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AERONAUTICAL MATERIALS LABORATORY

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CORROSION RESISTANCE AND DURABILITY OF FASTENERS IN AIRCRAFT STRUCTURES

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF PLATES

ABSTRACT

A corrosion and fatigue evaluation was made to determine whether the rounding of countersunk holes and/or fastener heads would improve the corrosion behavior at the fastener locations or affect the fatigue strength of 7075-T6 aluminum alloy joints assembled with cadmium plated steel countersunk head screws. Test assemblies were prepared with and without corrosion barrier materials, including a MIL-S-8802 polysulfide sealant, in the finishing system.

Rounded configurations did not significantly improve corrosion behavior but did improve the fatigue strength of the specimens. The greatest improvement in fatigue properties occurred with a combination of rounded fastener heads and rounded countersunk holes.

Of the various corrosion barrier materials tested, only the polysulfide sealant afforded good corrosion protection when used with a paint system overcoat. However, the use of the sealant more than negated the beneficial effect of the rounded configurations on fatigue strength.

The use of the sealant lowered the fatigue strength of the control specimens with standard fastener heads and standard countersunk holes by approximately 6%. This loss is counterbalanced by the improvement in corrosion behavior afforded by the sealant to fastener areas.

I. INTRODUCTION

For years, the strengths of aluminum structures in aircraft have been seriously impaired by excessive corrosion around steel fasteners, particularly in the countersunk areas. This has been a continually urgent problem and is due to the fact that existing preventive methods fail to provide adequate corrosion protection.

More recently, considerable effort has been expended in attempts to improve fastener coatings to provide a high level of protection to fastener installations in external locations in naval aircraft. While encouraging, this effort has not resulted in the degree of corrosion resistance in aircraft structures believed to be attainable through the use of optimum fastener configuration in combination with various insulating, sealing and coating materials and techniques.

This assignment was initiated by reference (a) to evaluate the corrosion protective action of various promising sealants placed in the countersunk area to insulate the fasteners from the aluminum alloy skin material, using different configuration of rounded fastener heads and rounded countersunk holes, and to assess their effects on the fatigue properties of metal joints. This initial investigation, as reported herein, using only a limited number of sealants and fastener coatings and a limited number of specimens, is intended only as a preliminary cursory evaluation of the fatigue and corrosion resistance effect of corrosion barrier materials and fastener hole configuration combinations.

If warranted and necessary, it is proposed to conduct an additional and considerably more detailed testing program to determine more precisely and statistically the extent of the detrimental effects, if any, of the sealant on fatigue properties of joints.

II. EXPERIMENTAL PROCEDURE

A. Corrosion Evaluation

1. For corrosion control evaluation, test specimens consisted of a three piece assembly of unclad 7075-T6 aluminum. The fasteners (MIL-S-7839) used in all assemblies were chromated cadmium plated steel screws. Plate 1 is a diagram of the test specimens.

2. Test assemblies consisted of one panel with rounded countersunk holes and the other with unrounded or conventional countersinks. This system permitted a comparison to be made within each test unit. One-half of the test units were assembled with fasteners with rounded heads. These fasteners were prepared as follows:

a. Sharp edges on fastener heads rounded;

b. Remaining cadmium plating stripped from fasteners;

c. Cadmium replated on fasteners to a thickness of 0.3 mils;

d. Fasteners chemically treated with chromate conversion coating.

3. The following operations were conducted on the specimens in sequence:

a. Specimens before assembly were treated with MIL-C-5541A, Class II, Grade C chromate conversion coating.

b. The countersinks were left untreated or filled with a MIL-S-8802 polysulfide sealant. The fasteners were installed while the sealant was still wet.

c. Several fasteners, both rounded head and standard, were dipped in zinc chromate primer and installed wet in untreated countersinks.

d. All fasteners were installed at 25 in.-lb. torque.

e. Some MIL-S-8802 treated countersinks and some bare countersinks received a sealant overlay. The sealant was applied over the fastener rows as follows: two strips of masking tape were put parallel to both sides of a fastener row. The sealant then was knife glazed over fastener heads to the masking tape thickness and the tapes removed. The sealant ribbon about 7 mils thick was air dried one week prior to overpainting.

f. The entire test assembly was overcoated with MIL-P-23377 epoxy primer and MIL-P-22750 epoxy topcoat and air dried three weeks in the laboratory.

g. Subsequently, each painted specimen was slowly loaded in tension at low temperature on a 120,000 lb. Baldwin-Southwark Universal Testing Machine. A nitrogen cold chamber placed around the specimen kept the test environment at -60°F ± 10. The load was gradually applied to a maximum of 15,000 lb. and maintained for 10 minutes.

h. The specimens were then subjected to exposure in an SO_2-salt spray chamber for a period of 1 month. This salt spray chamber was designed to simulate the environmental exposure faced by carrier based planes. A detailed description of this salt spray test is given in reference (b).

i. Specimens were placed in racks at an angle of 15° from the vertical. Beeswax was used to mask the edges and backs of the test assemblies from the severe salt spray environment so that any corrosive attack would have to originate on the top surface.

j. After salt spray exposure, fasteners were removed and the countersinks examined. The countersinks that evidenced the most severe visual corrosion were sectioned and a metallographic examination conducted to determine the extent of pitting, intergranular corrosion and exfoliation.

4. At the request of the Naval Air Systems Command, a proprietary coating was evaluated for possible use on fasteners. Rounded head and unrounded fasteners were forwarded to a vendor for vacuum deposition of a polymeric coating. Coating thicknesses of 0.3, 1.0, and 2.0 mils were requested. The fasteners were returned to the Aeronautical Materials Laboratory and installed in untreated countersinks.

5. An additional series of tests was conducted to determine whether the MIL-S-8802 sealant could withstand severe cyclic stressing without cracking.

a. Six specimens, of the type shown in Plate 2, were assembled with unrounded fasteners and countersinks.

b. These specimens were prepared in a manner similar to the others with sealant applied in the countersinks and as an overlay. Only three specimens received the paint system overcoat, the others being tested unpainted.

c. The specimens were fatigue loaded in the painted and unpainted conditions at the following temperatures: 70°F, -60°F, and -110°F. The low cycle fatigue test was conducted at a load of 5000 lb. for 15 cycles.

d. After loading, a conductivity path test (described in reference (c)) was employed to determine if cracks had developed in the sealant.

e. Subsequently, the specimens were salt spray tested and examined as described above.

B. Fatigue Evaluation

1. Fatigue Test Specimens

Fatigue test specimens, with basic configuration as shown on Plate 2, were fabricated from 1/8" unclad 7075-T6 aluminum alloy sheet material, with back-up plates of 3/8" unclad 7075-T6 aluminum plate material. Blanks for all the specimens were cut from the sheet and plate materials so that the long axis of the specimen was parallel to the direction of rolling. To ensure that all specimens were as identical as possible, component parts of the specimens were machined precisely, using jig fixtures and tooling throughout. Cadmium plated 100° countersunk flush head recessed steel screws of 3/16" diameter (MIL-S-7839, AN509-10R), were used to assemble the butt joints, using a uniform tightening torque of 25 in.-lbs.

Two types of fatigue specimens were prepared; one type assembled in the bare condition, and the other with the MIL-S-8802 sealant in the holes and countersunk areas and with sealant overlay covering the screw heads after proper tightening of the screws. The fatigue specimens were not treated in any manner whatsoever, except for the use of the sealant; none of the fatigue specimens received any paint system overcoat. The sealant was applied in the same manner as described earlier for the corrosion control specimens.

In order to ascertain whether the rounding of the sharp edges of the fastener heads and/or rounding of the sharp edges of the fastener countersunk holes, in conjunction with the use of sealants, would significantly improve the corrosion resistance without adversely affecting the fatigue properties, the two types of specimens were further sub-divided into four groups as follows:

a. Standard, i.e. edges of fastener heads and fastener holes untouched (S)

b. Edges of fastener heads rounded, edges of holes not rounded (RF)

c. Edges of fastener countersunk holes rounded, edges of fastener heads not rounded (RH)

d. Edges of fastener heads and fastener countersunk holes both rounded (RFH)

Edges of fastener heads and edges of countersunk fastener holes were rounded as shown on the configuration on the respective S-N curve plates for the particular group. Rounding of edges of the fastener heads and edges of the countersunk fastener holes was done by conventional means. For the purposes of the fatigue evaluation, the rounded fastener heads were not replated with cadmium but left bare.

In the interest of clarity and brevity, future reference to the various groups of specimens hereinafter will be in abbreviated form as shown in the parenthesis following the respective descriptions above.

2. Fatigue Test Equipment

A Krouse Direct Stress Fatigue Machine of 5,000 lbs. capacity was used in performing the fatigue tests. This machine utilizes the deflection of an elastic load lever as a means of determining the amount of force applied to the specimen, the deflection of the load lever being proportional to the load. The force from the load lever is transmitted to the specimen by means of flexure plates which change the angular lever motion to straight line motion and thus induces direct loading in the specimen. The load lever is actuated by an infinitely variable throw crank which makes it possible to obtain all ranges of tensile and compressive loads within the capacity of the machine.

The fatigue machine is equipped with an automatic load maintainer to compensate for creep occurring in the specimen during test, up to the point of fracture.

The fatigue machine had been calibrated statically and dynamically to evaluate inertia effects occurring during actual operation of the machine during tests. Correction factors, obtained from dynamic calibration studies, have been applied to the fatigue data reported herein.

A photograph of the fatigue machine is shown in Plate 3, and the arrangement of the specimen and holding fixtures is shown in Plate 4.

3. Description of Fatigue Test Procedures

The fatigue evaluation consisted essentially of establishing S-N curves and noting from the S-N curves the values of the fatigue strengths, to the nearest 100 lbs., of each test group at five million cycles, and references to fatigue strength hereinafter will be so designated.

The arrangement of the specimen and holding fixtures had been designed so that application of the tensile load occurred at the geometrical axis of the specimen, as shown on Plate 2, to place a bending force on the test plates so that failure would occur, in all cases, at the critical areas immediately adjacent to the countersunk holes.

The specimens were subjected to 1100 cycles of repeated load per minute. The range of load applied to the specimens during each pulsating cycle of tensile load varied between a minimum of 25% of a predetermined maximum and the maximum, for a load ratio of 0.25.

Accuracy of fatigue testing of the type performed in this investigation depends in a large measure upon proper alignment of specimens with the machine load screws and an equal distribution of load on the specimen holding bolts. This was accomplished by (1) securing specimens in the fixture by only the center bolt at both ends; (2) tightening the cover plate slightly; (3) applying a light tensile load on the specimen to induce alignment; (4) reaming the remaining holes to exact size and location to suit fixtures and (5) insertion and final tightening of all other bolts.

III. RESULTS

A. Corrosion Evaluation

1. Specimens Without Sealant

a. During loading, less flaking or peeling of the paint coating occurred at locations with rounded configurations, but hairline cracking of the epoxy system did occur around the periphery of the fastener heads. Plates 5 and 6 show painted specimens after salt spray exposure.

b. Metallographic examination revealed that surface corrosion was eliminated and gross corrosion reduced by rounding the edges at fastener holes and/or rounding fastener heads. However, pitting and intergranular attack still occurred in the countersinks, as shown in Plates 7 and 8.

2. Corrosion Barrier Materials

The MIL-S-8802 sealant proved effective in eliminating corrosion at countersink areas. At locations with sealant applied only in the countersinks, some corrosion did occur. However, the use of the sealant overlay alone gave complete corrosion protection. The photomicrographs of Plate 9 compare the results of these two methods. Similar results were obtained with rounded and unrounded configurationss.

Of the low-cycle fatigue stressed specimens, only those tested at -110°F developed cracks in the sealant. In addition to the cracks detected around the fastener heads, small particles of sealant chipped off the painted specimen during loading. While cracks appeared in the paint system overcoat of the other specimens, the sealant still remained intact.

Examination of the unpainted specimens after salt spray exposure revealed the presence of blisters in the sealant overlay, shown in Plate 10. The salt-sulfur electrolyte permeated the sealant and initiated corrosion in the countersink rim.

3. Zinc chromate applied to the fasteners became powdery under test conditions and afforded little corrosion protection. Photomicrographs of rounded and unrounded countersinks are contained in Plate 11.

4. The polymeric coating, deposited on the fasteners in three thicknesses, was partially stripped when the fasteners were torqued. The poor adhesion of the coating to the steel fasteners is illustrated in Plate 12. Despite this, corrosion was generally reduced in countersinks with the polymeric coated fasteners, probably because the coating did provide some insulation between the fastener and the aluminum alloy.

B. Fatigue Evaluation

Results of the fatigue tests are presented in tabular form in Tables 1 and 2, and in graphical form on Plates 15 to 20, inclusive. Plot points of the fatigue test results for the four groups or bare specimens and for the four groups of sealant specimens are shown together on Plates 15 and 16, respectively, for general comparison purposes to indicate the scatter effect on the fatigue properties of the different fastener and hole configurations. For the sake of clarity and to avoid the confusion arising from partial overlapping fatigue curves, S-N curves for these four groups of bare and sealant specimens were not drawn. However, S-N curves of the fatigue test results of each individual group of specimens, with and without sealant, for the S, RF, RH, and RFH groups of specimens are shown on Plates 17 to 20, respectively.

Below are summarized the values of the fatigue strengths of the various test groups at five million cycles, showing variations from the bare and sealant standard specimens used as controls, and variations of sealant specimens from bare specimens:

BARE SPECIMENS

Specimen Groups	Fatigue Strength	Variations from Standard
S	1700 lbs.	-
RF	1800 lbs.	+5.9%
RH	1800 lbs.	+5.9%
RFH	1900 lbs.	+11.8%

SEALANT SPECIMENS

Specimen Groups	Fatigue Strength	Variations From Standard Groups Bare (1700)		Variations From Similar Bare Groups
		Bare (1700)	Sealant (1600)	
S	1600 lbs.	-5.9%	-	-5.9%
RF	1600 lbs.	-5.9%	0	-11.1%
RH	1600 lbs.	-5.9%	0	-11.1%
RFH	1600 lbs.	-5.9%	0	-15.8%

The failure of the fatigue specimens was the same in all cases, occurring at the holes of the outer rows of screws, as shown on the photograph of a typical failure, Plate 13. Contrary to expectations, failure did not initiate at the countersunk side of the test sheet which is the location of the highest stress concentration and the smallest area. Rather, failure started at the holes at the inner or non-countersunk side of the test sheet, as shown on Plate 14, because of the fretting action due to the slight relative periodic motion between the 1/8" test sheet and the 3/8" back-up plate. The fretting action resulted in pitting and roughened inner faying surfaces in the area immediately adjacent to the holes, thus increasing the stress concentration factor there to a greater value than on the countersunk side of the holes.

IV. ANALYSIS OF RESULTS

A. Corrosion Control Evaluation

1. Removing sharp edges at fastener locations prevented the fastener head from gouging into the countersink rim during loading. Intimate contact of steel and aluminum at this site was, therefore, avoided and corrosion of the countersink rim and adjacent surface was eliminated. The severe pitting and intergranular attack that did occur at rounded configurations was only within the countersink and could not be visually detected without removal of fasteners. In service rounded configurations would present a precarious situation with the possibility of corroded fastener holes being by-passed during overhaul and repair of the aircraft.

2. The MIL-S-8802 sealant with a paint system overcoat proved capable of insulating the fastener locations from the SO_2-salt spray environment. This, plus its high flexibility and good adhesion to both paint and metal, make it highly desirable for application in service to combat wing skin corrosion on carrier based planes. However, use of a sealant overlay alone may not provide sufficient protection because of moisture penetration through joints and seams of the wing skin. Therefore, a more complete protective system would be to apply sealant both in the countersinks and as an overlay.

3. For supersonic aircraft where aerodynamic considerations might preclude the overlay, use of sealant in the holes is still advisable. The method of application used in this investigation did not completely protect the countersink from attack, but a uniform coverage was not obtained. Encapsulating the sealant with the fastener, or coating the countersink with a sealant gun should provide more uniform coverage.

B. Fatigue Evaluation

As was expected and verified by the fatigue test results, anything done to reduce sharp edges (lower stress concentration) will have a beneficial effect on the fatigue properties of fastened joints. However, the beneficial effects were not as pronounced as they might have been due to the fact that the faying surfaces of the test specimens were not coated so that critical fatigue factor effects were transferred from the countersunk side of the holes, where they normally are, to the inner faying surfaces adversely affected by fretting corrosion. Other investigators, reference (d), found that sealants sandwiched between the faying surfaces of standard joints prior to fastening had a beneficial effect on the fatigue properties of the joints.

Thus, a truer and more convincing test of the beneficial effects of round edge configuration on the fatigue properties of joints assembled with threaded countersunk fasteners would have been to coat the faying surfaces with some sort of appropriate coating which would have eliminated or minimized the deleterious effects of fretting corrosion. However, even under the inadvertent adverse conditions of the uncoated faying surfaces, there is sufficient evidence to indicate that significant beneficial effects on the fatigue strengths of bare fastened joints may be obtained by rounding off sharp edges of fastener heads and countersunk holes. However, it is to be noted from an examination of the plot points for the bare specimens, Plate 15, that the beneficial effects of rounded fastener heads and rounded edges of countersunk holes is only evident at the low load-high cycle life, whereas at the high load-low cycle life there is no effect, either harmful or beneficial. This is due to the fact that the effect of reduced stress concentration, by rounding sharp edges, plays a more important role in fatigue at high cycle life than it does at low cycle life.

It can be seen from an analysis of the fatigue results that the use of the sealant adversely affected the fatigue properties of the four groups of specimens, regardless of the fastener and hole configuration. These results confirmed the findings reported in reference (d) wherein it is stated that the fatigue lives of joints were reduced when a number of different sealants and coatings were applied to the fasteners or fastener holes, as compared to the fatigue lives of similar joints having bare fasteners and bare fastener holes.

It is interesting to note that the fatigue strengths of all four groups of sealant specimens, regardless of fastener and hole configuration, were reduced to the same value of 1600 lbs., despite the fact that corresponding groups of bare specimens had fatigue strengths of 1700 lbs., 1800 lbs., 1800 lbs., and 1900 lbs. for the S, RF, RH and RFH groups of specimens, respectively. It would seem that the deleterious effect of the sealant on the fatigue strength of each individual group of specimens is not a constant proportional amount of the fatigue strengths of its corresponding group of bare specimens. Rather, its harmful effect is of such a nature as to equalize the fatigue strengths of all the groups at a certain uniform value. In essence, the sealant quantitatively nullifies all the beneficial effects of the rounded fastener heads and the rounded countersunk holes, whatever the magnitude of these beneficial effects. In other words, the sealant limits the fatigue strengths of the test groups to a basic minimum value, despite the beneficial effects of the various configurations in the bare specimens.

The explanation for the reduced fatigue strengths of all the four test groups of specimens using sealant is that the sealant lowers the optimum degree of rigidity in the assembled joints, makes them more elastic and consequently causes reduction in fatigue strengths. After the jointed assemblies (with sealant) have been exposed to operational environment for some time, the fasteners are no longer under the initial tension. Further, the use of sealants between screws and the base material allows a looser fitting joint with subsequent greater relative motion at the faying surfaces, causing earlier fretting fatigue failures.

In addition to reducing the fatigue properties of the four groups of specimens with the different fastener and hole configurations, the sealant has a tendency to increase the general scatter of the test results. This is probably due to the fact that the use of the sealant introduces an additional variable which cannot be effectively controlled from specimen to specimen.

A further analysis of the composite scatter of the fatigue test results for the sealant specimens, with different fastener head and hole configurations, as shown on Plate 16, indicates a wide range of scatter at the high load-low cycle life, with no scatter at all at the fatigue strength corresponding to a life of five million cycles. This is the reverse of the scatter for the bare specimens, with different fastener head and hole configurations, where there was little or no scatter at the high load-low cycle life, but a somewhat increased scatter at the fatigue strength, for the reason previously mentioned that the effect of reduced stress concentration is more pronounced at low load-high cycle life. With a great number of repeated loadings at low loads, probably the sealant is evenly and smoothly distributed over the contact areas to reduce the harmful effects of the sealant to a common minimum value and comparatively no scatter. At high loads, fatigue failure initiates before there is a chance to adjust the rough, non-uniform application of the sealant; the non-uniformity of course being conducive to fatigue scatter.

It must be emphasized that the scope of this fatigue investigation was exploratory in nature and this limitation precluded the use of a large number of sealants and specimens to give statistical meaning to the results.

However, on the basis of this investigation and the investigation of others who obtained similar results, it is fairly safe to state that the use of sealants as coatings on fasteners and holes lower the fatigue properties of fastened joints.

V. CONCLUSIONS

1. The rounding of fastener holes and/or fastener heads without using a sealant did not significantly improve the corrosion resistance at fastener locations. Countersink rim corrosion was diminished with rounded configurations but extensive pitting and intergranular attack occurred within the countersink.

2. The MIL-S-8802 sealant afforded good corrosion protection. When applied over fastener holes in a 7 mil thickness and overcoated with an epoxy paint system, the sealant gave complete protection in the SO_2-salt spray environment.

3. The basic conclusions drawn from the results of the fatigue investigation are as follows:

a. Appropriate fastener and hole configuration improves the fatigue properties of the bare specimens;

b. The use of the sealant reduces the fatigue strength of the basic group of specimens, with standard screws and standard countersunk holes, by an amount approximately 6% of the fatigue strength of the bare group of specimens;

c. In general, the use of the sealant lowers the fatigue properties of all groups of jointed specimens, but more specifically it lowers the fatigue strengths of all the groups to an equal minimum value, regardless of the varying beneficial effects of the different fastener and hole configurations;

d. Application of sealant has a tendency to increase fatigue scatter.

VI. RECOMMENDATIONS

In view of the improvement in corrosion resistance imparted to the fastener joints by the use of the sealant with only a slight reduction in fatigue properties, it is recommended that an appropriate sealant be used between cadmium plated steel fasteners and aluminum sheet or plate material, with an overlay of the sealant over the screw heads where aerodynamic considerations are not restrictive.

Further fatigue evaluation studies should be conducted to statistically determine quantitatively the effect of the sealant on the fatigue properties of typical aircraft joints, both with bare faying surfaces and coated faying surfaces, since evidence indicates that coated faying surfaces will improve fatigue properties.

REFERENCES

(a) Assignment No. 11-21 under WEPTASK RRMA 02 011/200 1/F020 01 01 of 26 Jul 1965

(b) Report No. NAEC-AML-2258, Development of Methods to Improve Corrosion Behavior of Threaded Fastener Installations in Aluminum Alloys, L. S. Constantine, of 10 Sep 1965

(c) Report No. NAEC-AML-2482, Protection of the Aircraft Fastener Area, J. Ohr, of 2 Aug 1966

(d) Air Force Materials Laboratory Report; Report No. AFML-TR-66-132, Effect of Corrosion Control Techniques on Fatigue Life of Typical Aircraft Joints, of 6 Jun 1966

FATIGUE DATA FOR BARE SPECIMENS

Standard Specimens

Load/lbs.	Cycles
5000	51,800
4000	114,300
3500	137,100
3000	218,000
2500	453,000
2000	719,000
1900	950,000
1800	3,422,100
1700	5,000,000*
1700	5,410,300*

Fatigue Strength - 1700 lbs.

Specimens with Rounded Fastener Heads (RF)

Load/lbs.	Cycles
5000	48,400
4000	103,500
3500	147,100
3000	300,200
2500	456,600
2000	1,264,600
1900	4,040,000
1800	5,000,000*
1800	5,325,000*

Fatigue Strength - 1800 lbs.

Specimens with Rounded Countersunk Holes (RH)

Load/lbs.	Cycles
5000	51,600
4000	113,700
3500	170,300
3000	196,000
2500	481,400
2000	1,786,000
1900	2,148,200
1800	5,000,000*
1800	5,963,000*

Fatigue Strength - 1800 lbs.

Specimens with Rounded Fastener Heads and Rounded Holes (RFH)

Load/lbs.	Cycles
5000	52,500
4000	100,900
3500	222,700
3000	353,000
2500	612,000
2200	1,335,000
2000	2,365,100
1900	5,391,300*
1900	5,202,000*

Fatigue Strength - 1900 lbs.

*No failure

TABLE 1

FATIGUE DATA FOR SPECIMENS WITH SEALANT

Standard Specimens

Load/lbs.	Cycles
5000	15,400
4000	41,600
3500	97,400
3000	229,300
5000	121,100
2000	1,307,000
1800	1,868,000
1700	1,909,200
1600	5,409,000*
1600	5,000,000*

Fatigue Strength - 1600 lbs.

Specimens with Rounded Fastener Heads (RF)

Load/lbs.	Cycles
5000	19,800
4000	62,400
3500	149,700
3000	233,400
2500	197,300
2000	1,031,700
1800	1,130,000
1700	1,482,000
1600	7,878,000*
1600	5,103,000*

Fatigue Strength - 1600 lbs.

Specimens with Rounded Countersunk Holes (RH)

Load/lbs.	Cycles
5000	35,200
4000	105,600
3500	61,200
3000	153,700
2500	403,700
2000	1,707,900
1800	766,700
1700	1,137,700
1600	5,215,000*
1600	5,020,000*

Fatigue Strength - 1600 lbs.

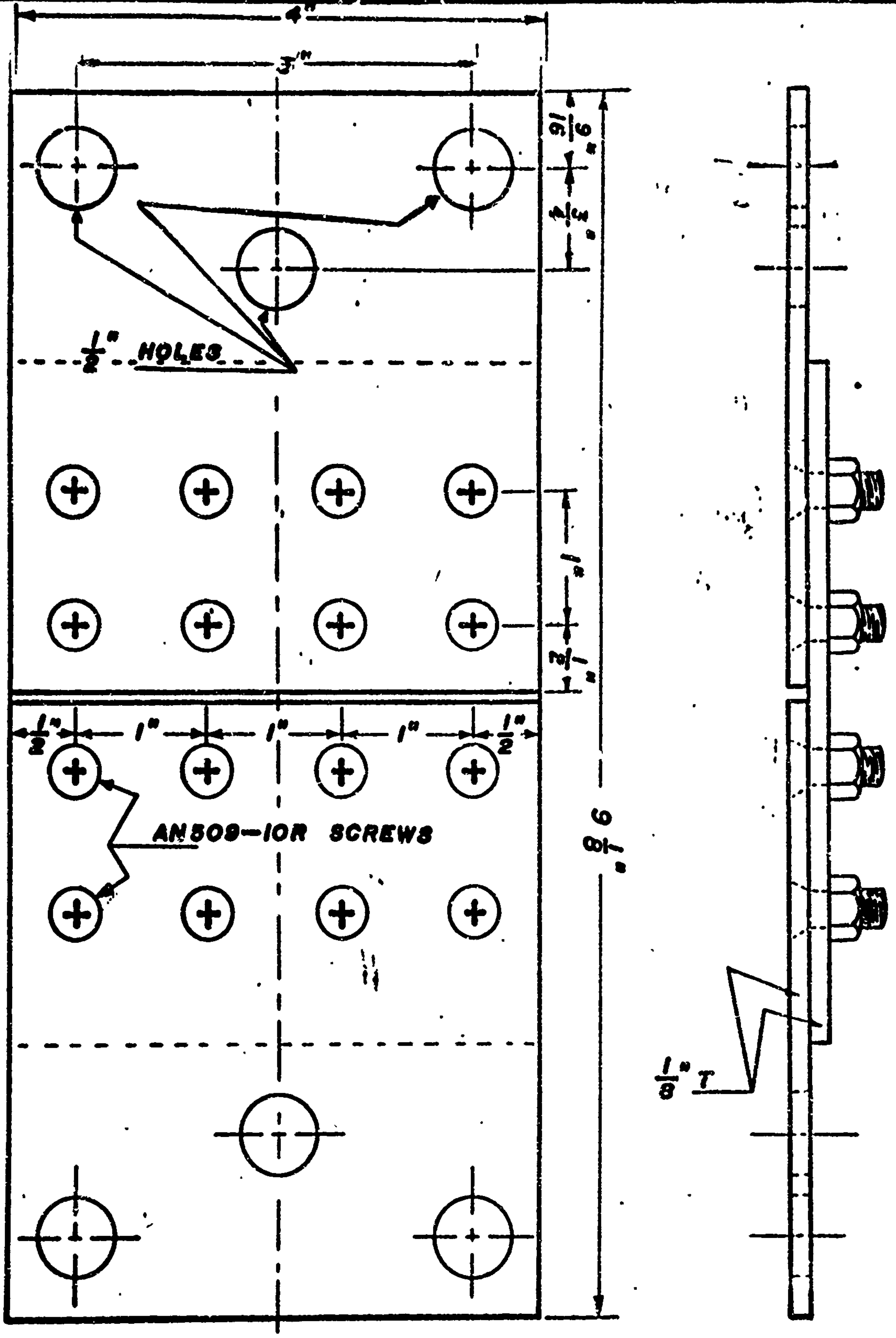
Specimens with Rounded Fastener Heads and Rounded Holes (RFH)

Load/lbs.	Cycles
5000	20,300
4000	72,800
3500	82,100
3000	250,700
2500	305,700
2000	356,300
1800	781,200
1700	1,350,000
1600	6,164,700*
1600	5,250,100*

Fatigue Strength - 1600 lbs.

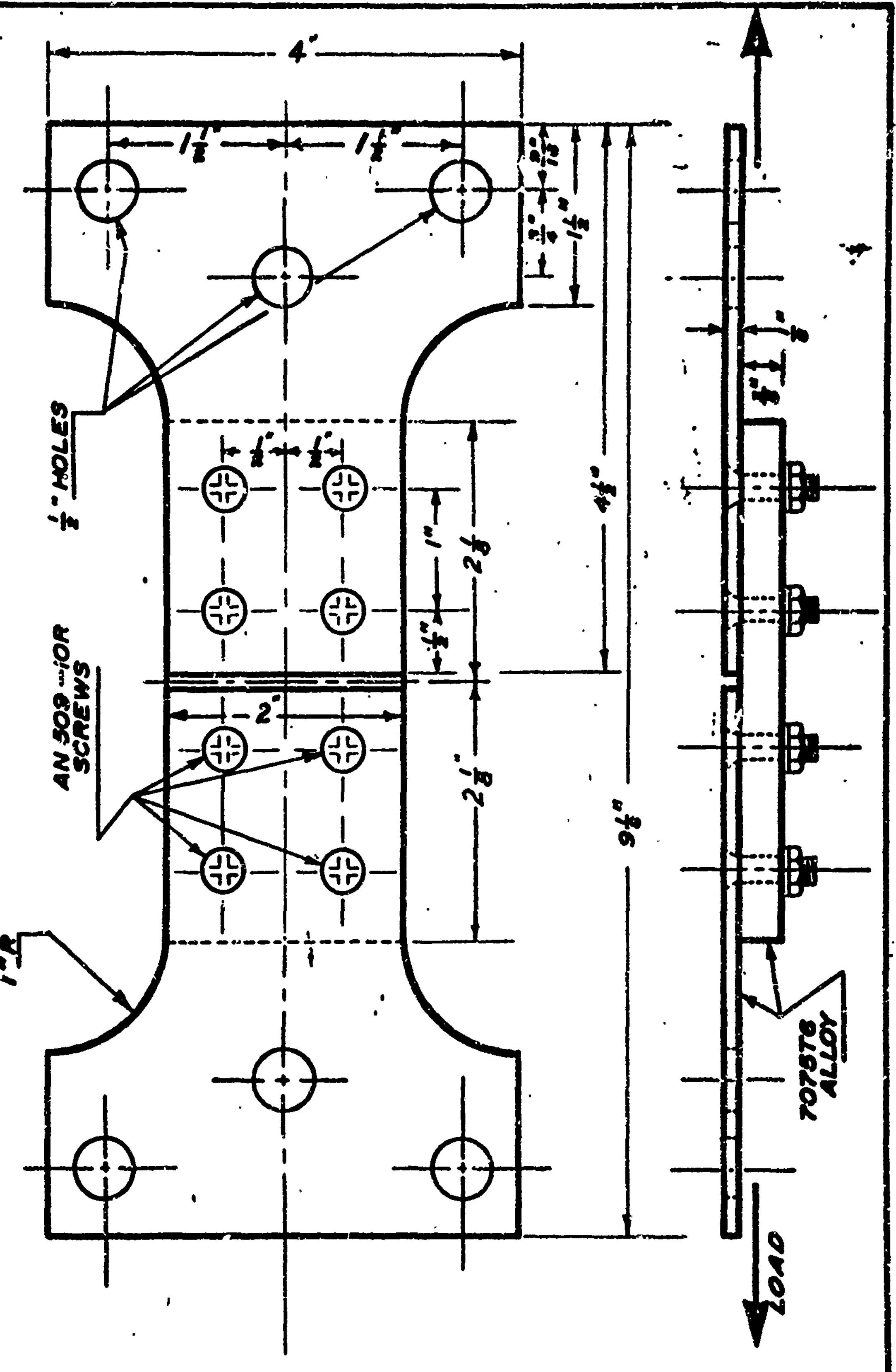
*No Failure

TABLE 2



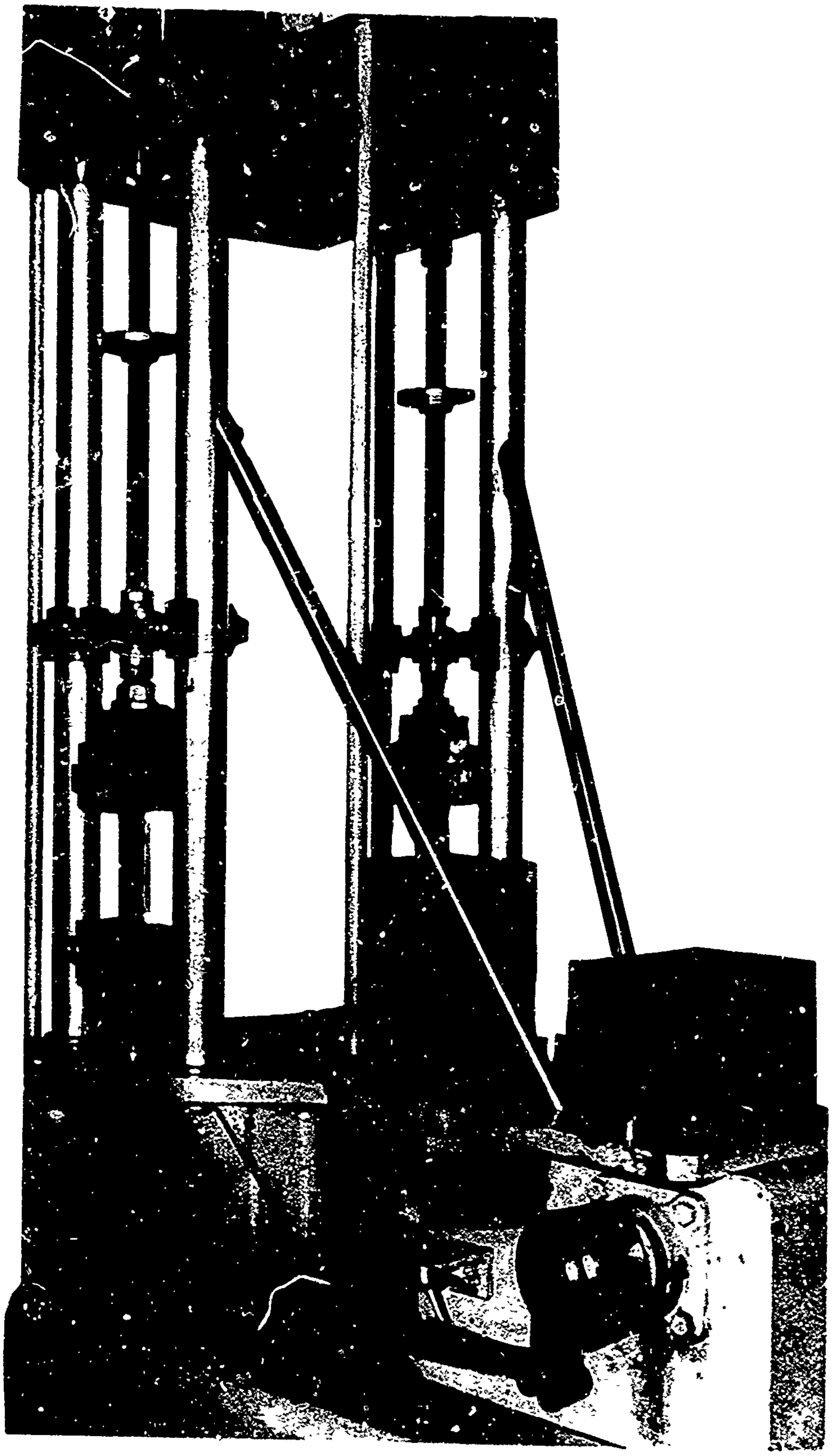
DETAILS OF CORROSION SPECIMEN

Plate I



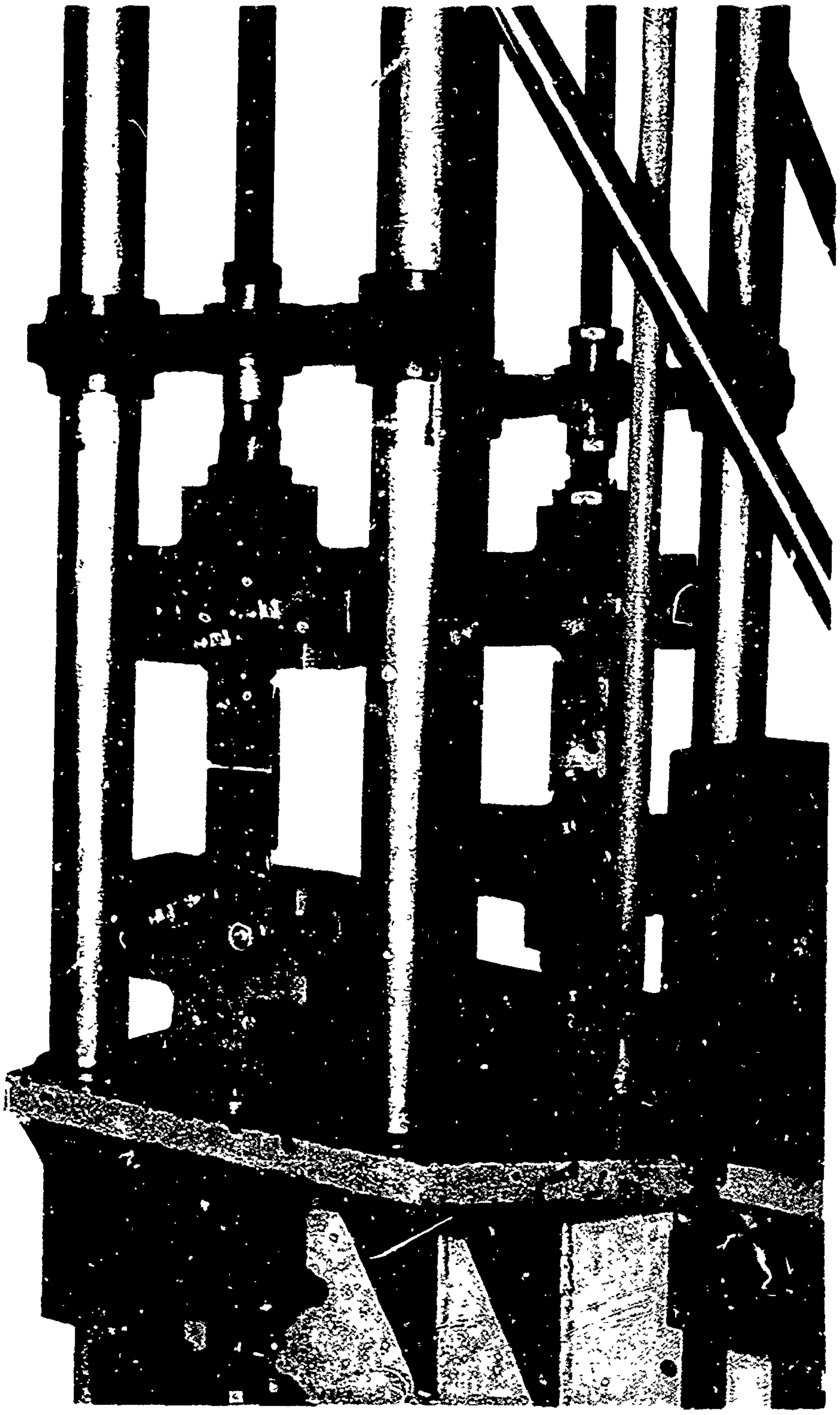
DETAILS OF FATIGUE SPECIMEN

Plate 2



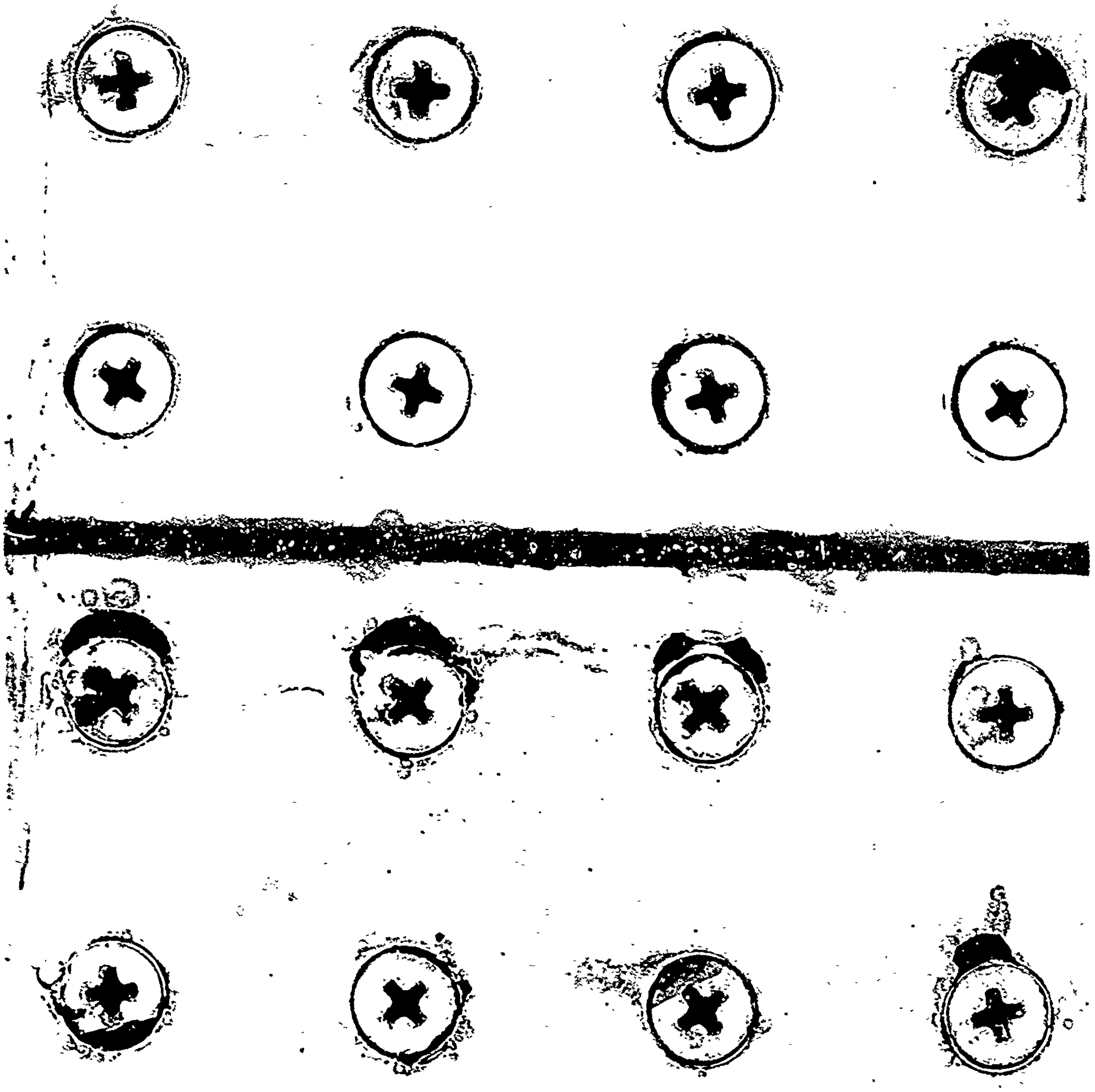
FATIGUE TESTING MACHINE

PHOTO NO: CAN-379352(L)-11-65



ARRANGEMENT OF FATIGUE SPECIMENS
AND HOLDING FIXTURES

PHOTO NO: CAN-379353(L)-11-65

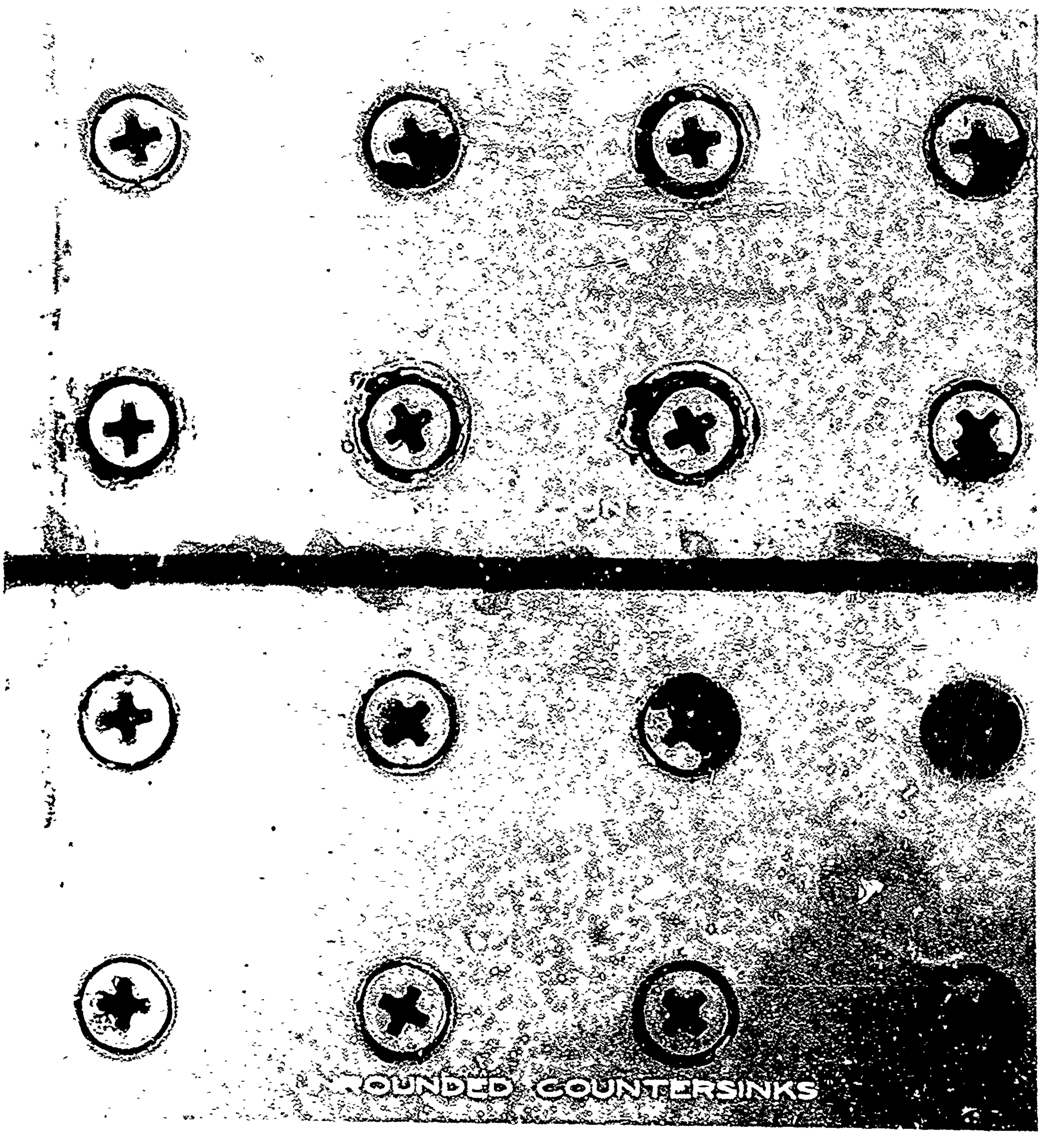


2X

TEST ASSEMBLY WITH UNROUNDED FASTENER HEADS AFTER 4 WEEKS IN $NaCl-SO_2$ CHAMBER

PHOTO NO: CAN-372257(L)-11-65

PLATE 5



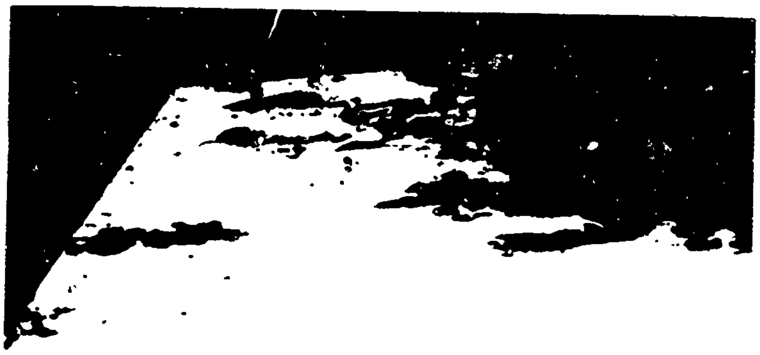
2X

TEST ASSEMBLY WITH ROUNDED FASTENER HEADS AFTER 4 WEEKS IN $NaCl-SO_2$ CHAMBER

PHOTO NO: CAN-372256(L)-11-65

PLATE 6

Rounded Countersinks



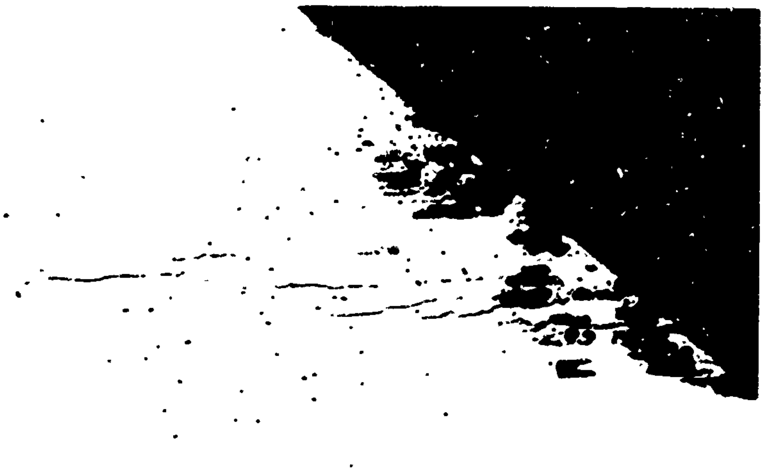
Unrounded Countersink

75X

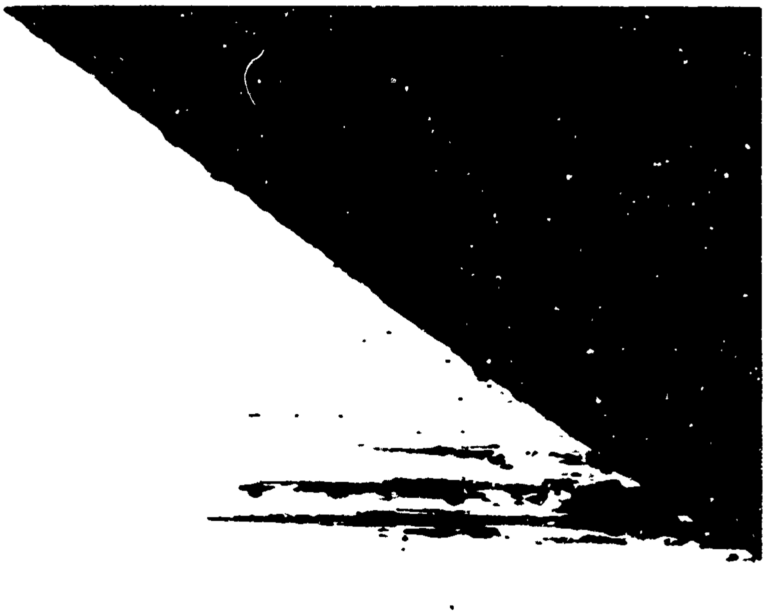
PHOTOMICROGRAPHS OF FASTENER HOLES FROM SPECIMEN SHOWN ON PLATE 5
(Fastener Heads were not Rounded)

PHOTO NO: CAN-380061(L)-1-67

PLATE 7



Rounded Countersinks



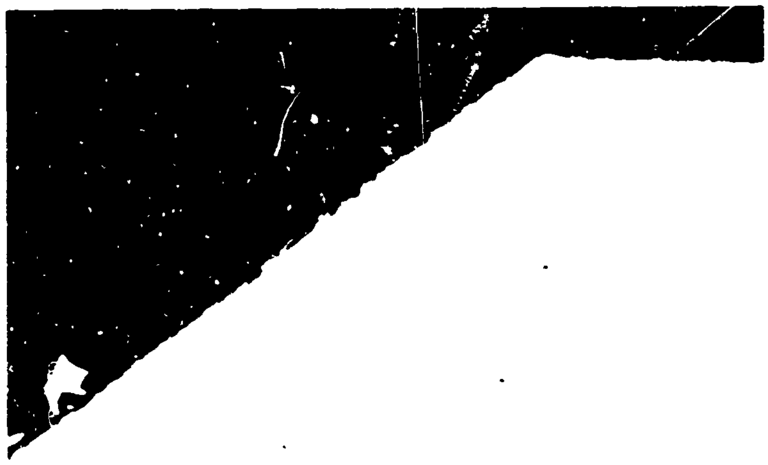
Unrounded Countersinks

75X

PHOTOMICROGRAPHS OF FASTENER HOLES FROM SPECIMEN SHOWN IN PLATE 6
(Fastener Heads were Rounded)

PHOTO NO: CAN-380062(L)-1-67

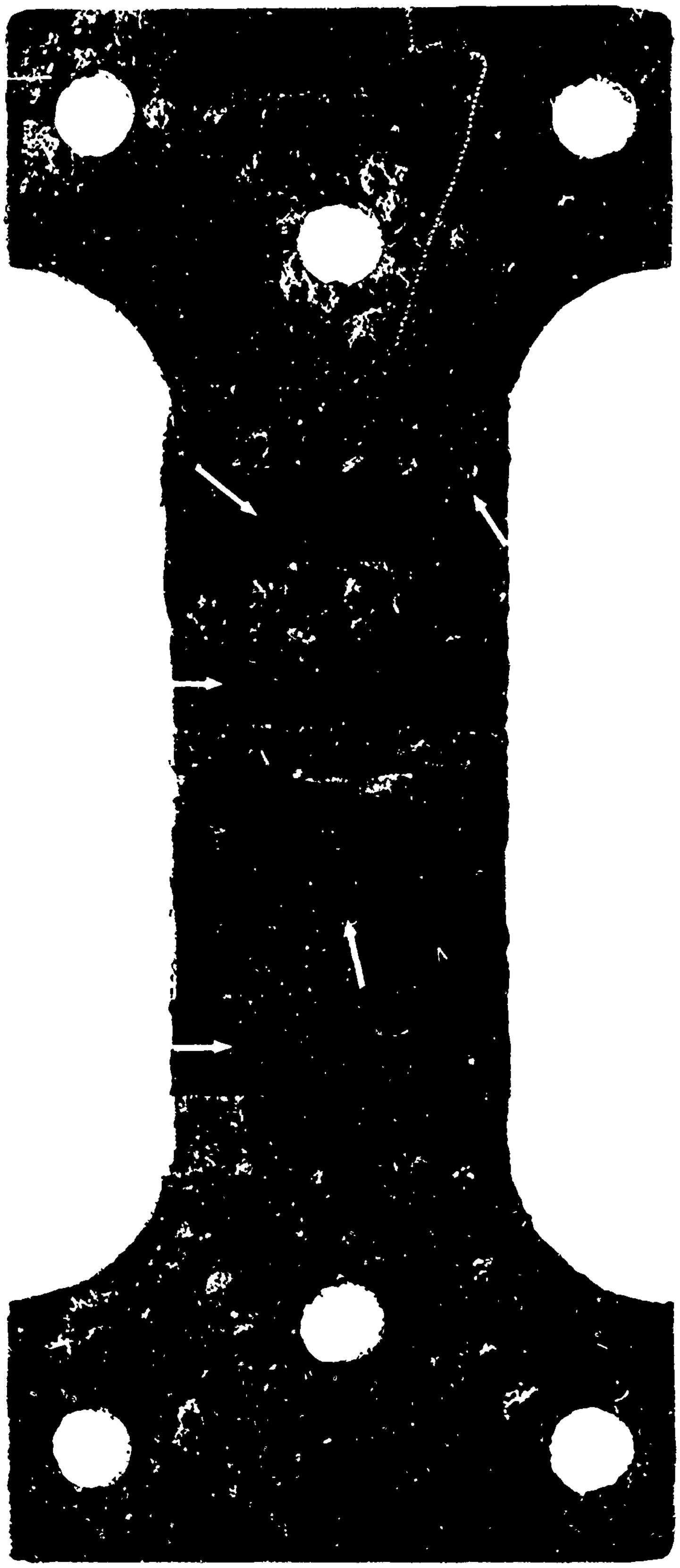
Sealant Applied Only in the Countersink



Sealant Overlay Only

COMPARISON OF CORROSION OF COUNTERSINK AREAS - DIFFERENT SEALANT APPLICATIONS

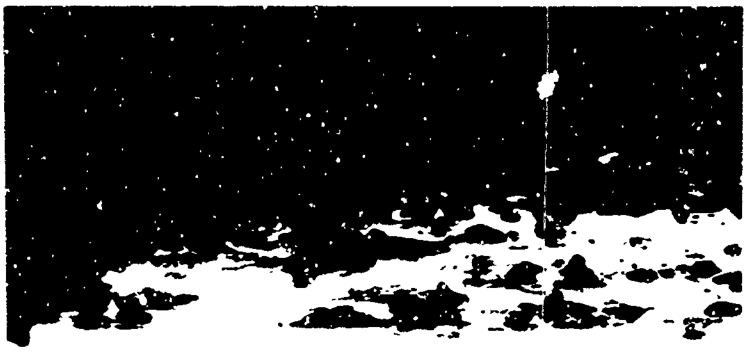
PHOTO NO: CAN-380063(L)-1-67



BLISTERING OF MIL-S-8802 SEALANT (Indicated by Arrows) ON UNPAINTED SPECIMEN

PHOTO NO: CAN-378999(L)-10-66

Rounded Countersink



Unrounded Countersink

75X

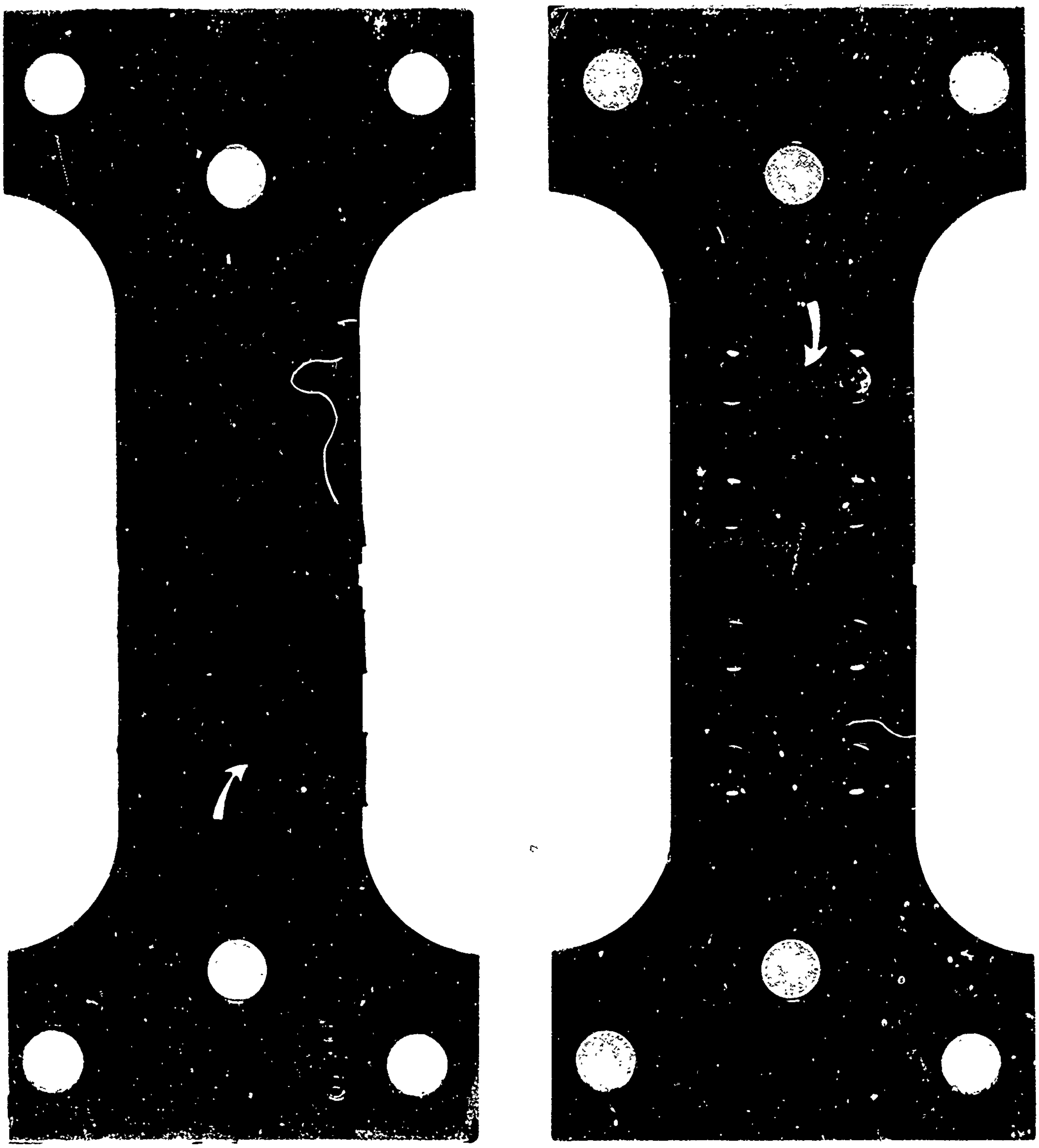
SEVERE PITTING CORROSION AT COUNTERSINKS WITH ZINC CHROMATE PRIMER COATED FASTENERS

PHOTO NO: CAN-380064(L)-1-67

1.5X

POLYMERIC COATED FASTENERS AFTER SPECIMEN DISASSEMBLY

PHOTO NO: CAN-378996(L)-10-66



Sealant Specimen Bare Specimen

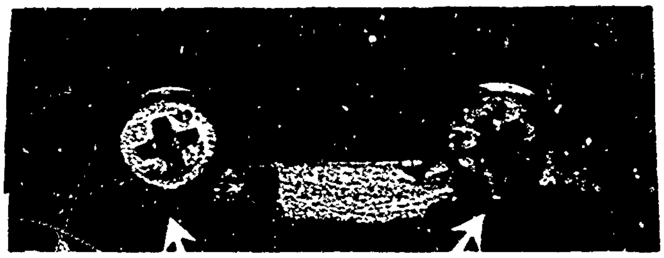
TYPICAL FATIGUE FAILURES

PHOTO NO: CAN-3 [illegible] (L)-1-67

PLATE 13

Failure Initiation

SEALANT SPECIMEN



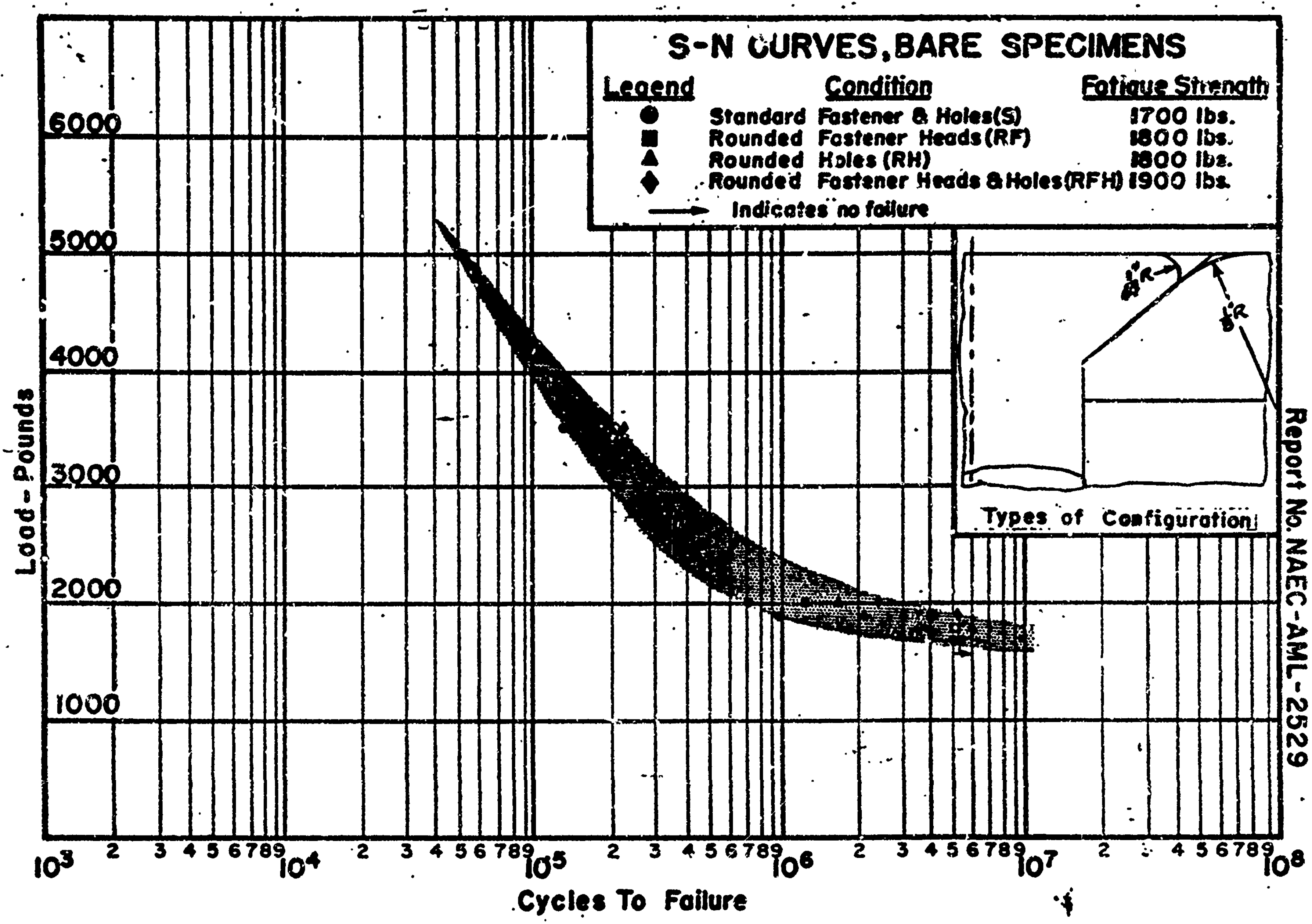
Failure Initiation

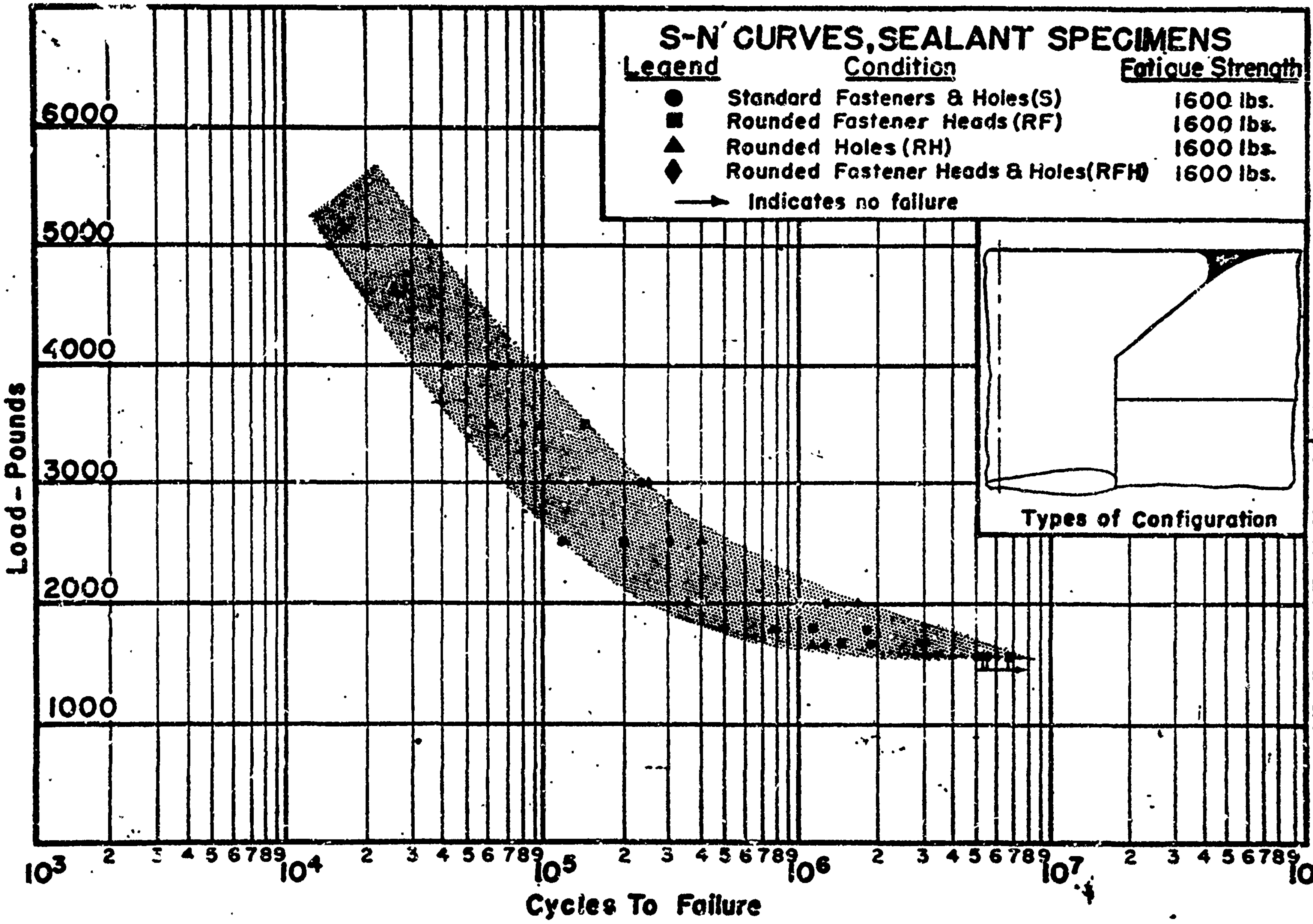
BARE SPECIMEN

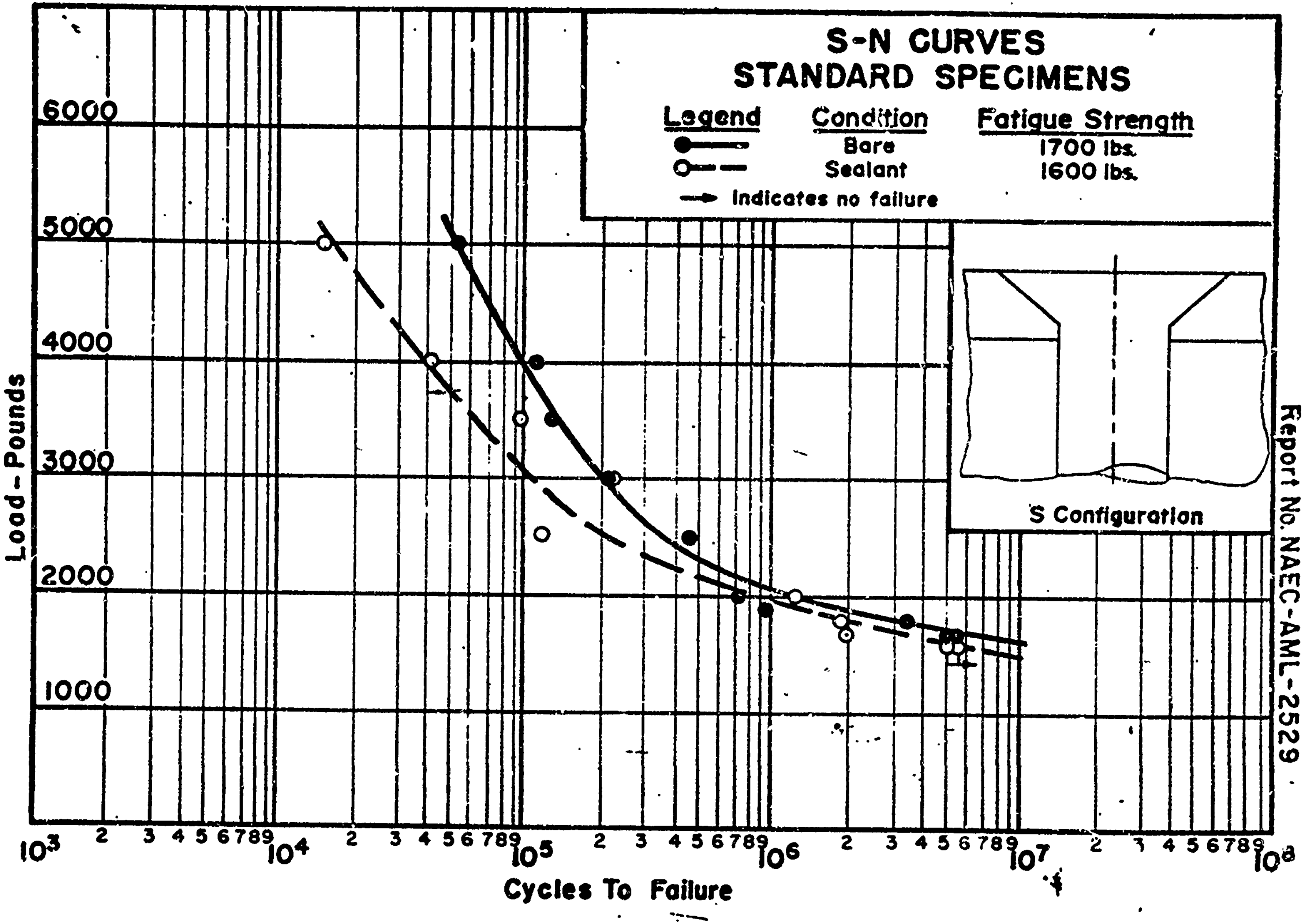
INITIATION OF FATIGUE FAILURES

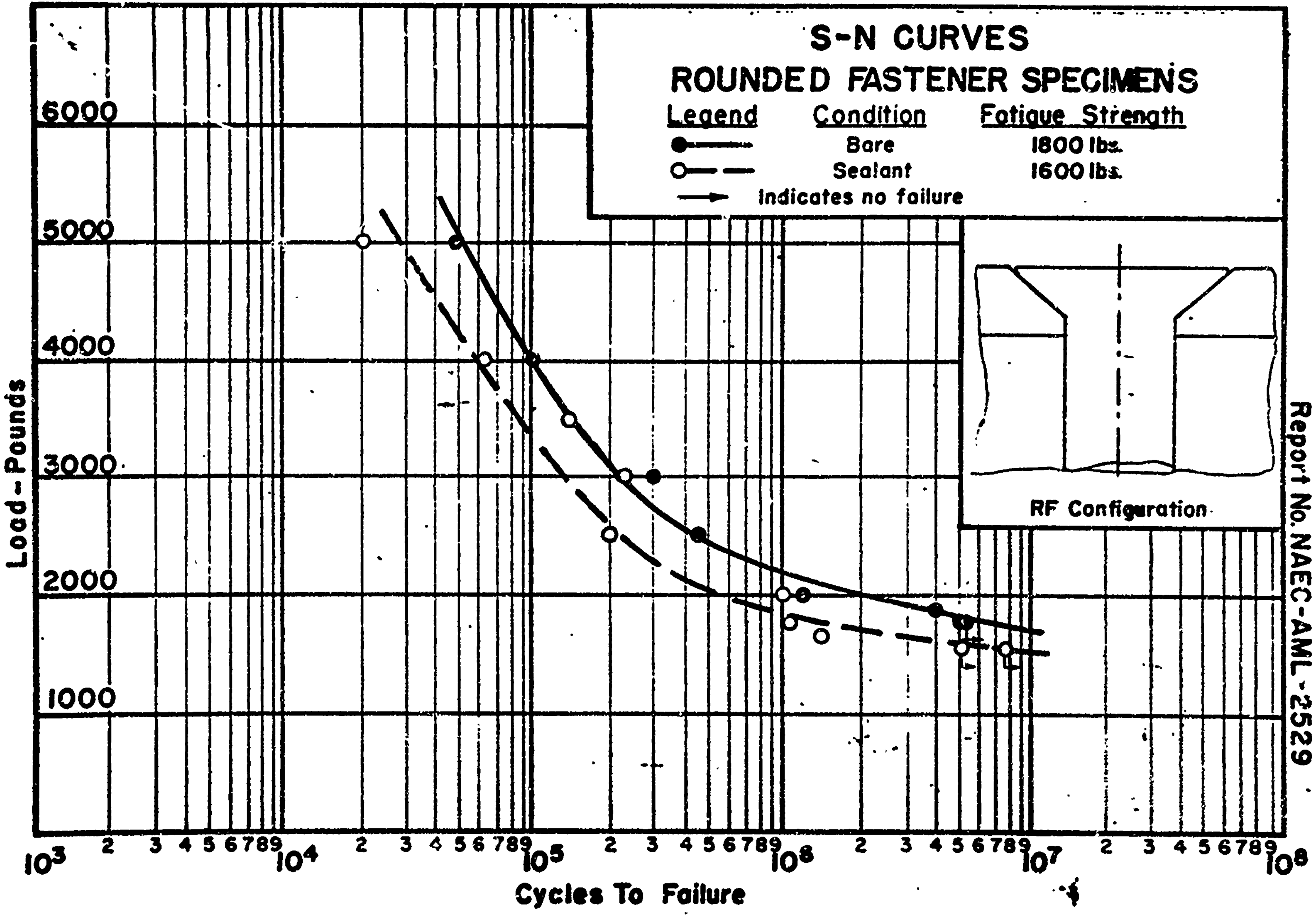
PHOTO NO: CAN-380066(L)-1-67

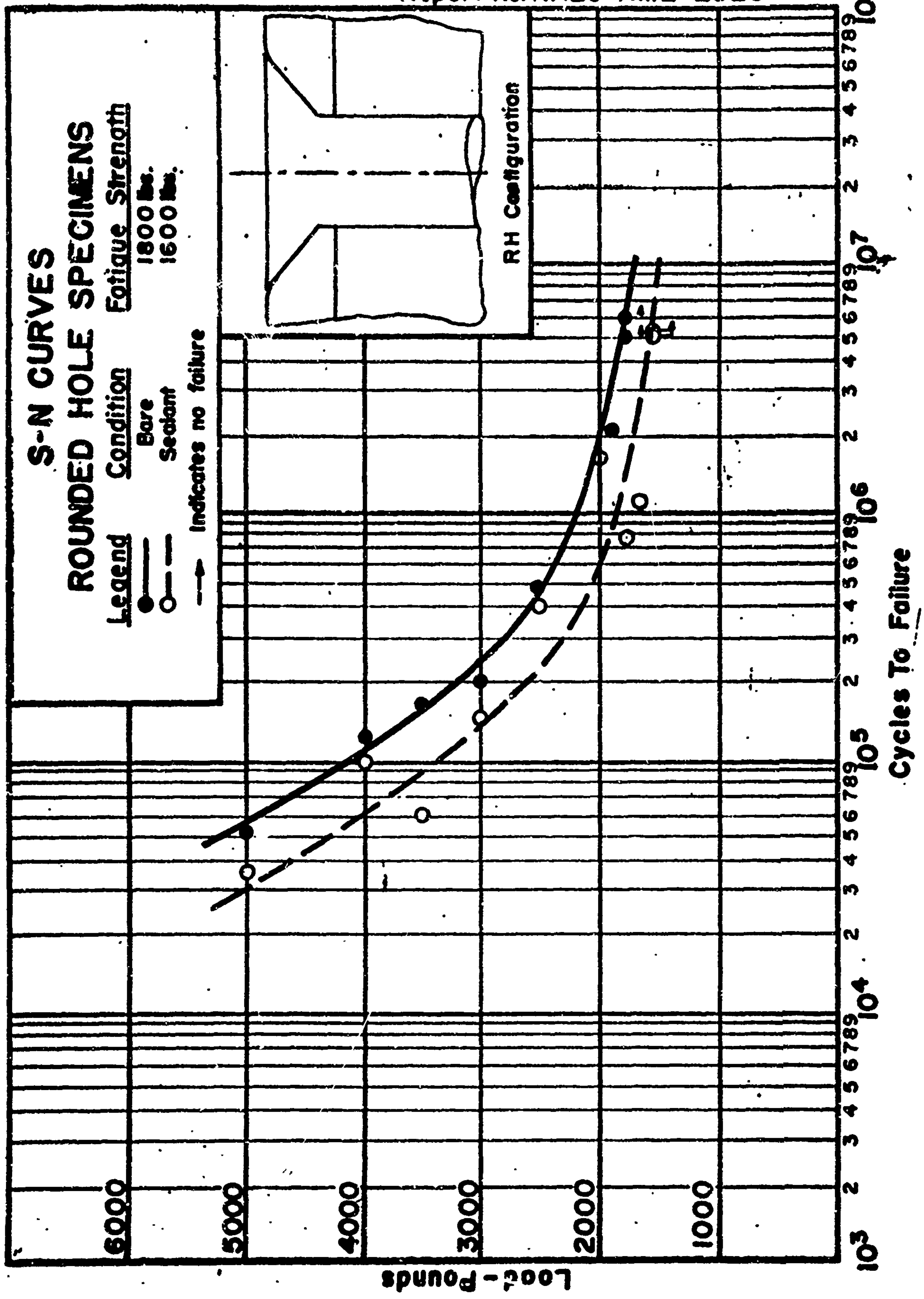
PLATE 14

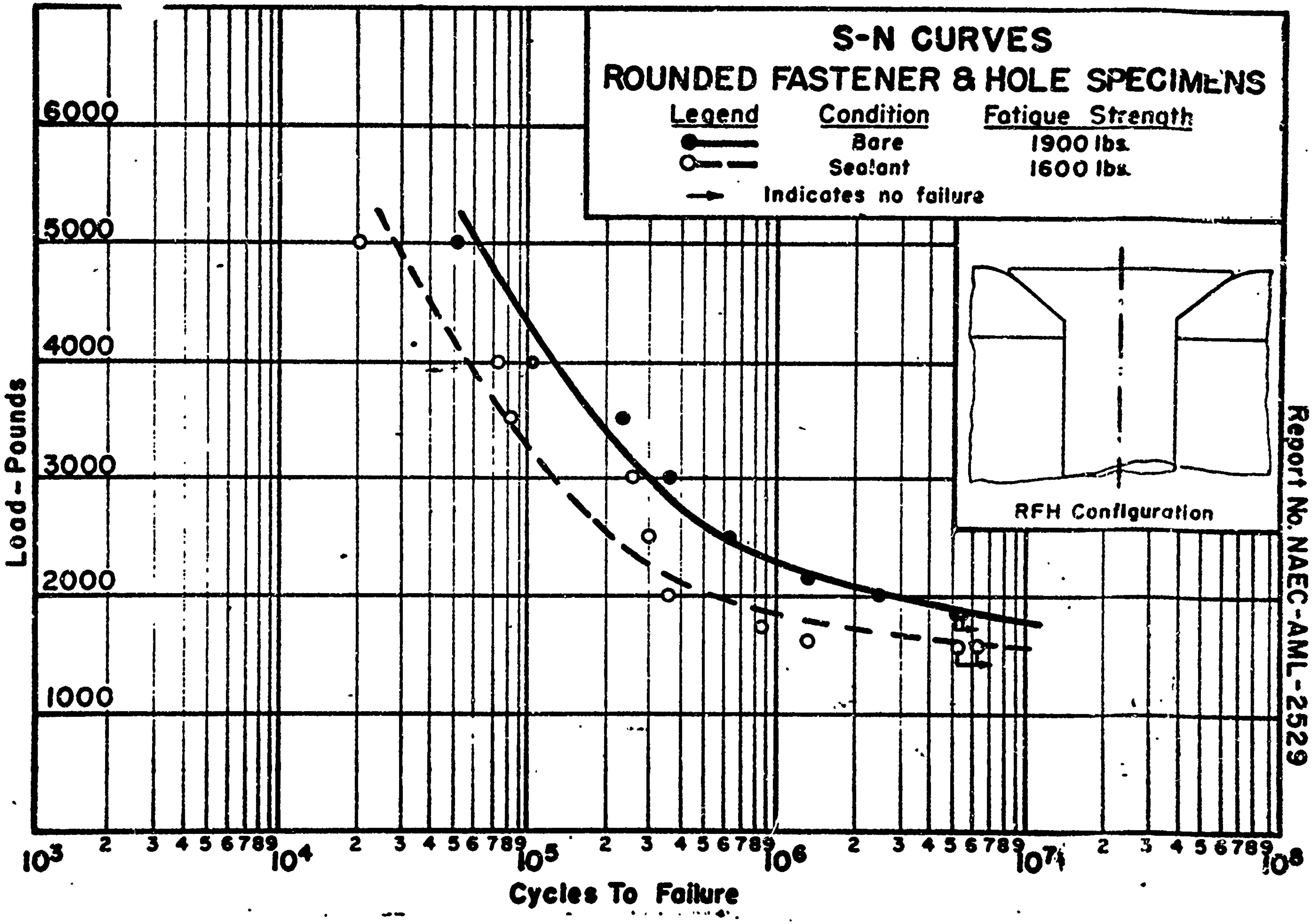

S-N CURVES, BARE SPECIMENS
Legend
Condition
Fatigue Strength
● Standard Fastener & Holes(S) 1700 lbs.
■ Rounded Fastener Heads(RF) 1800 lbs.
▲ Rounded Holes (RH) 1800 lbs.
◆ Rounded Fastener Heads & Holes(RFH) 1900 lbs.
→ Indicates no failure
Types of Configuration
R
R
Load - Pounds
6000
5000
4000
3000
2000
1000
10^3
2
3 4 5 6 7 8 9
10^4
2
3 4 5 6 7 8 9
10^5
2
3 4 5 6 7 8 9
10^6
2
3 4 5 6 7 8 9
10^7
2
4 5 6 7 8 9
10^8
Cycles To Failure


S-N' CURVES, SEALANT SPECIMENS
Legend
Condition
Fatigue Strength
● Standard Fasteners & Holes (S) 1600 lbs.
■ Rounded Fastener Heads (RF) 1600 lbs.
▲ Rounded Holes (RH) 1600 lbs.
◆ Rounded Fastener Heads & Holes (RFH) 1600 lbs.
→ Indicates no failure
Types of Configuration
Load - Pounds
6000
5000
4000
3000
2000
1000
10^3
2 3 4 5 6 7 8 9
10^4
2 3 4 5 6 7 8 9
10^5
2 3 4 5 6 7 8 9
10^6
2 3 4 5 6 7 8 9
10^7
2 3 4 5 6 7 8 9
10^8
Cycles To Failure


S-N CURVES
STANDARD SPECIMENS
Legend
Condition
Fatigue Strength
Bare
1700 lbs.
Sealant
1600 lbs.
Indicates no failure
S Configuration
Load - Pounds
6000
5000
4000
3000
2000
1000
10³
2
3 4 5 6 7 8 9
10⁴
10⁵
10⁶
10⁷
10⁸
Cycles To Failure


S-N CURVES
ROUNDED FASTENER SPECIMENS
Legend
Condition
Fatigue Strength
Bare
1800 lbs.
Sealant
1600 lbs.
Indicates no failure
RF Configuration
Load - Pounds
6000
5000
4000
3000
2000
1000
10^3
2
3
4 5 6789
10^4
10^5
10^6
10^7
10^8
Cycles To Failure


S-N CURVES
ROUNDED HOLE SPECIMENS
Legend
Condition
Fatigue Strength
● — Bare 1800 lbs.
○ — — Sealant 1600 lbs.
→ Indicates no failure
RH Configuration
Load - Pounds
6000
5000
4000
3000
2000
1000
Cycles To Failure
10³
2 3 4 5 6 7 8 9
10⁴
2 3 4 5 6 7 8 9
10⁵
2 3 4 5 6 7 8 9
10⁶
2 3 4 5 6 7 8 9
10⁷
2 3 4 5 6 7 8 9
10⁸


S-N CURVES
ROUNDED FASTENER & HOLE SPECIMENS
Legend
Condition
Fatigue Strength
Bare
1900 lbs.
Sealant
1600 lbs.
Indicates no failure
RFH Configuration
Load - Pounds
6000
5000
4000
3000
2000
1000
Cycles To Failure
10^3
2 3 4 5 6 7 8 9
10^4
2 3 4 5 6 7 8 9
10^5
2 3 4 5 6 7 8 9
10^6
2 3 4 5 6 7 8 9
10^7
2 3 4 5 6 7 8 9
10^8

UNCLASSIFIED

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13. ABSTRACT

A corrosion and fatigue evaluation was made to determine whether the rounding of countersunk holes and/or fastener heads would improve the corrosion behavior at the fastener locations or affect the fatigue strength of 7075-T6 aluminum alloy joints assembled with cadmium plated steel countersunk head screws. Test assemblies were prepared with and without corrosion barrier materials, including a MIL-S-8802 polysulfide sealant, in the finishing system.

Rounded configurations did not significantly improve corrosion behavior but did improve the fatigue strength of the specimens. The greatest improvement in fatigue properties occurred with a combination of rounded fastener heads and rounded countersunk holes.

Of the various corrosion barrier materials tested, only the polysulfide sealant afforded good corrosion protection when used with a paint system overcoat. However, the use of the sealant more than negated the beneficial effect of the rounded configurations on fatigue strength.

The use of the sealant lowered the fatigue strength of the control specimens with standard fastener heads and standard countersunk holes by approximately 6%. This loss is counterbalanced by the improvement in corrosion behavior afforded by the sealant to fastener areas.

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Security Classification

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	ROLE	WT	ROLE	WT	ROLE	WT
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Intergranular corrosion						
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