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PROCEDURES FOR EXTERNALLY LOADING AND CORROSION TESTING STRESS CORROSION SPECIMENS

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George C. Marshall Space Flight Center, Huntsville, Alabama

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By T. S. Humphries
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Page 6: Line 11, Equation 3 should read:

$$\Delta = OD - ODf = \frac{\pi S D^2}{4EtZ} \text{ or } \frac{\pi e D^2}{4tZ}$$

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ABSTRACT

The procedures for externally loading various types of stress corrosion specimens and a description of the test specimens are presented. An accelerated corrosion test method which consists of alternate immersion in a 3-1/2 percent sodium chloride solution is also described. The types of specimens described and the methods of externally loading and corrosion testing the specimens have been found to be reliable for stress corrosion evaluation of most aluminum alloys, and have shown promise for ferrous and nickel alloys.

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By T. S. Humphries

PROPULSION AND VEHICLE ENGINEERING LABORATORY
RESEARCH AND DEVELOPMENT OPERATIONS

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

TECHNICAL MEMORANDUM X- 53483

PROCEDURES FOR EXTERNALLY LOADING AND CORROSION TESTING STRESS CORROSION SPECIMENS

SUMMARY

The procedures for externally loading various types of stress corrosion specimens and a description of the test specimens are presented. A widely-used accelerated corrosion test method, alternate immersion in a 3-1/2 percent sodium chloride solution, is also described. The type and geometry of the material and the grain directions to be tested are some of the major factors to be considered in choosing the type of stress corrosion specimen. For instance, flat tensile specimens are normally used for sheet material; threaded-end, round tensile specimens are used for thick plate, forging, and rolled bar; bent-beam specimens are used for welded joints; and "C" rings are used for tubing, rod, and thin plate (Ref. 1).

The types of specimens described and the methods of externally loading and corrosion testing have been found to be reliable in yielding reproducible results for stress corrosion evaluation of most aluminum alloys, and have shown promise for ferrous and nickel alloys. More consistent results have been obtained with the threaded-end tensile specimens, stressed by constant deformation, than have been obtained with specimens (flat tensile, beam specimens, and "C" rings) stressed by constant deflection.

The data on which this report was based showed the need for additional work on evaluating the loss of applied stress due to creep and on methods for reducing excessive surface corrosion of aluminum-copper alloys in the described test environment.

INTRODUCTION

There are no specific methods or special test specimens for evaluating the stress corrosion cracking characteristics of the common structural materials such as those for determining mechanical properties. In general, the investigator is at liberty to choose the types of specimens and corrosive environments for conducting stress corrosion tests. This, of course, leads to conflicting published results which are confusing to the designer in appraising the susceptibility of various materials to stress corrosion cracking.

Other uses of stress corrosion cracking test data, in addition to the selection of structural material by the designer, are in developing alloys, maintaining uniformity of products, and determining new applications for specific structural materials. It is doubtful if any single stress corrosion test procedure would be suitable for evaluating all common structural materials or all service environments. However, standard stress corrosion test procedures are necessary to obtain comparable results among investigators.

There is little doubt that the most reliable method of stress corrosion testing is to expose the material in the specific atmosphere of service environment. This method, however, is far too time consuming, and it is necessary to use an accelerated test environment to obtain results within a reasonable period of time. It is of paramount importance that the accelerated test environment be realistic of general service conditions and yield reproducible results.

The type and geometry of the material and the grain direction to be tested are some of the major factors to be considered in choosing the specimen designs for stress corrosion tests. In most cases, specimen design must be based on the geometry of the material to be evaluated. For instance, flat tensile specimens normally are used for testing sheet material; for thick plate and forging, round specimens can be used; weldments generally require relatively thick specimens with the as welded surfaces intact. Several such specimens are described in the following section, and their advantages for the particular type of material to be evaluated are outlined.

STRESS CORROSION TEST SPECIMENS

Threaded-End Round Tensile Specimens

Round tensile specimens normally are used for testing the short transverse grain direction of thick (two inches or greater) plate, forgings, and bar stock. This type of specimen which is loaded by constant deformation gives a more accelerated test and more consistent results than those types of specimens that are loaded by constant deflection. The major disadvantage is the high cost of machining the round tensile specimens and the relatively elaborate equipment necessary for loading. The specimens normally used are 1/8-inch or 1/4-inch diameter with 1/2-inch gauge length and an overall length of 2 inches. The 1/8-inch diameter specimen has 1/4-20 NC threads on both ends and the 1/4-inch specimen has 1/2-13 NC threads on both ends (FIG 1).

The specimens are stressed in direct tension with the aid of a fixture (FIG 2a). The nuts are tightened until the specimen is held snugly in the fixture: then, the sides (wedges) of the fixture are squeezed in toward the center until the desired strain and corresponding stress in the specimen are obtained. The strain in the specimen is measured with an extensometer as the sides are forced in. A stressing fixture (FIG 3) is used so that both sides will be depressed an equal distance to ensure uniform stress across the specimens.

The round tensile stress corrosion assembly is shown in FIG 2a, and the components of the assembly are shown in FIG 2b, 2c , 2d, and 2e. The components are made of aluminum alloy 6061-T6, which is resistant to corrosion in most environments, and do not necessarily require a protective coating. After the specimens are stressed, the frames and ends of the specimens, not the reduced section, are dipped into a hot strippable coating such as "Maskcoat"* 1 or 2 to give added corrosion protection to the frames and to protect against galvanic corrosion between the frames and the specimens. After the frames are coated, the reduced section of each specimen is wiped with acetone, and the frames are placed in test.

*Trade name of Western Coating Company

Flat Tensile Specimens

Flat tensile specimens normally are used for testing sheet material. The specimens are easy to fabricate, and the stress frames and method of loading are very simple. This is probably the most inexpensive method of stress corrosion testing. The specimens that are used are ASTM standard sheet type (FIG 4).

The flat tensile specimens are stressed by constant deflection by using a fixed span snap-in frame or a four-point loading jig. The fixed span snap-in method is both simple and economical. The main advantage of the four-point loading method is the uniform stress distribution in the test specimen between the two center supports. In the fixed span method, the length of the specimen is calculated so that when sprung into the frame the outer fibers of the bent specimens at the maximum point of deflection will be stressed to the chosen level (usually some percent of the yield strength). The calculation is made by using the following equations (Ref. 2):

$$e = 4(2E-K)\left[\frac{k}{2}-\frac{2E-K}{12}\left(\frac{t}{H}\right)\right]\frac{t}{H} \qquad \text{Equation 1}$$

$$L = \frac{2H(K-E)}{2E-K} + H$$

where: e = strain, usually taken from the stress-strain curve but may be calculated by dividing the desired stress by the modulus of elasticity.

t = thickness of specimen in inches

H = span of stress frame in inches

L = length of specimen in inches

K, E = elliptic integrals for values of modulus, K.

The specimen lengths (L) which are required to obtain different stress levels are calculated by selecting arbitrary values of k and corresponding K and E values from elliptic integral tables and by solving for e (strain) in the first equation and L (specimen length) in the second equation. The resulting values of e and L are plotted for different material thicknesses (t) and span lengths (H) as shown in FIG 5. The specimen lengths which are required to obtain the desired stress levels are readily obtained from the curves. The specimens are machined to the calculated lengths, and, then, they are degreased and sprung into the frames. A typical fixed-span stress frame is shown in FIG 6. The length and/or width of the frame may be varied to accomodate a large number of a different length specimen. The frame is constructed of aluminum alloy 6061-T6, which is relatively strong and resistant to most exposure conditions and, therefore, does not necessarily require a protective coating.

In the four-point loading method, the specimens are machined to a predetermined length based on the design of the stressing fixture. The deflection equation for four-point loading is:

$$D = \frac{Pa}{6EI}\left(3/4\ l^2 - a^2\right) = \frac{\frac{SI}{c}}{6EI}\left(3/4\ l^2 - a^2\right) = \frac{S}{6EC}\left(3/4\ l^2 - a^2\right)$$

$$\text{or } \frac{e}{6C}\left(3/4\ l^2 - a^2\right) \qquad \text{Equation 2}$$

where: D = deflection in inches

S = stress on outer fibers in psi

E = modulus of elasticity in psi

$e = S/E$ = strain (obtained from stress-strain curve when available

C = 1/2 specimen thickness in inches

l = distance between the two outer supports in inches

a = distance between the outer and inner supports in inches

The specimen is placed in the loading jig, and the center of the specimen is deflected the calculated distance, measured with a dial gauge, by screwing out the center supports. A typical four-point loading device is shown in FIG 7. The length of this device also may be varied to accommodate different length specimens. The outer and center supports are constructed of laminated fiberboard, and the bolt is 300 series stainless steel.

Bent Beam Specimens

The bent beam specimens are used mainly for stress corrosion testing of welded joints, but they are sometimes used for testing plate in the longitudinal and long transverse direction. The specimens normally used are 1-inch wide, 8-3/8-inches long, with two 11/32 inch diameter holes drilled 3.5 inches from the center (FIG 8d). For convenience, the thickness of the specimens may be varied, but it usually ranges from 1/4 to 3/4 inch.

The beam specimens are stressed by constant deflection of one specimen against a duplicate by using suitable bolts and an "H" fixture. The centers of the duplicate specimens are placed across the top and bottom of the "H" fixture; the bolts through the ends of the specimens are tightened until the specimens are deflected the calculated distance, measured at the center of the bolts, to obtain the desired stress on the outer fibers of the specimens. The stressing formula and the stress corrosion assembly are shown in FIG 8a. Both ends of the assembly are dipped approximately one inch into a hot strippable coating such as "Maskcoat" 1 or 2 to protect the bolts and nuts. The components of the bent beam stress corrosion assembly are shown in FIG 8b and 8c. The components are made of aluminum alloy 6061-T6, which is resistant to most exposure environments. Thin strips of plastic sheet are inserted between the mating surfaces of the specimens and the legs of the "H" fixture to prevent galvanic action.

C-Ring Specimens

C-ring-type specimens are used for stress corrosion evaluation of tubing and short transverse direction of plate, rod, and bar when the thickness or diameter is less than two inches. This slotted ring-type specimen is prepared by removing a strip of metal, which composes about 60° of the ring, so that when viewed from the end, it resembles a "C". The length of the C-ring is normally one-half the diameter but with a mininum length of one inch (FIG 9a). Generally, the diameter should not be less than 3/4 inch.

The specimens are stressed by constant deflection by means of a bolt and nut which are tightened until the sides are pulled together to give the desired stress. The bolt and nut are insulated from the specimens with plastic washers (FIG 9b) which are inserted in holes that have been drilled through the ring wall. The ends of the rings may be dipped, to a depth, just above the bolt, into a hot strippable coating to protect the bolts and to prevent galvanic action. If this is done, plastic washers are not required. The maximum tensile stress occurs in the outer fibers of the ring 90° from the bolt holes. The deflection equation for loading C-rings is:

$$\Delta = OD - ODf = \frac{SD^2}{4EtZ} \text{ or } \frac{D^2e}{4tZ} \qquad \text{Equation 3}$$

where: Δ = change of OD measured at center of bolt in inches

$e = \frac{S}{E}$ = strain (obtained from stress-strain curve when available

OD = original outside diameter in inches

OD_f = final outside diameter in inches

S = desired stress in psi

D = mean diameter (OD-t) in inches

E = modulus of elasticity of alloy in psi

t = wall thickness of ring in inches

Z = constant (function of ring D/t): see FIG 10.

Specimen Preparation and Test Environment

The specimens to be tested are degreased with acetone or trichloroethylene vapors, stressed to the desired level, wiped with acetone, and then placed in the corrosive environment until failure occurs or until the tests are terminated. Prior to preparing the specimens for exposure, the mechanical properties of similar specimens from each lot of material and in the grain direction (long or short transverse or longitudinal) to be investigated are determined. Except for C-rings, duplicate unstressed specimens usually are exposed under identical conditions so that the losses in mechanical properties of stressed and unstressed specimens can be compared.

At least two types of test environments normally are used for stress corrosion investigations so that test results from at least two environments are available for comparison. These include an accelerated test exposure (alternate immersion in salt water) that has found wide acceptance and exposure to the atmosphere.

The alternate immersion tests are conducted in a Ferris wheel-type tester (FIG 11) containing an aqueous solution of 3-1/2 percent sodium chloride. The Ferris wheel cycles in such a manner that specimens in any of the six trays will be immersed in the solution for ten minutes, followed by fifty minutes of drying above the solution. The 3-1/2 percent salt solution is composed of 3,622 grams of sodium chloride (2.1.4 Federal Test Method Standard No. 151, normally U.S.P. or Reagent grade) dissolved in 100 liters of distilled or deionized water. After the salt has been dissolved, the solution concentration is checked by means of a pycnometer or hydrometer (see FIG 12 for graph of specific gravity vs. temperature and concentration range). The pH of the solution is then measured and maintained at 6.5 to 7.5 by adding hydrochloric acid or sodium hydroxide (1 normal). The temperature, pH, and specific gravity of the salt solution are checked weekly and when the solution is changed. The temperature and humidity of the surrounding atmosphere also are measured periodically. A water replenishing bottle is used to maintain a constant volume of water (constant water level in the basin) and is refilled as required with distilled or deionized water. The solution is changed every 2 to 4 weeks, based on the amount of corrosion product in the solution, and the apparatus is thoroughly cleaned and flushed with water. Access for cleaning the basin is accomplished by removing two of the trays. The normal test period is 3 to 6 months for aluminum alloys and 6 to 12 months for ferrous and nickel alloys. All stressed specimens are visually examined daily for failure.

The long term atmospheric stress corrosion test is used to supplement the alternate immersion test. The specimens, exposed to the atmosphere, are inclined at a 30 degree angle facing south with an exposure period of from 1 to 2 years. Visual examinations vary for the first month from daily to approximately two weeks after six months of exposure. There is, however, no strict schedule for visual examination of specimens exposed to the atmosphere.

Cracks normally are readily visible unless the specimen is badly corroded. A badly corroded specimen which is suspected of being cracked is dried with compressed air and examined with the aid of a viewer (7X to 30X). The duplicate, unstressed mate is removed from test at the time of failure of the stressed specimen, and the mechanical properties are measured. Stressed specimens that do not fail are removed along with their duplicate, unstressed mates at the end of the test period, and the mechanical properties are measured.

DISCUSSION

The major problem encountered with stress corrosion testing of aluminum alloys by alternate immersion in salt water is excessive surface corrosion of the aluminum-copper alloys (2000 series) which interferes with stress corrosion evaluation of these alloys. This is very pronounced with specimens having small cross sections. For example, 1/8-inch diameter round tensile specimens of alloy 2024 lose up to 35% tensile strength in 15 days when exposed in the unstressed condition to alternate immersion in salt water; 1/4-inch diameter specimens only lose up to 20% tensile strength in 15 days and 30% in 30 days of exposure. It is difficult to assign a maximum allowable loss in tensile strength resulting from surface corrosion to a stress corrosion test method. However, a maximum allowable loss of 30% in tensile strength resulting from surface corrosion of unstressed specimens seems reasonable. This is obtained from duplicate unstressed specimens exposed under conditions identical to those of the stressed specimens.

It has been found that the constant deformation method of externally loading (round tensile specimens) is a more accelerated test than the constant deflection method (flat tensile and C-ring specimens). This might be expected since constant deformation loading results in a uniform tensile stress across the entire cross sectional area of the specimens; the stress on specimens loaded by constant deflection varies from maximum tensile stress on the outer fibers on the outside surface to maximum compressive stress on the fibers on the inside surface.

CONCLUSIONS AND RECOMMENDATIONS

The types of specimens described and the method of externally loading have been found to be reliable in yielding reproducible results for stress corrosion evaluation of most aluminum alloys and have shown promise for ferrous and nickel alloys.

The constant deformation method of externally loading specimens (round tensile specimens) is a more accelerated test (accelerates stress corrosion cracking of specimen) and is more reliable in yielding reproducible results than the constant deflection method.

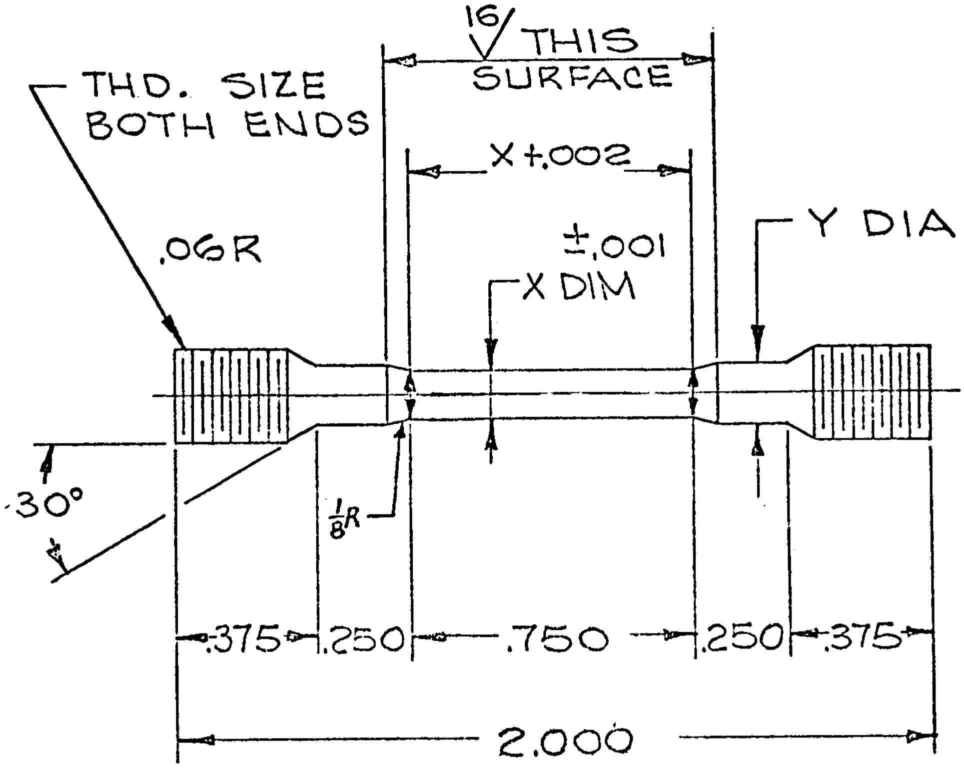
A major problem that has been encountered with stress corrosion testing of aluminum alloys by alternate immersion in salt water has been excessive surface corrosion of the aluminum-copper alloys (2000 series) which interfered with the stress corrosion evaluation of these alloys.

The data on which this report was based indicate the need for more information on the rate and aggregate loss of applied tensile stress resulting from metal creep of specimens externally loaded either by constant deflection or constant deformation. Further work is also needed to solve the problem of interference by excessive surface corrosion with stress corrosion evaluation of the aluminum-copper alloys when the described alternate immersion salt water test method is used. Although only limited data are available, it appears that corrodents that are more representative of general service conditions than boiling concentrated magnesium chloride solution and that yield reliable and reproducible results are needed for stress corrosion testing of ferrous and nickel alloys. Work in these three areas is now in progress.

REFERENCES

1. Sager, G. F.; Brown, R. H.; and Mears, R. B.: Tests for Determining Susceptibility to Stress Corrosion Cracking. ASTM-AIME, Symposium on Stress Corrosion Cracking of Metals, 1944, pp. 255-272.

2. Haaijer, G.; and Loginow, A. W.: Stress Analysis of Bent-Beam Stress Corrosion Specimens. Corrosion, Vol. 21, No. 4, 1965, pp. 105-112.



DWG. NO.	X DIM	Y DIA	THD. SIZE
DS218A	.125	.156	1/4-20
DS218B	.250	.281	3/8-16
DS 218 C	.250	.281	1/2-13

FIGURE 1. ROUND TENSILE SPECIMEN

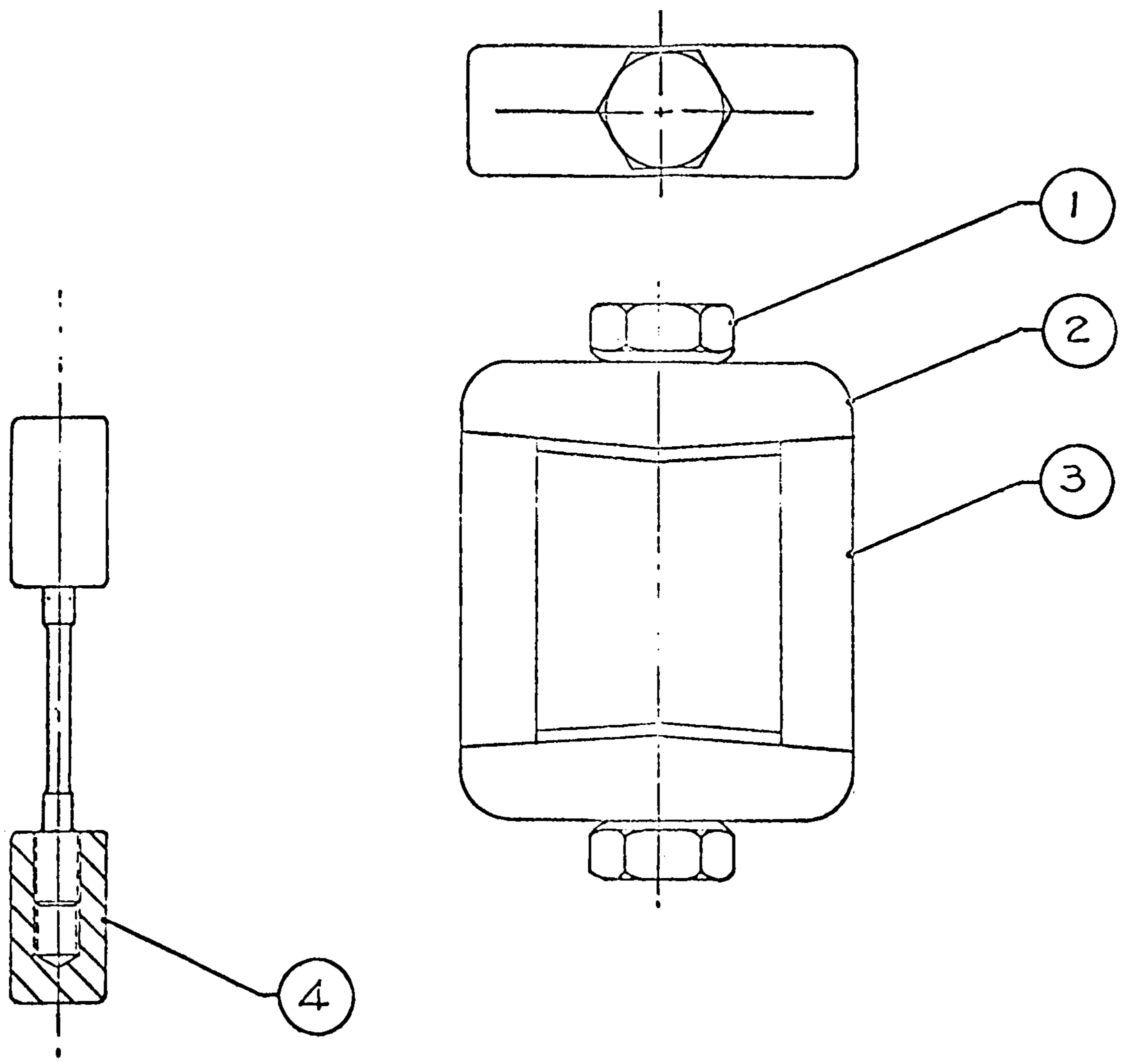


FIGURE 2A.. ROUND TENSILE STRESS CORROSION ASSEMBLY

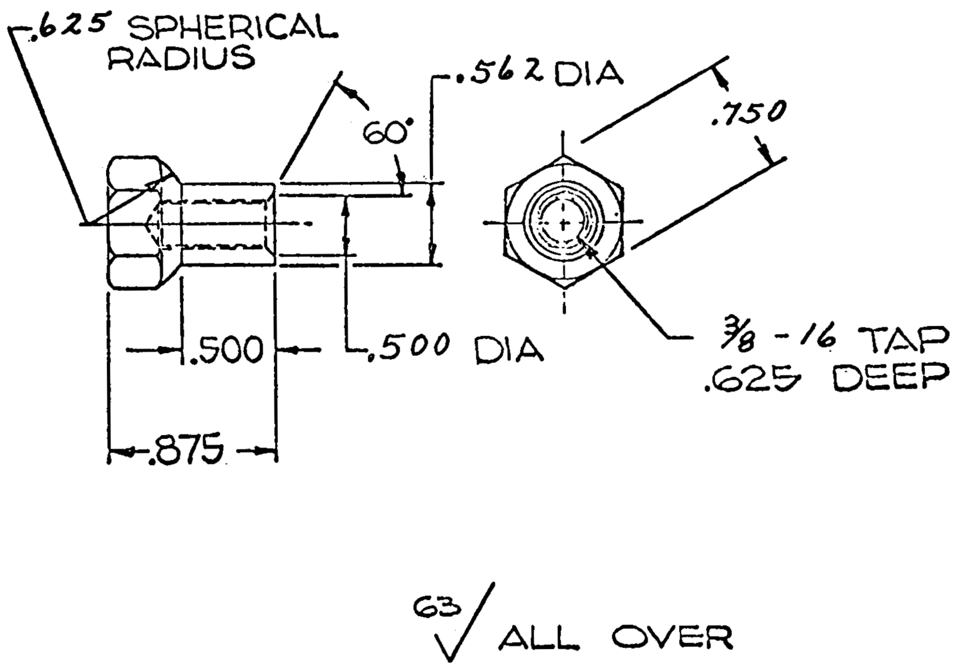


FIGURE 2B. NUT FOR ROUND TENSILE STRESS CORROSION ASSEMBLY

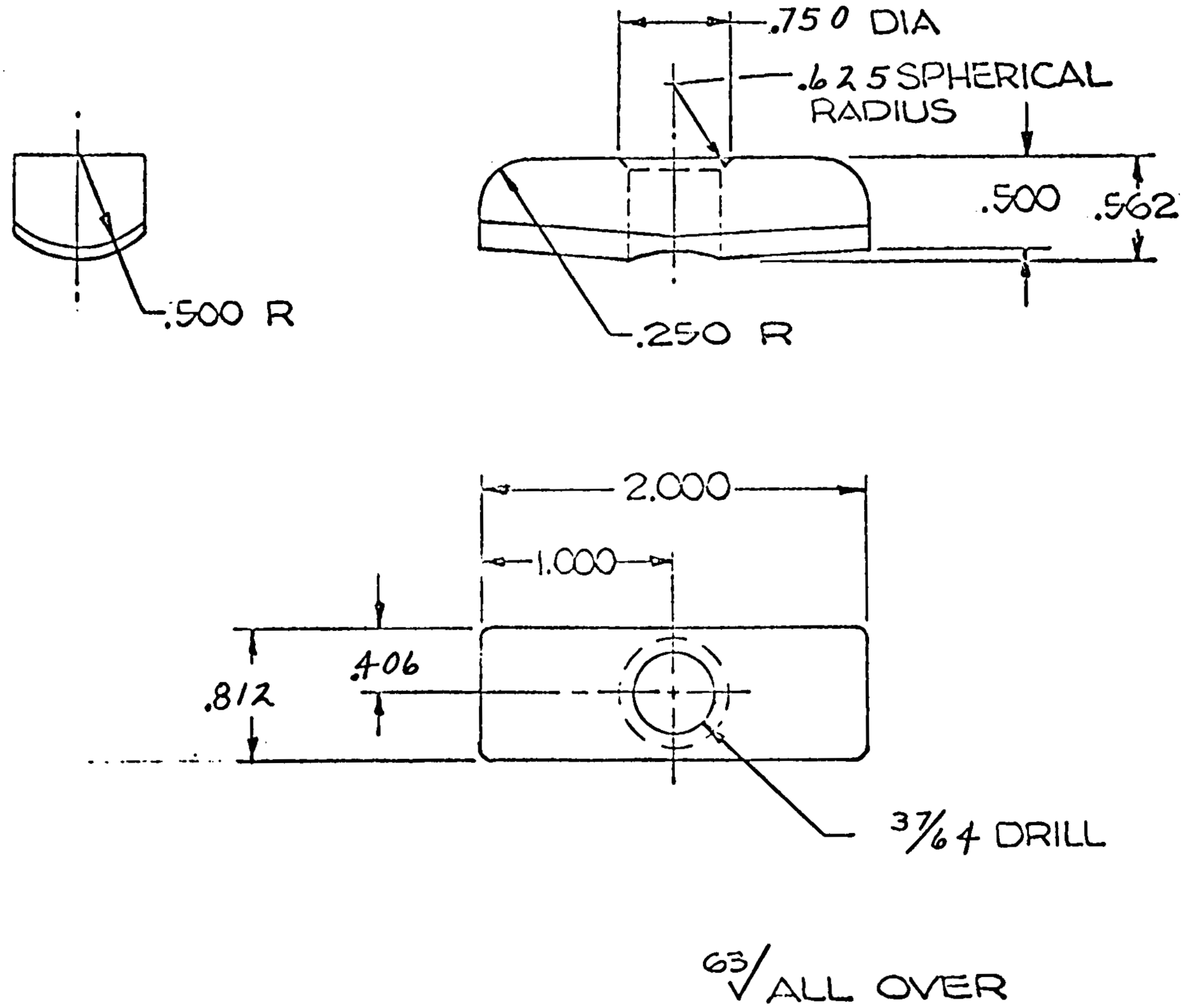
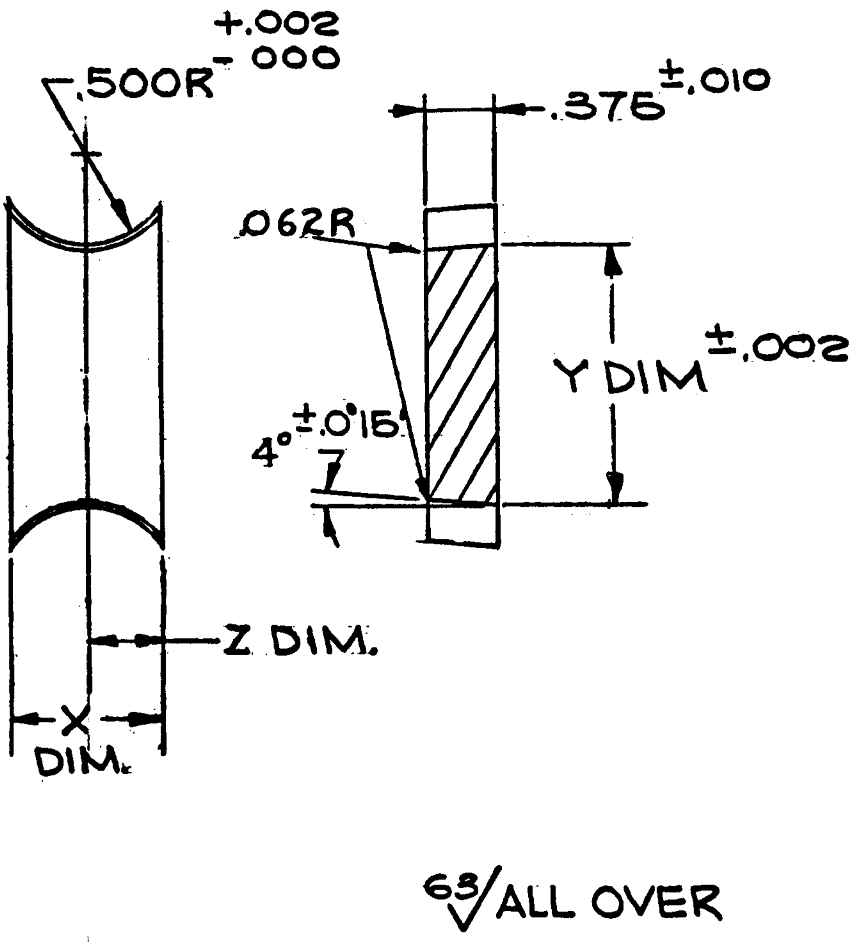


FIGURE 2C. CROSSHEAD FOR ROUND TENSILE STRESS CORROSION ASSEMBLY



DWG. NO.	X DIM	Y DIM	Z DIM
DS208A	.688	1.391	.344
DS208B	.812	1.391	.406

FIGURE 2D SIDE BAR FOR ROUND TENSILE STRESS CORROSION ASSEMBLY

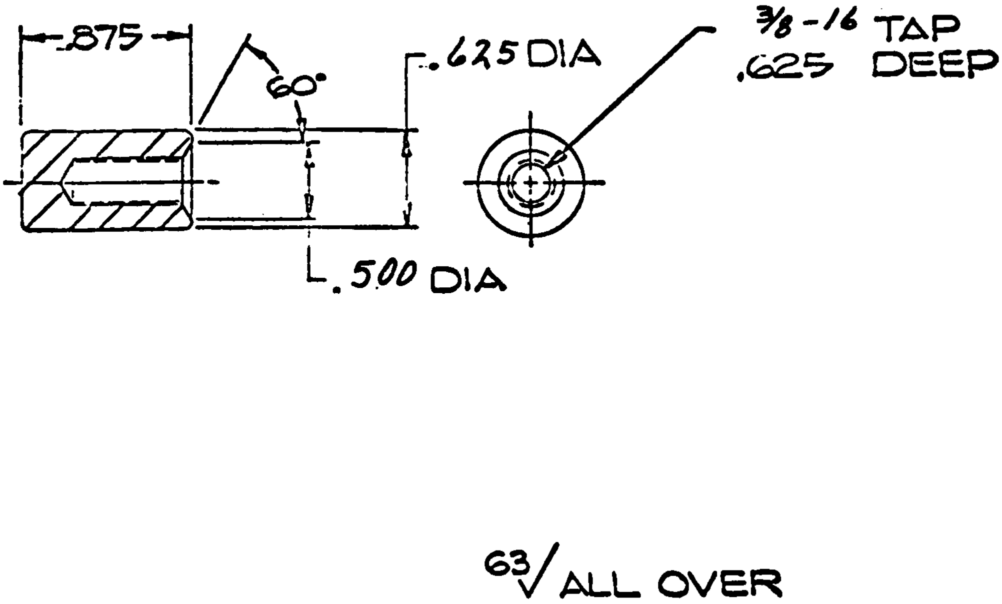


FIGURE 2E. PROTECTIVE CAP FOR ROUND TENSTILE STRESS CORROSION ASSEMBLY

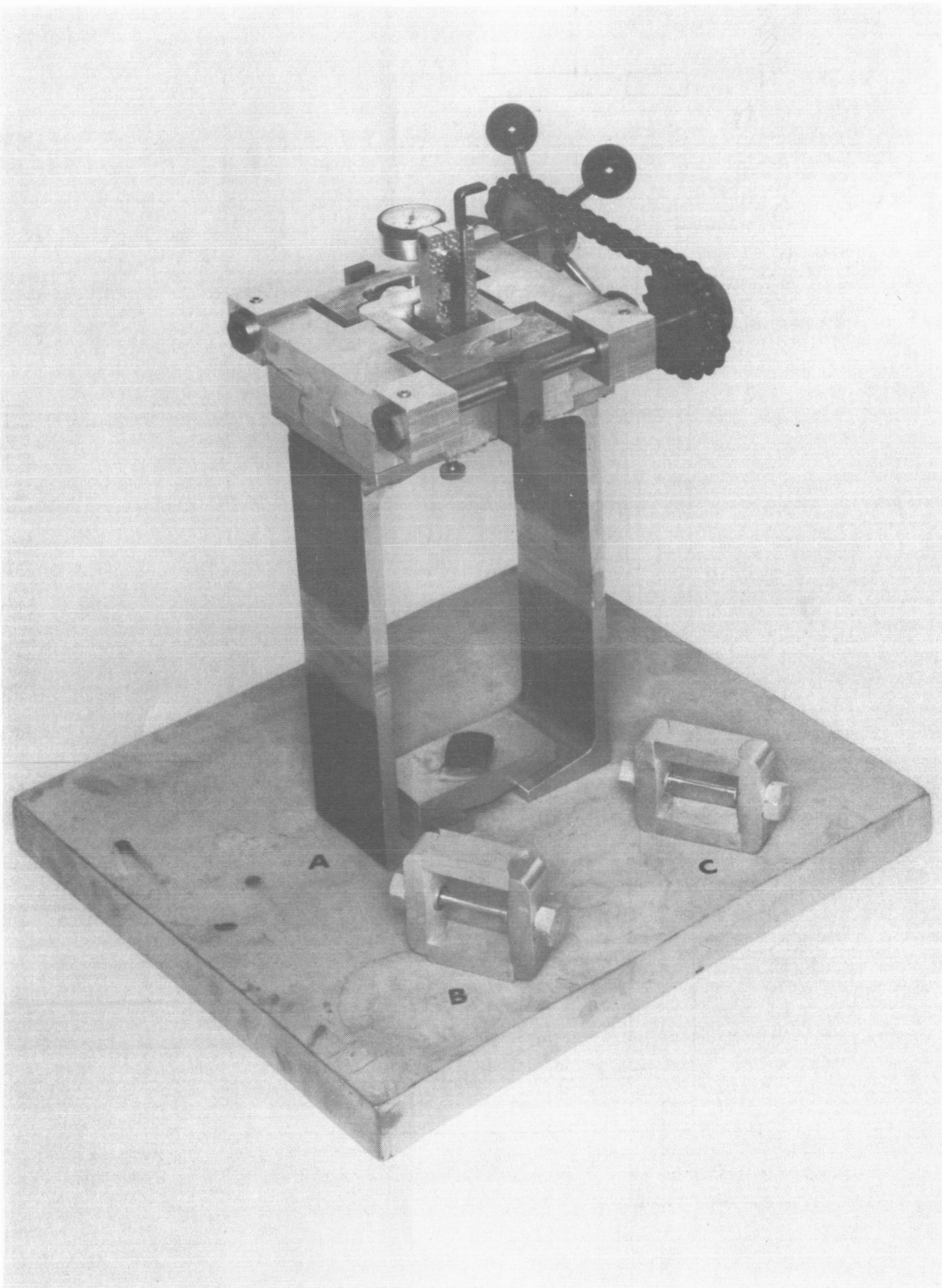


FIGURE 3. FIXTURE FOR STRESSING ROUND TENSILE SPECIMEN

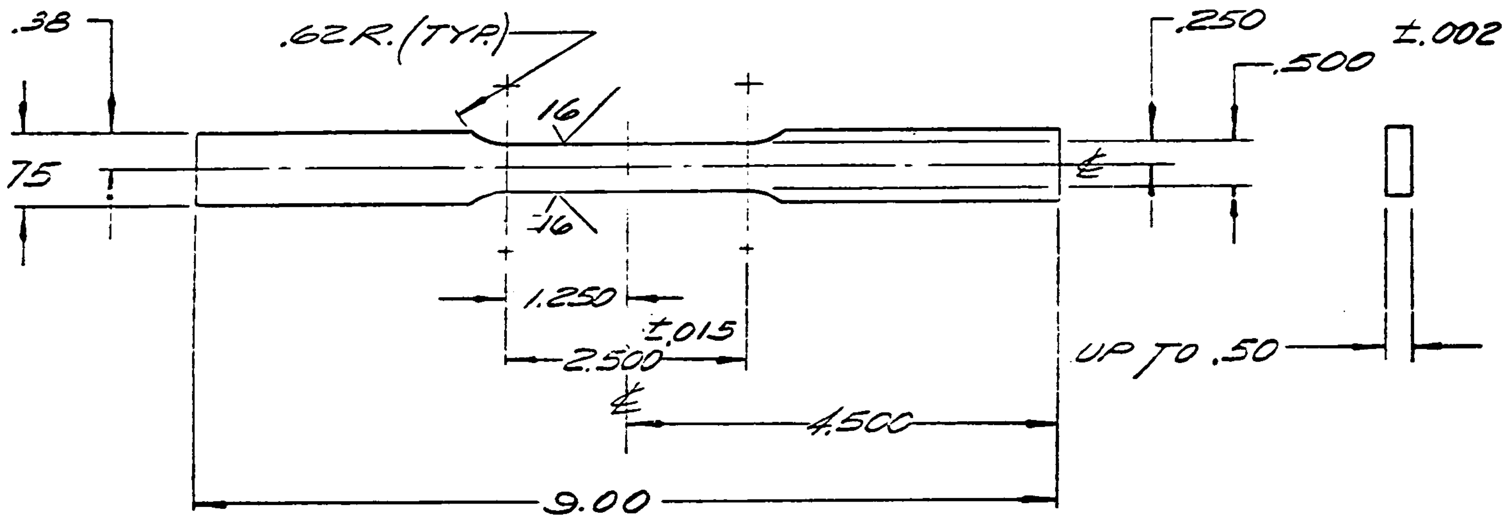


FIGURE 4. FLAT TENSILE SPECIMEN

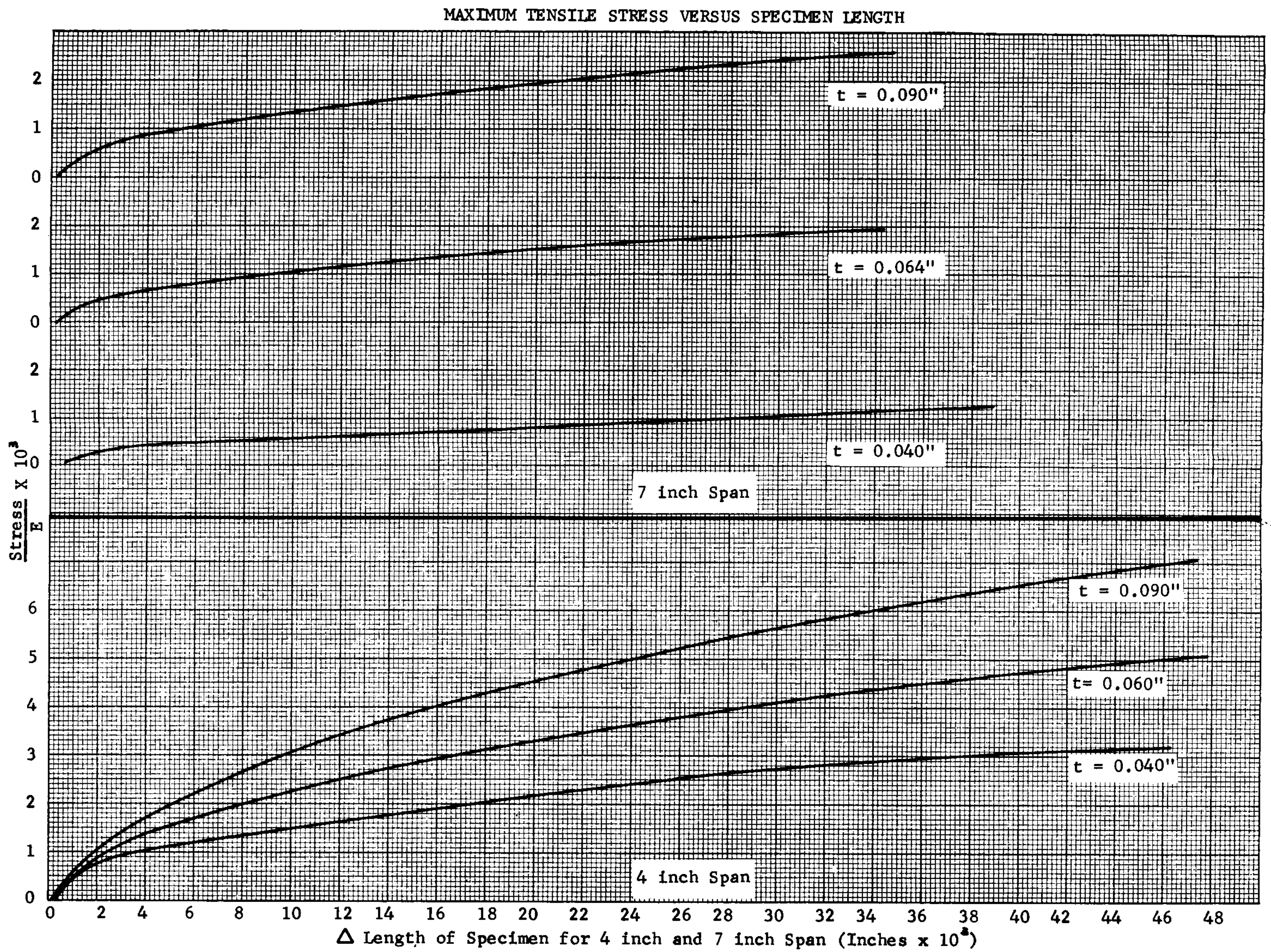
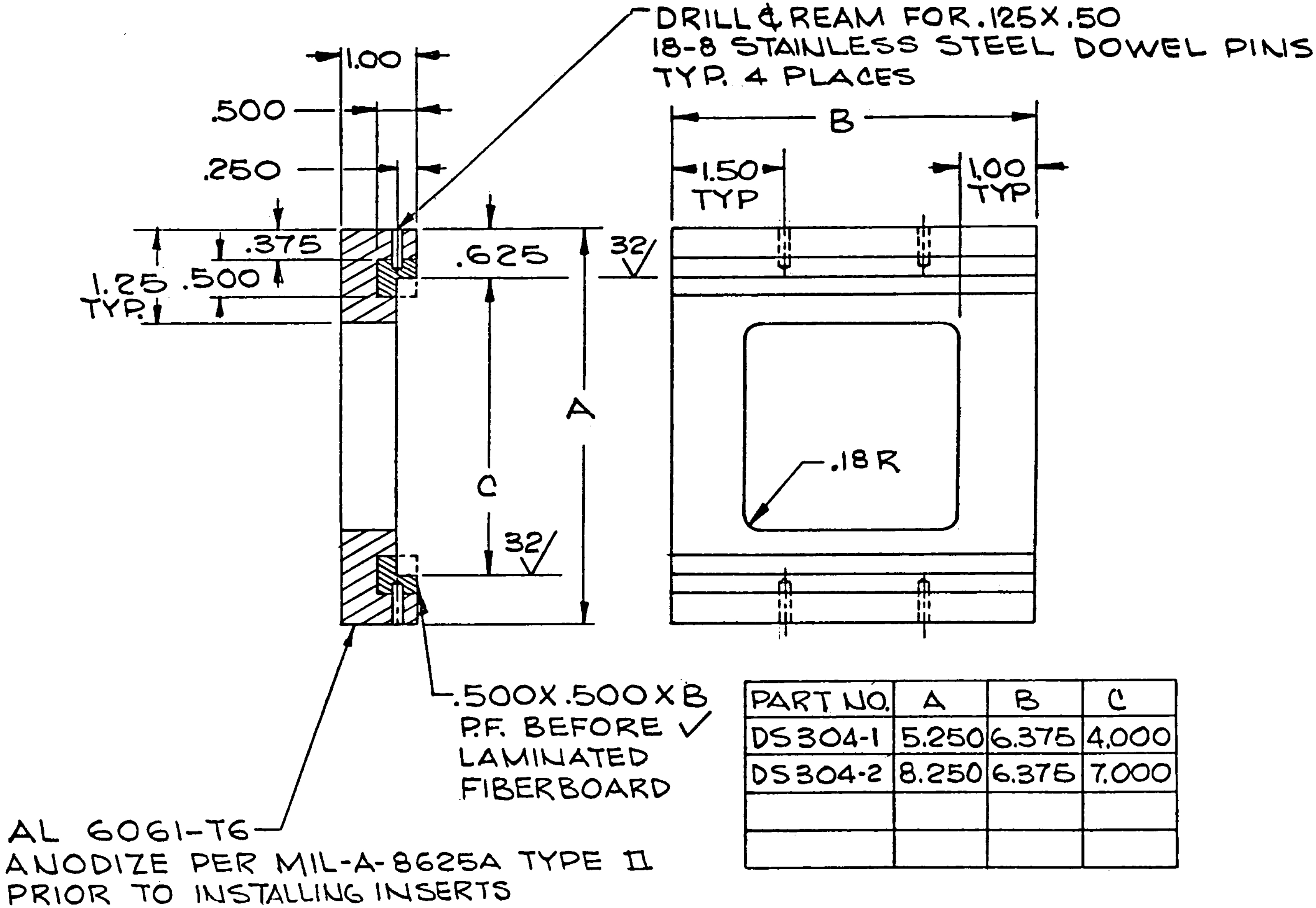


FIGURE 5. DETERMINATION OF SPECIMEN LENGTH FOR VARIOUS STRESS LOADS



PART NO.	A	B	C
DS304-1	5.250	6.375	4.000
DS304-2	8.250	6.375	7.000

FIGURE 6. FIXED SPAN STRESS CRROSION FRAME

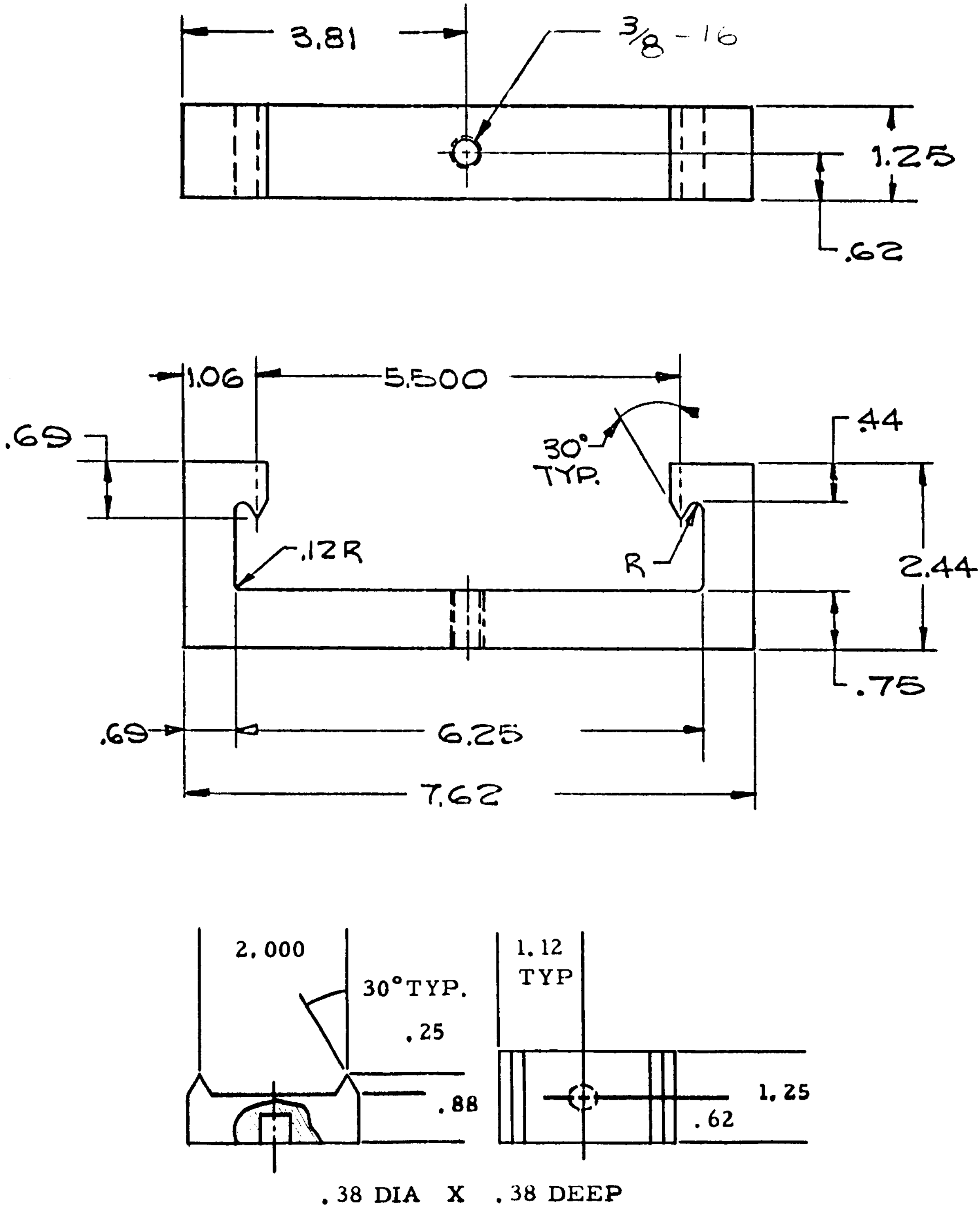
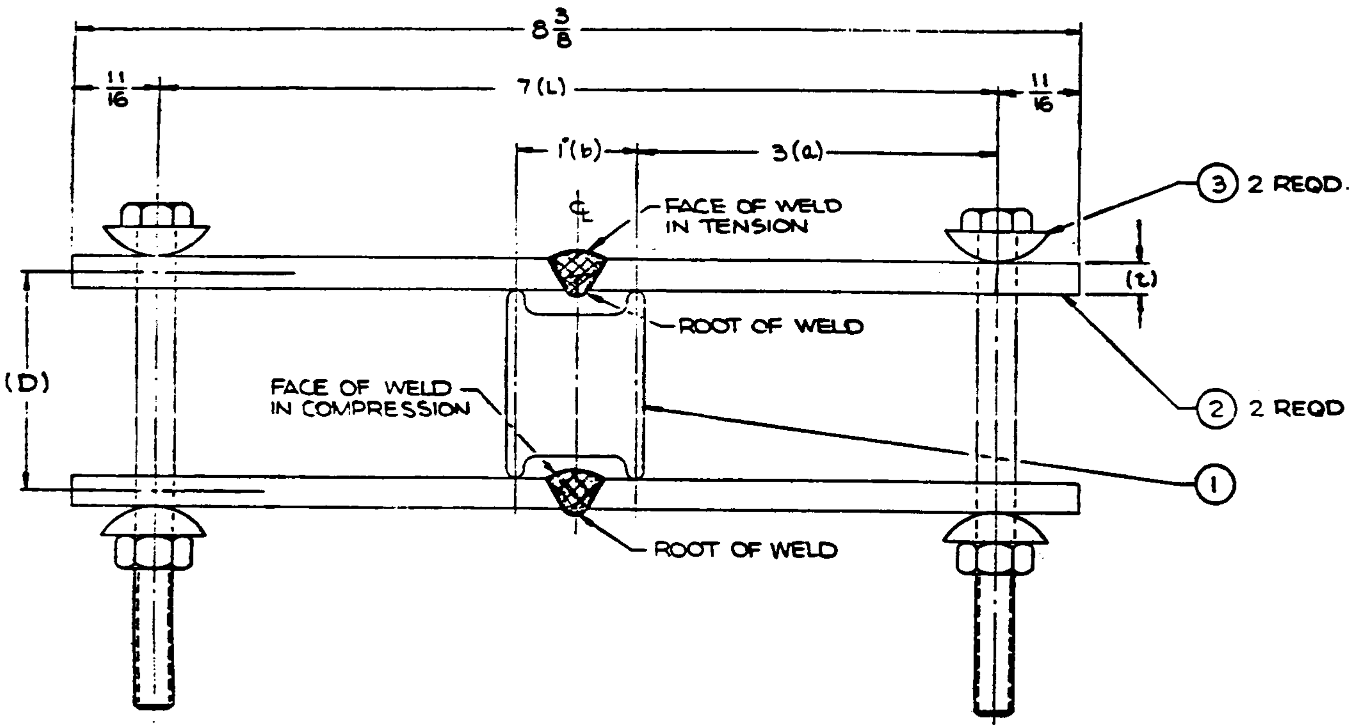


FIGURE 7. FOUR-POINT STRESS CORROSION ASSEMBLY



STRESSING FORMULA

$$D = \frac{2Sa(3L-4a)}{3Et}$$

WHERE D = DEFLECTION IN INCHES MEASURED AT ℄ OF BOLTS
S = DESIRED STRESS IN P.S.I.
L & t = MARKED ON DWG.
E = MODULUS OF ELASTICITY

FIGURE 8A. BENT BEAM STRESS CORROSION ASSEMBLY

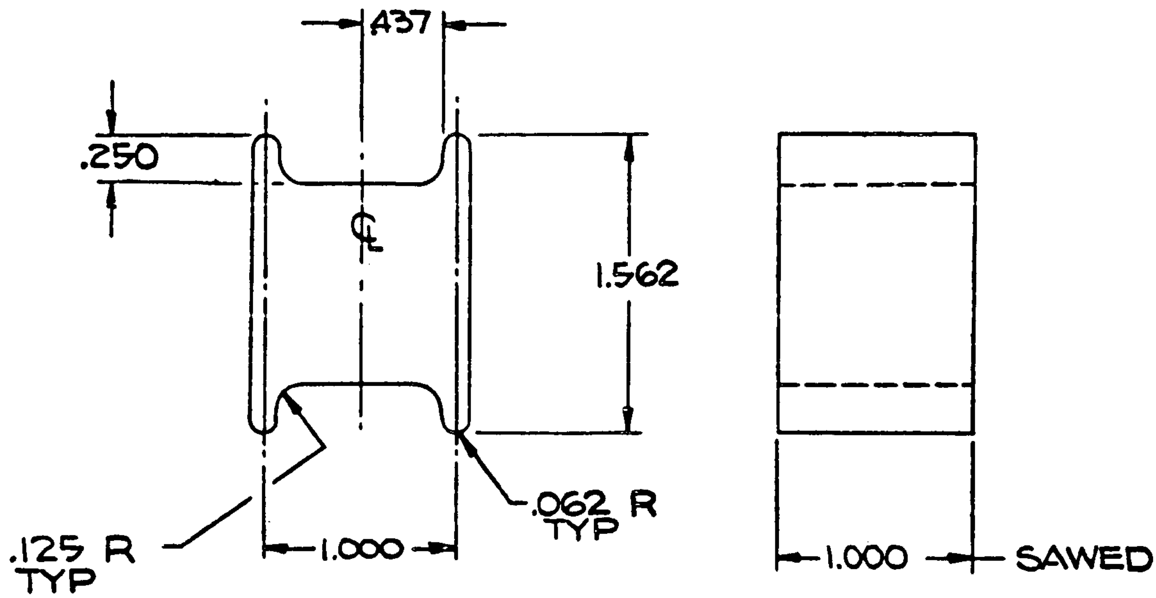


FIGURE 8B. H FIXTURE FOR BENT BEAM STRESS CORROSION ASSEMBLY

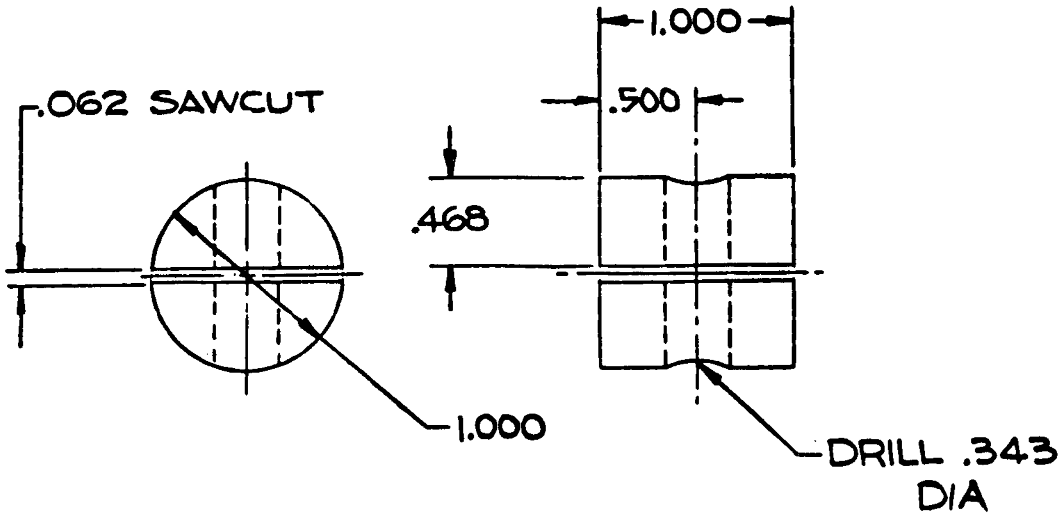


FIGURE 8C. ROCKER FOR BENT BEAM STRESS CORROSION ASSEMBLY

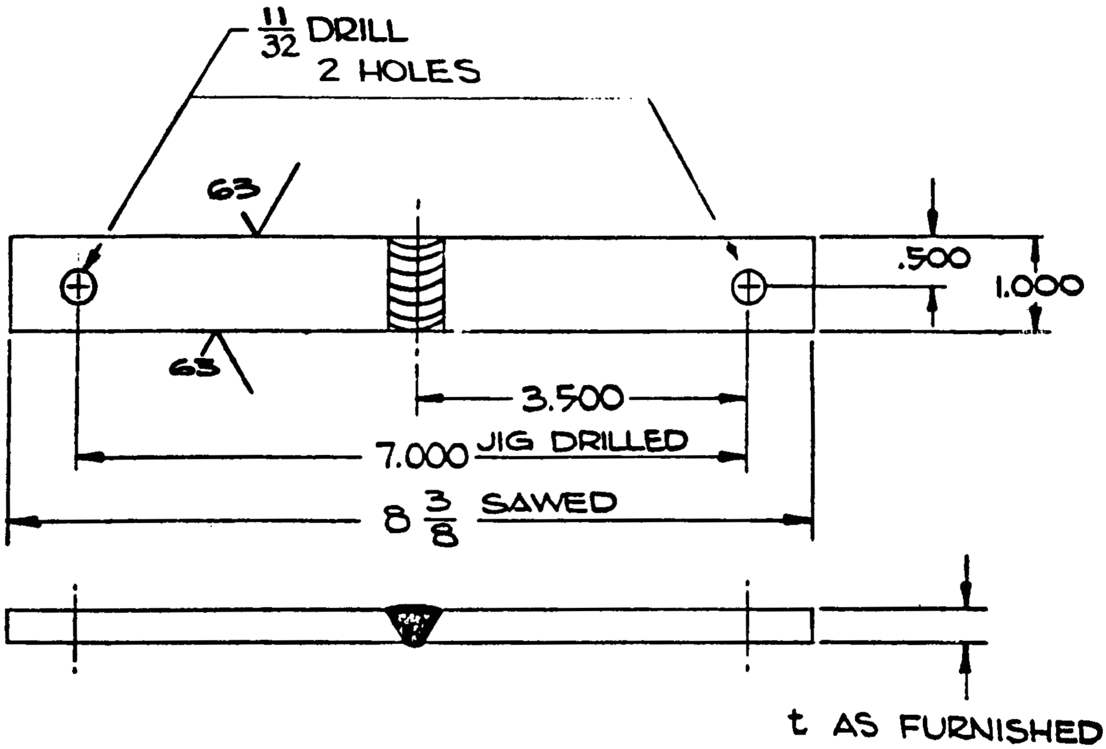


FIGURE 8D. BENT BEAM SPECIMEN

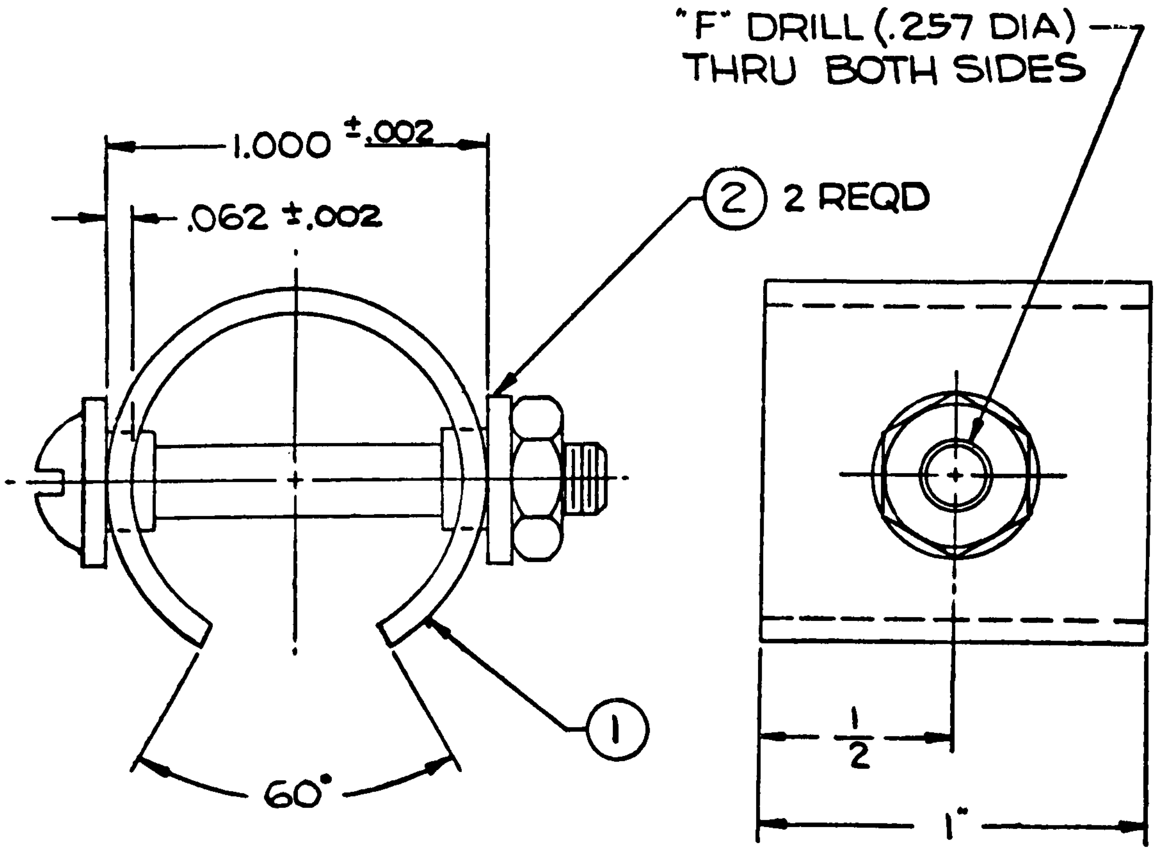


FIGURE 9A. C-RING STRESS CORROSION ASSEMBLY

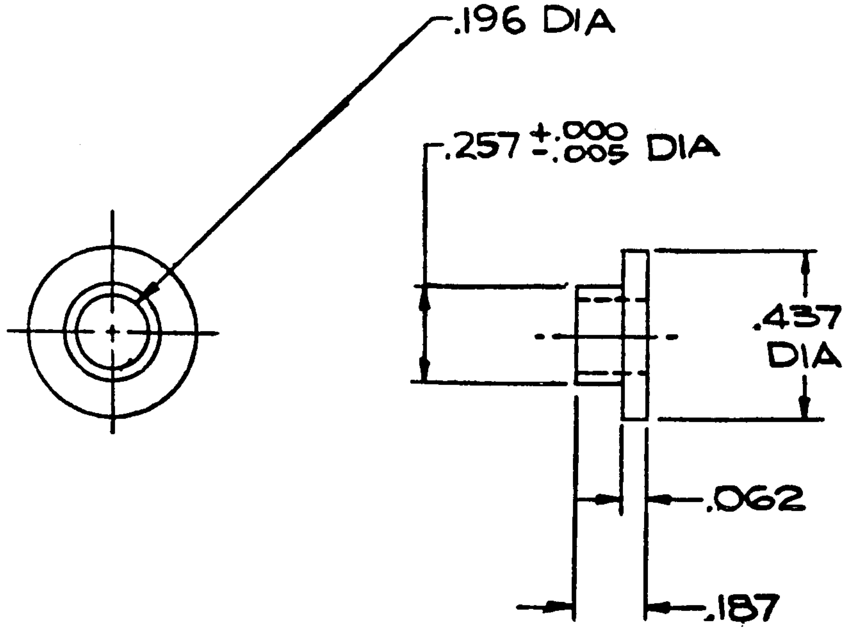


FIGURE 9B. PLASTIC WASHER FOR C-RING STRESS CORROSION ASSEMBLY

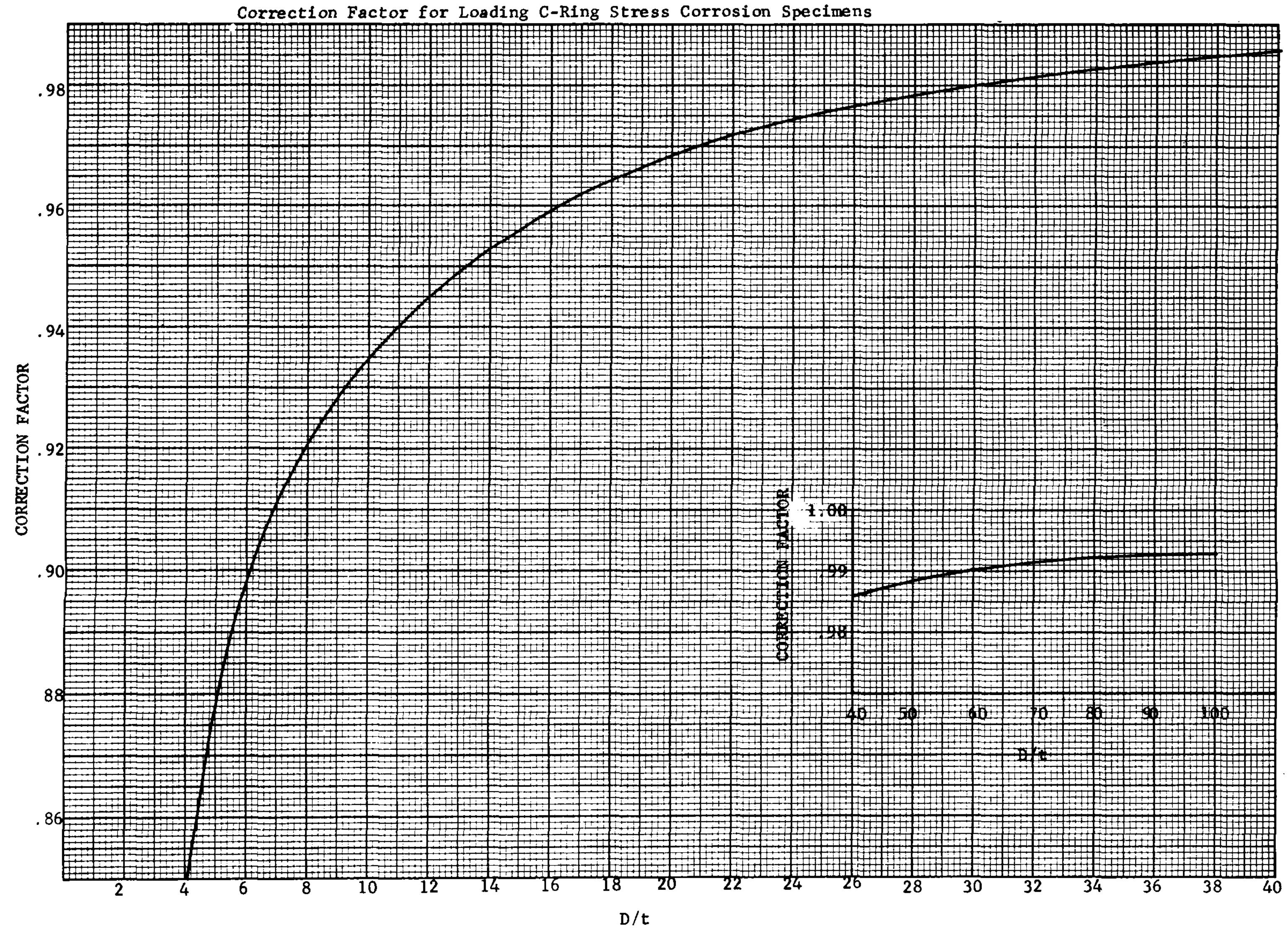


FIGURE 10. CORRECTION FACTOR FOR C-RING DEFLECTION EQUATION

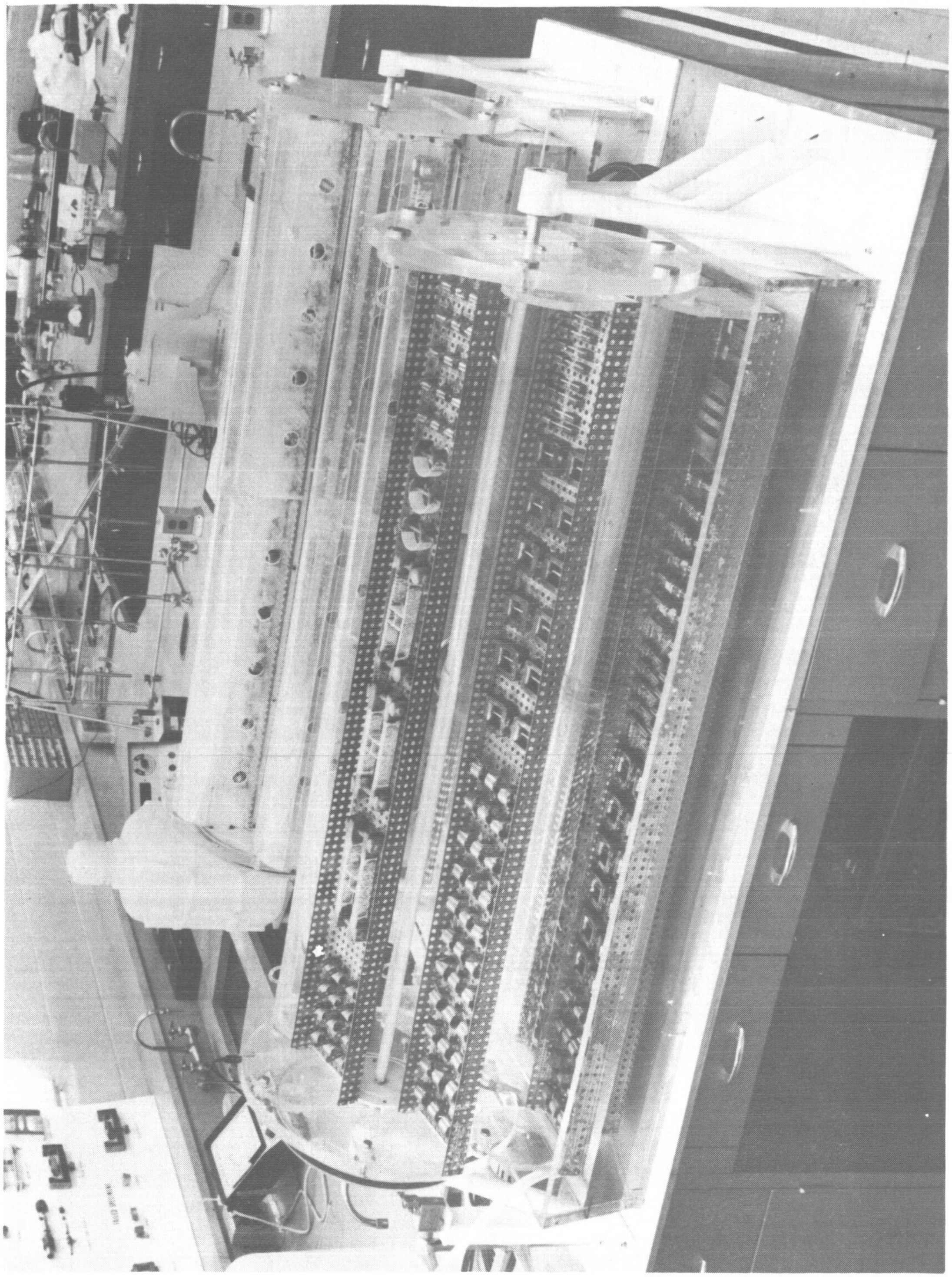


FIGURE 11. ALTERNATE IMMERSION TESTER

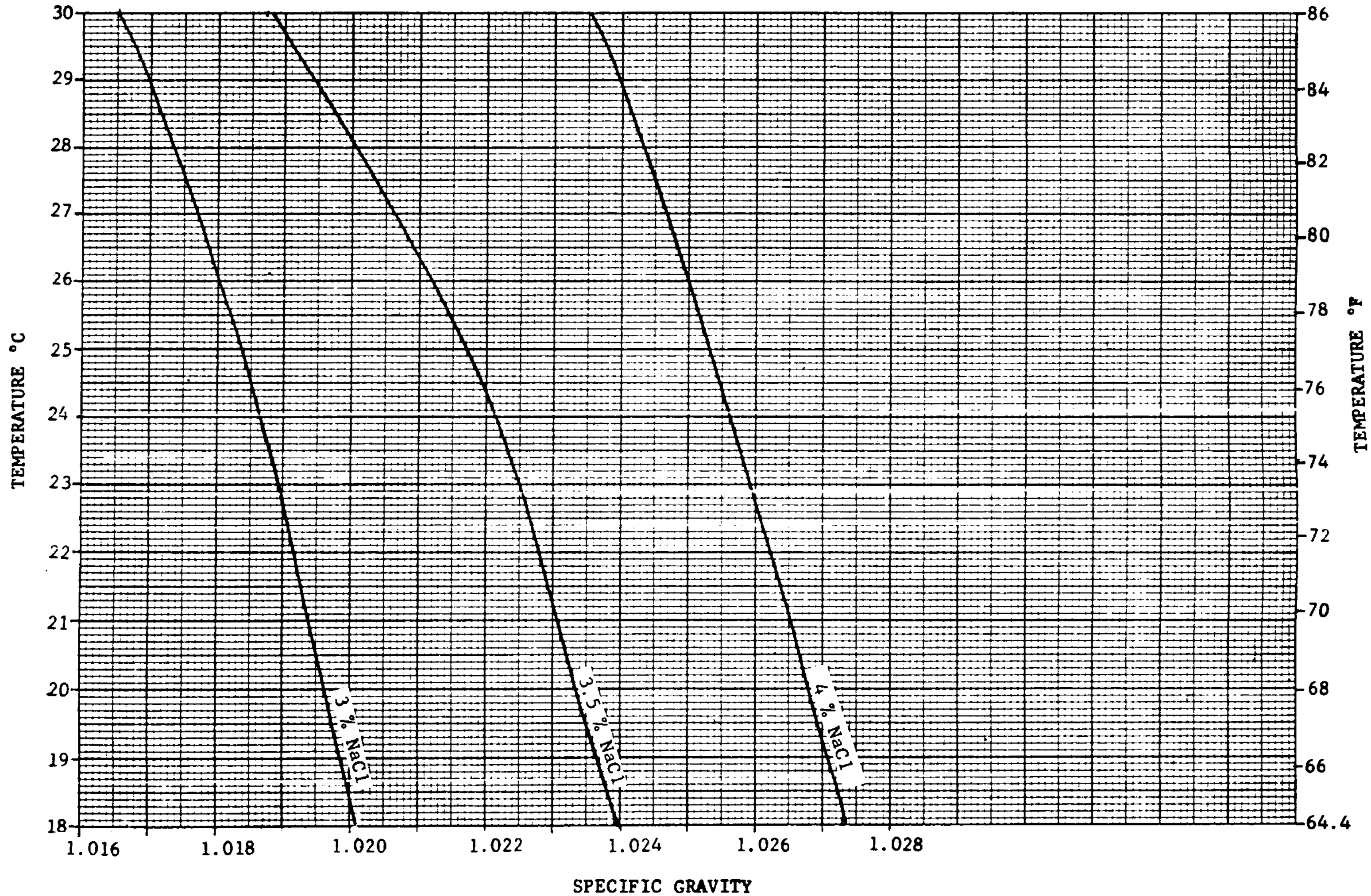


FIGURE 12. DETERMINATION OF SODIUM CHLORIDE CONCENTRATION BY SPECIFIC GRAVITY

June 29, 1966 APPROVAL TM X 53483

PROCEDURES FOR EXTERNALLY LOADING AND CORROSION TESTING STRESS CORROSION SPECIMENS

By T. S. Humphries

The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission Programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

This document has also been reviewed and approved for technical accuracy.

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