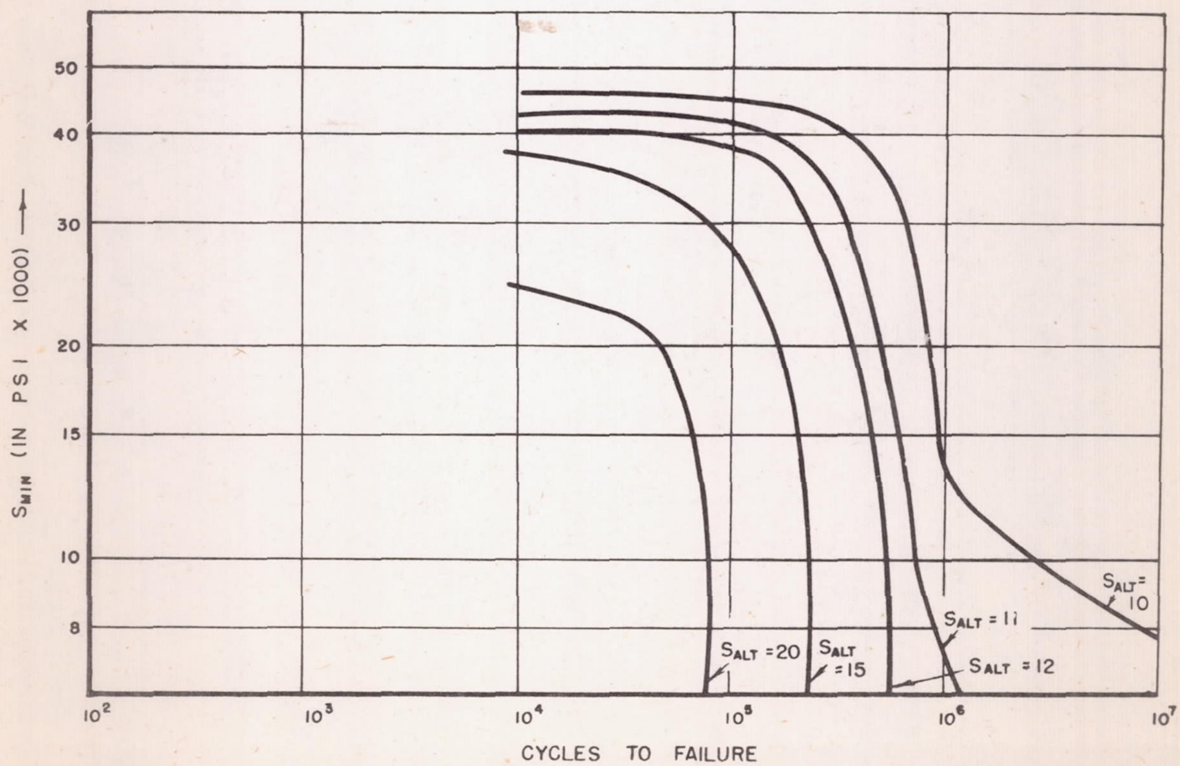


FIG. 37.- CONSTANT ALTERNATING LOAD CURVES, MINIMUM LOAD VS. LIFETIME.

W-63

W-63

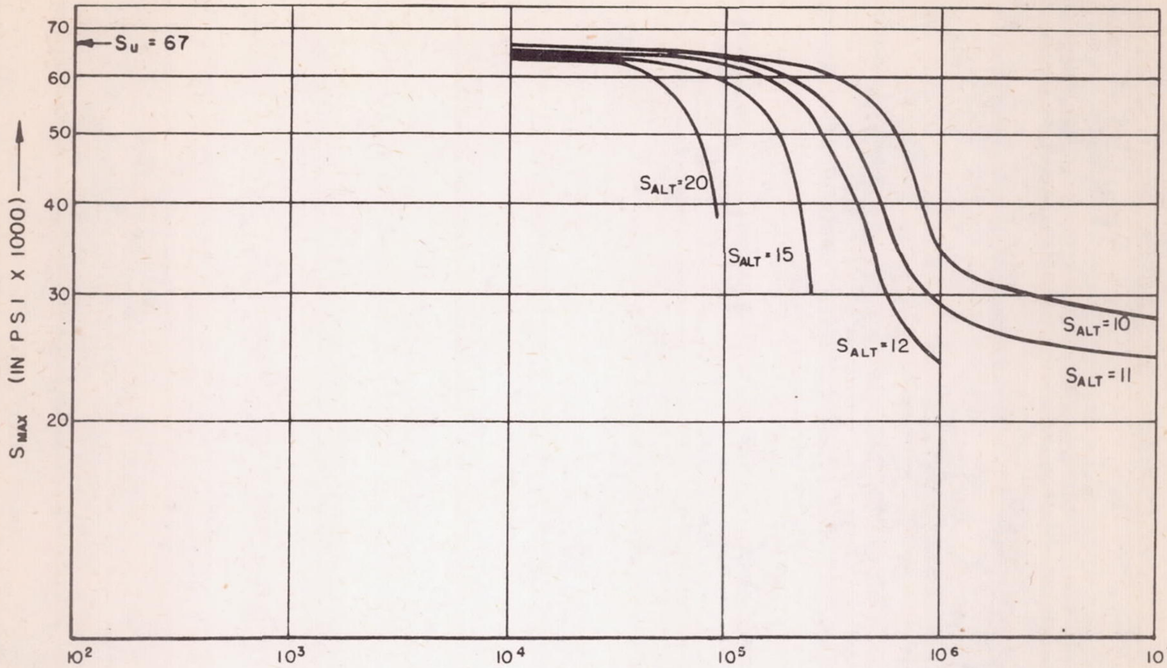


FIG. 38.-CONSTANT ALTERNATING LOAD CURVES, MAXIMUM LOAD VS. LIFETIME

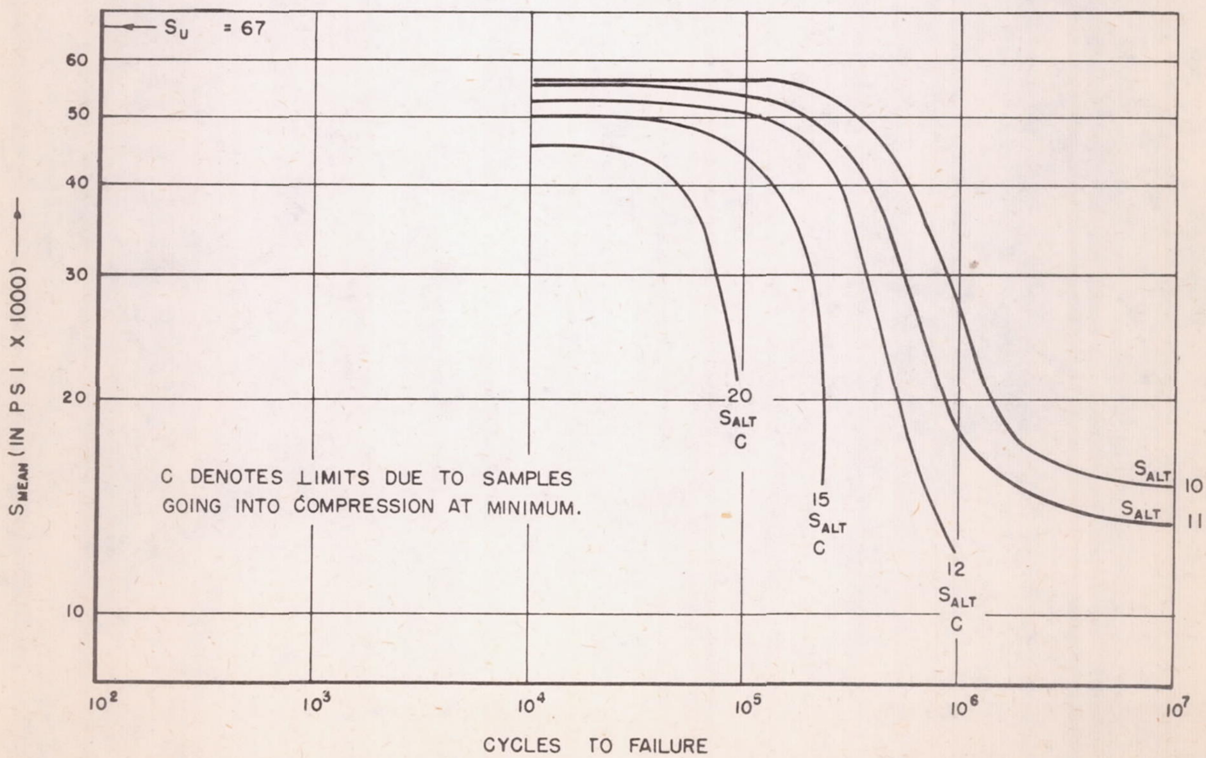


FIG. 39.- CONSTANT ALTERNATING LOAD CURVES, MEAN LOAD VS. LIFETIME.

W-63

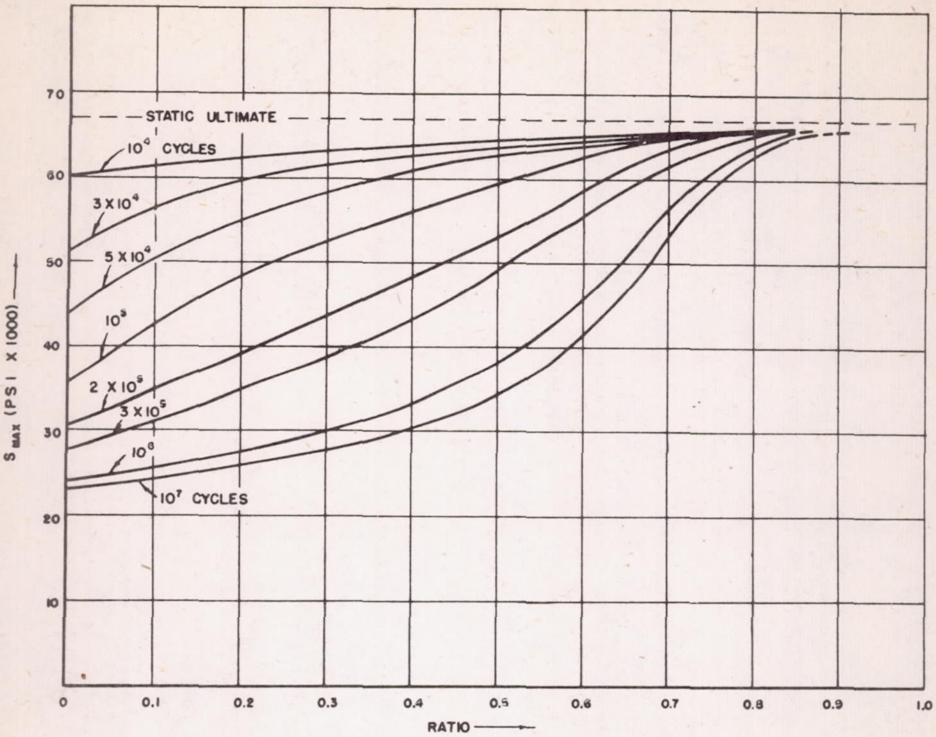


FIG. 40.- CONSTANT LIFETIME CURVES, MAXIMUM LOAD VS. RATIO.

24775

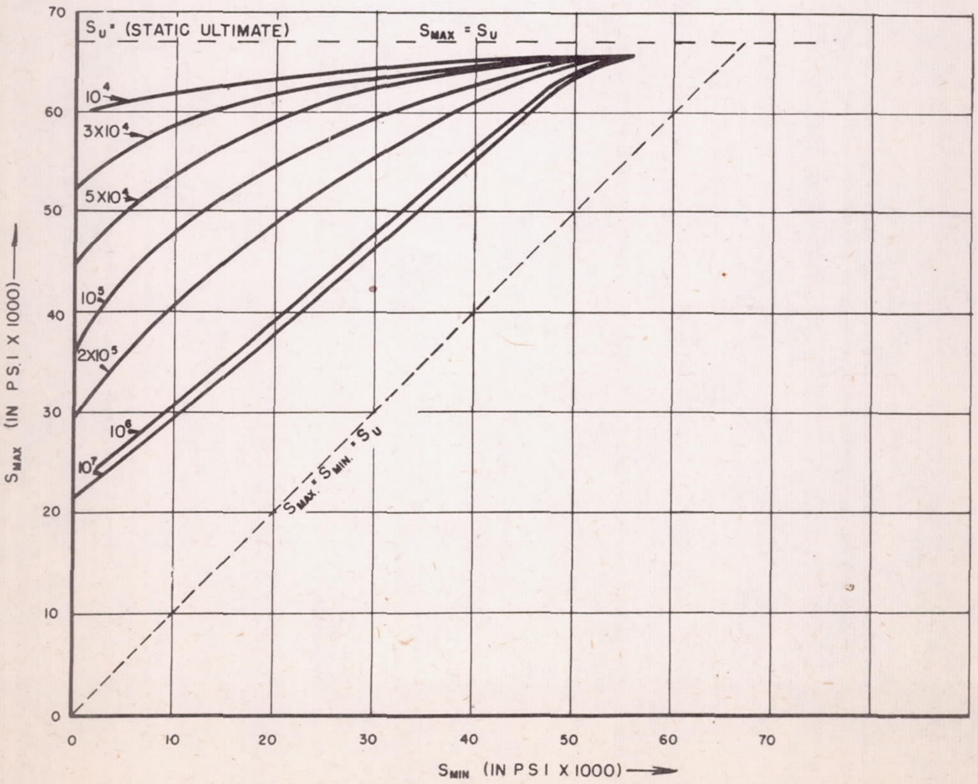


FIG. 41.- CONSTANT LIFETIME CURVES, MAXIMUM LOAD VS MINIMUM LOAD

24776

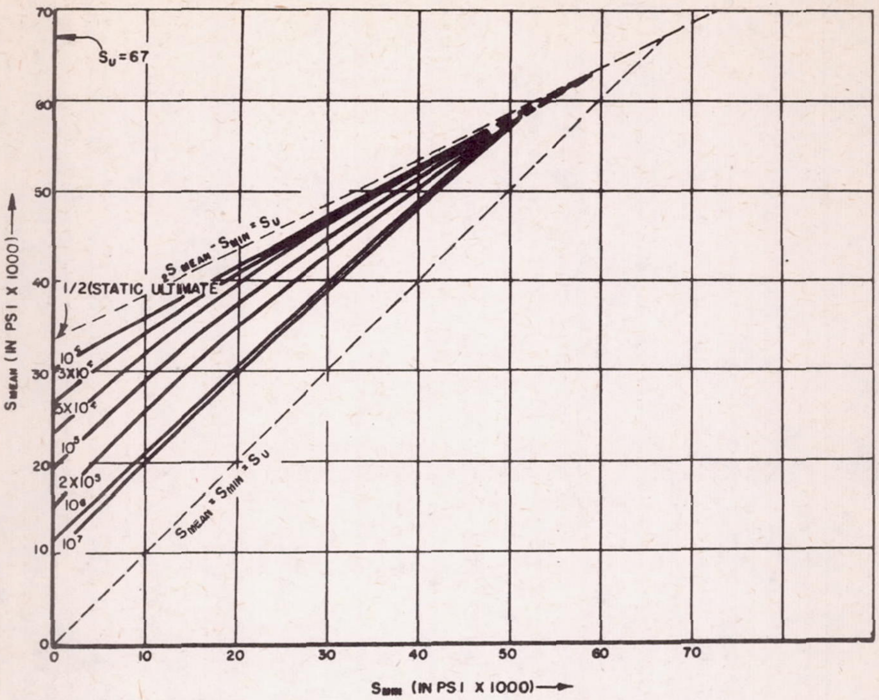


FIG. 42.-CONSTANT LIFETIME CURVES MEAN LOAD VS. MINIMUM LOAD.

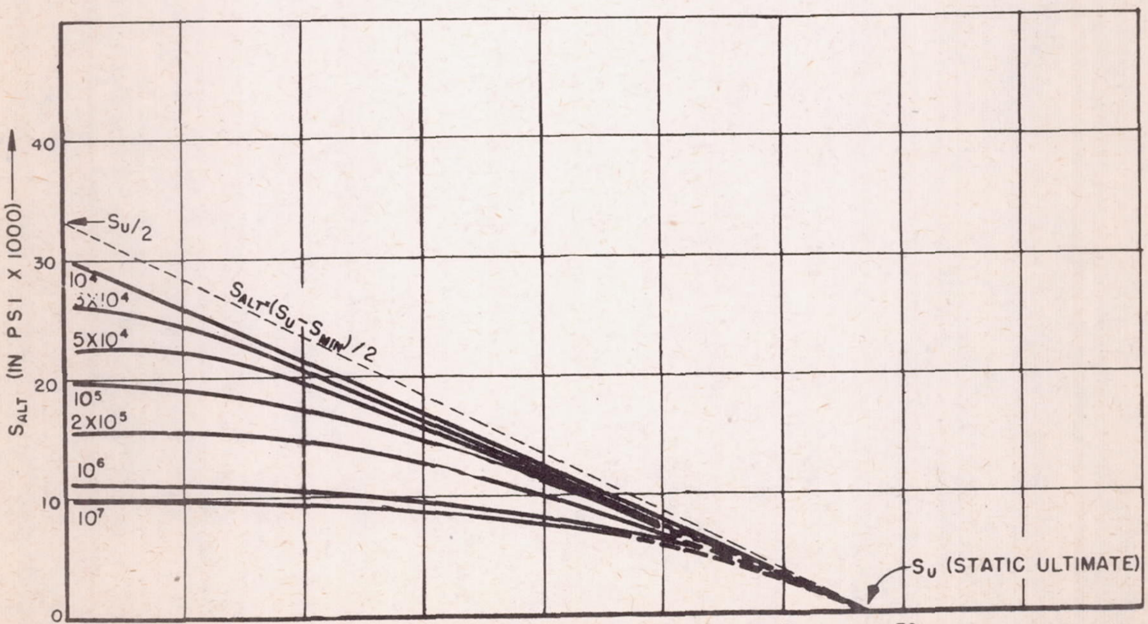


FIG. 43.-CONSTANT LIFETIME CURVES, ALTERNATING LOAD V.S. MINIMUM LOAD.

W-63

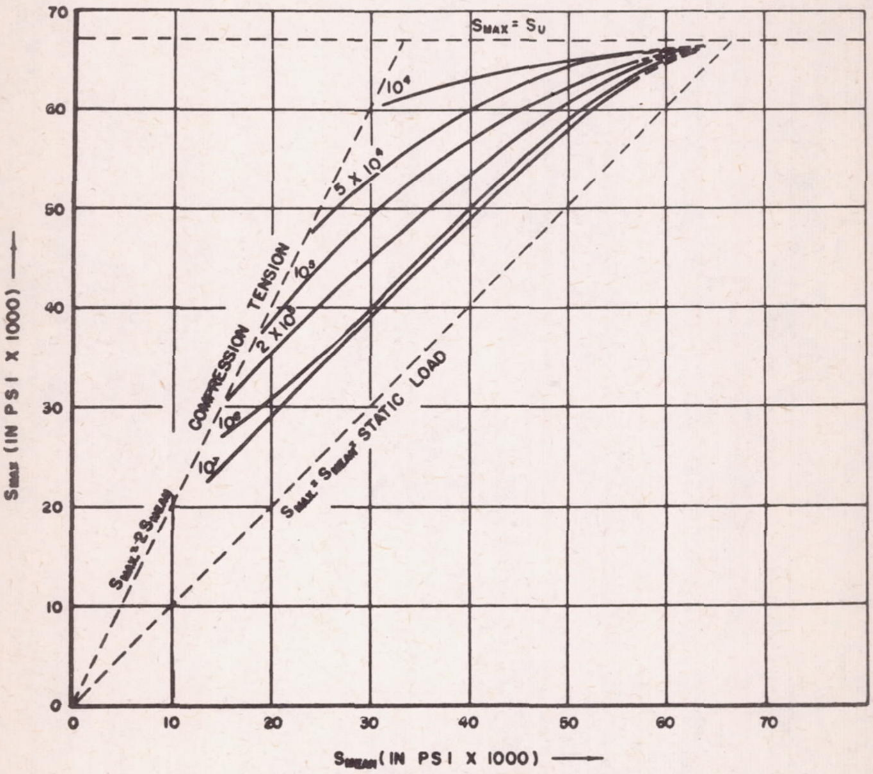


FIG. 44.- CONSTANT LIFETIME CURVES, MAXIMUM LOAD VS. MEAN LOAD.

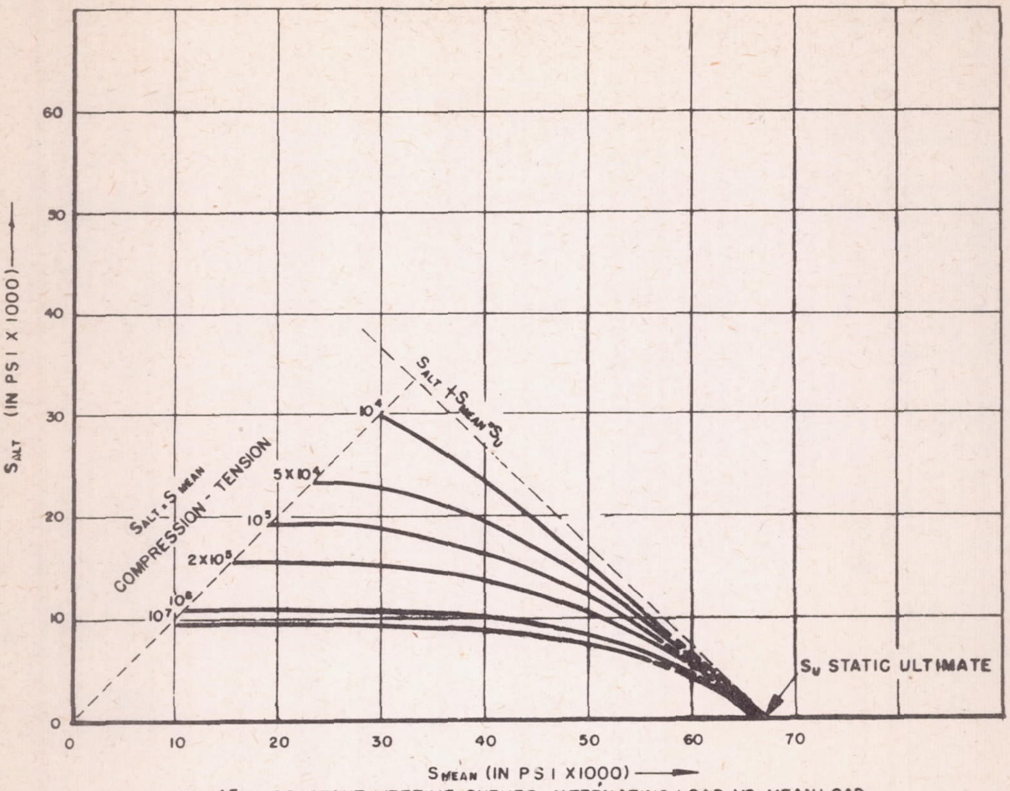


FIG 45.- CONSTANT LIFETIME CURVES, ALTERNATING LOAD VS. MEANLOAD

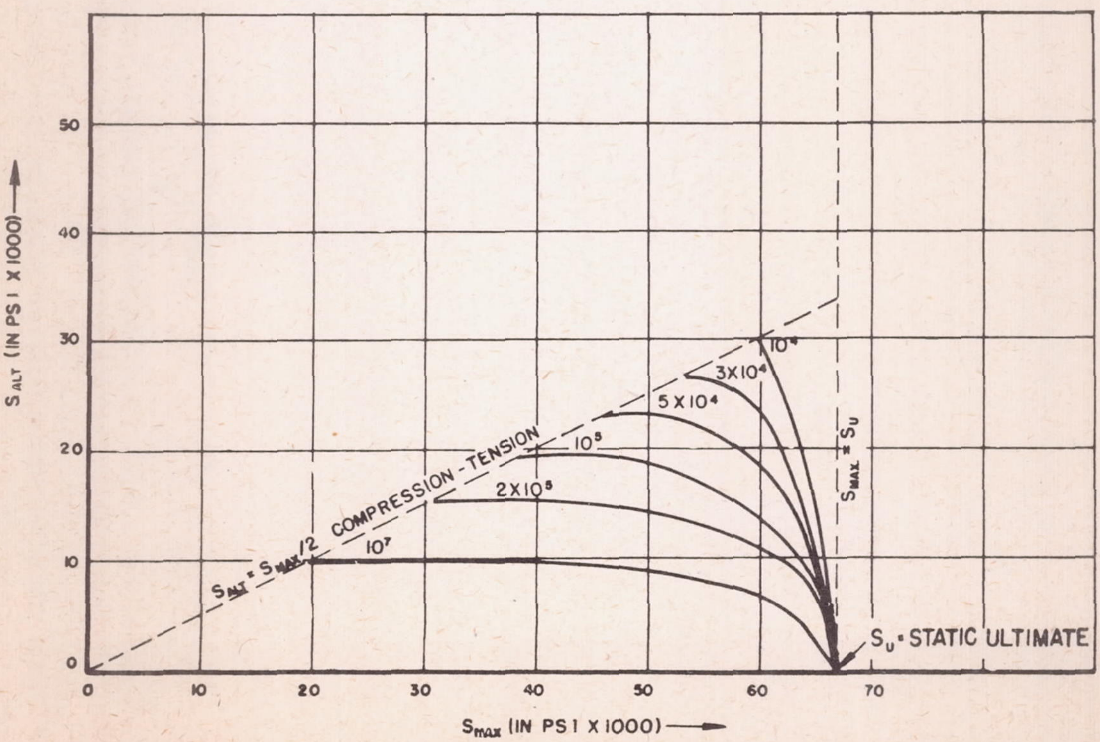


FIG.46. CONSTANT LIFETIME CURVE, ALTERNATING LOAD VS. MAXIMUM LOAD

W-63