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FATIGUE STRENGTH AND RELATED CHARACTERISTICS OF AIRCRAFT JOINTS

I - COMPARISON OF SPOT-WELD AND RIVET PATTERNS IN 24S-T ALCLAD SHEET - COMPARISON OF 24S-T ALCLAD AND 75S-T ALCLAD

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ADVANCE RESTRICTED REPORT

FATIGUE STRENGTH AND RELATED CHARACTERISTICS OF AIRCRAFT JOINTS

I - COMPARISON OF SPOT-WELD AND RIVET PATTERNS IN 24S-T ALCLAD SHEET - COMPARISON OF 24S-T ALCLAD AND 75S-T ALCLAD

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SUMMARY

This report contains detailed results of a number of fatigue tests on spot-welded joints in aluminum alloys. The tests described include:

1. Fatigue tests on spot-welded lap joints in sheets of unequal thickness of alclad 24S-T. These tests indicate that the fatigue strength of a spot-welded joint in sheets of two different gages is slightly higher than that of a similar joint in two sheets of the thinner gage but definitely lower than that of a similar joint in two sheets of the thicker gage.

2. Fatigue tests on spot-welded alclad 75S-T. Spot-welded lap-joint specimens of alclad 75S-T were not any stronger in fatigue than similar specimens of alclad 24S-T.

3. Fatigue tests on lap-joint specimens spot-welded after various surface preparations. These included AC welding wire-brushed surfaces, DC welding wire-brushed surfaces, and DC welding chemically cleaned surfaces. While the AC welds were strongest statically, the DC welds on wire-brushed surfaces were strongest in fatigue. Specimens prepared in this way were very nearly as strong as the best riveted specimens tested for comparison.

4. Fatigue tests on specimens spot-welded with varying voltage so as to include a wide range of static spot-weld strengths. The fatigue strengths were in the same order as the static strengths but showed less range.

5. Fatigue tests on lap-joint specimens with several patterns of spot welds. In general, those patterns which gave highest static strengths gave also highest fatigue strengths.

6. Fatigue tests on lap-joint specimens with various rivet patterns. Again fatigue strengths were in the same order as static strengths. These riveted joints were generally stronger in fatigue than corresponding spot-welded joints.

INTRODUCTION

This report describes the results of several investigations which are extensions of previous work. (See references 1, 2, and 3.)

Preceding reports have given results of tests on lap-joint specimens consisting of two sheets of 24S-T alclad of equal thickness joined by a single row of spot welds in a line transverse to the direction of loading.

Part I of this report describes tests on specimens comprising two sheets of different thickness joined by a single row of spot welds. All other tests described here concern specimens made of two sheets of equal thickness.

Part II describes tests on spot-welded specimens of alclad 75S-T alloy.

Part III gives results of tests on specimens spot-welded after different surface preparations. Part IV describes tests on specimens spot-welded at different voltages to obtain spots of widely varying size and static strength. These tests were made in an endeavor to learn what type of spot weld may be best in fatigue.

Part V describes a series of tests with multi-row lap joints. Part VI describes a few tests with one-row and with two-row riveted joints for comparison against results on spot-welded joints. These two groups of tests allowed some examination of the question of what spot-weld pattern is best in fatigue and of what fatigue joint efficiency may be attainable in spot-welded lap joints.

This investigation, conducted at 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 and Dr. Maurice Nelles of the Lockheed Aircraft Corporation for advice and assistance in obtaining materials and jointed specimens for this investigation. Specimens for determining the effects of surface preparation were received through the courtesy of Mr. C. W. Steward of the Curtiss-Wright Corporation. Specimens for determining the effect of range in spot-weld size were furnished through the courtesy of Mr. R. C. McMaster of California Institute of Technology. Specimens of 75S-T were received through the courtesy of Mr. T. Piper of Northrop Aircraft, Inc.

I. SPOT-WELDED LAP JOINTS IN SHEETS OF UNEQUAL THICKNESS

Test Pieces and Static Tests

Two lots of specimens have been tested. Lot A comprised specimens using sheet gages 0.032 to 0.040 inch and 0.040 to 0.051 inch. The other lot, B, included gages 0.025 to 0.032 inch, 0.032 to 0.040 inch, and 0.032 to 0.051 inch. Each specimen was made by joining two pieces (each 9 in. long by 5 in. wide) by a single row of spots spaced 3/4 inch apart in a line along the center of a 1-inch overlap section. (See, for example, fig. 1D in reference 1.)

Table 1 indicates the welding conditions. Figures 1 and 2 show sectioned welds. Table 2 gives average weld dimensions and static strength values. Values for some specimens made under comparable conditions with equal gage sheets have been included for comparison.

It may be observed from figures 1 and 2 and from table 2 that welds in sheets of unequal gage show generally greater percentage penetration in the thinner sheet. It also may be noted that the static strength of a weld joining different gage sheets is between the strength value for a weld joining two sheets of the thinner gage and the strength value for a weld joining two sheets of the thicker gage. The weld strength for the unequal sheets is nearer the lower of these strengths (that for a weld joining sheets of the lesser gage).

Fatigue Test Results

Tables 3 and 4 show the fatigue test results for the first lot of specimens. Figure 3 shows load-life curves plotted from these data for the load ratios 0.25 and 0.75 (curves for R = 0.50 have been omitted to avoid confusion, but these curves do not present any new features).

Table 5 shows fatigue test results for the other lot of samples and figure 4 the load-life curves plotted from these data.

In figures 3 and 4, there have been included curves for specimens made by spot-welding equal gage sheets. Fatigue failures (see, for example, fig. 2d) were similar to those in joints of equal-thickness sheet. In a few cases, at high loads, a button was torn out of the thinner sheet. (See, for example, fig. 2e.) In general, the fatigue-strength values bear out the observation made for static-strength values: the strength of a weld joining different gage sheets is slightly higher than that for a weld joining sheets of the thinner gage and definitely lower than that for a weld joining sheets of the thicker gage. It seems probable that this statement has limitations, and the conclusion should not be extended to unreasonable differences in sheet gage or applied without due regard for the welding conditions concerned.

II. FATIGUE TESTS ON SPOT-WELDED ALCLAD 75S-T

Test Pieces and Results of Fatigue Tests

Comparative tests were made on (1) sheet specimens of 75S-T and of 24S-T and on (2) spot-welded lap-joint specimens of 75S-T and of 24S-T. All specimens were made of 0.040-inch alclad sheet.

Monobloc sheet specimens were 1 inch wide at the center section. (See reference 3, fig. 1.) Tables 6 and 7 show data for these specimens, and figure 5 shows resulting load-life curves. The 75S-T does not appear stronger in fatigue than the 24S-T despite the difference in static properties.

Each spot-welded specimen was made of two pieces 9 inches long by 5 inches wide joined by a single row of spots in the center of a 1-inch overlap section. Tables 8 and 9 show the fatigue test results, and figure 6 shows the load-life curves. For lifetimes beyond 10^5 cycles and for both load ratios (R = 0.25 and R = 0.60) used, the 75S-T specimens appear slightly weaker than the 24S-T specimens. It may be noted that the 75S-T spot welds were slightly (about 8 percent) stronger in static shear than the 24S-T welds.

Examination of Spot Welds

Figure 7 (a, b) shows spot welds in the alclad 24S-T; while figure 7 (c, d) shows welds in the 75S-T alclad.

Welds in the two materials are similar in size, shape, and general appearance. Hardness readings at the dendritic zone (where fatigue failure generally took place) gave 90 Vickers for the 75S-T against 100 for the 24S-T.

The photographs in figure 7 show characteristic fatigue failures. Except for the weld in figure 7b, the welds were from specimens loaded similarly (116 lb per spot at $R = 0.25$). It may be noted that failure in the 75S-T welds (c, d) occurred at the projection of the inner alclad. Failure in the 24S-T (a) took place in the sheet outside the weld slug. However, at higher loads (b), failure in the 24S-T occurred at the projection of the inner alclad.

Conclusions

For the tests made, spot-welded 75S-T seemed no stronger in fatigue than spot-welded 24S-T.

It should be remembered that several factors may be concerned: the relative strengths of bare sheet materials, the effect of the cladding, and the type of spot weld.

III. LAP-JOINT SPECIMENS SPOT-WELDED WITH VARIOUS SURFACE PREPARATIONS

Test Pieces and Static Test Results

Several test pieces of 0.040-inch alclad 24S-T spot-welded after various surface preparations were furnished through the courtesy of Mr. C. W. Steward of Curtiss-Wright. Table 10 lists five groups of specimens. There were three groups of spot-welded test pieces prepared by different processes. For each of these groups, two lots of specimens (A and B) were prepared at different times with, inadvertently, slightly different welding conditions. For comparison of joint efficiencies, two groups (4 and 5) of riveted specimens were furnished.

Figure 8 shows photographs of three failed specimens. One illustrates the spot-weld pattern characteristic of groups 1, 2, and 3, having three rows of spots, with the distance between spots in each row 1/2 inch and the distance between rows 1/2 inch. The other two specimens shown in figure 8 illustrate the rivet patterns of groups 4 and 5.

Table 10 also shows static strength values and static joint efficiency values. It may be noted that the AC wire-brushed specimens had a static joint efficiency (95 percent) considerably higher than that (83 percent) of the strongest riveted joints.

Fatigue Test Results

Nine specimens of each group were furnished. At Mr. Steward's suggestion, three of these were run at each of three preselected loads.

Table 11 presents the results of the fatigue tests. The method of running the tests at three preselected loads brings out the features of scatter in test results. However, with so few load values, it is not feasible to draw load-life curves or to calculate fatigue joint efficiency values for various constant lifetimes. Nevertheless, figure 9 shows approximate load-life curves in the form of scatter bands which do not attempt to distinguish among the different spot-weld groups. From these curves and from a fatigue curve (reference 3, fig. 5) for alclad 24S-T sheet, limiting values of joint efficiencies may be estimated. Such values are given in table 12. Comparison of these values with values for other specimens tested (see sec. 5 of this report) indicates that these test pieces were strong in fatigue.

From table 11, it may be observed that, of the spot-welded specimens tested here, those made by DC welding wire-brushed surfaces appeared slightly the strongest in the fatigue tests. From table 11 and figure 9, it appears that these same spot-welded specimens were nearly as strong as the best riveted specimens.

Examination of Spot Welds

Figures 10, 11, and 12 show photographs of sectioned spot welds. Table 13 gives average values of spot-weld dimensions for samples from the various groups.

Careful examination of table 13 affords an interesting observation. For the AC wire-brushed pieces, specimen 7 had a smaller nugget area and a smaller total weld area than specimen 8 but an appreciably longer fatigue life. This may be connected with the larger corona area of specimen 7. A similar observation applies on comparing specimens 1 and 2. Generally the same observation applies on comparing DC welded specimens with each other. The apparently important contribution of corona bonding to fatigue strength does not appear to extend to the comparison of AC welds with DC welds.

Conclusions

The following conslusions are suggested by the data described:

1. Spot-welded joints can be made to have as high static joint efficiencies and nearly as high fatigue joint efficiencies as riveted joints.

2. Of the three types of spot-welded specimens (AC - wire brush, DC - wire brush, and DC - chemically cleaned), the AC wire-brushed were strongest statically, but the DC wire-brushed strongest in fatigue.

3. There is a suggestion that, for a given type of welding (AC or DC), corona bonding contributes considerably to fatigue strength.

In view of the relatively small number of specimens, these conclusions must be regarded as tentative.

IV. LAP-JOINT SPECIMENS WITH SPOT WELDS OF WIDELY VARYING SIZE AND STATIC STRENGTH

Test Pieces and Static Strength

Nine panels with spot welds of successively larger sizes were received, together with radiographs of all welds, from California Institute of Technology through the courtesy of Mr. R. C. McMaster.

Table 14 gives the welding conditions for each panel. Figure 13 shows photographs of spots illustrating the variation in spot size. (See also figs. 15, 16, 17, and 18.) Table 15 gives the results of measurements of the various spot dimensions and also values of static shear strength from tests on single-spot coupons. The terms used to designate weld dimensions have been defined in a previous report. (See reference 2, p. 4.)

Examination of the welds and calculations from the data in table 15 showed that the corona area was nearly constant throughout the range of welds (0.0316 sq in. for Panel 1 to 0.0320 sq in. for Panel 9). On the other hand, the weld-nugget area increased from 0.0398 to 0.0804 square inch. The static shear strength increased approximately in direct proportion to the nugget area.

Fatigue Test Results

Strips 3 inches wide containing three spot welds each were sheared from the various panels and tested in fatigue. All tests were run at a load ratio $R = 0.25$.

Table 16 presents the results of the fatigue tests, and figure 14 shows load-life curves plotted from these data. To avoid confusion, only results for every odd-numbered panel have been plotted - results for other panels, in general, follow the same pattern.

Two observations are interesting. First, the spread in fatigue strengths is less than that in static-strength values. This seems particularly true for lower loads and longer lifetimes. Second, there is an increase in fatigue strength with increasing weld size and increasing static-strength values. Neither of these observations held for some previously reported tests on spot-welded lap joints (reference 2, p. 10). It seems that fatigue strengths may increase in the same order as static strengths, for welds varied in size only by varying the welding voltage.

Examination of Failed Specimens

Figures 15, 16, 17, and 18 show sections of spot welds from failed samples of the various panels.

It may be noticed that the smaller welds sheared at high loads but cracked from the alclad protrusion at lighter loads. Larger welds "pulled buttons" (figs. 16d and 17a) at higher loads and sometimes gave rise to failure in the sheet at lighter loads. Overheated and cracked welds (see fig. 18c) showed no signs of weakness in fatigue or of failure through the transverse crack.

V. FATIGUE TESTS ON LAP JOINTS WITH VARIOUS SPOT-WELD PATTERNS

Test Pieces and Static Test Results

Table 17 outlines a series of tests on the effect on fatigue strength of varying the spot-weld pattern in simple lap joints, and table 18 shows strength properties of the sheet material used. The purpose was to determine the effects of such variables as the number of rows of spots, the spacing between spots, staggering spots in adjacent rows, and post-aging multi-rowed joints. The Boeing joint pattern has been included as representative of a joint that is successful in actual service conditions. Figures 19, 20, and 21 show photographs of various joint patterns.

Table 18 gives static test results on test pieces made from the various lots of sheet used for the spot-weld specimens.

Tables 19 and 20 give the welding conditions for the various jointed specimens. Figures 22, 23, and 24 show photographs of sectioned welds. In general, all welds were of good appearance. The one exception was for group 3 M2C, where welds appeared to be overheated.

Table 21 gives static strength values averaged for two representative specimens of each group. It may be observed that:

1. Increasing the number of rows decreases the strength per spot but increases total joint strength and joint efficiency. (Cf. results for 3 B1C-D, 3 K1C-D, and 3 M1C-D.)

2. A spot spacing of 1/2 inch appears to afford a strong joint. (Cf. 3 K1C-D and 3 K1C-F. Note also the high joint efficiencies in groups 3 M1C-F to 3 M3C-F.)

3. There does not appear to be any notable effect due to staggering spots in adjacent rows. (Cf. 3 K1C-D and 3 L1C-D.)

4. Post-aging (10 hr at 370° F) before welding appears to increase the static joint efficiency; while post-aging after welding may even decrease the static joint efficiency.

5. The pattern consisting of three rows of spots, with the spots 1/2 inch apart in each row and with the rows 1/2 inch apart, gave very high static strengths. Of the specimens used in these tests, this pattern produced the strongest joint in static strength (a joint stronger than the Boeing joints tested).

These results are in reasonable accord with test results reported in the literature (references 4 and 5).

Fatigue Test Results

To insure that the alclad 24S-T sheet used in making the spot-welded test pieces had normal fatigue strength properties, and to afford base curves for the evaluation of fatigue joint efficiencies, fatigue tests were run on samples of the particular lots of sheet materials used. The resulting data are given in tables 22, 23, and 24, and some of these data are shown as load-life curves in figures 25, 26, and 27. The values for the 0.040-inch sheet are nearly the same as those reported for other lots. (See reference 3, table 2.) Values for the 0.064-inch sheet are close to those for 0.040 inch. For both gages, the effect of post-aging (10 hr at 370° F) on fatigue strengths was slight and was in the direction of reducing the fatigue strength (cf. reference 3, fig. 5). The 0.016-inch sheet tested appeared to have slightly higher fatigue strengths for lifetimes beyond 10^6 cycles at a load ratio of $R = 0.25$ than either the 0.040- or the 0.064-inch sheet.

Tables 25 through 36 give the results of fatigue tests on the variously patterned joints. Most of the tests were run at the load ratio $R = 0.25$ for which the alternating component of load is high, so that effects produced by dynamic loading might be expected to show up. In many cases, a few tests were run at a higher load ratio ($R = 0.60$) in order to note any possible unexpected effect of varying the ratio. Figures 28 through 32 show the results plotted as load-life curves.

In particular, figure 28 shows fatigue test results for specimens of 0.040-inch sheet having one row of spots and for specimens having two rows of spots. It seems fair to conclude that:

1. Two rows of spots afford a joint more than 50 percent stronger than a single row.

2. It does not make much difference whether the spots in the two rows are staggered or in alinement.

3. Using a 1/2-inch spacing between spots in a row gives a stronger joint than a spacing of 3/4 inch, both in static tests and in fatigue tests at $R = 0.25$. However, the strength increase is somewhat dubious at lifetimes in excess of 2×10^5 cycles.

Joint efficiency values will be discussed later.

Figure 29 shows load-life curves at $R = 0.25$ for specimens having three rows of spot welds. It may be observed that:

1. Joints with the spots spaced 1/2 inch apart in each row were stronger in fatigue (as well as in static tests) than joints with spots spaced 3/4 inch apart. (Cf. 3 M1C-D and 3 M1C-F.)

2. Post-aging the sheet before joining increased the static strength and did not significantly affect the fatigue strength. (Cf. 3 M1C-F and 3 M3C-F.)

3. Post-aging the joints after welding decreased slightly both the static strength and the fatigue strength. (Cf. 3 M1C-F and 3 M2C-F.)

Figures 30 and 31 show load-life curves for specimens with the Boeing type joint. It is interesting to note the relatively large decrease in fatigue strength with decreasing load and lifetimes increasing to 10^7 cycles.

Figure 32 shows load-life curves for lap-joint specimens of 0.064-inch sheet. It will be noticed that the same general results held for joints in 0.064-inch sheet as held for joints in 0.040-inch material.

Table 37 shows some values of joint efficiencies. Joint efficiency is here defined as the ratio of the strength per inch of joint to the strength-per-inch width of the sheet material at the same lifetime and at the same load ratio. Values for post-aged sheet were used for all jointed specimens post-aged either before or after welding.

Figure 33 shows smoothed-out curves of joint efficiency against lifetime plotted from the values in table 37. With one exception, the fatigue joint efficiencies preserve the same order as the static values. The fatigue values are always lower and decrease somewhat with decreasing load and increasing lifetime. The one exception is the curve for 3 N1E-D (three rows of spots in 0.064-in. sheet) which shows joint efficiencies decreasing rapidly with decreasing load and increasing lifetime. This trend can be observed, of course, in the steep load-life curves for these specimens. (See fig. 32.) No explanation will be attempted now. In comparing the Boeing joint (5 U1C-F) results with results for the other patterns, it must be kept in mind that these Boeing joints were made with roller welds. Previous tests (reference 3) have indicated that roller welds may be slightly weaker in fatigue than spot welds.

Conclusions

Useful interpretation of the results noted above requires correlation with previously reported data and very careful consideration of the limitations necessary in drawing general conclusions from particular laboratory tests. It is believed desirable to omit premature conclusions from this progress report.

It may be observed that, in general, variations of fatigue strength with variations of spot-weld patterns have followed the order of variations in static strength.

VI. FATIGUE TESTS ON LAP-JOINT SPECIMENS WITH VARIOUS RIVET PATTERNS

Test Pieces and Static Test Results

For purposes of comparison, tests were made on lap-joint specimens fastened by various patterns of flush rivets. Table

38 gives specifications for the test pieces and figures 34, 35, and 36 show photographs of the various types of joints. In choosing the rivet patterns, it was not the intention to duplicate exactly the spot-weld patterns but rather to use rivet spacings characteristic of good commercial practice.

Table 39 gives the results of static tests and shows static joint efficiency values (based on a static ultimate of 66,700 psi for the sheet as received and 69,000 psi for the post-aged sheet). The joint efficiency is here defined to be the strength per gross inch of the jointed specimen divided by the strength-per-inch width of a monobloc specimen of the same gage sheet.

It may be observed from the values listed in table 39 that:

1. For the single-row specimens (P1C-D and P1C-F), the 1/2-inch spacing gave a stronger joint than did the 3/4-inch spacing.

2. For the 3/4-inch spacing single row (P1C-D and P2C-D), the post-aged specimens gave a higher joint efficiency.

3. For specimens with two rows those (Q1C-D and T1C-D) with approximately 3/4-inch spacing between rows were stronger than those with closer spaced rows. Of these two, Q1C-D, which had its rivets in line, appeared stronger than T1C-D in which the rivets were staggered.

Fatigue Test Results

Tables 40 through 45 show the results of fatigue tests on the various specimens. Figures 37, 38, 39, and 40 show various load-life curves plotted from these data.

Figure 37 shows curves at three load ratios for group P1C-D (a single row of rivets spaced 3/4 in. apart). The dotted line shows, for R = 0.25, the curve for the same type of specimens post-aged (P2C-D). Apparently, although post-aging increased the static joint strength, it slightly decreased the fatigue strengths except at very high loads and very short lifetimes.

Figure 38 shows curves (solid lines) for specimens (P1C-F) with rivets spaced 1/2 inch apart. The specimens with the closer spaced rivets appear stronger both statically and in fatigue.

The strength difference is most marked at very low loads and long lifetimes. For example, at a lifetime of 3×10^6 cycles at a load ratio $R = 0.25$, the 3/4-inch spacing gives only about 60 percent the strength of the 1/2-inch spacing.

Figure 39 shows curves at $R = 0.25$ for specimens with rivets 3/4 inch apart in each row. The increase in strength on adding a second row 3/4 inch away is evident on comparing the two curves. The effect of staggering the spots for the two-row pattern is insignificant. (Both observations apply generally to fatigue curves at $R = 0.60$.)

Figure 40 shows the load-life curves for three groups of specimens, all of which had a pattern consisting of two rows of staggered rivets spaced 3/4 inch apart in each row. The spacing between rows varied from 3/16 to 11/16 inch. Apparently, joints with the largest spacing between rows were strongest, being above that for the specimens (3 B1C-D) with a single row of spot welds and generally near the curve for specimens (3 L1C-D) with two rows of spots. Again the curve for specimens (Q1C-D) with two rows of rivets lies very near that for specimens (3 M1C-F) with three rows of spot welds.

With the possible exception of the curve for a single row of rivets, the order of the joint efficiencies in fatigue is much the same as that for static values (fig. 4). Thus, while the results indicate a generally lower joint efficiency in fatigue than in static tests, they imply that riveted joints are better than spot-welded ones in fatigue only as they are also better statically (fig. 42). It also appears possible that spot-welded joints can be made that are as strong in fatigue as riveted joints at the possible expense of having an extra row of spot welds.

Battelle Memorial Institute,
Columbus, Ohio, June 1, 1944.

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TABLE 1. WELDING CONDITIONS FOR SHEET OF UNEQUAL THICKNESS

A. Specimens of Lot A Welded on a PMCO-2-S Sciaky Welder

Settings	Sheet Thicknesses .032 - .040	.040 - .051
Max. energy relay	162	180
Resistance blocks	5&6	5&6
Contactor pales	8	8
Initiating switch	30	35
Welding press., gage	50	54
Forging press., gage	50	54
Forge time relay	3	3
Pressure Appl$^{\underline{n}}$	variable	variable
Hold time relay	6	6

B. Specimens of Lot B Welded on a Taylor-Winfield rocker arm type stored energy machine

Settings	Sheet Thicknesses 025 - 032,	032 - 032,	032 - 040,	032 - 051
Pressure (Lbs.)	680	800	910	850
Charging Voltage	1200	1350	1400	1350
Capacity (mfds)	960	960	1200	1200
Holding time (dial)	3	3	3	3

TABLE 2. WELD DIMENSIONS AND STATIC STRENGTHS - SHEETS UNEQUAL GAGE

Specimen Designation	Gages of Sheet	Diameter of Weld	Penetration of Weld	Indentation in Thinnest Sheet	Static (Lbs./Spot)(2)	Remarks
EIBC-D	.032" - .040"	0.190" ± 0.01"	50% in 0.040" 80% in 0.032"	0.004"	529	Welded on PMCO-2-S Sciaky machine
(1)	.040" - .040"	0.230"	65%	0.005"	615	
EICD-D	.040" - .051"	0.190"	50% in 0.051" 75% in 0.040"	0.004"	675	
EIAB-D C	0.025" - 0.032"	0.120"	35% in 0.032" 50% in 0.025"	0.004"	310	Welded on Taylor - Winfield rocker arm type stored energy machine
	0.032" - 0.032"	0.125"	50%	0.002"	378	
EIBC-D	0.032" - 0.040"	0.140"	50% in 0.040" 65% in 0.032"	0.004"	438	
(1)	0.040" - 0.040"	0.175"	58%	0.006"	520	
EIBD-D C	0.032" - 0.051"	0.190"	65% in 0.051" 45% in 0.032"	0.006"	484	

(1) These comparison values have been taken from previously reported work. In general the welding conditions were similar to those given in Table 1.

(2) Static values were obtained at Battelle on six spot specimens exactly like those tested in fatigue. Values reported by the welders for single spot coupons vary slightly from those given above but show exactly the same order for different gages.

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TABLE 3. FATIGUE TEST RESULTS FOR SPOT-WELDED LAP JOINT SPECIMENS OF SHEETS OF UNEQUAL THICKNESS

Specimens of Lot A, Sheets 0.032" to 0.040"

Specimen No.	Maximum Load Total Lbs.	Maximum Load Lbs./In.	Maximum Load Lbs./Spot	Cycles to Failure	Remarks
Ratio .25					
EIBC-9D	1650	330	275	14,800	.040" sheet cracked welds pulled in .032"
7	1500	300	250	19,200	Welds pulled in .032" sheet
1	1250	250	208	61,700	Partially pulled welds in .032" sheet
2	1000	200	167	260,500	Fatigue cracks in both sheets
3	875	175	146	489,400	Fatigue cracks in both sheets
5	780	156	130	545,200	Fatigue cracks in .032" sheets
6	780	156	130	547,700	Fatigue cracks in .032" sheets
4	750	150	125	1,576,800	" " " " "
8	650	130	108	1,861,900	" " " " "
10	625	125	104	3,174,400	" " " " "
Ratio .50					
16	2100	420	350	7,300	Pulled welds in .032" sheet
13	1800	360	300	35,300	" " " " "
12	1500	300	250	120,500	Fatigue cracks in both sheets
11	1250	250	208	286,900	
36	1200	240	200	342,100	Fatigue cracks in .032" sheet
15	1000	200	167	1,115,100	" " " " "
18	850	170	142	2,384,100	Fatigue cracks in .032" sheet
17	825	165	138	1,446,800	Fatigue cracks in .032" sheet
19	750	150	125	4,036,900	Fatigue cracks in .040" sheet
20	700	140	117	>18,936,700	
Reload	1800	360	300	34,300	Pulled welds in .032" sheet
14	600	120	100	>10,213,200	
Reload	1500	300	250	172,200	Fatigue cracks in both sheets
Ratio .75					
22	2600	420	433	23,000	
32	2300	460	383	113,200	Pulled welds in .032" sheet
26	2000	400	333	121,300	" " " " "
24	1750	350	291	326,800	Fatigue cracks in .040" sheet
35	1500	300	250	1,130,300	Fatigue cracks in both sheets
25	1400	280	233	1,085,100	" " " " "
27	1250	250	208	1,567,200	" " " " "
34	1200	240	200	3,822,500	" " " " "
21	1125	225	188	4,263,000	Fatigue cracks in .040" sheet
23	1000	200	167	4,320,700	Fatigue cracks in .032" sheet
33	900	180	150	>15,972,900	
Reload	1500	300	250	1,544,700	Fatigue cracks in both sheets

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TABLE 4. FATIGUE TEST RESULTS FOR SPOT-WELDED LAP JOINT SPECIMENS OF SHEETS OF UNEQUAL THICKNESS

Specimens of Lot A, Sheets 0.040" to 0.051"

Specimen No.	Maximum Load			Cycles to Failure	Remarks
	Total Lbs.	Lbs./In.	Lbs./Spot		
Ratio .25					
EICD-8D	2250	450	375	7,000	Pulled welds in .040" sheet
7	2100	420	350	14,300	" " " " "
3	2000	400	333	14,900	" " " " "
1	1750	350	292	39,500	Fatigue cracks in .040" sheet
2	1350	270	225	109,400	" " " " "
4	1100	220	183	228,700	" " " " "
5	875	175	146	1,097,200	" " " " "
10	850	170	142	767,100	" " " " "
28	825	165	137	1,705,800	
6	800	160	133	> 9,849,300	
Reload	1500	300	250	123,100	Fatigue cracks in .040" sheet
Ratio .50					
19	2750	550	458	1,100	Pulled welds in .040" sheet
13	2375	475	396	32,400	" " " " "
18	2250	450	375	39,400	
12	2000	400	333	108,500	Fatigue cracks in both sheets
11	1500	300	250	220,700	" " " " "
17	1400	280	233	427,700	Fatigue worse in .040" sheet
14	1125	225	187	1,268,100	Fatigue cracks in .040" sheet
16	1000	200	167	3,039,900	" " " " "
15	1000	200	167	> 9,412,200	
Reload	1750	350	292	144,800	
9	900	180	150	> 10,229,400	
Reload	1500	300	250	263,300	Fatigue cracks in both sheets
Ratio .75					
27	3250	650	542	40,700	Pulled welds in .040" sheet
25	2850	570	475	179,200	" " " " "
22	2500	500	417	429,200	Fatigue cracks in both sheets
35	2400	480	400	286,900	Pulled welds in both sheets
36	2100	420	350	426,300	Fatigue cracks in both sheets
21	2000	400	333	1,291,800	" " " " "
23	1700	340	283	2,255,000	Fatigue cracks in .040" sheet
26	1600	320	267	3,485,500	
32	1500	300	250	2,576,000	Fatigue cracks in .040" sheet
34	1400	280	233	> 17,886,500	
Reload	2500	500	417	148,900	Fatigue cracks in .040" sheet
33	1300	260	217	> 11,472,500	
Reload	2700	540	450	143,400	Pulled welds in .040" sheet
20	1200	240	200	> 10,368,400	
Reload	2400	480	400	344,900	Fatigue cracks in both sheets

TABLE 5. FATIGUE TEST RESULTS FOR SPOT-WELDED LAP JOINT SPECIMENS OF SHEETS OF UNEQUAL THICKNESS

Specimens of Lot B

Specimen No.	Maximum Load Total Lbs.	Maximum Load Lbs./In.	Maximum Load Lbs./Spot	Cycles to Failure	Remarks
			Sheet 0.025" to 0.032"		
Ratio .25					
EIAB 2 D	1000	200	167	7,400	Sheared welds
C 7	875	175	146	24,900	3 sheared welds - 3 pulled buttons
1	750	150	125	65,000	Fatigue cracks in both sheets
3	625	125	104	318,100	" " " " "
9	540	108	90	936,600	Fatigue cracks in 0.025" sheet
4	500	100	83	1,119,400	" " " " "
5	400	80	67	1,822,200	" " " " "
8	400	80	67	4,154,100	" " " " "
6	360	72	60	4,755,600	" " " " "
			Sheet 0.032" to 0.040"		
EIBC 2 D	1250	250	208	20,800	Fatigue cracks in 0.032" sheet
1	900	180	150	177,000	" " " " "
3	650	130	108	944,600	" " " " "
4	550	110	92	1,287,700	" " " " "
			Sheet 0.032" to 0.051"		
EIBD 2 D	1500	300	250	11,700	Sheared welds
C 4	1200	240	200	79,700	Fatigue cracks in 0.032" sheet Buttons pulled in 0.051" sheet
1	1000	200	167	245,000	Fatigue cracks in 0.032" sheet
7	810	162	135	770,300	Fatigue cracks in 0.032" sheet
8	810	162	135	595,500	" " " " "
3	750	150	126	1,706,000	Fatigue cracks in both sheets
5	675	135	112	1,407,600	Fatigue cracks in 0.032 sheet
6	600	120	100	>17,166,900	
Reload	300	60	50	> 1,967,400	
2nd Reload	2500	500	417	300	Sheared welds
9	550	110	92	2,344,800	Fatigue cracks in 0.032" sheet

TABLE 6. FATIGUE TEST RESULTS FOR MONOBLOCK SPECIMENS OF 24S-T ALCLAD 1.000" X 0.040" AT CENTER SECTION

Specimen No.	Maximum Load		Cycles to Failure	Type of Failure
	Total Lbs.	p.s.i.		
Ratio .25				
4AlC 5	2560	64,000	26,700	1/4" off center
4	1948	50,000	112,000	3/8" ditto
1	1560	40,000	234,900	9/16" "
2	1166	30,000	927,100	1/2" "
3	1054	27,000	>11,410,500	Did not fail
Ratio .60				
7	2496	64,000	138,500	7/16" off center
6	2106	54,000	492,900	1/4" ditto
8	1710	44,100	1,722,200	1/8" "

Static Tensile Results

Specimen No.	Static Ultimate, p.s.i.	Static Yield, p.s.i.	Elongation, % in 2"
4AlC 9	67,180	41,800	15.3
10	66,150	41,100	15.7

TABLE 7. FATIGUE TEST RESULTS FOR MONOBLOCK SPECIMENS OF 75S-T ALCLAD 1.000" X 0.040" AT CENTER SECTION

Specimen No.	Maximum Load		Cycles to Failure	Type of Failure
	Total Lbs.	p.s.i.		
Ratio .25				
XAlC 6	2496	64,000	22,400	5/16" off center
3	1948	50,000	72,900	1/8" " "
5	1634	43,000	65,000	1/2" " "
1	1560	40,000	111,900	at "
4	1292	34,000	250,700	1/4" off "
2	1170	30,000	>10,116,300	
Reload	1655	45,000	84,600	1/8" " "
Ratio .60				
8	2220	57,000	347,400	9/16" off center
7	1362	35,000	>12,117,200	
Reload	1950	50,000	921,900	

Static Tensile Results

Specimen No.	Static Ultimate, p.s.i.	Static Yield, p.s.i.	Elongation, % in 2"
XAlC 9	78,300	66,800	9.3
10	77,600	66,600	9.6

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TABLE 8. FATIGUE TEST RESULTS FOR LAP JOINT SPECIMENS OF 24S-T ALCLAD WITH ONE ROW OF SPOT WELDS 3/4" SPACED

(Group 4BI$_c$CD)

Specimen No.	Maximum Load Total Lbs.	Lbs./Spot	Lbs./In.	Cycles to Failure	Remarks
Ratio .25					
4BI$_c$C 4D	2000	333	400	2,900	Shear
1	1500	250	300	38,000	" and pulled button
2	1000	167	200	423,800	Fatigue cracks
5	800	133	160	1,055,600	ditto
3	700	116	140	5,453,800	"
Ratio .60					
8	2000	333	400	49,500	Pulled buttons
6	1500	250	300	249,200	Fatigue cracks
7	1000	167	200	1,683,200	ditto
9	800	133	160	> 13,743,700	
Reload	1700	283	340	127,300	Pulled bottons

Static Tensile Results

Specimen No.	Static Ultimate Total Lbs.	Lbs./Spot	Lbs./Inch
4BI$_c$C 14D	2700	450	533
15	2600	433	507

TABLE 9. FATIGUE TEST RESULTS FOR LAP JOINT SPECIMENS OF 75S-T ALCLAD WITH ONE ROW OF SPOT WELDS 3/4 INCH SPACED

(Group B1C^x_c-D)

Specimen No.	Maximum Load Total Lbs.	Lbs./Spot	Lbs./In.	Cycles to Failure	Remarks
Ratio .25					
B1C^x_c-3D	2000	333	400	3,800	Shear
1	1500	250	300	32,000	Fatigue cracks
2	1000	167	200	147,100	Ditto
4	700	116	140	983,200	"
5	580	97	116	1,279,100	"
6	480	80	96	> 11,462,500	"
Reload	1000	166	200	197,500	"
Ratio .60					
10	2400	400	480	8,500	Shear and pulled bottons
9	2000	333	400	36,300	Pulled buttons
7	1500	250	300	149,200	Fatigue cracks
8	1000	167	200	895,800	Ditto

Static Tensile Results

Specimen No.	Static Ultimate Total Lbs.	Lbs./Spot	Lbs./In.
B1C-11D	2780	463	556
12	2960	493	578

TABLE 10. SPECIFICATIONS OF SPECIMENS WITH VARIED SURFACE PREPARATIONS AND WELDING CONDITIONS

Group	Surface Preparation	Welding conditions[2]	Static Load, (lbs.)[3]	Joint Eff. (%)	Cracks via X-ray	Remarks
1	A. Alcohol dip and wipe. Sol. 14 etch. (1) Wire brushed. Welded within 10 min.	D.C. weld. Tip force 1370#, 1.65KV 800 mfd, 195 turns ratio 700#/spot setup	4840	89.0[5]	No	Specially made welds with fused Alclad ring around nugget (good corona bonding) adds approx. 35% to spot strength.
	B. Diversey cleaner, Clepo etch, wire brushed. Welded within 10 min.	D.C. weld. Tip force 1200#, 1.88KV 800 mfd, 195 turns ratio Dome tips 3"R 825#/spot setup	4530	84.3[4]	Yes	Note larger welds compared to first group of specimens.
2	A. Alcohol dip and wipe. Sol. 14 etch only	D.C. weld. Tip force 1370#, 1.75KV, 800 mfd, 195 turns ratio 570#/spot setup	4150	73.4[5]	Yes	Corona bonding poor. Larger nuggets than Group 1. Lower eff. due chem cleaning.
	B. Diversey cleaner then Clepo etch only	D.C. weld. Tip force 1200#, 1.88KV, 800 mfd, 195 turns ratio Dome tips 3"R, 650#/spot setup	3800	70.3[4]	Yes	Note larger welds compared to first group of specimens.
3	A. Alcohol dip and wipe. Sol. 14 etch. Wire brushed. Welded within 10 min.	A.C. weld. Tip force 790#, 24000 amps, timing 8c; 750#/spot setup	5180	95.0[5]	No	Good corona bonding adds approx. 40% to spot strength.
	B. Diversey cleaner, Clepo etch, wire brushed. Welded within 10 min.	A.C. weld. Tip force 600#, 24700 amp. timing 8c, Dome tips 3" R 850#/spot setup	5000	94.3[4]	No	Note larger welds compared to first group of specimens.
4	5-A17ST 100° rivets 3/16" diam. Both sheets dimpled. 1000#/rivet		4100		73.6[5]	
5	12-A17ST 100° rivets, 1/8" diam.		4410		82.7[4]	Believed to be best rivet combination

(1) Sol. 14 developed by R.P.I.
(2) D. C. welds made on Federal Model P3-12-RA machine, throat 21", Tips ElK alloy 3" R.
A. C. welds made on Federal P3-12-RA, throat 21", G. E. Control Panel CR7503, Tips 3" R.
(3) Average values for these specimens.
(4) Based on actual dimensions and 66,400 p.s.i. for parent metal.
(5) Based on actual dimensions and 66,900 " " " "
The above information was furnished through the courtesy of Mr. C. W. Steward.

TABLE 11. FATIGUE TEST RESULTS FOR SPECIMENS WITH VARIED SURFACE PREPARATIONS AND WELDING CONDITIONS

Specimen and Group	Maximum Load (Total Lbs.)	Cycles to Failure	Average Cycles to Failure
Group 1: D.C. Welds wire brush			(Lot B)
Lot A			
1	3070	15,300	
4	1535	104,900	
7	920	2,243,800	
Lot B			
2	3070	14,100	13,550
3	3070	13,000	
5	1535	98,400	110,350
6	1535	122,300	
8	920	600,000	590,900
9	920	583,800	
Group 2: D.C. Welds chem clean			
Lot A			
1	3070	19,700	
4	1535	65,800	
7	920	307,900	
Lot B			
2	3070	3,700	4,050
3	3070	4,400	
5	1535	73,500	73,600
6	1535	73,700	
8	920	412,100	426,050
9	920	580,000	

TABLE 11. CONTINUED

Specimen and Group	Maximum Load (Total Lbs.)	Cycles to Failure	Average Cycles to Failure
Group 3: AC Welds wire brush			(Lot B)
Lot A			
1	3070	6,200	
4	1535	89,300	
7	920	512,100	
Lot B			
2	3070	5,400	6,050
3	3070	6,700	
5	1535	81,500	81,150
6	1535	80,800	
8	920	287,500	275,800
9	920	264,100	
Group 4: 5 rivets			
1	3070	6,200	
2	3070	8,200	6,400
3	3070	4,800	
4	1535	89,300	
5	1535	99,800	109,600
6	1535	139,700	
7	920	719,300	
8	920	406,300	597,000
9	920	665,400	
Group 5: 12 rivets			
1	3070	11,300	
2	3070	10,300	10,300
3	3070	9,300	
4	1535	140,200	
5	1535	129,700	148,400
6	1535	175,200	
7	920	2,167,800	
8	920	1,137,300	1,503,600
9	920	1,205,600	

Note: All tests at load ratio of 0.25.

TABLE 13. FATIGUE STRENGTH AS A FUNCTION OF SPOT SIZE IN SPOT WELDS MADE WITH DIFFERENT SURFACE PREPARATION

Specimen	Lbs., Total Load	Cycles to Failure	Corona Diameter, Inches (Total)	Corona Area*, Square Inches	Nugget Diameter, Inches	Nugget Area, Sq. Inches	Weld Penetration, % of Total Sheet (2 X 0.040)
AC-WB-#1	3070	8300	0.278	.0502	0.115	.0104	50
AC-WB-#2	3070	5400	0.288	.0389	0.183	.0264	65
AC-WB-#7	920	512,100	0.275	.0469	0.126	.0125	50
AC-WB-#8	920	287,500	0.290	.0416	0.177	.0246	65
DC-WB-#1	3070	15,300	0.230	.0242	0.149	.0174	50
DC-WB-#2	3070	14,100	0.250	.0275	0.166	.0216	65
DC-WB-#7	920	2,243,800	0.285	.0384	0.180	.0255	65
DC-WB-#8	920	600,000	0.265	.0269	0.190	.0283	65
DC-CC-#1	3070	19,700	0.260	.0277	0.180	.0265	50
DC-CC-#2	3070	3,700	0.256	.0202	0.200	.0314	65
DC-CC-#7	920	307,900	0.251	.0296	0.159	.0199	50
DC-CC-#8	920	412,100	0.258	.0218	0.197	.0305	50

AC - Alternating current
DC - Direct current
WB - Wire brush cleaned
CC - Chemically cleaned

* Area assumed bonded. The extent of bonding was estimated from the appearance of welds after the sheets were torn apart.

TABLE 12. APPROXIMATE JOINT EFFICIENCIES FOR SPECIMENS WITH VARYING SURFACE PREPARATIONS

Specimen Type	Joint Eff. in Per Cent at Various Lifetimes				
	10^4 Cycles	5×10^4 Cycles	10^5 Cycles	5×10^5 Cycles	10^6 Cycles
Spot welded	54-63	38-47	31-42	30-38	— -39
Riveted	58-64	42-47	40-44	36-41	36-41

Above are approximate limiting values from the scatter bands shown in Figure 3. Calculations use gross area in both cases and sheet data from Reference 3 page 302.

TABLE 14. WELDING CONDITIONS FOR PANELS FROM CALIFORNIA INSTITUTE OF TECHNOLOGY

Material:	0.040" to 0.040" Alclad 24S-T	
Machine:	Taylor-Winfield Hi-wave, condenser discharge welder, 440 line volts.	
Electrode pressure:	1100 lbs.	(constant)
Capacitance:	960 mfd.	(constant)
Voltage:	-----	(variable)
Throat:	3½ inches	(constant)
Arm:	9 1/2 inches	(constant)
Radius top electrode	4 inches	(constant)
Radius bottom electrode	4 inches	(constant)

Material cleaned in Oakite #63 and Oakite #64

Panel No.	Voltage
1	1350
2	1500
3	1600
4	1700
5	1800
6	1925
7	2025
8	2125
9	2250

TABLE 15. PROPERTIES OF SPOT WELDS FROM CALIFORNIA INSTITUTE OF TECHNOLOGY SPECIMENS

Panel Number	Avg. Weld Nugget Diameter		Avg. Corona Diameter (1)		Average Penetration, Inches	Max. Offset from Center Line, Inches	Max. Indentation on One Side, Inches	Average (2) Static Shear Strength, Pounds/Spot	Remarks
	Radiographs, Inches	Micrographs, Inches	Radiographs, Inches	Micrographs, Inches					
1	0.131±0.010	0.102±0.010	0.214±0.010	0.225±0.001	0.020±0.003	0	0.004	230±30	A few abnormally large welds are in this group. Some welds unbonded with included Alclad.
2	0.139±0.010	0.122±0.010	0.224±0.010	0.236±0.001	0.031±0.002	0	0.005	320±20	Very evenly shaped, no cracks or included Alclad in nugget.
3	0.170±0.010	0.162±0.005	0.247±0.010	0.249±0.001	0.037±0.003	0	0.006	419±20	Ditto #2
4	0.179±0.010	0.171±0.010	0.250±0.010	0.259±0.002	0.040±0.005	0.002	0.007	490±20	Nugget shape becomes distorted, otherwise OK.
5	0.198±0.010	0.193±0.005	0.260±0.004	0.270±0.001	0.051±0.005	0.003	0.007	570±10	Nugget rounded on one side.
6	0.213±0.010	0.202±0.010	0.271±0.010	0.283±0.002	0.058±0.005	0.004	0.007	583±5	Nugget approaching "dumbbell shape".
7	0.228±0.010	0.220±0.005	0.263±0.007	0.294±0.002	0.062±0.008	0.005	0.008	735±10	Some small transverse cracking.
8	0.244±0.010	0.245±0.005	0.301±0.010	0.312±0.005	0.065±0.005	0.007	0.010	963±10	Cracks and porosity
9	0.252±0.020	0.248±0.010	0.314±0.020	0.320±0.015	0.070±0.005	0.007	0.012	1075±40	Nugget melted through outer Alclad. A few abnormally small welds are in this group. All welds overheated with cracks, porosity and melting of outer Alclad.

(1) Total diameter of corona ring - not a direct measurement of corona area.
(2) Average of results from 3 specimens.

Note: Nearly all welds were round with respect to the surface having the same diameters parallel and perpendicular to the direction of testing.

TABLE 16. FATIGUE TEST RESULTS FOR SPECIMENS WITH A WIDE RANGE OF SPOT WELD SIZE AND STATIC STRENGTH VALUES

Specimens: 3" Wide, 0.040" - 0.040" Alclad 24S-T, 3 Spots in row Transverse to Loading

Specimen No.	Maximum Load Total Lbs.	Lbs./Spot	Lbs./In.	Cycles to Failure	Type of Break
Ratio .25					
HIC 1-3	522	174	174	59,000	Shear
1-4	398	133	133	1,613,900	Fatigue crack
1-2	318	106	106	2,958,000	
2-3	750	250	250	2,900	Shear
2-4	570	190	190	130,100	
2-2	474	158	158	831,900	
2-5	390	130	130	2,499,000	
3-3	900	300	300	4,800	
3-1	615	205	205	138,500	
3-2	393	131	131	1,206,200	
3-4	348	116	116	3,410,100	
4-1	736	245	245	800	Shear
4-3	735	245	245	46,900	
4-2	468	156	156	974,400	
4-4	390	130	130	4,158,000	
5-1	846	282	282	44,100	Pulled buttons
5-4	540	180	180	321,500	
5-3	339	113	113	>9,275,100	
Reload	1200	400	400	3,200	
6-1	864	288	288	17,200	
6-2	552	184	184	416,000	
6-3	480	160	160	818,000	
6-4	408	136	136	2,298,600	
7-1	1104	368	368	13,100	
7-4	840	280	280	82,700	
7-2	702	234	234	147,400	
7-3	450	150	150	2,351,800	
8-1	1428	476	476	5,500	
8-2	912	304	304	67,400	
8-3	630	210	210	331,100	
8-4	420	140	140	4,075,600	
9-1	1596	532	532	2,100	Pulled buttons
9-2	1014	338	338	102,900	
9-3	720	240	240	247,300	
9-4	450	150	150	>10,238,700	
Reload	1800	600	600	3,300	

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TABLE 17. SPECIFICATIONS FOR SPECIMENS WITH VARIOUS SPOT WELD PATTERNS

Specimen Designation	No. Rows	Total No. Spots	Spot Spacing (Inches)	Overlap (Inches)	Distance (2) Between Rows (Inches)	Remarks
0.016" sheet						
U1F-F	4	40 (1)	$\frac{1}{2}$	$1\frac{1}{2}$	(See Fig. 3)	Boeing joint
0.040" sheet						
3 B1C-D	1	6	3/4	1		
3 K1C-D	2	12	3/4	$1\frac{1}{2}$	$\frac{1}{2}$ L	
3 K1C-F	2	18	$\frac{1}{2}$	$1\frac{1}{2}$	$\frac{1}{2}$ L	
3 L1C-D	2	12	3/4	$1\frac{1}{2}$	$\frac{1}{2}$ S	
3 M1C-D	3	18	3/4	2	$\frac{1}{2}$ S	
3 M1C-F	3	29	$\frac{1}{2}$	2	$\frac{1}{2}$ S	
M2C-F	3	29	$\frac{1}{2}$	2	$\frac{1}{2}$ S	Post-aged (3) after welding
3 M3C-F	3	29	$\frac{1}{2}$	2	$\frac{1}{2}$ S	Post-aged before welding (3)
5 U1C-F	4	40 (1)	$\frac{1}{2}$	2	(See Fig. 3)	Boeing joint roll - welds
0.064" sheet						
3 B1E-D	1	6	3/4	1		
3 N1E-D	3	18	3/4	$2\frac{1}{2}$	3/4 S	
3 N2E-D	3	18	3/4	$2\frac{1}{2}$	3/4 S	Post-aged (3) after welding
3 N3E-D	3	18	3/4	$2\frac{1}{2}$	3/4 S	Post-aged before welding (3)

(1) In these tests, the total number of spots varied slightly from one specimen to another. Values given here are average ones. Slight variations in individual groups are discussed in the text.

(2) S denotes spots in adjacent rows staggered, L spots in line. See Figures 19, 20 and 21 for illustrations.

(3) Heat treated ten hours at 370°F.

TABLE 18. STATIC TEST RESULTS FOR SHEET USED IN SPOT WELD PATTERN SPECIMENS

(All Sheet 24S-T Alclad)
(All Test Pieces 1" Wide at Center Section)

Specimen	Gage (Inches)	Ultimate (p.s.i.)	Yield (0.2% in 2") (p.s.i.)	Elongation (in 2") (%)
As Received				
A1F 8	0.016	66,250	45,600	13.2
A1F 9	0.016	66,250	46,100	13.9
3 A1C 12	0.040	66,200	46,800	14.2
3 A1C 13	0.040	66,700	45,600	14.1
5 A1C 9	0.040	67,200	43,680	14.3
5 A1C 10	0.040	67,200	43,680	16.6
3 A1E 12	0.064	69,900	50,266	16.2
3 A1E 13	0.064	69,900	50,266	16.4
Post-Aged*				
3 A2C 22	0.040	68,700	64,200	4.5
3 A2C 23	0.040	69,000	63,900	4.4
3 A2E 20	0.064	73,200	68,300	4.8
3 A2E 21	0.064	73,200	67,900	4.5

* Heat treated ten hours at 370°F.

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TABLE 19. WELDING CONDITIONS FOR LAP JOINTS WITH VARIOUS SPOT PATTERNS

Machine: Federal Spot Welding Machine, Model P3-12-RA
Roytheon Condenser Discharge Unit, Spec. No. W-4508.

Specimen Groups	Degreasing	Etchant
	Surface Preparation	
3 B1C-D, 3 K1C-D, 3 K1C-F,) 3 L1C-D, 3 M1C-D, 3 M1C-F,) 3 B1E-D, 3 N1E-D, 3 N2E-D,) 3 N3E-D	Diversey	Clepo
3 M2C-F, 3 M3C-F	Acetone dip and wipe	R.P.I. Sol'n. 14

Specimen Groups	Tip Force (Lbs.)	K.V.	Mfd.	Turns Ratio
	Machine Settings			
3 B1C-D, 3 K1C-D, 3 K1C-F,) 3 L1C-D, 3 M1C-D, 3 M1C-F,) 3 M2C-F, 3 M3C-F	1200	1.75	800	195
3 B1E-D, 3 N1E-D, 3 N2E-D	2000	1.98	1800	390
3 N3E-D	2000	1.80	1800	390

Note: 3" Rad. dome tips used for all groups.

TABLE 20. WELDING CONDITIONS FOR BOEING JOINT SPECIMENS

1. Details for joints in 0.016" sheet are not available. Conditions were those of commercial practice.

2. Joints in 0.040" sheet were made on a Federal Condenser Discharge Roll Spot Welder, Serial 8908, 440 volt, 60 cycles. Conditions:

   Etch - Six minutes in Oakite 84-A
   Upper Wheel: (10" diameter
   ($\frac{1}{2}$" wide face with $1\frac{1}{2}$" radius

   Lower Wheel: ($11\frac{1}{2}$" diameter
   (7/8" wide flat face

Note: Spots not exactly in chain alignment, but same as those being made for airplanes.

TABLE 21. STATIC STRENGTH FOR LAP JOINTS WITH VARIOUS SPOT PATTERNS

Specimen Group	Total Lbs.	Lbs. per Spot	Joint Eff. (%)
U1F-F	3,630	61	68
3 B1C-D	3,805	634	29
3 K1C-D	6,930	577	52
3 K1C-F	8,970	500	68
3 L1C-D	6,615	550	50
3 M1C-D	8,860	493	67
3 M1C-F	10,250	354	77
3 M2C-F	9,360	319	68*
3 M3C-F	11,050	381	80*
5 U1C-F	9,700	226	72
3 B1E-D	6,970	1,161	31
3 N1E-D	14,750	820	66
3 N2E-D	17,170	955	75*
3 N3E-D	18,240	1,013	80*

*Used static ultimate of post-aged sheet.

TABLE 22. FATIGUE TEST RESULTS FOR MONOBLOCK SPECIMENS OF SHEET USED FOR BOEING JOINT SPECIMENS

Specimen No.	Maximum Load Total Lbs.	Maximum Load p.s.i.	Cycles to Failure	Position of Break
(0.016" gage as received) Ratio .25				
A1F 5	1024	64,000	28,400	Failed 1/8" off ctr.
4	966	60,000	31,100	Failed in center
2	836	52,000	72,700	Failed 1/16" off ctr.
1	640	40,000	368,000	Failed 5/8" off ctr.
6	578	35,000	3,147,300	Failed in center
3	482	30,000	> 9,947,100	Did not fail
Reload	644	40,000	306,400	Failed in center
Ratio .60				
A1F 10	966	60,000	551,400	Failed 1/2" off ctr.
12	912	57,000	545,200	" " " "
11	880	55,000	2,708,500	Failed 11/32" off ctr.
7	800	50,000	>10,168,800	Did not fail
Reload	976	62,000	497,100	Failed 1/8" off ctr.
(0.040" gage as received) Ratio .25				
5 A1C 8	2600	65,000	32,800	
3	2410	60,000	63,600	
1	2010	50,000	117,100	
2	1610	40,000	262,500	
4	1360	34,000	563,400	
5	1044	26,000	2,384,900	
Ratio .60				
5 A1C 7	2400	60,000	239,800	
6	1800	45,000	2,942,800	

TABLE 23. FATIGUE TEST RESULTS FOR MONOBLOCK SPECIMENS OF 0.040" 24S-T ALCLAD

Specimen No.	Maximum Load Total Lbs.	Maximum Load p.s.i.	Cycles to Failure	Position of Break
Ratio .25		As received		
3 A1C 6	2600	65,000	26,000	Failed in center
5	2400	60,000	49,200	" " "
2	2000	50,000	101,000	Failed 1/4" off center
4	1760	44,000	171,300	Failed in center
1	1520	38,000	301,000	Failed 1/2" off center
17	1288	33,000	410,200	Failed 7/16" off center
3	1200	30,000	775,100	Failed 1/8" off center
7	1080	27,000	910,200	Failed 1/2" off center
9	1020	25,500	2,333,200	Failed in center
8	960	24,000	7,546,900	Failed in lower grip
Ratio .50				
3 A1C 15	2605	65,000	99,500	Failed 3/8" off center
11	2205	55,000	206,100	Failed 1/4" off center
14	1522	38,000	1,434,800	Failed in center
16	1440	36,000	2,946,400	Failed 1/4" off center
18	1320	33,000	>11,347,700	Did not fail
Reload	2000	50,000	224,800	Failed in center
Ratio .75				
3 A1C 10	2600	65,000	805,600	Failed in center
21	2210	55,000	4,423,600	
Ratio .25		Post-aged*		
3 A2C 26	2000	50,000	72,200	Failed in center
25	1600	40,000	145,200	Failed 1/8" off center
20	1200	30,000	469,300	Failed 1/2" off center
24	972	25,000	>11,835,800	Did not fail
Reload	1556	40,000	55,400	Failed 1/4" off center
30	2400	60,000	30,200	Failed 1/4" off center

* Heat treated ten hours at 370°F.

TABLE 24. FATIGUE TEST RESULTS FOR MONOBLOCK SPECIMENS OF 0.064" 24S-T ALCLAD

Specimen No.	Maximum Load Total Lbs.	Maximum Load p.s.i.	Cycles to Failure	Position of Break
Ratio .25	As received			
3 A1E 9	4224	66,000	36,400	Failed 1/8" off ctr.
8	3840	60,000	48,400	Failed ½" off center
6	3200	50,000	53,600	
1	2560	40,000	201.300	Failed in center
2	2180	34,000	439,300	" " "
3	1860	29,000	894,500	Failed 7/16" off ctr.
7	1730	27,000	>10,273,300	Removed unbroken
4	1600	25,000	> 9,900,000	Removed unbroken
Ratio .25	Post-aged*			
3 A2E 17	4550	71,000	5,800	Failed ½" off ctr.
16	3840	60,000	33,000	Failed 5/8" off center
18	3644	57,000	34,200	Failed 1/8" off center
14	3200	50,000	113,600	Failed 1/16" off center
10	2560	40,000	187,600	Failed 3/4" off center
11	1920	30,000	756,800	Failed ½" off ctr.
15	1730	27,000	>10,705,700	
Reload	2560	40,000	176,900	

*Heat treated ten hours at 370°F.

TABLE 25. FATIGUE TEST RESULTS FOR LAP JOINT SPECIMENS WITH A SINGLE ROW OF SPOT WELDS

(Group 3 B1C-D 0.040" Sheet)*

Specimen No.	Maximum Load			Cycles to Failure	Remarks
	Total Lbs.	Lbs./ Spot	Lbs./ Inch		
Ratio .25					
3 B1C-1 D	3200	533	640	300	Pulled buttons
2	2000	666	400	9,700	" "
3	1250	208	250	397,300	Fatigue cracks
5	1000	167	200	1,132,300	Fatigue cracks
6	900	150	180	1,015,600	Fatigue cracks
8	775	129	155	2,386,500	Fatigue cracks
11	650	108	130	> 10,003,100	" "
Reload	1200	200	240	376,700	" "
Ratio .60					
3 B1C-9 D	3000	500	600	4,400	Five pulled buttons, 1 shear
4	2000	333	400	121,000	Five pulled buttons
7	1250	208	250	1,170,700	Fatigue cracks
12	1000	166	200	>10,807,800	Did not fail
Reload	1800	300	360	108,700	Pulled buttons
10	950	158	190	>10,141,500	Did not fail
Reload	2500	416	500	11,000	Pulled buttons

* Specimen 3 B1C-D: Single row of spots 3/4" apart in 1" overlap.

TABLE 26. FATIGUE TEST RESULTS FOR LAP JOINT SPECIMENS WITH TWO ROWS OF SPOT WELDS

(Group 3 K1C-D 0.040" Sheet)*

Specimen No.	Maximum Load			Cycles to Failure
	Total Lbs.	Lbs./Spot	Lbs./Inch	
Ratio .25				
3 K1C-3D	4000	333	800	2,300
1	3000	250	600	13,700
12	3000	250	667	18,200
2	2500	208	500	105,100
14	2400	200	533	92,600
4	1800	150	360	541,200
13	1800	150	400	349,500
5	1400	117	280	1,393,800
7	1250	104	250	3,244,800
Ratio .60				
3 K1C-8D	1800	150	360	1,745,900
9	1400	117	280	> 36,001,400

*Specimens 3 K1C-D: Spot spacing within each row 3/4". Distance between rows 1/2". Spots of alternate rows in line (of load); overlap 1 1/2".

TABLE 27. FATIGUE TEST RESULTS FOR LAP JOINT SPECIMENS WITH TWO ROWS OF SPOT WELDS

(Group 3 K1C-F 0.040" Sheet)*

Specimen No.	Maximum Load Total Lbs.	Maximum Load Lbs./Spot	Maximum Load Lbs./Inch	Cycles to Failure
Ratio .25				
3 K1C-9F	5000	277	1000	6,500
8	4000	222	800	21,600
1	3000	167	600	72,500
2	1800	100	360	476,100
3	1800	100	360	568,000
5	1500	83	300	6,614,500
6	1000	56	200	>10,786,400
Ratio .60				
3 K1C-13F	6000	333	1200	11,500
11	4500	250	900	95,000
7	3000	167	600	774,900
10	1800	100	360	1,707,800
12	1400	78	280	>12,210,100
Reload	3000	167	600	1,001,700

*Specimens 3 K1C-F: Spot spacing within each row $\frac{1}{2}$".
Distance between rows $\frac{1}{2}$".
Spots of alternate rows in line (of load); overlap $1\frac{1}{2}$".

TABLE 28. FATIGUE TEST RESULTS FOR LAP JOINT SPECIMENS WITH TWO ROWS OF SPOT WELDS

(Group 3 L1C-D 0.040" Sheet)*

Specimen No.	Maximum Load Total Lbs.	Maximum Load Lbs./Spot	Maximum Load Lbs./Inch	Cycles to Failure
Ratio .25				
3 L1C-2D	4000	333	800	3,500
5	3400	283	680	7,700
1	2400	200	480	83,300
3	1750	146	350	331,000
6	1300	108	260	913,000
8	1000	83	200	>11,582,200
Ratio .60				
3 L1C-9D	4500	375	900	34,600
4	3400	283	680	126,800
7	2000	167	400	1,072,400
10	1750	146	350	>10,269,100
Reload	2500	209	500	723,100

*Specimens 3 L1C-D: Spot spacing within each row 3/4".
Distance between rows 1/2".
Spots of alternate rows staggered.
Overlap 1 1/2".

TABLE 29. FATIGUE TEST RESULTS FOR LAP JOINT SPECIMENS WITH THREE ROWS OF SPOT WELDS STAGGERED

(Group 3 M1C-D 0.040" Sheet)*

Specimen No.	Maximum Load			Cycles to Failure	Remarks
	Total Lbs.	Lbs./Spot	Lbs./Inch		
Ratio .25					
3 M1C-2D	6000	333	1200	2,700	
13	5000	278	1000	13,450	
10	4400	244	880	62,700	Result uncertain. Load varied during test.
12	3800	211	760	71,800	
1	3000	167	600	133,100	
6	2400	133	480	180,100	
3	1700	94	340	1,146,700	
5	1400	78	280	>10,694,500	
Reload	2200	122	440	363,300	
Ratio .60					
11	8000	444	1600	1,000	
8	6000	333	1200	27,500	
7	4000	222	800	175,200	
4	3000	167	600	623,000	
9	1800	100	360	4,301,700	

*Specimens 3 M1C-D: Spot spacing within each row 3/4".
Distance between rows 1/2".
Spots of alternate rows staggered.
Overlap 2".

TABLE 30. FATIGUE TEST RESULTS FOR LAP JOINT SPECIMENS WITH THREE ROWS OF SPOT WELDS

(Group 3 M1C-F 0.040" Sheet)*

Specimen No.	Maximum Load			Cycles to Failure
	Total Lbs.	Lbs./Spot	Lbs./Inch	
Ratio .25				
3 M1C-16F	8000	276	1600	2,900
3	7000	241	1400	12,000
1	6000	207	1200	18,600
2	4200	145	840	60,600
4	2800	97	560	382,500
5	2400	83	480	811,000
6	2000	69	400	1,476,100
10	1600	55	320	> 9,468,500
Ratio .60				
3 M1C-15F	9400	324	1880	7,800
9	8000	275	1600	32,700
8	6000	207	1200	134,000
14	4700	161	940	212,500
7	3800	131	760	1,965,800
13	3000	103	600	>12,626,600
Reload	3800	131	760	857,000

*Specimens 3 M1C-F: Spot spacing within each row 1/2".
Distance between rows 1/2".
Spots of alternate rows staggered.
Overlap 2".

TABLE 31. FATIGUE TEST RESULTS FOR LAP JOINT SPECIMENS WITH THREE ROWS OF SPOT WELDS

(Group 3 M2C-F 0.040" Sheet)*

Specimen No.	Maximum Load Total Lbs.	Maximum Load Lbs./Spot	Maximum Load Lbs./Inch	Cycles to Failure
Ratio .25				
3 M2C- 6F	6000	207	1200	5,800
2	3800	131	760	75,900
1	2400	184	480	396,200
3	1800	62	360	856,000
4	1400	48	280	>11,360,300
Reload	3200	110	640	100,300
Ratio .60				
3 M2C-10F	7500	258	1500	12,100
7	6000	207	1200	27,400
5	4000	138	800	218,600
9	3000	104	600	1,134,100

*Specimens 3 M2C-F Spot spacing within each row 1/2".
Distance between rows 1/2".
Spots of alternate rows staggered.
Overlap 2".
Post-aged after welding (heat treated 10 hrs. at 370°F.)

TABLE 32. FATIGUE TEST RESULTS FOR LAP JOINT SPECIMENS WITH THREE ROWS OF SPOT WELDS

(Group 3 M3C-F 0.040" Sheet)*

Specimen No.	Maximum Load Total Lbs.	Maximum Load Lbs./Spot	Maximum Load Lbs./Inch	Cycles to Failure	Remarks
Ratio .25					
3 M3C-4F	7000	241	1400	11,800	
1	5500	190	1100	23,700	
2	3800	131	760	101,500	
3	2600	90	520	320,800	
8	2000	69	400	2,716,900	
10	1700	60	340	>10,344,600	
Reload	3800	131	760	118,400	
Ratio .60					
3 M3C-6F	6000	207	1200	96,800	
5	3800	131	760	700,700	
7	2800	97	560	1,667,000	Result uncertain. Load varied during run.
9	2400	83	480	>11,161,700	
Reload	3800	131	760	750,800	

*Specimens 3 M3C-F: Spot spacing within each row 1/2".
Distance between rows 1/2".
Spots of alternate rows staggered.
Overlap 2".
Post-aged before welding (heat treated 10 hours at 370°F.)

TABLE 33. FATIGUE TEST RESULTS FOR LAP JOINT SPECIMENS WITH BOEING TYPE SPOT WELD PATTERN

(Group U1F-F Boeing Joint in 0.016" Sheet)*

Specimen No.	Maximum Load Total Lbs.	Lbs./Spot	Lbs./Inch	Cycles to Failure
Ratio .25				
U1F 11 F	3000	75	600	10,600
2	2000	50	400	40,900
1	1580	39	318	87,600
17	1400	35	280	109,200
3	1250	31	250	114,400
4	1000	25	200	207,200
5	750	19	150	485,200
6	500	12.5	100	1,021,100
7	360	9	72	2,204,400
12	260	6.5	52	>10,044,700
Reload	3000	75.0	600	100
Ratio .60				
14	3000	75	608	34,200
13	2000	50	400	141,700
18	1400	35	280	436,800
19	1000	25	200	1,067,000
20	720	18	144	1,528,500

*Specimens U1F-F: Spot spacing within each row 1/2".
No. of rows of spots - 4.
Distance between inner rows 3/4".
Distance between outer rows 1 1/8".
Overlap 1 1/2".

TABLE 34. FATIGUE TEST RESULTS FOR LAP JOINT SPECIMENS 0.040 INCH BOEING TYPE JOINT

(Group 5 U1C-F - 0.040 Inch Sheet)*

Specimen No.	Maximum Load Total Lbs.	Lbs./Weld	Lbs./In.	Cycles to Failure
Ratio .25				
5 U1C-11F	7500	178	1500	4,400
9	6000	143	1200	12,000
1	4200	100	840	38,600
2	3000	70	600	137,100
4	1750		350	1,283,900
10	1500	35	300	3,141,400
6	1250	29	250	>13,591,000
Reload	4000	93	800	39,900
Ratio .60				
5 U1C-12F	7500	183	1500	23,500
8	5700	129	1140	78,300
2	3000	70	600	137,100
7	2200	53	440	2,863,500
13	1850	42	370	>34,000,000

* Specimens 5 U1C-F - 4 rows of roll welds 1/2" spaced
7/8" between center rows
1-3/4" between outer rows
2" overlap

TABLE 35. FATIGUE TEST RESULTS FOR LAP JOINT SPECIMENS WITH ONE ROW OF SPOT WELDS

(Group 3 B1E-D - 0.064" Sheet) *

Specimen No.	Maximum Load			Cycles to Failure
	Total Lbs.	Lbs./Spot	Lbs./In.	
Ratio .25				
3 B1E-14D	4000	667	800	5,500
1	3000	500	600	35,300
12	2400	400	480	116,700
3	1750	291	350	639,500
4	1300	217	260	1,297,100
5	1100	183	220	1,573,600
6	850	142	170	> 10,000,000
Reload	2400	400	480	136,500
Ratio .60				
3 B1E-10D	5200	867	1040	1,700
8	4000	667	800	78,500
7	2000	333	400	1,262,100
11	1500	250	300	3,700,000
13	1200	200	240	> 20,433,400

* Spot welds 3/4" spaced
1" overlap

TABLE 36. FATIGUE TEST RESULTS FOR LAP JOINT SPECIMENS WITH THREE ROWS OF SPOT WELDS (0.064" SHEET)

Specimen No.	Maximum Load			Cycles to Failure
	Total Lbs.	Lbs./Spot	Lbs./In.	
Ratio .25	As received (Group 3 N1E-D) (1)			
3 N1E-1D	6000	333	1200	43,000
2	4000	222	800	127,500
3	2600	144	520	586,800
5	1500	83	300	2,544,000
7	900	50	180	> 11,879,600
Ratio .60				
3 N1E-9D	7000	388	1400	335,200
4	5000	278	1000	567,300
6	2800	156	560	4,324,600
Ratio .25	Post-aged(2) after welding (Group 3 N2E-D)(1)			
3 N2E-1D	6000	333	1200	29,100
2	4000	222	800	87,700
3	2400	133	480	499,800
5	1600	89	320	1,301,600
7	1250	69	250	2,448,200
Ratio .60				
3 N2E-4D	5000	278	1000	385,300
6	3500	194	700	907,900
Ratio .25	Sheet post-aged(2) before welding (Group 3 N3D-D (1)			
3 N3E-3D	7500	417	1500	24,300
1	3800	211	760	168,200
8	2400	133	480	421,100
2	1500	83	300	4,690,200
4	950	52	190	> 7,925,000
Reload	1900	105	380	527,600

(1) Specimens 3 N1E-D, 3 N2E-D, and 3 N3E-D:
3 rows of spot welds staggered
3/4" between rows
3/4" spacing within the rows

(2) Heat treated 10 hours at 370°F.

TABLE 37. JOINT EFFICIENCY VALUES FOR SPOT-WELDED PATTERNS

	Static	Various Lifetimes for R = 0.25					
		10^4	4×10^4	10^5	4×10^5	10^6	4×10^6
0.040" 24S-T Alclad lap joints							
3 B1C-D	29	15	15	14	17	17	15
3 K1C-D	52	23	22.5	24	28	28	24
3 L1C-D	50	27	22.5	23	25	22	25
3 M1C-D	67	40	33	31	32	34	31
3 K1C-F	68	35	29	26	26	31	23
3 M1C-F	77	54	41	37	39	38	35
3 M2C-F	68	—	37	39	37.5	37	32
3 M3C-F	80	54	41	37	39	38	35
5 U1C-F	72	46	32	30	31	29	29
0.064" 24S-T Alclad lap joints							
3 B1E-D	31	17	15	17	17	16	11
3 N1E-D	66	—	31	30	26	22	14
3 N2E-D	75	—	29	25	23	19	13
3 N3E-D	80	—	33	30	26	22	14
0.016" 24S-T Alclad with Boeing type joints							
U1F-F	68	57	42	40	24	17	11

Joint efficiency here means the ratio of the fatigue strength of a gross width of joint to the fatigue strength of the same width of sheet at the same lifetime under the same load ratio.

TABLE 38. SPECIFICATIONS FOR RIVETED LAP JOINT SPECIMENS

Specimen Designation	Width (Inches)	No. Rows	Total No. Rivets	Rivet Spacing (Inches)	Overlap (Inches)	Distance(2) Between Rows (Inches)
P1C-D) (1)P2C-D)	4 1/2	1	6	3/4	3/4	
P1C-F	5	1	10	1/2	3/4	
Q1C-D	4 1/2	2	12	3/4	7/16	3/4 L
R1C-D	4 15/16	2	13	3/4	15/16	3/16 S
S1C-D	4 15/16	2	13	3/4	1 1/8	3/8 S
T1C-D	4 15/16	2	13	3/4	1 5/16	11/16 S

(1) P2C-D specimens were post-aged after riveting.
(2) S denotes rivets in adjacent rows staggered, L rivets in line.

Riveting Procedure

1. All material 0.040" Alclad 24S-T.
2. Rivets AN426AD-5, 100° countersunk, 5/32 D. Rivet material A17S-T specification An-FF-R551.
3. Both sheets drilled with hand motor using #21 (0.159") drill. Holes burred with countersunk type burring tool.
4. Surface skin dimpled 100° on one shot rivet gun (Chicago Pneumatic)
5. Sub-dimpled other skin 110° on same equipment.
6. Riveting performed with a Chicago Pneumatic Squeezer.

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TABLE 39. STATIC TEST RESULTS FOR RIVETED LAP JOINT SPECIMENS

Specimen Designation	Static Ultimate Values (1) Total lbs.	Lbs./Rivet	Lbs./Inch	Static Joint (2) Eff. (%)
P1C-D	4160	693	925	35
P2C-D	5130	855	1140	41
P1C-F	6940	694	1385	52
Q1C-D	8700	725	1935	75
R1C-D	8750	675	1762	67
S1C-D	9100	700	1820	69
T1C-D	9290	715	1858	70

(1) Note, in Table 1, that specimens of different groups differ considerably in width.

(2) Joint efficiencies are based on gross width of the jointed test pieces and on 66,700 p.s.i. static ultimate for as received sheet and 69,000 static ultimate for post aged sheet.

TABLE 40. FATIGUE TEST RESULTS FOR LAP JOINT SPECIMENS WITH ONE ROW OF FLUSH RIVETS

(Group P1C-D) (1) As received

Specimen No.	Maximum Load Total Lbs.	Lbs./Rivet	Lbs./In.	Cycles to Failure
Ratio .25				
P1C-25D	3800	633	864	17,500
22	3600	600	823	22,600
10	3000	500	668	55,000
15	2550	425	570	93,300
2	2550	425	566	75,400
1	2400	400	534	101,600
14	2400	400	538	131,400
16	2100	350	466	175,900
3	2100	350	466	180,200
4	1800	300	400	305,600
5	1560	260	347	572,000
6	1350	225	300	937,800
7	1140	190	254	1,288,800
8	960	160	213	1,677,900
9	810	135	180	> 8,438,000
Ratio .50				
P1C-20D	3900	650	873	57,600
11	3000	500	668	228,500
17	2400	400	526	423,800
18	1800	300	406	704,300
19	1440	240	322	2,406,300
Ratio .60				
P1C-26D	3800	633	858	186,600
27	2800	467	626	318,800
28	2000	333	448	927,300
30	1700	283	390	1,773,900
29	1600	267	360	1,680,900
31	1500	250	337	3,730,000
Ratio .75				
P1C-23D	3900	650	880	747,300
24	3300	550	745	1,828,900
21	3000	500	678	8,008,200
(Group P2C-D) (1) Post-aged (2)				
Ratio .25				
P2C-49D	4500	750	1010	5,700
46	3380	565	762	29,700
43	2400	400	534	96,700
44	1680	280	374	261,300
45	1200	200	267	778,800
47	900	150	205	1,264,400
48	750	125	150	3,436,800

(1) Specimens P1C-D, P2C-D: 4-1/2" wide, single row of rivets 3/4" apart, 3/4" overlap.

(2) Heat treated 10 hours at 370°F.

TABLE 41. FATIGUE TEST RESULTS FOR LAP JOINT SPECIMENS WITH ONE ROW OF FLUSH RIVETS

(Group P1C-F) *

Specimen No.	Maximum Load Total Lbs.	Maximum Load Lbs./Rivet	Maximum Load Lbs./In.	Cycles to Failure
Ratio .25				
P1C-14 F	6000	600	1220	10,500
8	5100	510	1030	15,100
7	4500	450	914	23,800
3	3600	360	730	37,800
1	3000	300	608	101,200
2	2500	250	506	140,900
4	2000	200	405	923,800
5	1750	175	354	8,650,400
6	1700	170	344	9,381,300
Ratio .50				
P1C-10F	5000	500	1010	50,700
11	3500	350	700	188,900
18	2350	235	480	527,300
16	2250	225	450	467,200
Ratio .60				
P1C-23F	6000	600	1212	49,000
20	3800	380	772	253,200
21	2600	260	520	615,900
22	2300	230	467	634,600
24	2000	200	402	1,099,500
25	1800	180	370	4,377,000
Ratio .75				
P1C-17F	5500	550	1100	266,900
15	4200	420	846	539,600

* Specimens P1C-F: 5" wide, single row of rivets 1/2" apart, 3/4" overlap

TABLE 42. FATIGUE TEST RESULTS FOR LAP JOINT SPECIMENS WITH TWO ROWS OF FLUSH RIVETS. (GROUP Q1C-D)*

Specimen No.	Maximum Load Total Lbs.	Maximum Load Lbs./Rivet	Maximum Load Lbs./in.	Cycles to Failure
Ratio .25				
Q1C 9D	7500	576	1550	10,100
6	6000	500	1340	18,700
4	4800	400	1080	37,800
1	3600	300	810	89,000
2	2640	220	590	298,800
3	1920	160	427	1,665,000
5	1680	140	375	3,473,600
Ratio .50				
11	4200	350	940	142,200
14	3000	250	670	1,733,700
Ratio .60				
10	8000	666	1830	31,500
15	6000	500	1343	89,700
8	3800	292	840	453,600
7	3000	250	678	734,300
16	2500	192	559	> 9,972,000
Reload	3500	291	760	1,371,600

* Specimens Q1C-D. 4 1/2" wide. Two rows of rivets 3/4" spacing within each row. Distance between rows 3/4". Rivets of the two rows in line. Overlap 7/16".

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TABLE 43. FATIGUE TEST RESULTS FOR LAP JOINT SPECIMENS WITH TWO ROWS OF FLUSH RIVETS (GROUP R1C-D)*

Specimen No.	Maximum Load Total Lbs.	Lbs/Rivet	Lbs./in.	Cycles to Failure
Ratio .25				
R1C 7D	7500	577	1500	5,100
6	5500	422	1100	12,700
1	4000	308	800	37,000
2	2800	215	560	93,200
3	2000	154	400	436,200
4	1600	123	320	2,223,300
5	1350	104	270	3,941,800
8	1200	92	243	> 13,018,200
Reload	3000	231	608	97,800
Ratio .60				
15	8000	615	1600	32,600
11	6000	461	1200	70,600
10	4200	323	709	181,000
9	3000	231	608	1,292,700
16	2832	218	566	2,268,400
14	2700	208	544	8,242,300

* Specimens R1C-D. 4 15/16" wide. Two rows of rivets, 3/4" spacing within each row. Distance between rows 3/16". Rivets staggered. Overlap 15/16".

TABLE 44. FATIGUE TEST RESULTS FOR LAP JOINT SPECIMENS WITH TWO ROWS OF FLUSH RIVETS (GROUP S1C-D)*

Specimen No.	Maximum Load Total Lbs.	Lbs./Rivet	Lbs./in.	Cycles to Failure
Ratio .25				
S1C 14D	8400	646	1700	4,300
6	6800	522	1360	12,100
1	6000	461	1200	17,900
2	4000	308	810	60,000
3	3000	230	605	179,800
4	2200	170	446	695,000
7	1850	142	369	2,616,900
5	1700	131	342	> 10,060,400
Ratio .60				
15	8400	646	1700	25,800
8	6800	522	1360	61,400
10	5200	400	1040	156,000
9	4000	308	800	302,000
11	3000	230	600	4,116,400
19	3000	230	600	8,151,700

* Specimens S1C-D. 4 15/16" wide. Two rows of rivets, 3/4" spacing within each row. Distance between each row 3/8". Rivets staggered. Overlap 1 1/8".

TABLE 45. FATIGUE TEST RESULTS FOR LAP JOINT SPECIMENS WITH TWO ROWS OF FLUSH RIVETS (GROUP T1C-D)*

Specimen No.	Maximum Load			Cycles to Failure
	Total Lbs.	Lbs./Rivet	Lbs./in.	
Ratio .25				
T1C 5D	8000	615	1600	10,500
1	6000	461	1200	25,000
2	4400	338	894	68,000
3	2800	215	560	317,500
4	2200	169	228	1,533,800
6	2000	154	414	5,565,800
Ratio .60				
11	8500	654	1700	37,000
9	5400	415	1080	190,900
7	3800	292	760	1,889,200
10	3300	254	670	2,511,900
8	3000	230	608	7,600,000

* Specimens T1C-D. 4 15/16" wide. Two rows of rivets, 3/4" spacing within each row. Distance between each row 11/16". Rivets staggered. Overlap 1 5/16".

TABLE 46. JOINT EFFICIENCIES FOR RIVETED TEST PIECES

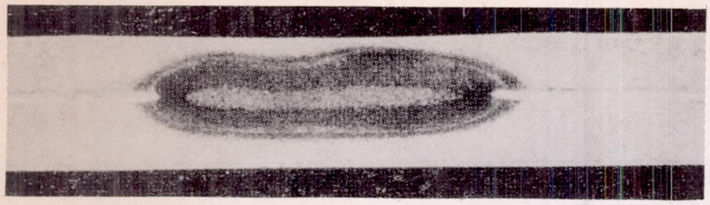
Specimen (1) Designation	Static	Joint Efficiency in Per Cent (2)					
		10^4 Cycles	4×10^4 Cycles	10^5 Cycles	4×10^5 Cycles	10^6 Cycles	4×10^6 Cycles
P1C-D	35	35	30	26	26	24	20
P2C-D	38	36	29	28	27	21	14
P1C-F	52	46	31	29	31		
Q1C-D	73	60	41	39	39	40	42
R1C-D	66	47	31	29	28	28	27
S1C-D	68	53	38	36	35	35	37
T1C-D	70	62	41	39	39	40	42

(1) For meaning of specimen designation, see Table 38.

(2) Defined as ratio of strength per inch of joint to strength at same lifetime of an inch width of monoblock sheet.

All fatigue joint efficiency values quoted above are for a load ratio R = 0.25.

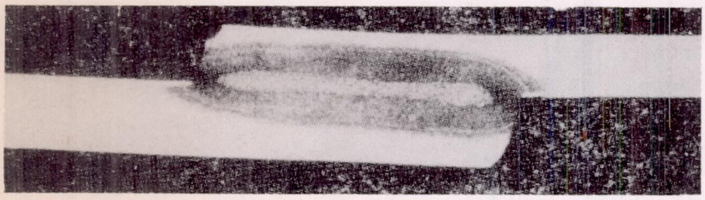
W-56



Keller's etch 10X
29159

(a)

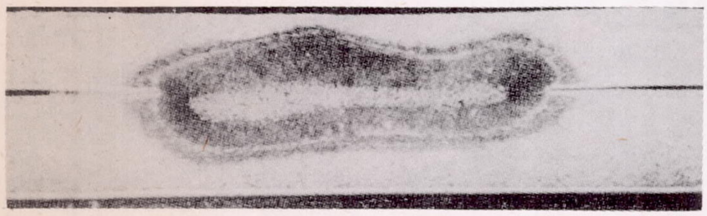
(a) 0.032" - 0.040"
As received



Keller's etch 10X
29159

(b)

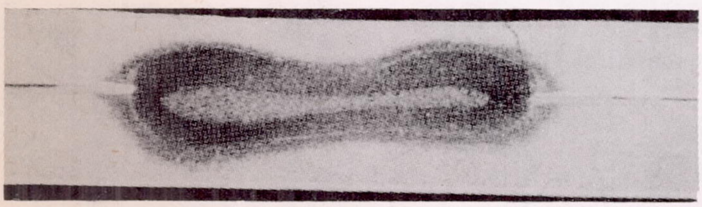
(b) 0.032" - 0.040"
Fatigue break



Keller's etch 10X
29160

(c)

(c) 0.040" - 0.051"
As received



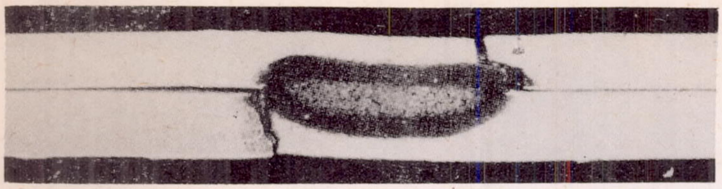
Keller's etch 10X
29161

(d)

(d) 0.040" - 0.051"
Fatigue break

Figure 1.- Spot welds in dissimilar gauge sheet - Company B welds.

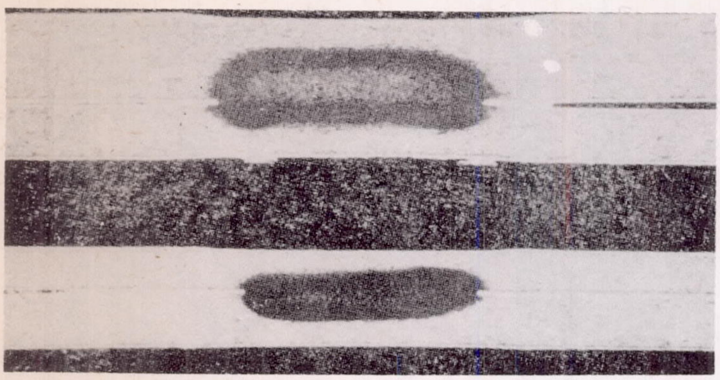
W-56



(a) 0.032" - 0.040" Fatigue break

Keller's etch 10X 29162

(a)

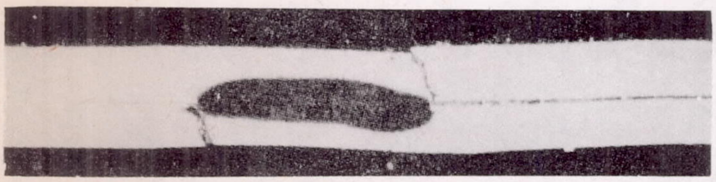


(b) 0.032" - 0.051" As received

(c) 0.032" - 0.025" As received

Keller's etch 10X 29163

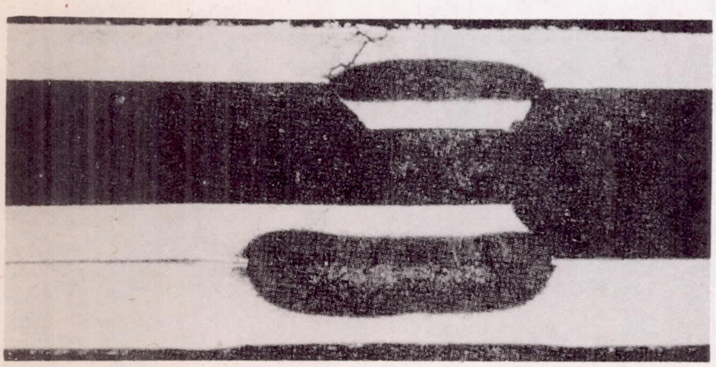
(b-c)



(d) 0.032" - 0.025" Fatigue break

Keller's etch 10X 29164

(d)



(e) 0.032" - 0.025" Fatigue break

(f) 0.032" - 0.051" Fatigue break

Keller's etch 10X 29164

(e-f)

Figure 2.- Spot welds in dissimilar gauge sheet - Company C welds.

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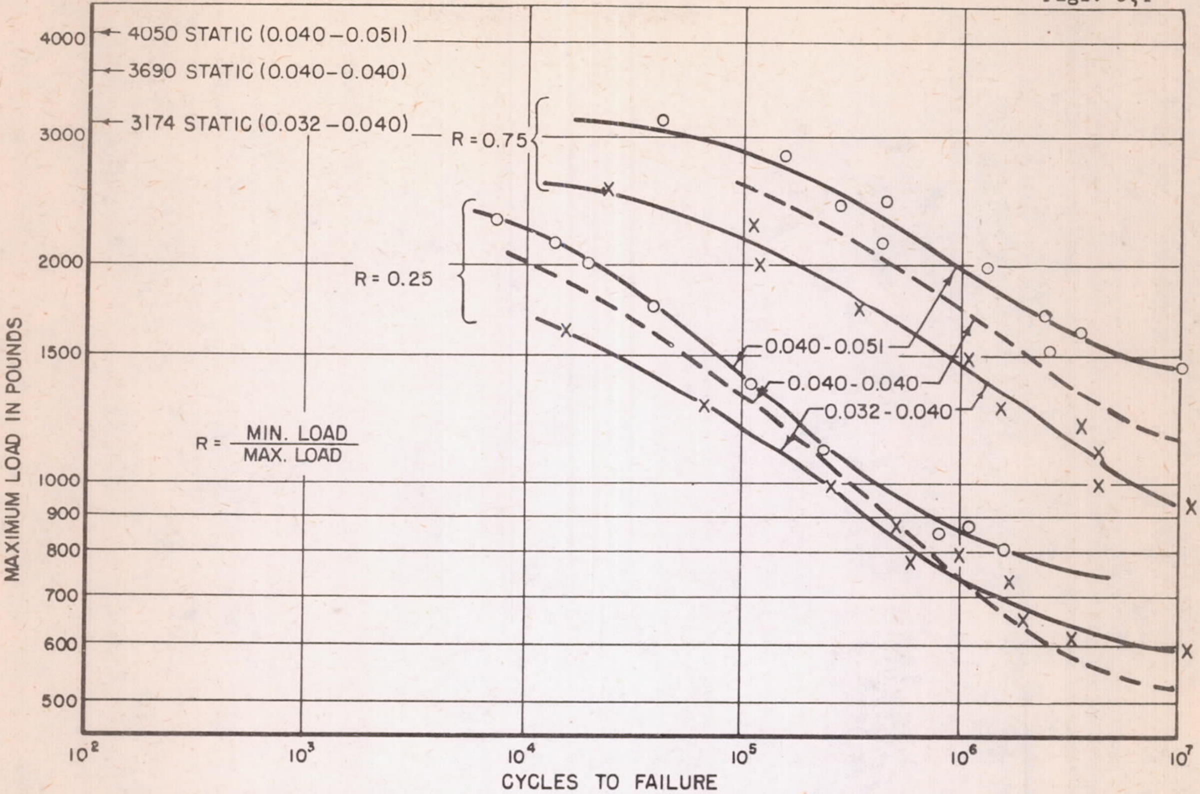


FIG. 3 — FATIGUE CURVES FOR SPOT-WELDED SHEETS OF DIFFERENT GAGES. (ALL SPECIMENS 5" WIDE, WITH 6 SPOT-WELDS, $\frac{3}{4}$" BETWEEN CENTERS, ON SCIAKY MACHINE.)

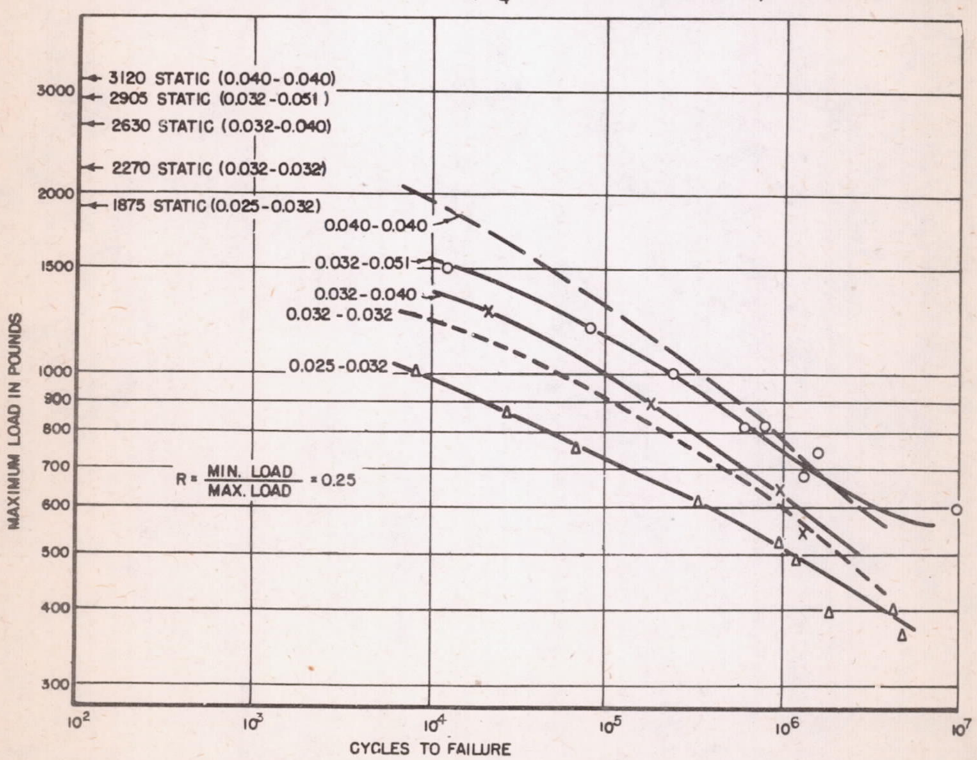


FIG. 4 - FATIGUE CURVES FOR SPOT-WELDED SHEETS OF DIFFERENT GAGES (ALL SPECIMENS 5" WIDE, WITH 6 SPOT WELDS, $\frac{3}{4}$" BETWEEN CENTERS, ON TAYLOR-WINFIELD MACHINE)

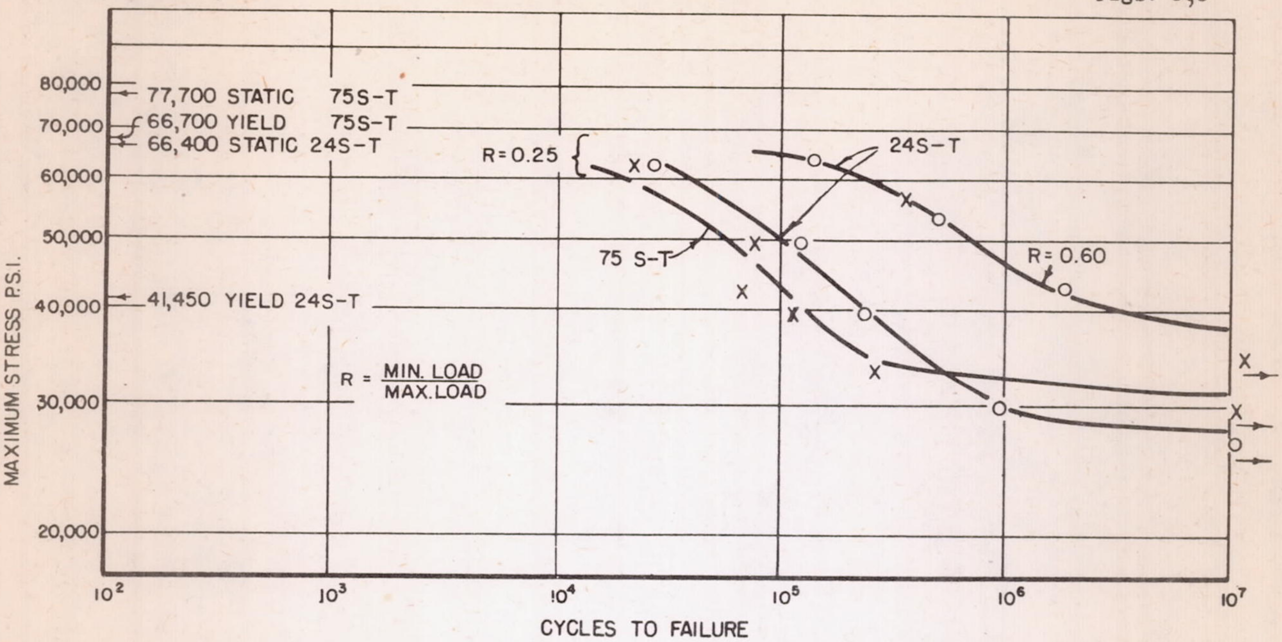


FIG. 5 - FATIGUE CURVES FOR MONOBLOCK SPECIMENS OF ALCLAD SHEET (24S-T AND 75S-T). (SPECIMENS 1.000" X 0.040" AT CENTER SECTION.)

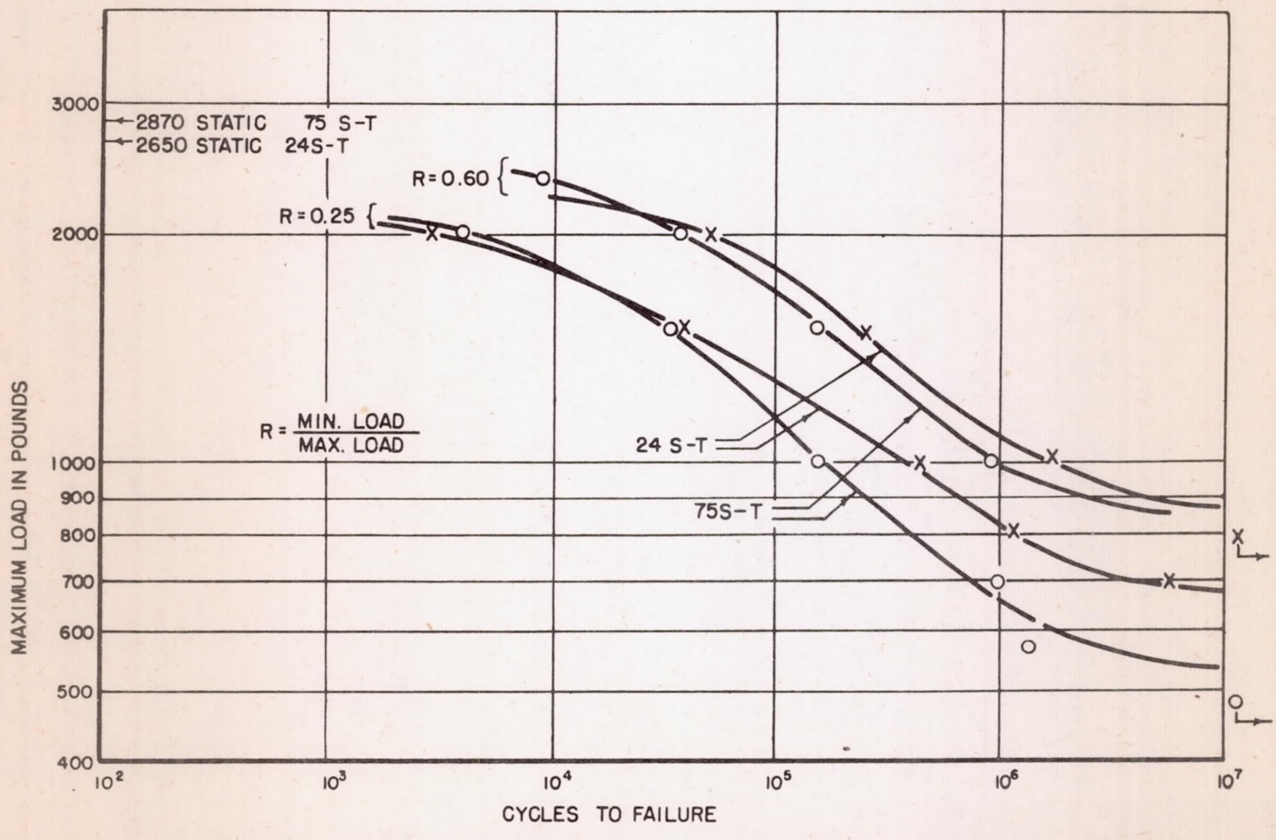
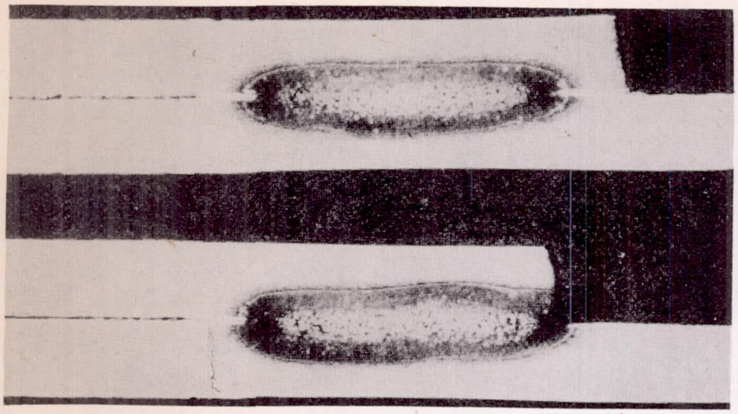


FIG. 6 - FATIGUE CURVES FOR SPOT-WELDED LAP JOINT SPECIMENS OF ALCLAD 75S-T AND OF ALCLAD 24 S-T.

W-56

W-56

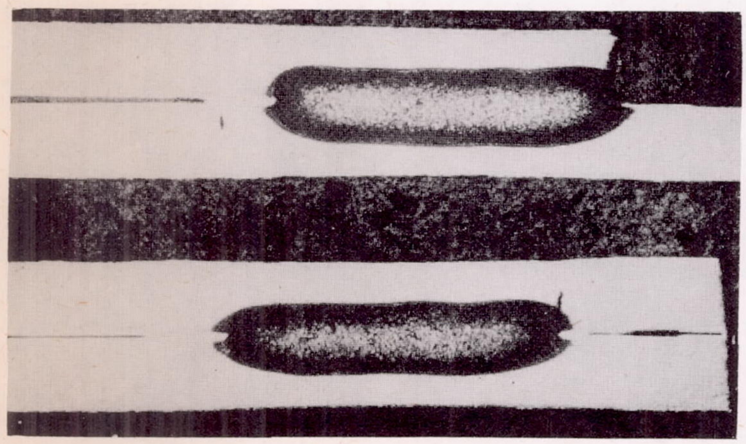


(a) 116 lbs./spot
R = 0.25

(b) 166 lbs./spot
R = 0.25

Keller's etch 10X
29165

24S-T Alclad



(c) 116 lbs./spot
R = 0.25

(d) 116 lbs./spot
R = 0.25

Keller's etch 10X
29166

75S-T Alclad

Figure 7.- Comparison of fatigued spot welds made in 24S-T Alclad and 75S-T Alclad sheet.

W-56

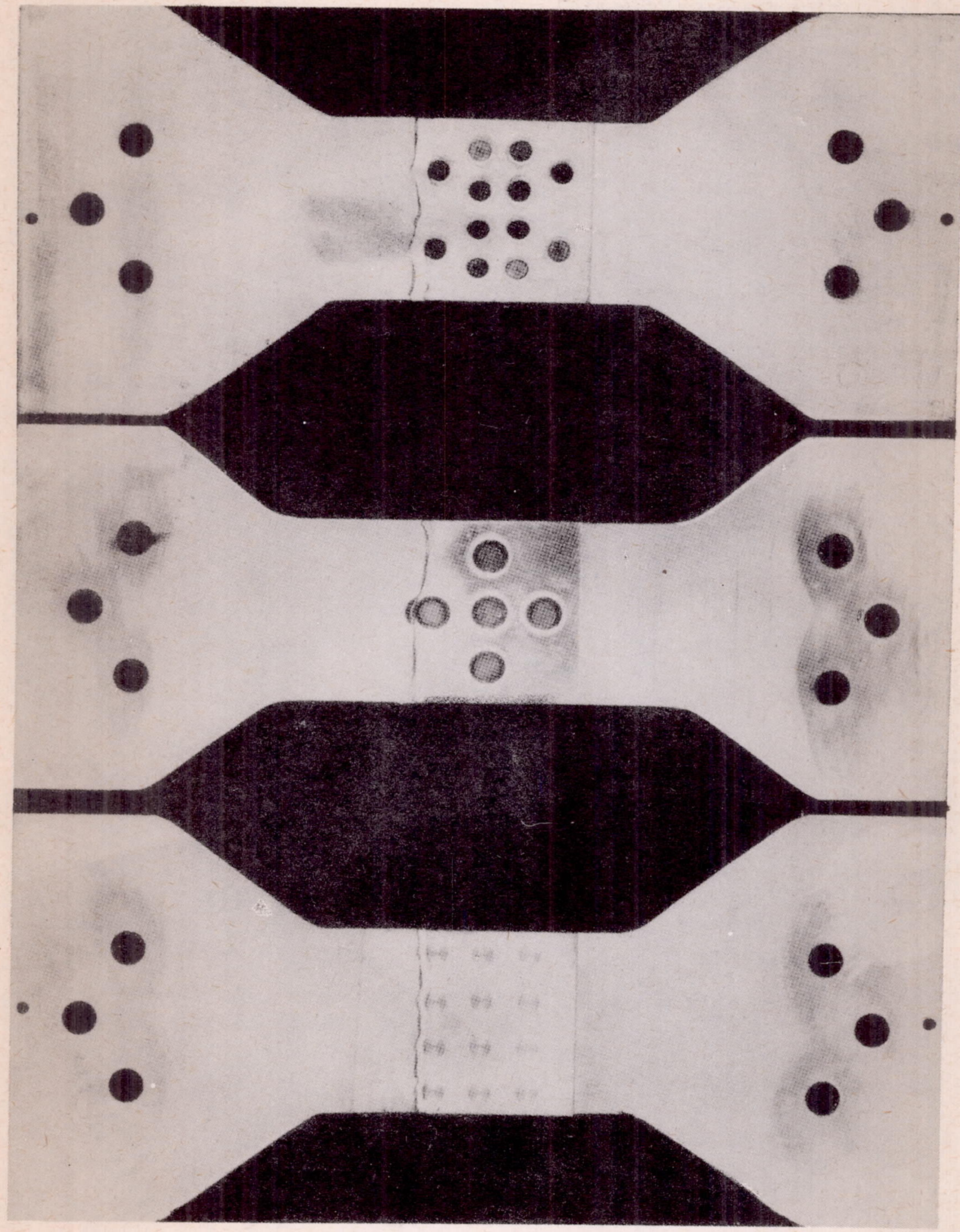


Figure 8.- Photograph of fatigue test pieces.

Each specimen was 10" long, and 2" wide at the center section, and had a 2" overlap. The material was 0.040" Alclad 24S-T.

W-56

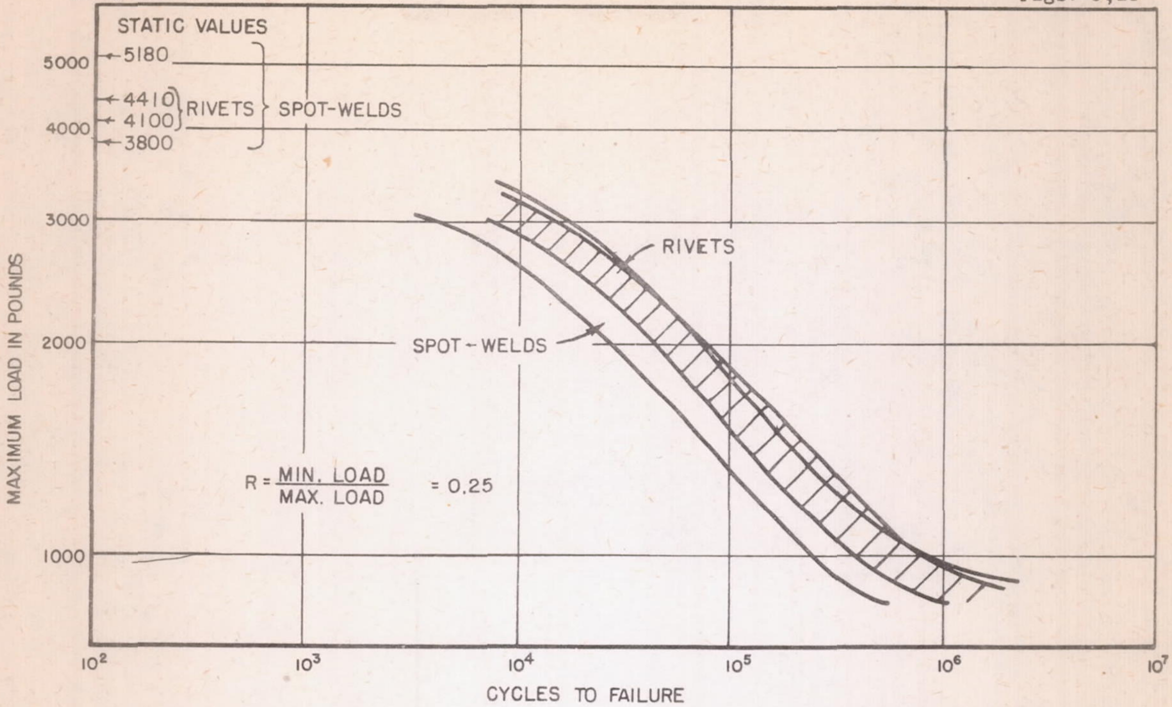


FIG. 9 - SCATTER BANDS FOR SPOT-WELD AND RIVET LAP JOINT SPECIMENS WITH DIFFERENT SURFACE PREPARATION.

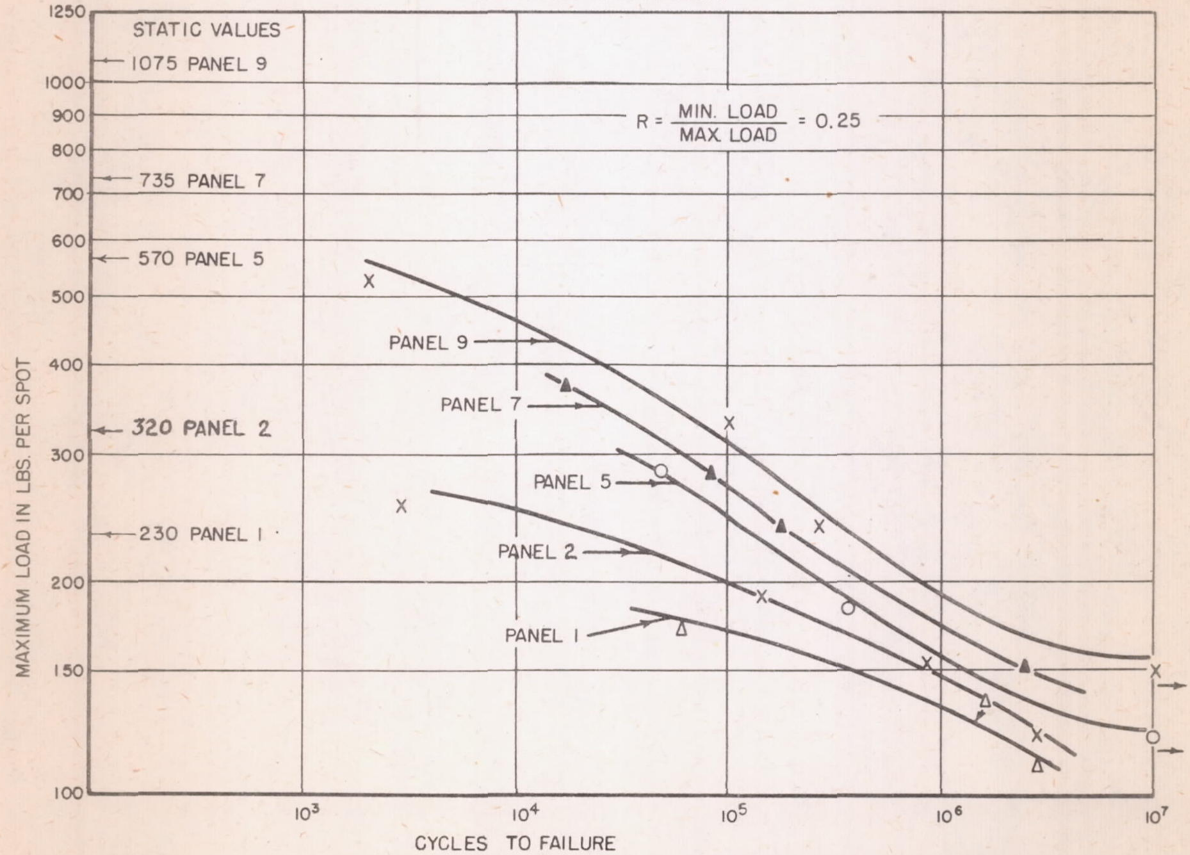
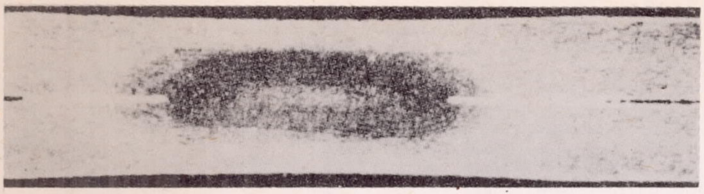


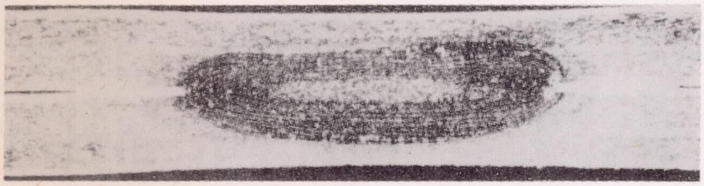
FIG. 14 - FATIGUE CURVES FOR SPOT-WELDED LAP JOINTS WITH VARYING WELD SIZE.

W-56



#1 - 3070 lbs.
8300 cycles

Keller's etch 10X
(a) 29677

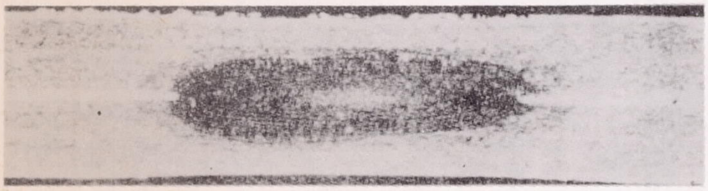


#2 - 3070 lbs.
5400 cycles

Keller's etch 10X
(b) 29678

#7 - 920 lbs.
512,100 cycles

Keller's etch 10X
(c) 29679

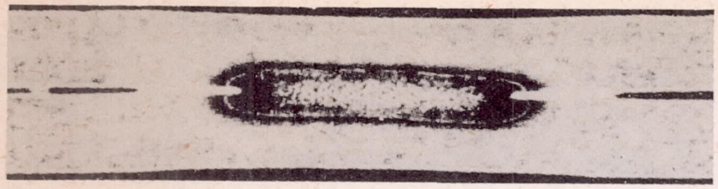


#8 - 920 lbs.
287,500 cycles

Keller's etch 10X
(d) 29680

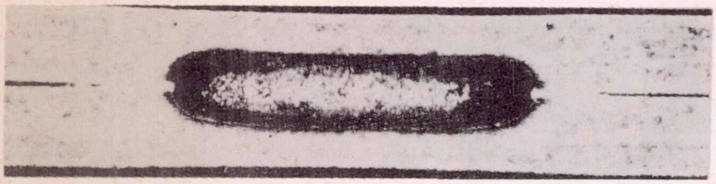
Figure 10.- Spot welds from panels cleaned by wire brushing
A.C. welds.

W-56



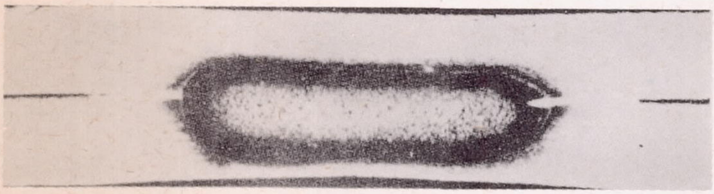
#1 - 3070 lbs.
15,300 cycles

Keller's etch 10X
(a) 29681



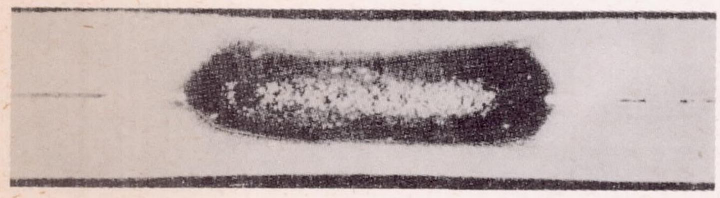
#2 - 3070 lbs.
14,100 cycles

Keller's etch 10X
(b) 29682



#7 - 920 lbs.
2,243,800 cycles

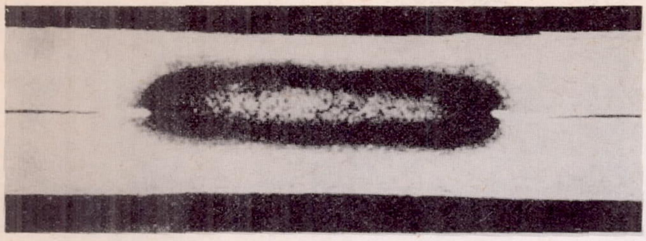
Keller's etch 10X
(c) 29683



#8 - 920 lbs.
600,000 cycles

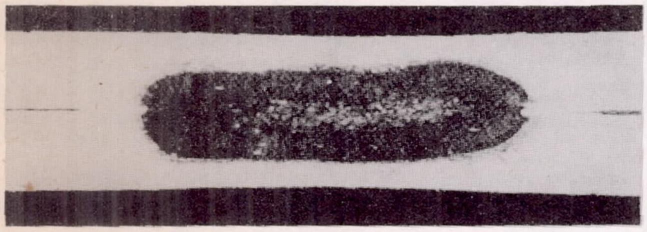
Keller's etch 10X
(d) 29684

Figure 11.- Spot welds from panels cleaned by wire brushing D.C. welds.



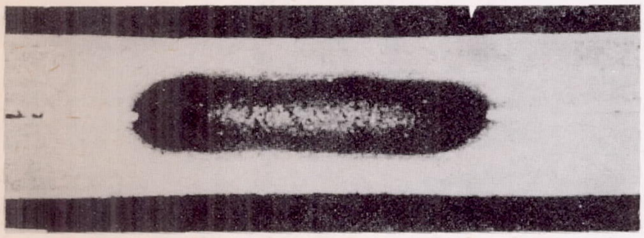
#1 - 3070 lbs.
19,700 cycles

Keller's etch 10X
(a) 29685



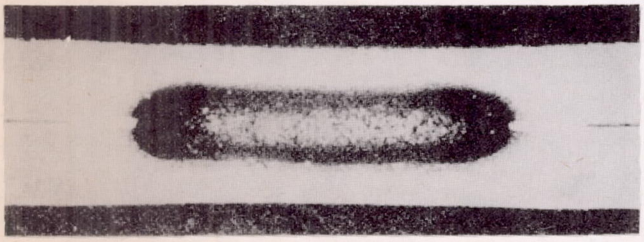
#2 - 3070 lbs.
3700 cycles

Keller's etch 10X
(b) 29686



#7 - 920 lbs.
307,900 cycles

Keller's etch 10X
(c) 29687

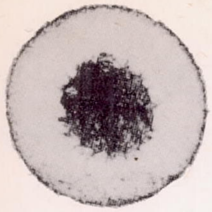


#8 - 920 lbs.
412,100 cycles

Keller's etch 10X
(d) 29688

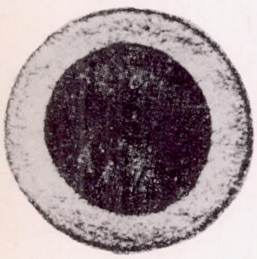
Figure 12.- Spot welds from panels cleaned by chemical methods - D.C. welds.

W-56



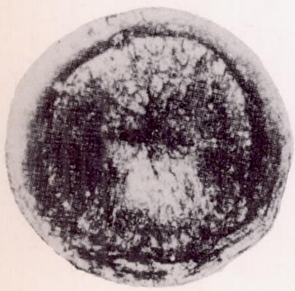
Panel #1, Weld #2
Dark area - weld
Light area - corona

5X (a) 29167



Panel #5, Weld #64
Optimum weld size

5X (b) 29168

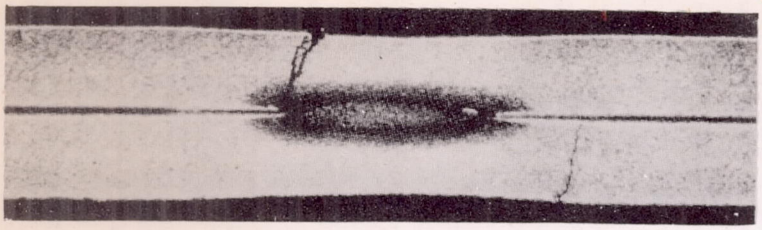


Panel #8, Weld #108
Note crack in center

5X (c) 29169

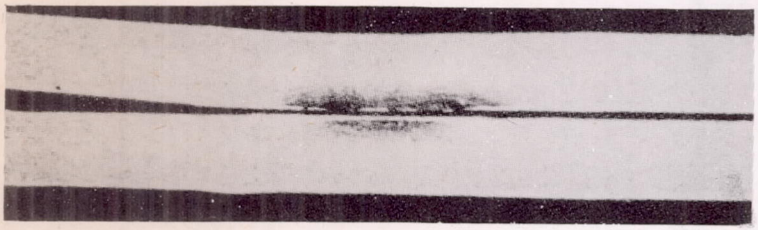
Figure 13.- Sheared spot welds showing weld area and surrounding corona.

W-56



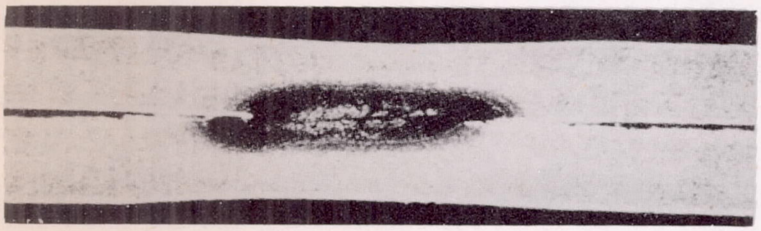
Panel #1, Specimen #4
133 lbs./spot
1,613,900 cycles

Keller's etch 10X
(a) 29170



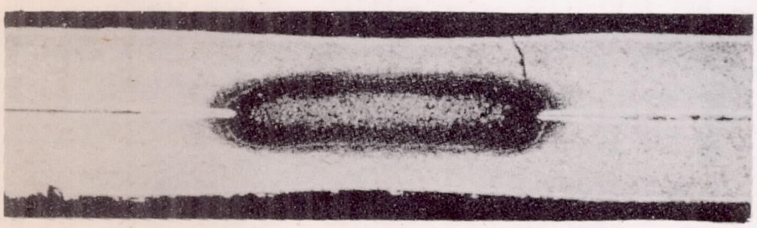
Panel #1, Specimen #3
174 lbs./spot
59,000 cycles

Keller's etch 10X
(b) 29171



Panel #2, Specimen #3
250 lbs./spot
2,900 cycles

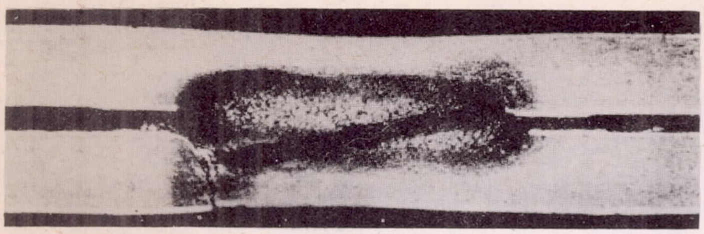
Keller's etch 10X
(c) 29172



Panel #3, Specimen #2
131 lbs./spot
1,206,200 cycles

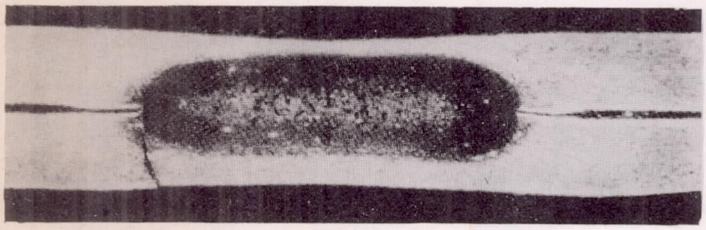
Keller's etch 10X
(d) 29173

Figure 15.- Spot welds in Panels #1, #2, and #3.



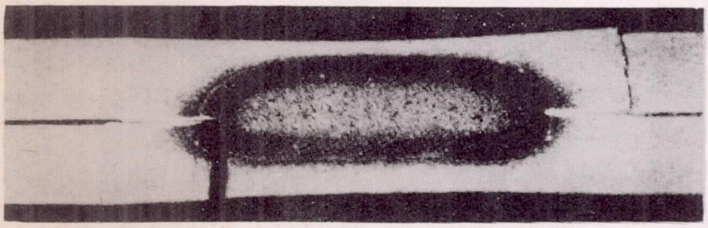
Panel #4, Specimen #1
245 lbs./spot
800 cycles

Keller's etch 10X
(a) 29174



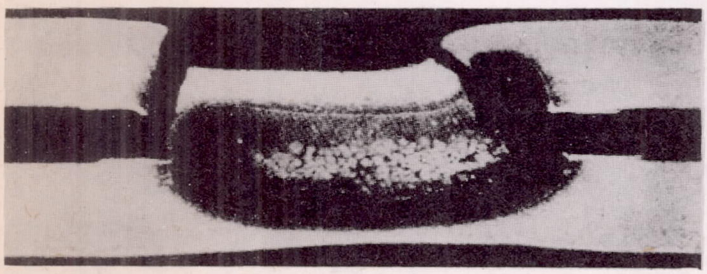
Panel #5, Specimen #4
180 lbs./spot
321,500 cycles

Keller's etch 10X
(b) 29175



Panel #6, Specimen #2
184 lbs./spot
416,000 cycles

Keller's etch 10X
(c) 29176



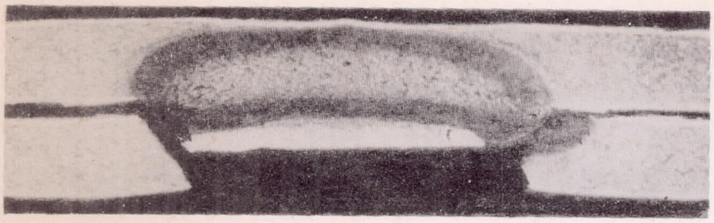
Panel #6, Specimen #1
280 lbs./spot
17,200 cycles

Keller's etch 10X
(d) 29177

Figure 16.- Spot welds in Panels #4, #5, and #6.

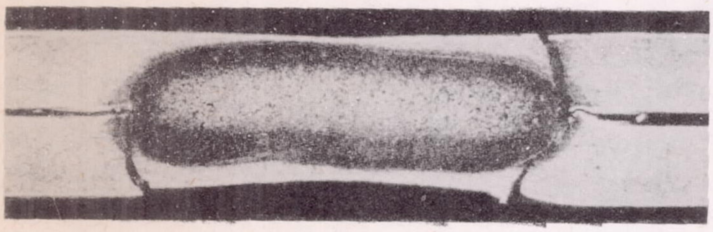
W-56

W-56



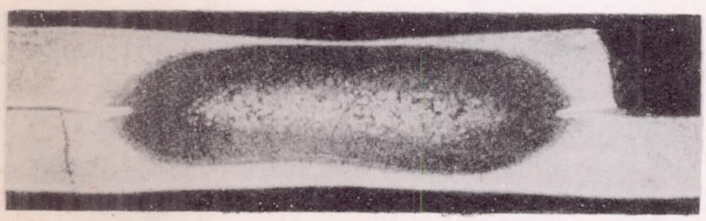
Panel #7, Specimen #1
368 lbs./spot
13,100 cycles

Keller's etch 10X
(a) 29178



Panel #7, Specimen #4
280 lbs./spot
82,700 cycles

Keller's etch 10X
(b) 29179

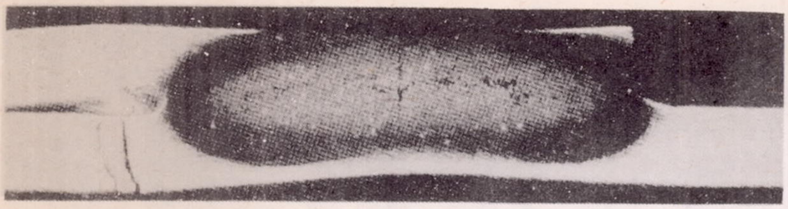


Panel #7, Specimen #3
150 lbs./spot
2,351,800 cycles

Keller's etch 10X
(c) 29180

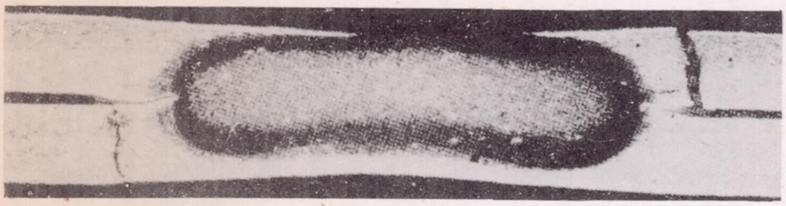
Figure 17.- Spot welds in Panel #7.

W-56



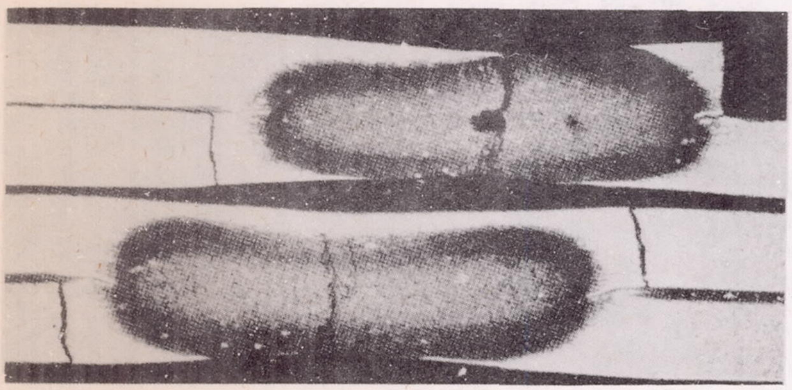
Panel #8, Specimen #2
304 lbs./spot
67,400 cycles

Keller's etch 10X
(a) 29181



Panel #8, Specimen #4
140 lbs./spot
4,075,600 cycles

Keller's etch 10X
(b) 29182

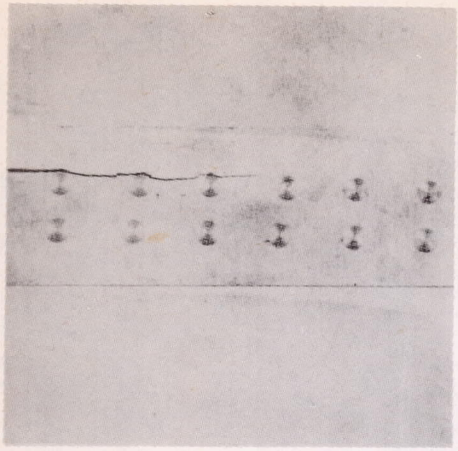


Panel #9, Specimen #3
240 lbs./spot
247,300 cycles

Keller's etch 10X
(c) 29183

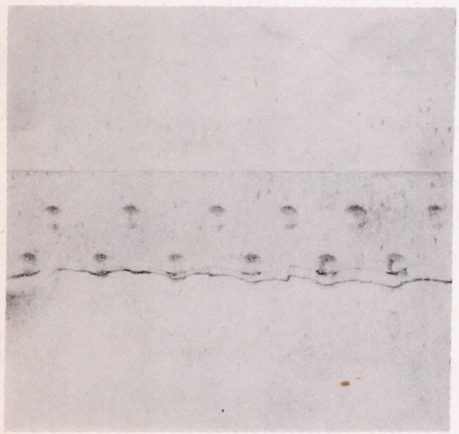
Figure 18.- Spot welds in Panels #8 and #9.

W-56



(a) 29388

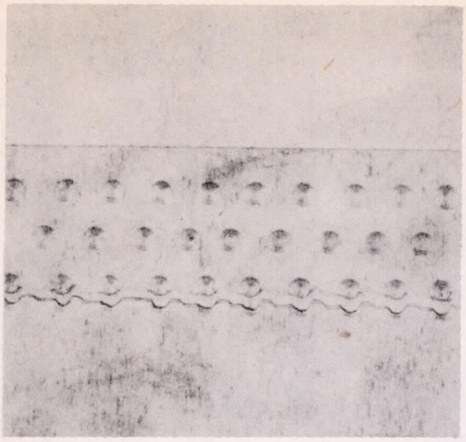
Spot welds in line (Test 3 K1C-D)



(b) 29388

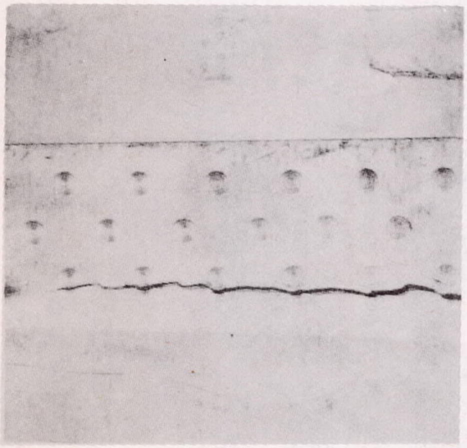
Spot welds staggered (Test 3 L1C-D)

Figure 19.- Lap joint specimens with two rows of spot welds Specimens 5" wide, with $1\frac{1}{2}$" overlap. Spots $\frac{1}{2}$" apart within rows. Spacing between rows $\frac{1}{2}$".



(a) 29392

Spot spacing 1/2" within row
(Test 3 M1C-F)



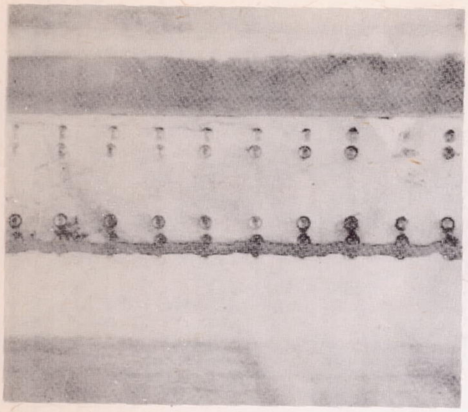
(b) 29392

Spot spacing 3/4" within row
(Test 3 M1C-D)

Figure 20.- Lap joint specimens with three rows of spot welds Specimens 5" wide, with 2" overlap. Spacing between rows $\frac{1}{2}$". Note spots in adjacent rows staggered.

W-56

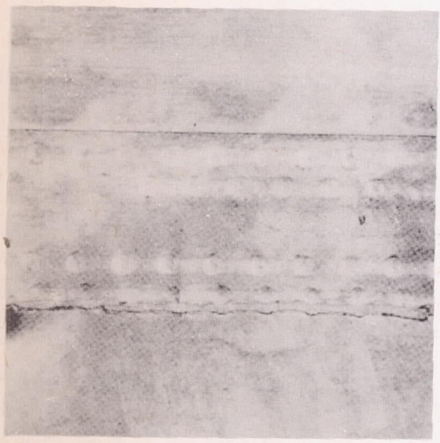
W-56



1/2" between welds in a row
3/4" between inner rows
3/16" between outer and nearest inner row
1-1/2" overlap

(a) 29391

0.016" sheet (Test U1F-F)

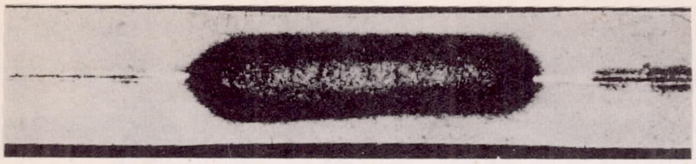


Roll welds, rows staggered
1/2" between welds in a row
7/8" between inner rows
7/16" between outer and nearest inner row
2" overlap

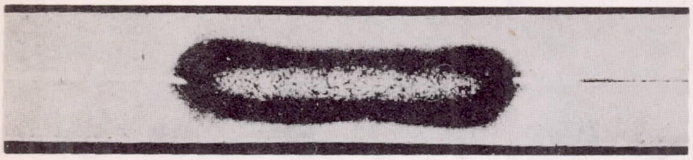
(b) 29391

0.040" sheet (Test 5 U1C-F)

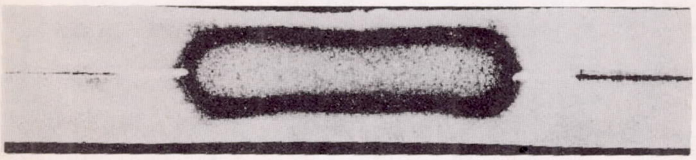
Figure 21.- Lap joint specimens with Boeing type joint.



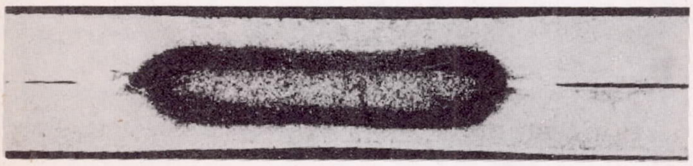
Keller's etch 3K1C-8D 10X
(a) 29668



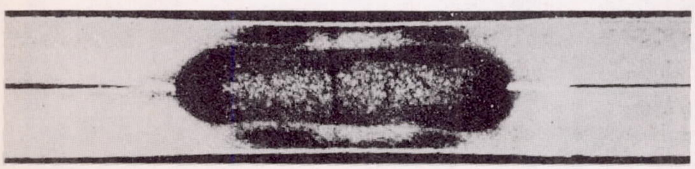
Keller's etch 3L1C-7D 10X
(b) 29669



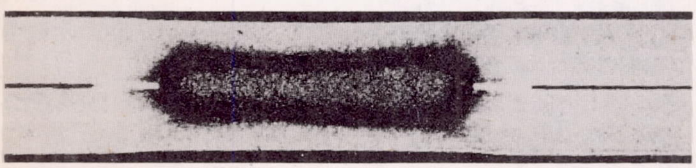
Keller's etch 3 M1C-4D 10X
(c) 29670



Keller's etch 3 M1C-6F 10X
(d) 29671



Keller's etch 3 M2C-3F 10X
(e) 29671

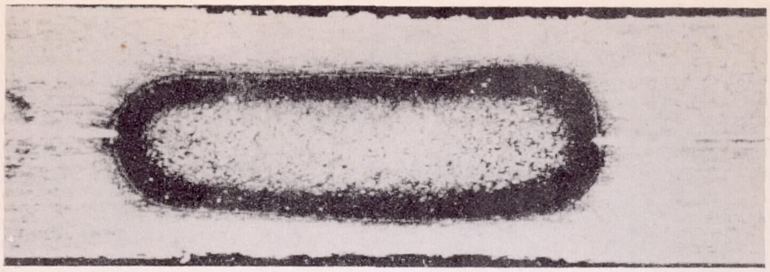


Keller's etch 3 M3C-3F 10X
(f) 29672

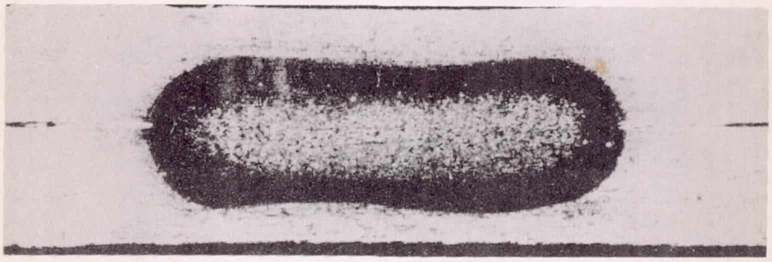
Figure 22.- Representative welds from spot pattern specimens (0.040")

W-56

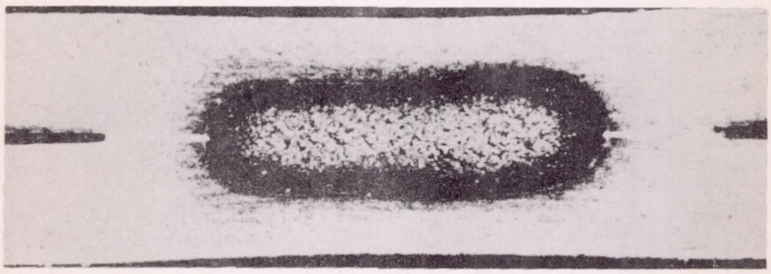
W-56



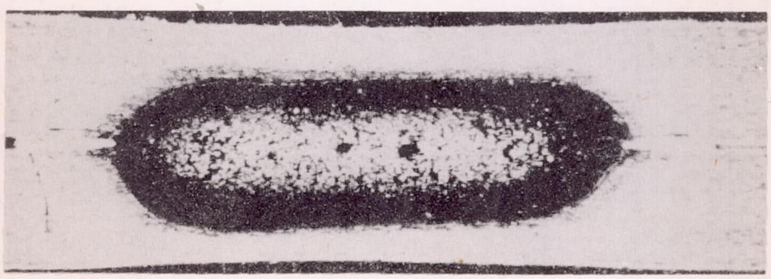
Keller's etch 3 N1E-2D 10X
(a) 29673



Keller's etch 3 N2E-3D 10X
(b) 29674



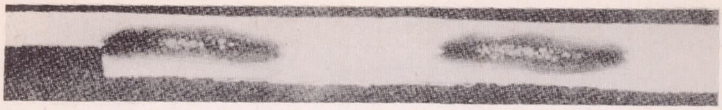
Keller's etch 3 N3E-1D 10X
(c) 29675



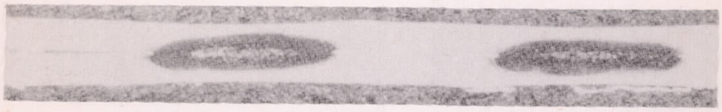
Keller's etch 3 B1E-12D 10X
(d) 29676

Figure 23.- Representative welds from spot pattern specimens (0.064")

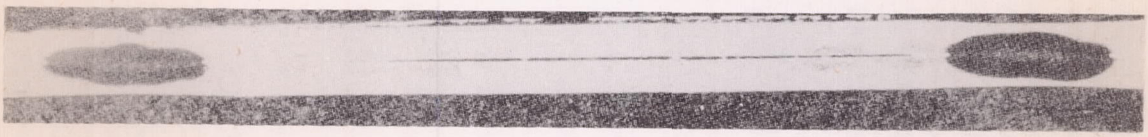
W-56



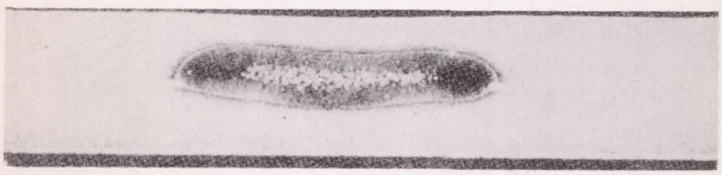
Keller's etch (a) 10X
29665
0.016" - Fatigued-sectioned parallel to direction of testing



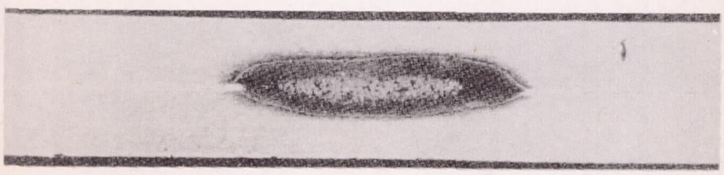
Keller's etch (b) 10X
29666
0.016" - As received-parallel to direction of testing



Keller's etch (c) 10X
29666
0.016" - As received-normal to testing



Keller's etch (d) 10X
29667
0.040" - Roller weld-parallel to direction of rolling



Keller's etch (e) 10X
29667
0.040" - Roller weld-normal to direction of rolling

Figure 24.- Spot welds from Boeing joint specimens.

W-56

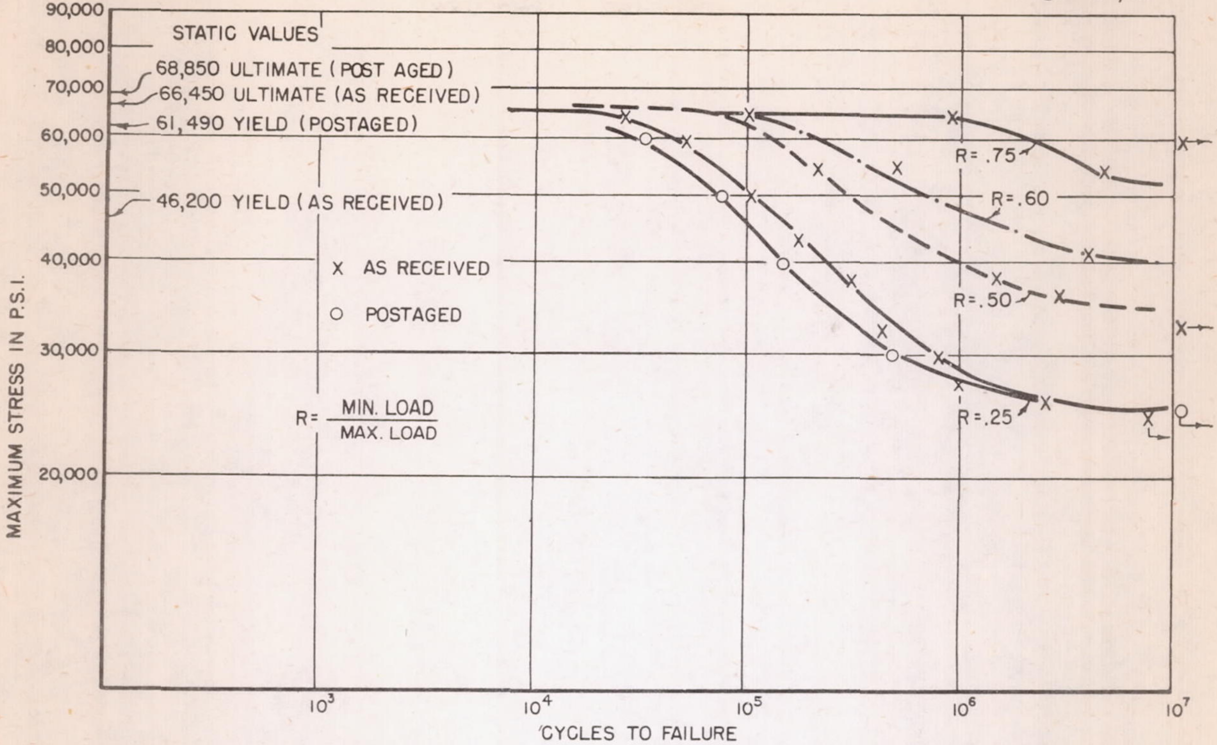


FIG. 25- FATIGUE CURVES FOR 0.040" ALCLAD 24S-T SHEET (SPECIMENS 1.000" X 0.040" AT CENTER SECTION)

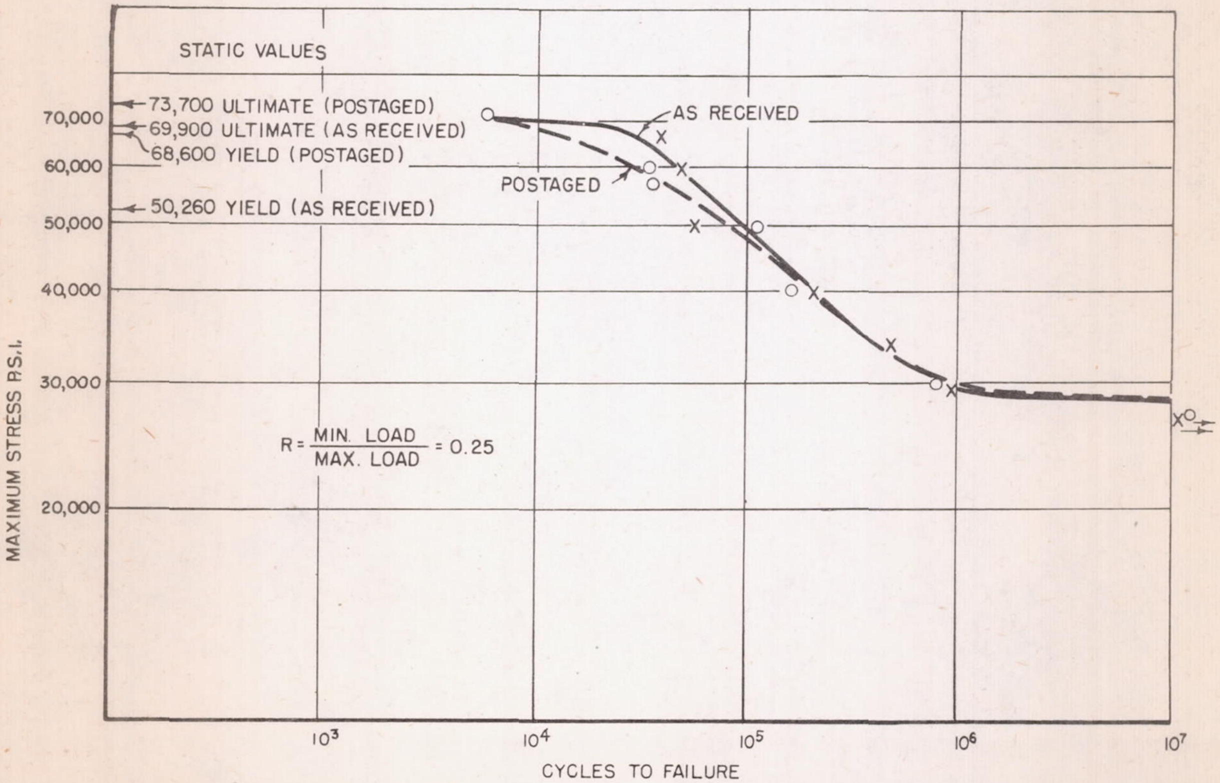


FIG. 26 - FATIGUE CURVES FOR 0.064" 24S-T ALCLAD SHEET (SPECIMENS 1.000" X 0.064" AT CENTER SECTION).

W-56

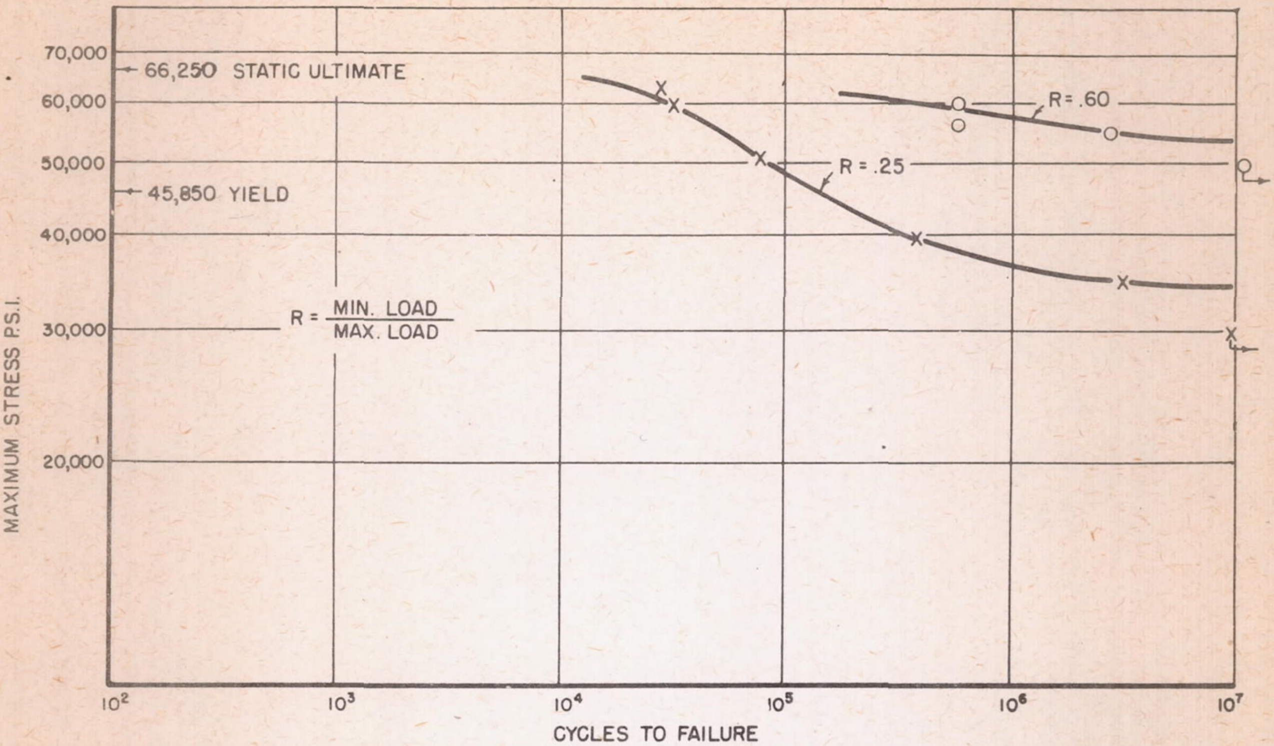


FIG. 27 - FATIGUE CURVES FOR 0.016" 24 S-T ALCLAD SHEET (SPECIMENS 1.000" AT CENTER SECTION.)

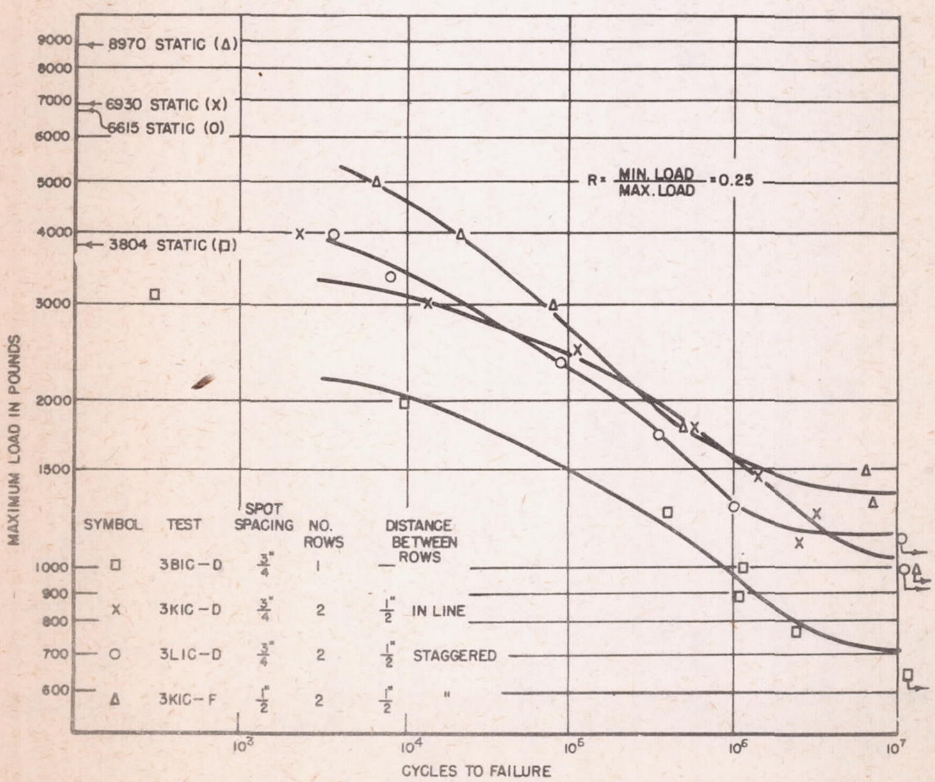


FIG. 28-FATIGUE CURVES FOR LAP JOINTS 0.040"-0.040" WITH ONE AND TWO ROWS OF SPOT-WELDS.

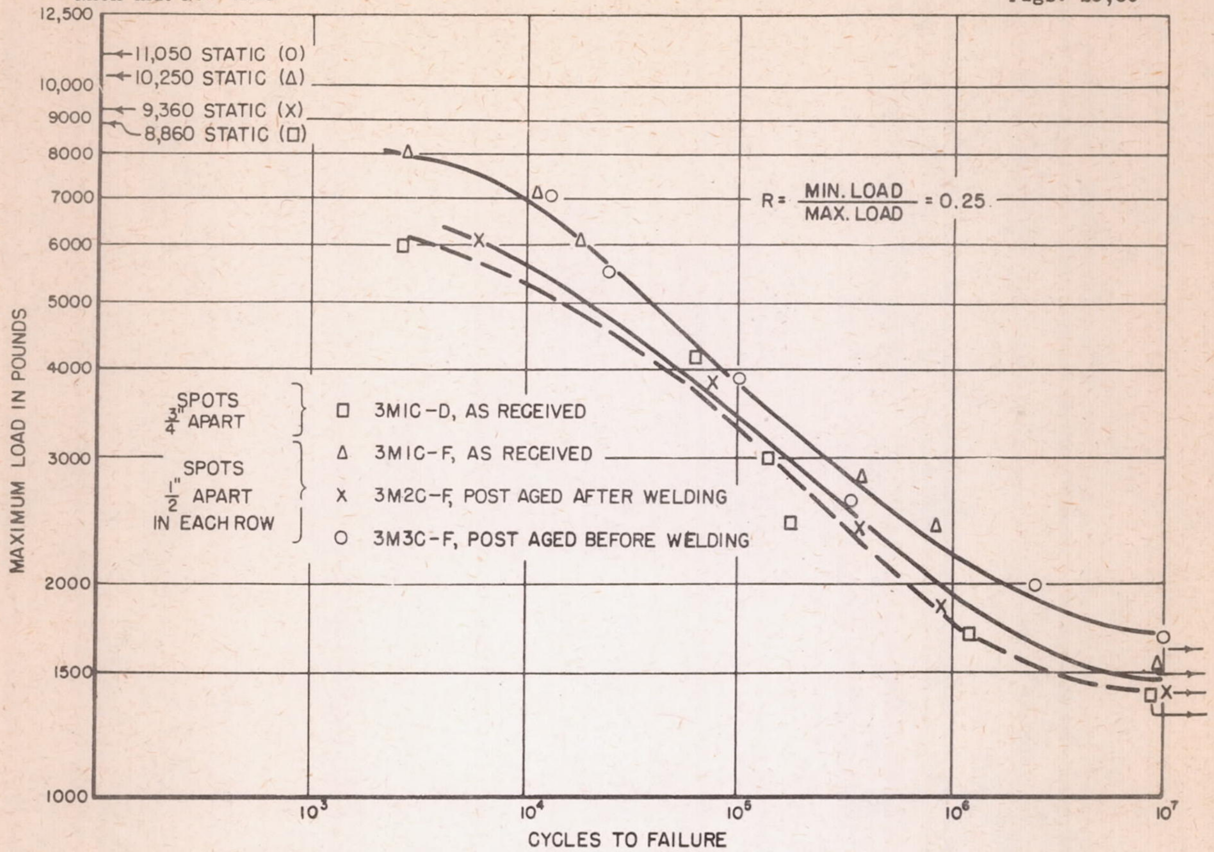


FIG. 29 - FATIGUE CURVES FOR LAP JOINTS WITH 3 ROWS OF SPOT-WELDS.

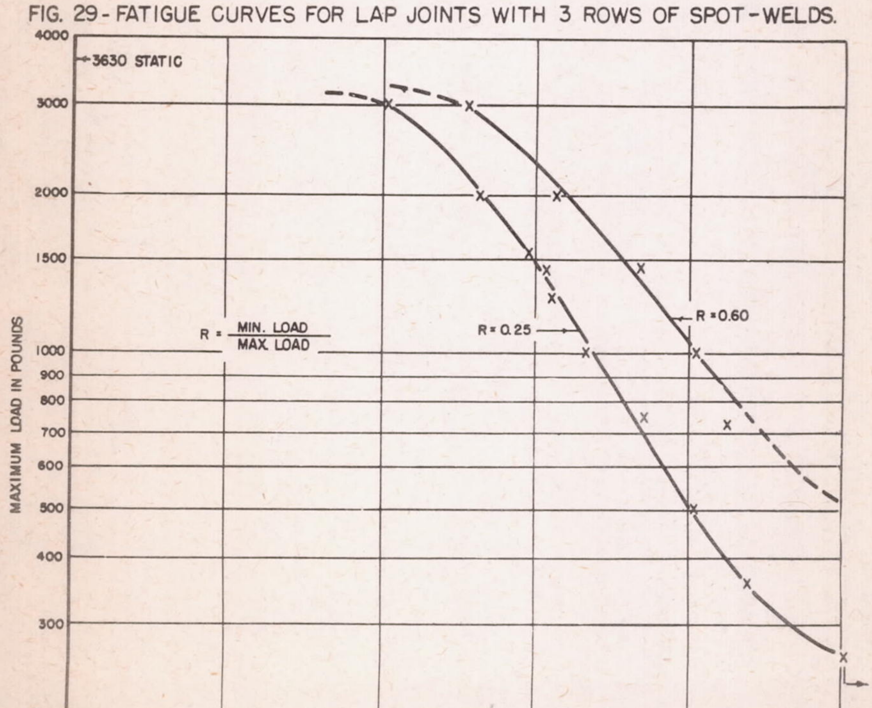


FIG. 30 - FATIGUE CURVES FOR LAP JOINT SPECIMENS OF 0.016" ALCLAD 24S-T WITH BOEING TYPE SPOT WELD PATTERN.

W-56

W-56

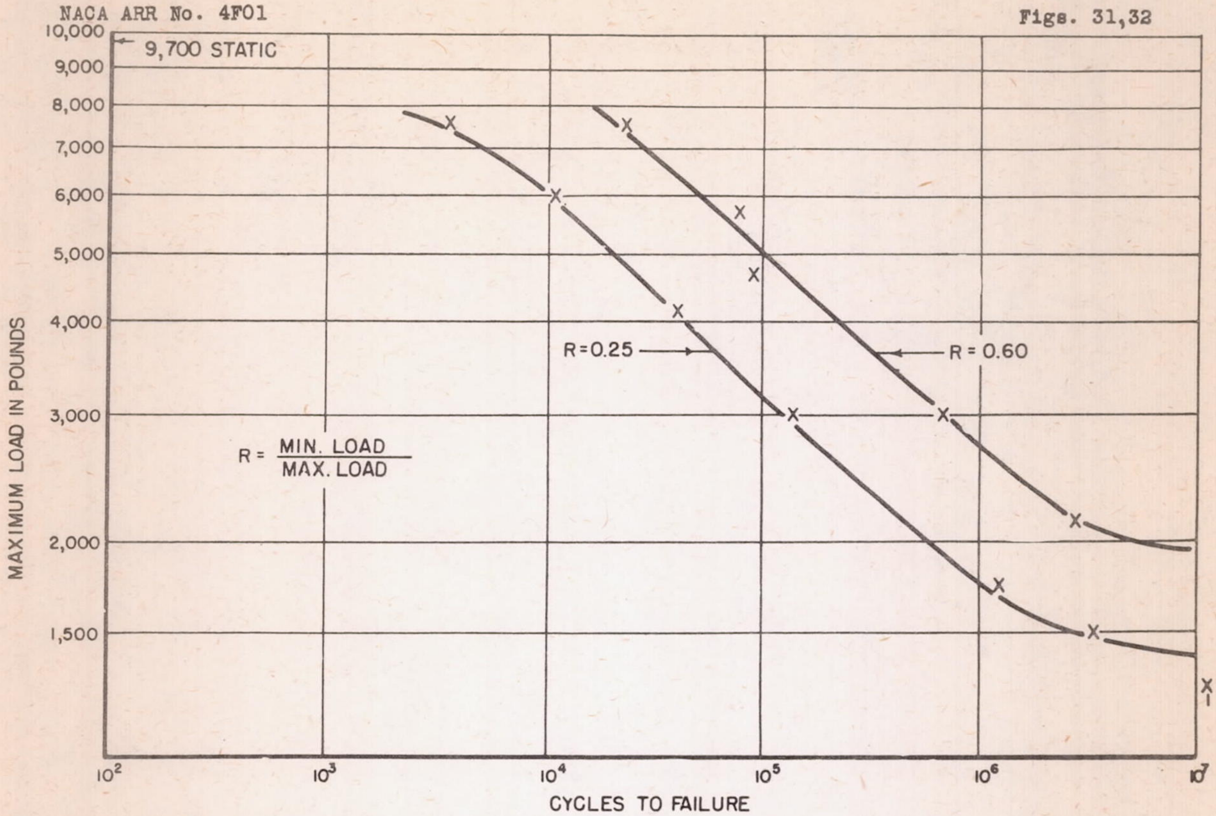


FIG. 31 - FATIGUE CURVES FOR LAP JOINT 0.040" SPECIMENS WITH BOEING TYPE SPOT-WELD PATTERN.

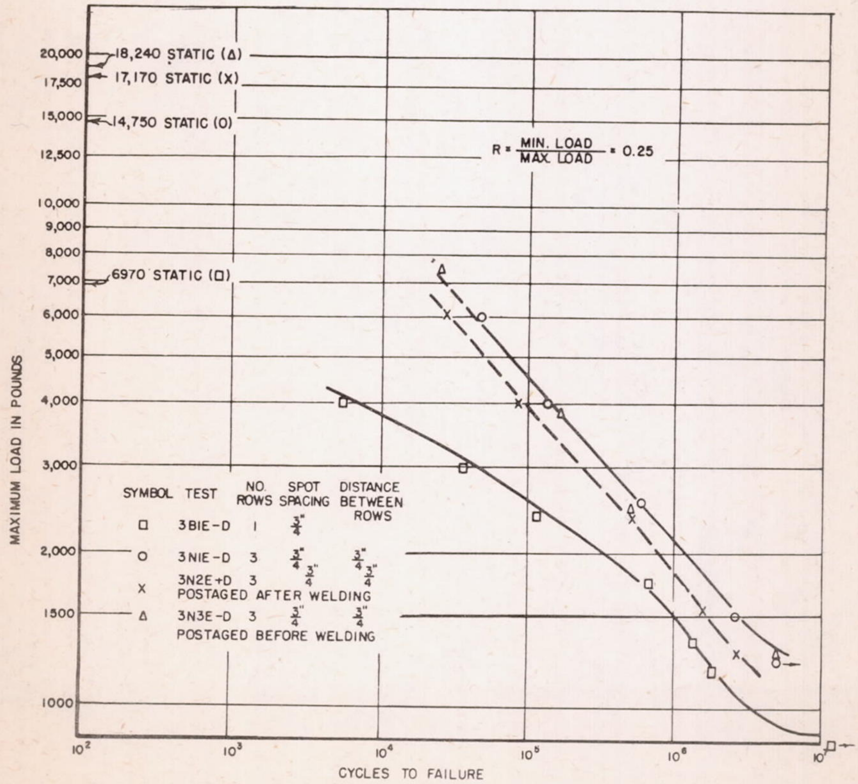


FIG. 32 - FATIGUE CURVES FOR LAP JOINT SPECIMENS OF 0.064" SHEET WITH ONE AND WITH TWO ROWS OF SPOT-WELDS.

W-56

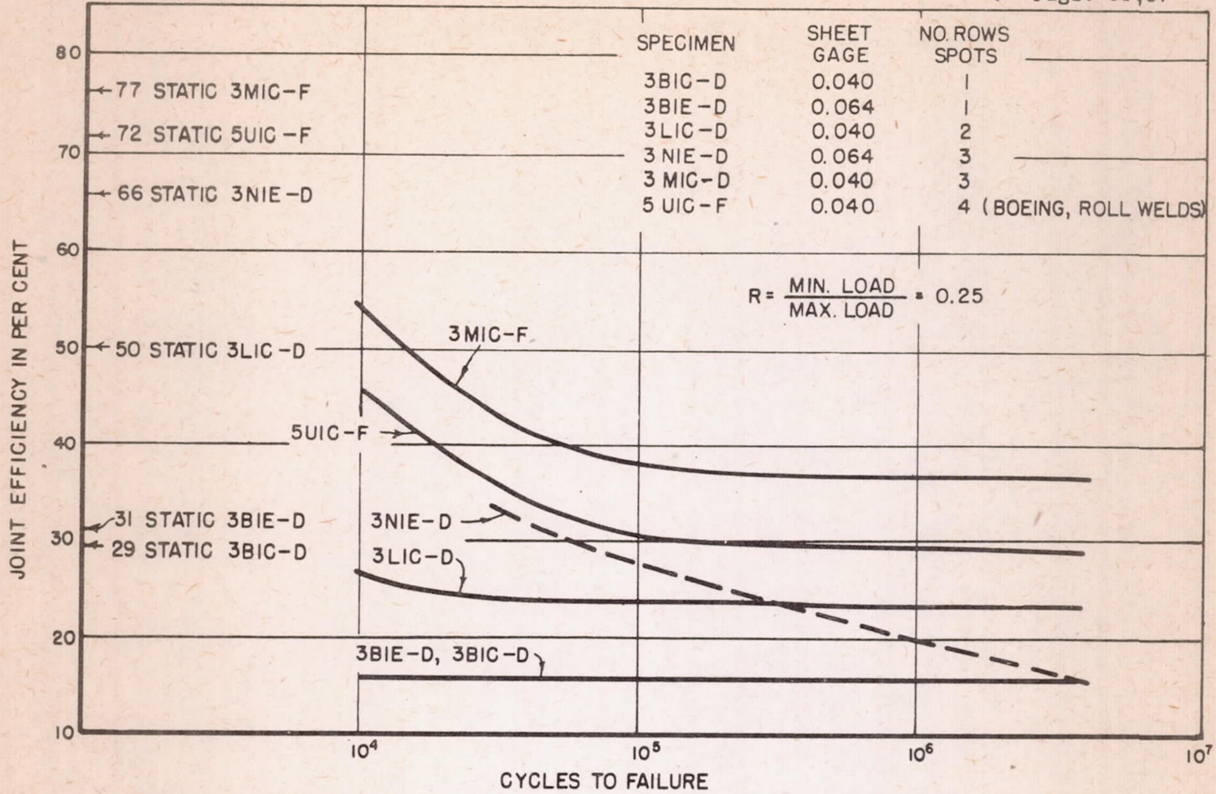


FIG. 33—JOINT EFFICIENCY CURVES FOR SPOT-WELDED LAP JOINT SPECIMENS.

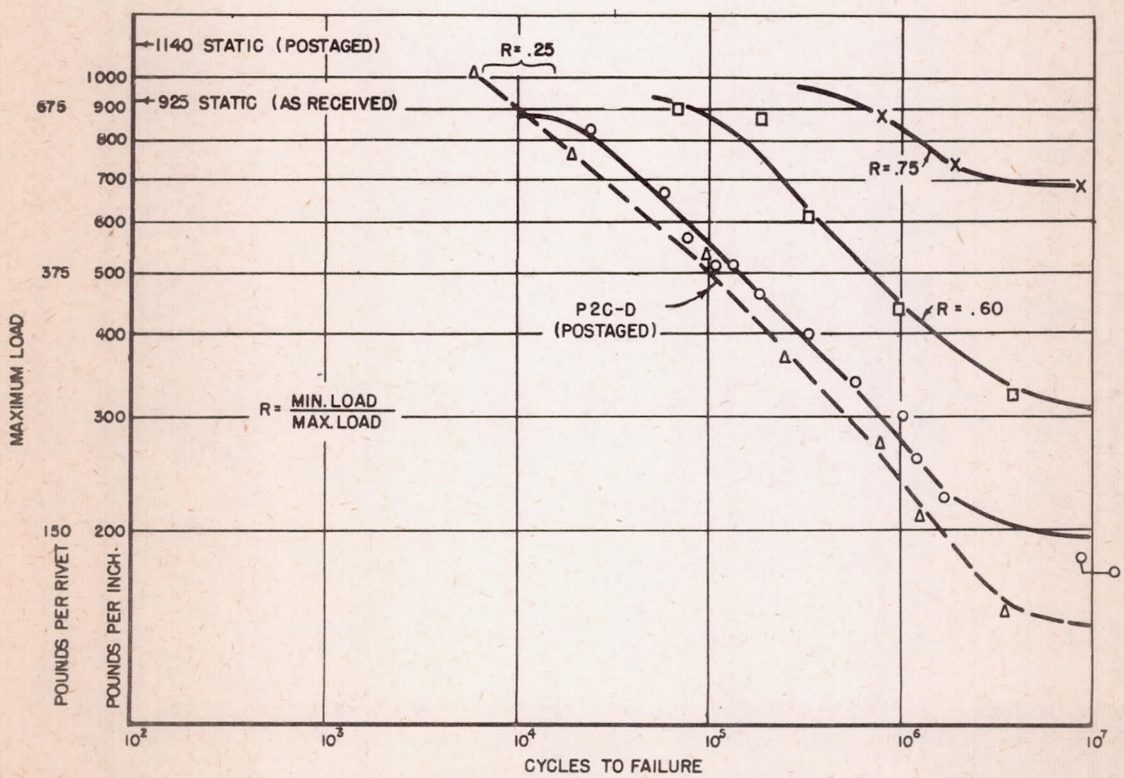
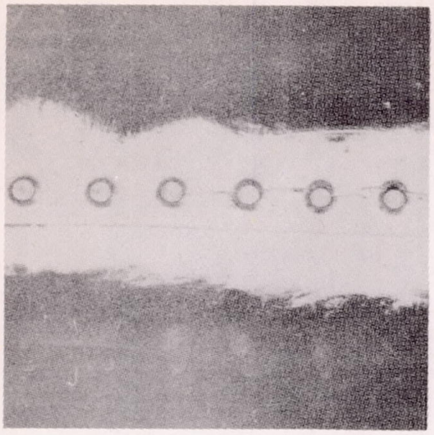
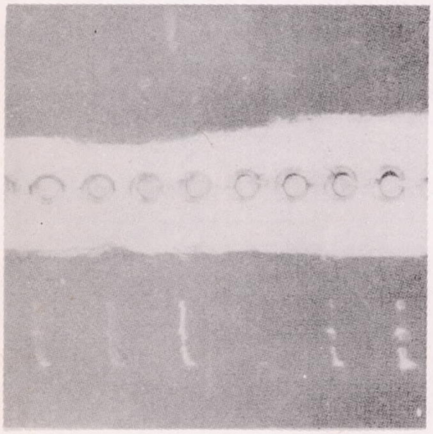


FIG. 37- FATIGUE CURVES FOR LAP JOINT SPECIMENS WITH ONE ROW OF RIVETS. GROUP PIC-D: RIVETS SPACED $\frac{3}{4}''$ APART GROUP P2C-D: SAME BUT SHEET POSTAGED.

W-56



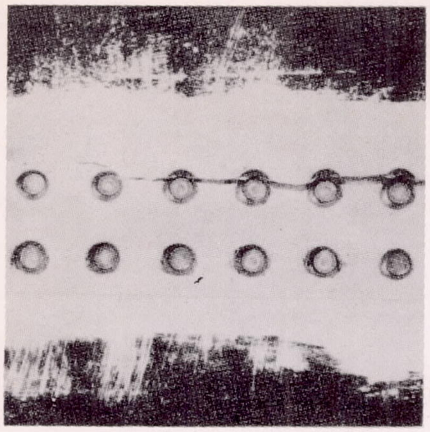
(a) 29389
Specimen P1C-D - 4-1/2" wide - 3/4" rivet spacing



(b) 29389
Specimen P1C-F - 5" wide - 1/2" rivet spacing

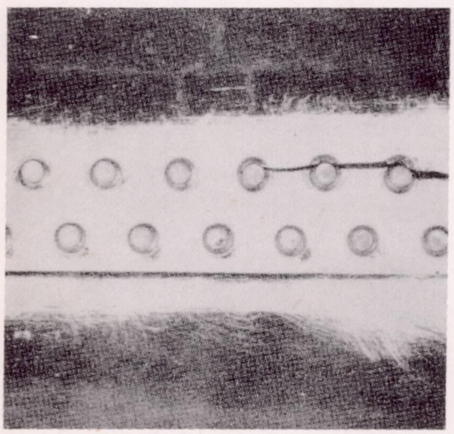
Figure 34.- Lap joint specimens with one row of flush rivets.

W-56



(a) 29390

Rivets in line (Q1C-D)

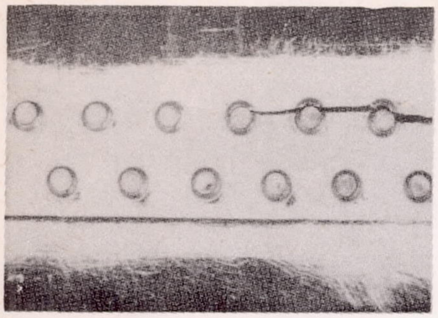


(b) 29390

Rivets staggered (T1C-D)

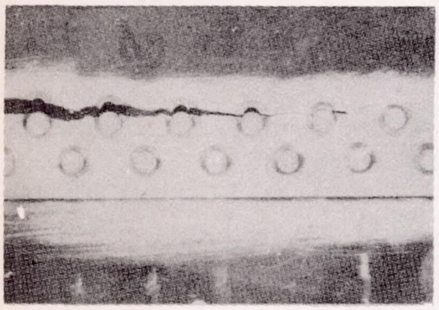
Figure 35.- Lap joint specimens with two rows of flush rivets $\frac{3}{4}$" spaced, $\frac{3}{4}$" between rows.

W-56



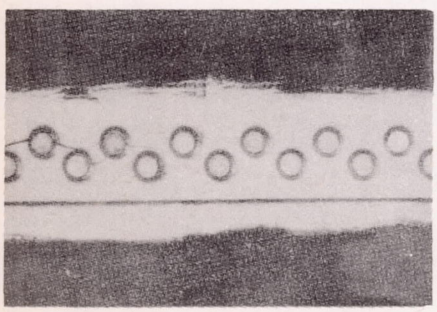
T1C-D
11/16" between rows

(a) 29391



S1C-D
3/8" between rows

(b) 29386



R1C-D
1/4" between rows

(c) 29386

Figure 36.- Lap joint specimens with two rows of flush rivets staggered, $\frac{3}{4}$" rivet spacing within rows.

W-56

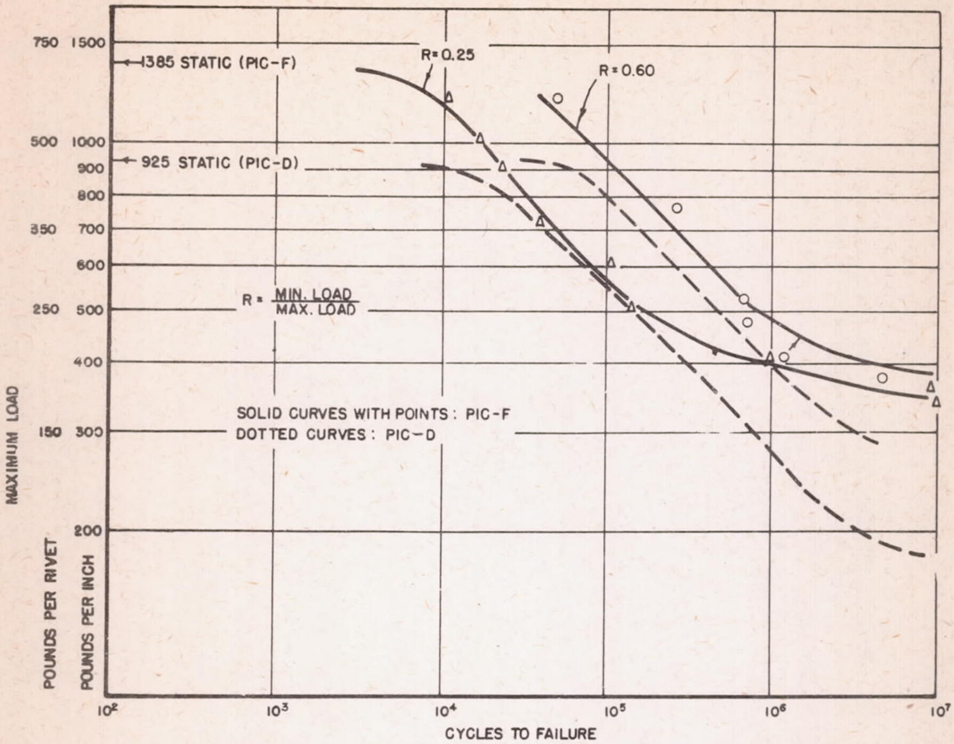


FIG. 38-FATIGUE CURVES FOR LAP JOINT SPECIMENS WITH ONE ROW OF RIVETS GROUP PIC-F RIVETS $\frac{1}{2}$" APART. GROUP PIC-D: RIVETS $\frac{3}{4}$" APART.

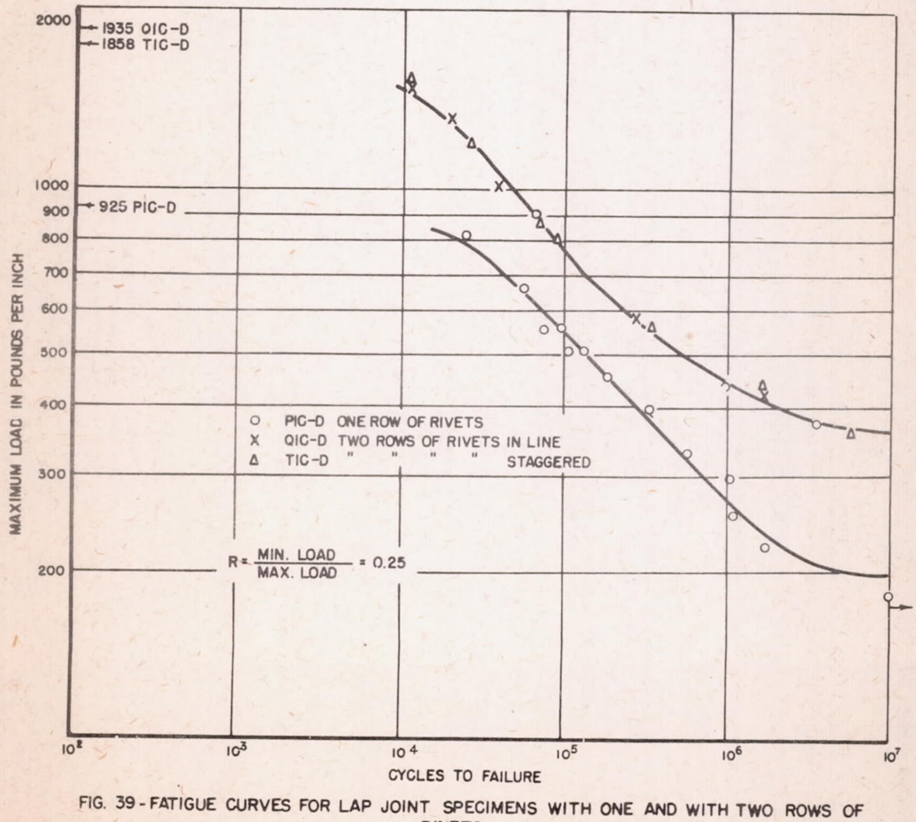


FIG. 39-FATIGUE CURVES FOR LAP JOINT SPECIMENS WITH ONE AND WITH TWO ROWS OF RIVETS.

W-56

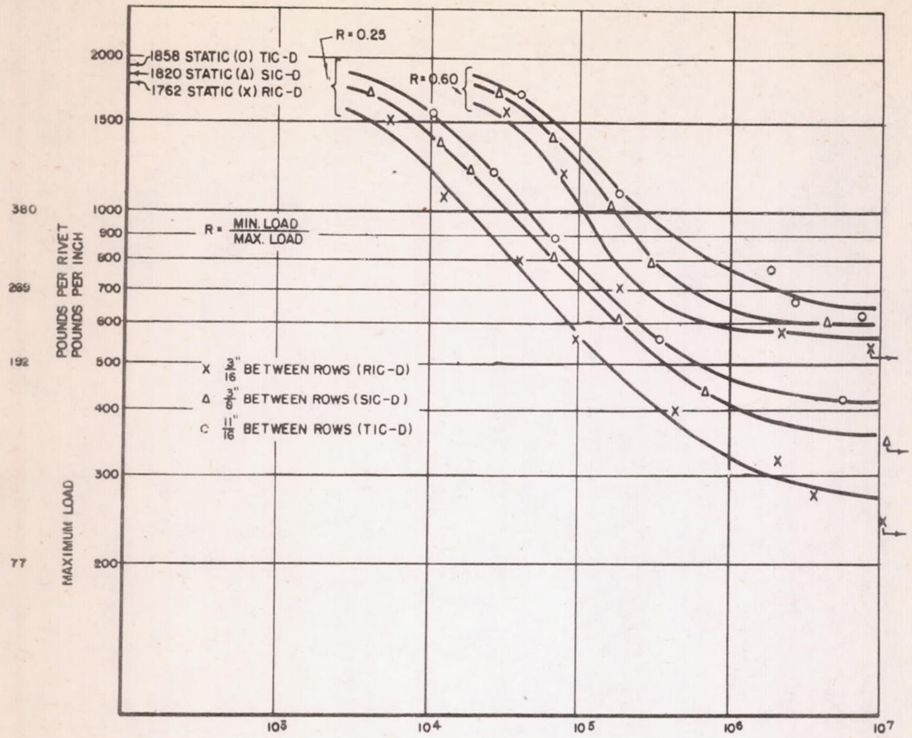


FIG. 40-FATIGUE CURVES FOR LAP JOINT SPECIMENS WITH TWO ROWS OF FLUSH RIVETS STAGGERED-EFFECT OF VARYING SPACING BETWEEN ROWS.

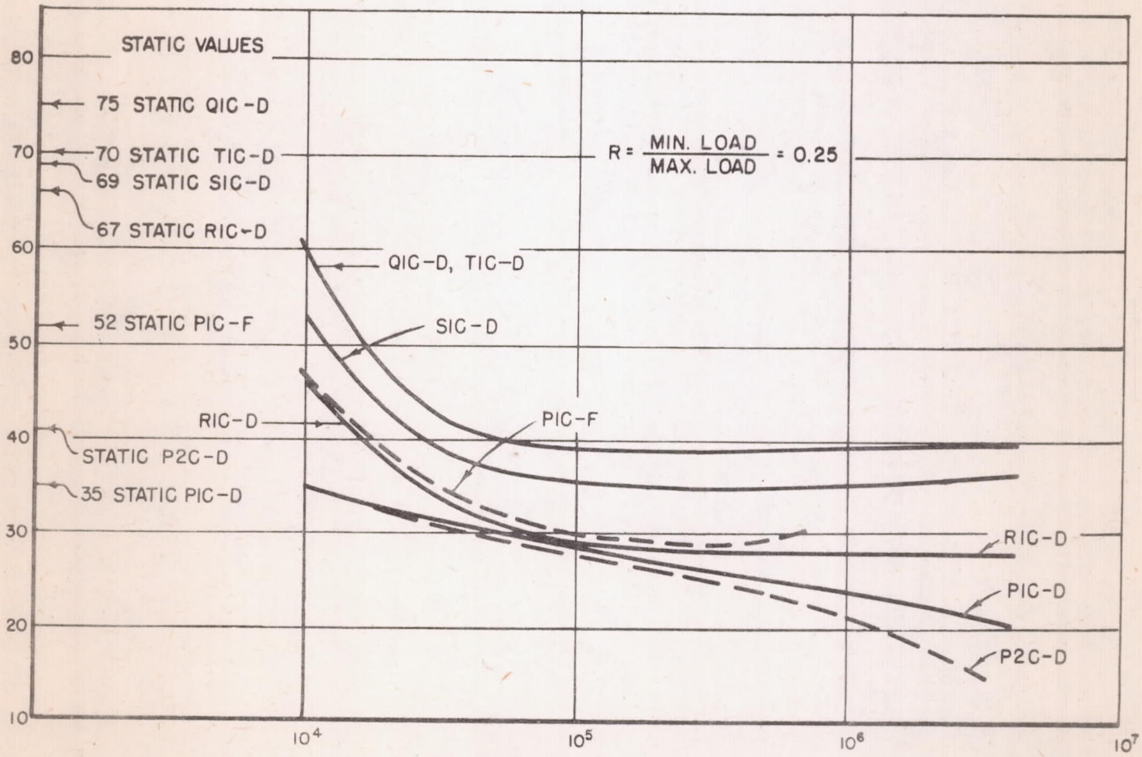


FIG. 41-JOINT EFFICIENCY VALUES FOR RIVETED LAP JOINT SPECIMENS FOR DETAILS OF SPECIMEN GROUPS SEE TABLE 38.

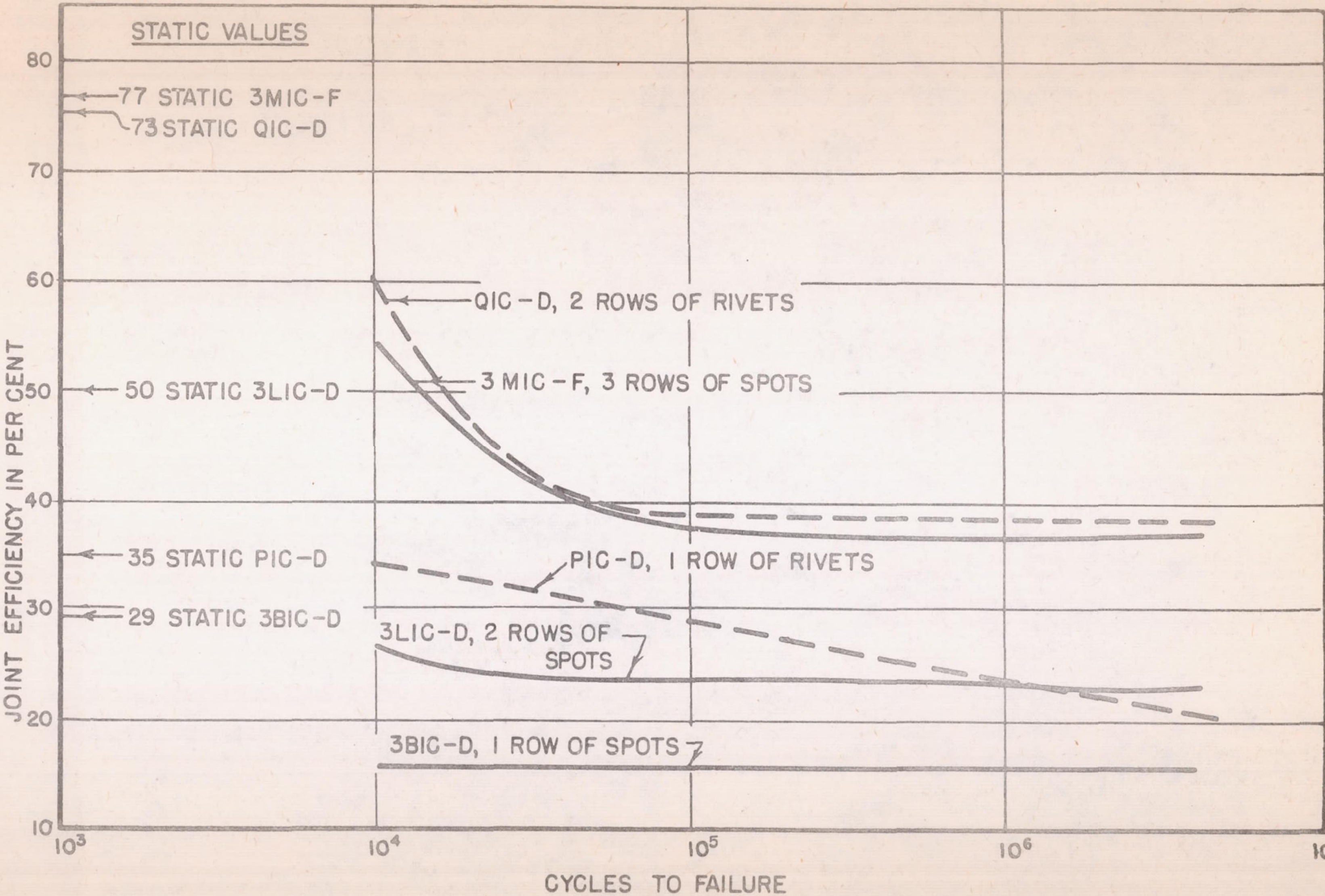


FIG. 42 - COMPARISON OF JOINT EFFICIENCIES FOR RIVETED AND SPOT-WELDED JOINTS.