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A STRESS CORROSION EVALUATION OF AISI - H-11 ALLOY STEEL PLATED WITH NICKEL-CADMIUM COATING

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16. Abstract

This report presents the mechanical properties of AISI - H-11 alloy steel bar specimens (0.125 inch diameter), C-ring specimens (1.0 inch diameter) and charpy V-notched impact specimens, heat treated to 220-240 ksi ultimate tensile strength range and plated with nickel-cadmium. The tensile specimens and C-ring specimens were stressed to 0, 50 and 90 percent and 25, 50 and 90 percent of the 0.2 percent longitudinal yield strength respectively, and exposed to: (a) 180 days of exposure to the atmospheric conditions prevalent at the Marshall Space Flight Center during the months of December through June, and (b) 180 days of alternate immersion (A.I.) testing in a 3.5 percent sodium chloride solution. Unplated control specimens were also used in the stressed and unstressed condition for comparison purposes.

In general, the ultimate tensile strength of the plated specimens was unaffected with exposure time, however, in some instances there was a slight decrease in the 0.2 percent yield strength after 180 days exposure.

There were no failures in the plated tensile specimens or in the C-ring specimens which were exposed to the MSFC atmosphere. Two failures occurred in the plated C-ring specimens which were subjected to the alternate immersion test. One of these failures can possibly be attributed to the damage of the nickel-cadmium plating (prior to the test) when stressing the C-ring specimen.

All the unplated control tensile specimens, which were stressed, failed prior to 36 days of A.I. testing. Based on this study, nickel-cadmium plating per AMS 2416 provides the necessary environmental protection for AISI - H-11 alloy steel, heat treated to the 220-240 ksi strength range.

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SUMMARY

The mechanical properties of AISI - H-11 alloy steel bar specimens, tensile, "C"-ring, plated and unplated, stressed and unstressed, were determined after exposure to 30, 60 and 180 days of (a) exposure to the atmospheric conditions prevalent at the Marshall Space Flight Center during the months of December through June and (b) alternate immersion (A.I.) testing in a 3.5 percent NaCl solution. The nickel-cadmium plating offered satisfactory protection against stress corrosion in both environments, resulting in only two "C"-ring failures and no tensile specimen failures. Unstressed, bare specimens subjected to the alternate immersion test lost 10, 20 and 50 percent of the original ultimate tensile strength and yield strength after 30, 60 and 180 days, respectively. The loss in elongation (percent in 4D) was 63, 89 and 85 percent, respectively. All unplated tensile control specimens, which were stressed, failed prior to 36 days exposure to the A.I. test.

Charpy V-notched impact specimens, plated and unplated, were also exposed to the testing environments and impact tested after 30, 60, 90 and 180 days of exposure. The impact strength of the plated specimens was unaffected; however, the bare specimens were so corroded that valid impact testing was precluded.

INTRODUCTION

On Friday, April 22, 1966, the Materials Division initiated a failure analysis of three 1 3/8-inch diameter, H-11 alloy steel bolts, which failed in the thrust structure of SAT-SIC-501 vehicle. These bolts had experienced approximately a year of installation and two firings. The three failures initiated in the head-to-shank fillet area and propagated into the heads of the bolts. After careful examination of the installation procedure a misalignment problem was suspected. Additional research indicated the possibility of a fatigue environment coupled with the misalignment. The complete bolt system composed of the bolt, lock nut, head washer, and the PLI load indicating washers was investigated. Compressive tests were performed on the PLI washer system which is composed of two outer washers and a spinner ring which houses an inner washer. The inner washer has a greater thickness than the spinner ring, and when the inner washer is compressed by applying the desired torque to the bolt, the spinner indicator will not turn. Our compressive tests were made independent of the bolt system and consisted of compressing the PLI washer system only.

The test indicated that the compressive load that the PLI washer system required to prevent movement of the load indicator is 163,000 pounds. The specification guaranteed minimum compression load of this PLI washer system is 171,270 pounds indicating that the bolts did not fail by overloading.

Additional tests were made for hardness by sectioning and polishing the bolt head. A Rc hardness of 49 existed in the head and a Rc 51 hardness in the head-to-shank fillet area. These hardness values correspond to an approximate strength of 260,000 psi, which is not in accordance with the specification range of 220-240 ksi.

Fractographic analysis indicated a brittle type failure with possibly stress corrosion involved. An examination of the cadmium fluorborate plating on the bolt revealed insufficient protection, especially in the head-to-shank fillet area.

The Boeing Company performed an independent investigation which resulted in the bolts being stripped of their cadmium fluorborate coating and replaced with vacuum deposited cadmium for hydrogen embrittlement purposes. They also surmised that the failure was of a brittle nature initiated by a stress corrosion crack which created a cell generating hydrogen as a product of corrosion. The failure from this point was propagated by hydrogen embrittlement, according to their analysis.

A publication by the Standard Pressed Steel Company (SPS), entitled, "Stress Corrosion Cracking of High Strength Bolts, (ref. 1) indicated that vacuum cadmium coating offered the least protection of any coating evaluated by SPS as related to stress corrosion. Their data indicated that electroplated nickel covered with vacuum deposited cadmium offered the best protection. Their data also indicated that the electroplating process did not cause hydrogen embrittlement.

The SPS Company furnished the Materials Division with ten feet of one-inch diameter H-11 alloy steel for stress corrosion tests. The bars were machined into test specimens and returned to the SPS Company who heat treated the specimens and plated then with the electro-deposited nickel plus cadmium according to AMS 2416. Impact and stress corrosion tests were then made by this division.

EQUIPMENT AND TEST SPECIMENS

The equipment used in the stress corrosion test is described in a report by Williamson (ref. 2). The actual tensile specimens and "C"-ring specimen configurations are illustrated in Figures 1a and 1b respectively.

Longitudinal tensile specimens (0.125 inch diameter), transverse "C"-ring specimens (0.980 inch diameter), and charpy V-notched impact specimens were machined from the annealed bar stock. The specimens were heat treated as follows:

Hardened: 1850°F for 1/2 hour and air cooled

Double Tempered: 1080°F for 1 1/2 hours and air cooled to room temperature

1090°F for 1 1/2 hours and air cooled to room temperature

One half of the test specimens were then nickel-cadmium plated per AMS 2416.

The "C"-ring specimens, stressed by the constant deflection method explained in Appendix 1, were stressed in the transverse direction to 25, 50 and 90 percent of the 0.2 percent longitudinal yield strength. One half of the specimens were placed in a 3.5 percent sodium chloride solution for 30, 60 and 180 days of alternate immersion (A.I.) testing (10 minutes in solution, 50 minutes above solution). The other half of the specimens were placed in the M S F C atmosphere for 30, 60 and 180 days of stress corrosion testing. The nominal chemical composition and the actual composition of the test material are presented in Table I.

RESULTS AND DISCUSSION

The AISI - H-11 alloy steel tensile specimens, "C"-ring specimens, and charpy V-notched impact specimens, which were heat treated and nickel-cadmium plated by the Standard Pressed Steel Company were evaluated.

A stress corrosion evaluation was made by stressing both the bare and plated "C"-ring and tensile specimens to a definite percentage of the 0.2 percent longitudinal yield strength and exposing one half of the specimens to a 3.5 percent NaCl solution and exposing the remaining half of the specimens to the M S F C atmosphere. These exposed specimens were tested as follows:

a. "C"-ring specimens (both bare and plated) were examined daily for 180 days to check for specimen cracking or damage to the coating.

b. Tensile specimens (both bare and plated) were removed from the corrosive environment and tensile tested after 30, 60 and 180 days of exposure to check for tensile strength deterioration versus time exposure.

c. Charpy V-notched impact specimens (both bare and plated) were removed from the testing environment after intervals of 30, 60, 90 and 180 days of exposure and impact tested.

The tensile test results are tabulated in Tables II and III and are presented graphically in Figures 2 and 3. The "C"-ring stress corrosion test specimen configuration and the tensile test stress corrosion specimen configuration are illustrated in Figures 1a and 1b. Actual stress corrosion test samples are illustrated in Figures 4-18. Photomicrographs are presented in Figure 19.

In Figure 2, the data for the plated specimens, exposed to the M.S.F.C atmosphere indicated a slight increase in yield strength after 60 days exposure, and a slight decrease in yield strength after 180 days exposure. The elongation (percent in 4D) indicated erratic values ranging from approximately 15 percent to 6 percent. The range of values for elongation can possibly be attributed to the small size of the specimens (0.125 inch diameter) and the difficulty encountered in measuring the elongation.

Figure 3, illustrates the mechanical properties of plated specimens, exposed to the 3.5 percent NaCl alternate immersion bath. The data indicates a slight increase in yield strength after 60 days exposure, and a slight decrease in yield strength after 180 days exposure. The elongation (percent in 4D) indicates some scatter, ranging from approximately 11.5 percent to 15 percent.

Figure 4, shows typical stressed "C"-ring specimens prior to alternate immersion testing. Figures 5-9 illustrates the tensile and "C"-ring specimens which failed prior to completion of the test. Figures 10-18 picture the specimens which were exposed for 180 days of testing.

Tables II and III represent the mechanical properties of the longitudinal tensile specimens (0.125 inch diameter) after 0, 30, 60 and 180 days exposure to the test environment.

Table IV indicates the nickel-cadmium plated charpy V-notched impact data for unstressed specimens exposed to 0, 30, 60 and 180 days of exposure to the test environments. Unplated charpy V-notched specimens were so corroded that the notch radius was no longer valid, therefore, this data has been excluded.

Tables V and VI are stress corrosion failure records for the test specimens. There were no failures in the plated tensile specimens or the "C"-ring specimens which were exposed to the M S F C atmosphere; however, two failures occurred in the plated "C"-ring specimens which were subjected to the alternate immersion test. One of these failures can possibly be attributed to the damage of the nickel-cadmium plating (prior to the test) when stressing the specimen.

All the unplated control tensile specimens, which were stressed, failed prior to 36 days of A.I. testing. There was only one specimen failure in the bare specimens (stressed or unstressed) exposed to M S F C atmosphere exposure.

CONCLUSION

Based upon the results of this evaluation, nickel-cadmium plating per AMS 2416 offers satisfactory protection against stress corrosion of AISI - H-11 alloy steel, heat treated to 220-240 ksi strength range.

REFERENCES

1. Hood, A. C.: Manager, Research and Development, Standard Pressed Steel Company, "Stress Corrosion Cracking of High Strength Bolts," April, 1966.

2. Williamson, J. G., "Stress Corrosion Studies of AM-355 Stainless Steel," NASA TM-X-53317, August, 1965.

APPENDIX 1

METHOD FOR STRESSING "C"-RING STRESS CORROSION SPECIMENS

The following is a procedure for stressing "C"-ring stress corrosion specimens:

1. Measure with a micrometer to the nearest 1/1000 of an inch the outside parallel to the stressing screw (averaging the two ends of the ring) and the wall thickness.

2. Set up a table to calculate the final diameter (OD_f) required to give the desired stress using the following equations:

$$OD_f = OD - \Delta$$

$$\Delta = \frac{f \cdot \pi \cdot D^2}{4 \cdot E \cdot t \cdot Z}$$

where Δ = Change of OD giving desired stress, inch
f = Desired stress, psi
OD = Outside diameter, inch
t = Wall thickness, inch
D = Mean diameter (OD-t),
E = Modulus of elasticity
Z = Constant (function of ring D/t)

OD_f = Final outside diameter of stressed "C"-ring

3. To simplify calculations, certain terms in the above equation may be combined into a constant that will be applicable for a group of rings of the same alloy and size.

Let $\frac{4 \cdot E}{\pi} = K$, a constant

Then $\Delta = \frac{f \cdot D^2}{K \cdot t \cdot Z}$

TABLE I

CHEMICAL COMPOSITION OF SHEET AND BAR STOCK

Element	SPS M-107 Spec. Limits	Actual Analysis
Iron	Main	Main
Carbon	0.38 - 0.43	0.44
Chromium	4.75 - 5.25	4.80
Molybdenium	1.20 - 1.40	1.20
Vanadium	0.40 - 0.60	0.60
Manganese	0.20 - 0.40	0.29
Silicon	0.80 - 1.00	0.87
Phosphorus	0.020 Max.	0
Sulfur	0.020 Max.	0.01
Copper	--	0.047

TABLE II

MECHANICAL PROPERTIES OF NI-CAD PLATED H-11 ALLOY STEEL
LONGITUDINAL TENSILE SPECIMENS (.125" Dia) STRESSED TO 0, 50, AND
90% OF THE 0.2% YIELD STRENGTH AND EXPOSED TO STRESS CORROSION CONDITIONS

Exposure Time Days	Stressed Condition Percent of 0.2% Y.S.	U.T.S. ksi	Y.S. 0.2% Offset ksi	Elongation in 1/2 Inch (4D %)	Environment	Number of Tests
0	0	242.7	207.6	12.0	As Received	2
30	0	239.8	205.5	13.0	A.I.	1
30	50	245.3	210.2	14.0	A.I.	1
30	90	243.3	232.0	12.0	A.I.	1
60	0	242.9	210.0	11.5	A.I.	2
60	50	244.0	213.2	14.0	A.I.	2
60	90	245.6	234.2	15.0	A.I.	2
180	0	243.0	206.8	14.0	A.I.	2
180	50	240.6	208.7	15.5	A.I.	2
180	90	243.6	229.2	13.0	A.I.	1
0	0	242.7	207.6	12.0	As Received	2
30	0	244.8	212.8	10.0	MSFC-ATM	1
30	50	245.3	222.8	13.0	MSFC-ATM	1
30	90	244.0	232.5	15.0	MSFC-ATM	1
60	0	245.7	215.0	12.0	MSFC-ATM	1
60	50	245.7	227.4	9.5	MSFC-ATM	2
60	90	245.8	237.6	6.5	MSFC-ATM	2
180	0	240.5	207.1	10.0	MSFC-ATM	1
180	50	242.5	207.8	12.0	MSFC-ATM	2
180	90	242.1	229.9	14.0	MSFC-ATM	1

Manual Strain = .05 in/min

TABLE III

MECHANICAL PROPERTIES OF BARE H-11 ALLOY STEEL
LONGITUDINAL TENSILE SPECIMENS (.125" Dia) STRESSED TO 0, 50 AND
90% OF THE 0.2% YIELD STRENGTH AND EXPOSED TO STRESS CORROSION CONDITIONS

Exposure Time Days	Stressed Condition Percent of 0.2% Y.S.	U.T.S. ksi	Y.S. 0.2% Offset ksi	Elongation in 1/2 Inch (4D %)	Environment	Number of Tests
0	0	246.5	215.2	13.7	As Received	3
30	0	221.4	194.0	5.0	A.I.	1
60	0	198.0	174.2	1.5	A.I.	2
180	0	*177.3	*151.2	2.0	A.I.	1
180	0	*107.1	* 98.7	2.0	A.I.	1
0	0	246.5	215.2	13.7	As Received	3
30	0	267.5	225.0	10.0	MSFC-ATM	1
30	50	248.8	219.5	14.0	MSFC-ATM	1
30	90	252.1	228.6	7.0	MSFC-ATM	1
60	0	245.5	214.6	6.0	MSFC-ATM	1
60	50	244.6	219.7	6.0	MSFC-ATM	1
60	90	248.0	244.9	7.0	MSFC-ATM	1
180	0	229.2	197.8	10.0	MSFC-ATM	2
180	50	243.2	212.4	8.0	MSFC-ATM	2
180	90	244.5	216.1	7.0	MSFC-ATM	1

* Values Based on Original Area Due to Excess Corrosion of Bare Specimens

Manual Strain = .05 in/min

TABLE IV

PROPERTIES OF NICKEL-CADMIUM PLATED AISI-H-11 ALLOY STEEL
CHARPY V-NOTCHED IMPACT SPECIMENS
EXPOSED TO STRESS CORROSION CONDITIONS

Exposure Time Days	Impact Energy Ft/LB	Specimen Condition	Environment	Number of Tests
0	10.8	Coated	As Received	1
30	11.25	Coated	A.I.	2
60	10.9	Coated	A.I.	2
90	13.0	Coated	A.I.	2
180	--	--	--	-
0	10.8	Coated	As Received	1
30	11.1	Coated	MSFC-ATM	2
60	10.75	Coated	MSFC-ATM	2
90	11.9	Coated	MSFC-ATM	2
180	9.5	Coated	MSFC-ATM	1

TABLE V

STRESS CORROSION FAILURE RECORD FOR H-11 ALLOY STEEL C-RING SPECIMENS BARE AND NICKEL-CADMIUM PLATED

Environment	Specimen Condition	Stressed Condition Percent of 0.2% Y.S. (%)	Failure Time Days
A.I.	Bare	25	N.F.*
A.I.	Bare	25	N.F.
A.I.	Bare	50	29
A.I.	Bare	50	27
A.I.	Bare	90	2
A.I.	Bare	90	2
A.I.	Bare	90	2
MSFC	Bare	25	N.F.
MSFC	Bare	25	N.F.
MSFC	Bare	50	N.F.
MSFC	Bare	50	N.F.
MSFC	Bare	90	167
MSFC	Bare	90	N.F.
A.I.	Plated	25	N.F.
A.I.	Plated	25	N.F.
A.I.	Plated	50	N.F.
A.I.	Plated	50	N.F.
A.I.	Plated	90	161**
A.I.	Plated	90	67
A.I.	Plated	90	N.F.
MSFC	Plated	25	N.F.
MSFC	Plated	25	N.F.
MSFC	Plated	50	N.F.
MSFC	Plated	50	N.F.
MSFC	Plated	90	N.F.
MSFC	Plated	90	N.F.
MSFC	Plated	90	N.F.

* N.F. - No Failure - Test Stopped After 183 Days

** Specimen Coating Possibly Damaged When Stress Was applied

TABLE VI

STRESS CORROSION FAILURE RECORD FOR H-11 ALLOY STEEL
LONGITUDINAL TENSILE SPECIMENS (.125 Inch Dia)
BARE AND NICKEL-CADMIUM PLATED

Environment	Specimen Condition	Stressed Condition Percent of 0.2% Y.S. (%)	Failure Time Days
A.I.	Bare	50	22
A.I.	Bare	50	26
A.I.	Bare	50	35
A.I.	Bare	50	20
A.I.	Bare	50	31
A.I.	Bare	90	7
A.I.	Bare	90	8
A.I.	Bare	90	9
A.I.	Bare	90	13
A.I.	Bare	90	13
MSFC	Bare	90	141

Other Specimens Removed From Testing Environment After 30, 60 and 180 Days for Tensile Testing.

Results Tabulated in Tables II and III

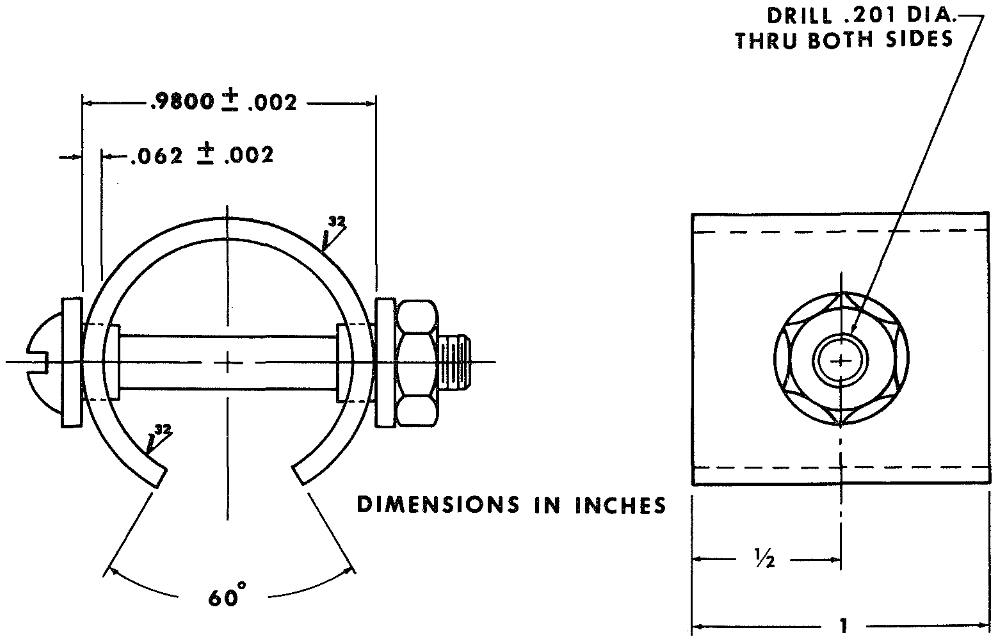


FIGURE 1B-STRESS CORROSION 'C'-RING SPECIMEN

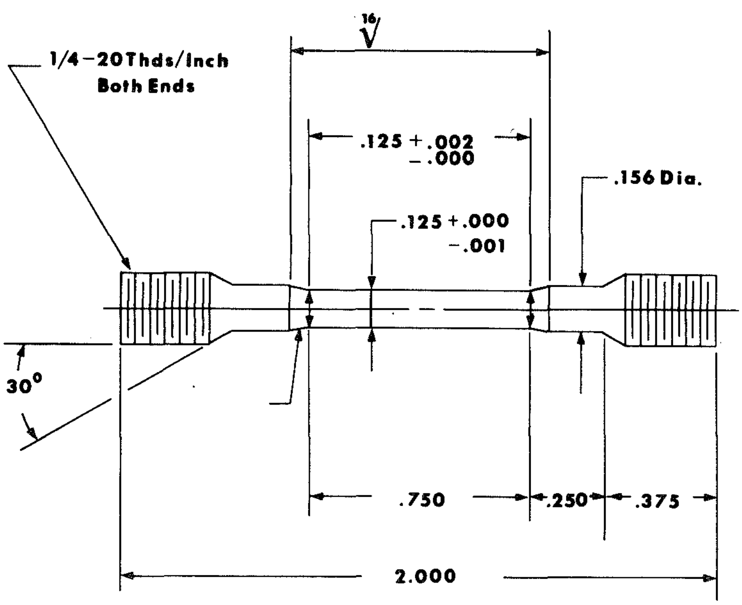


FIGURE 1A-STRESS CORROSION TENSILE SPECIMEN

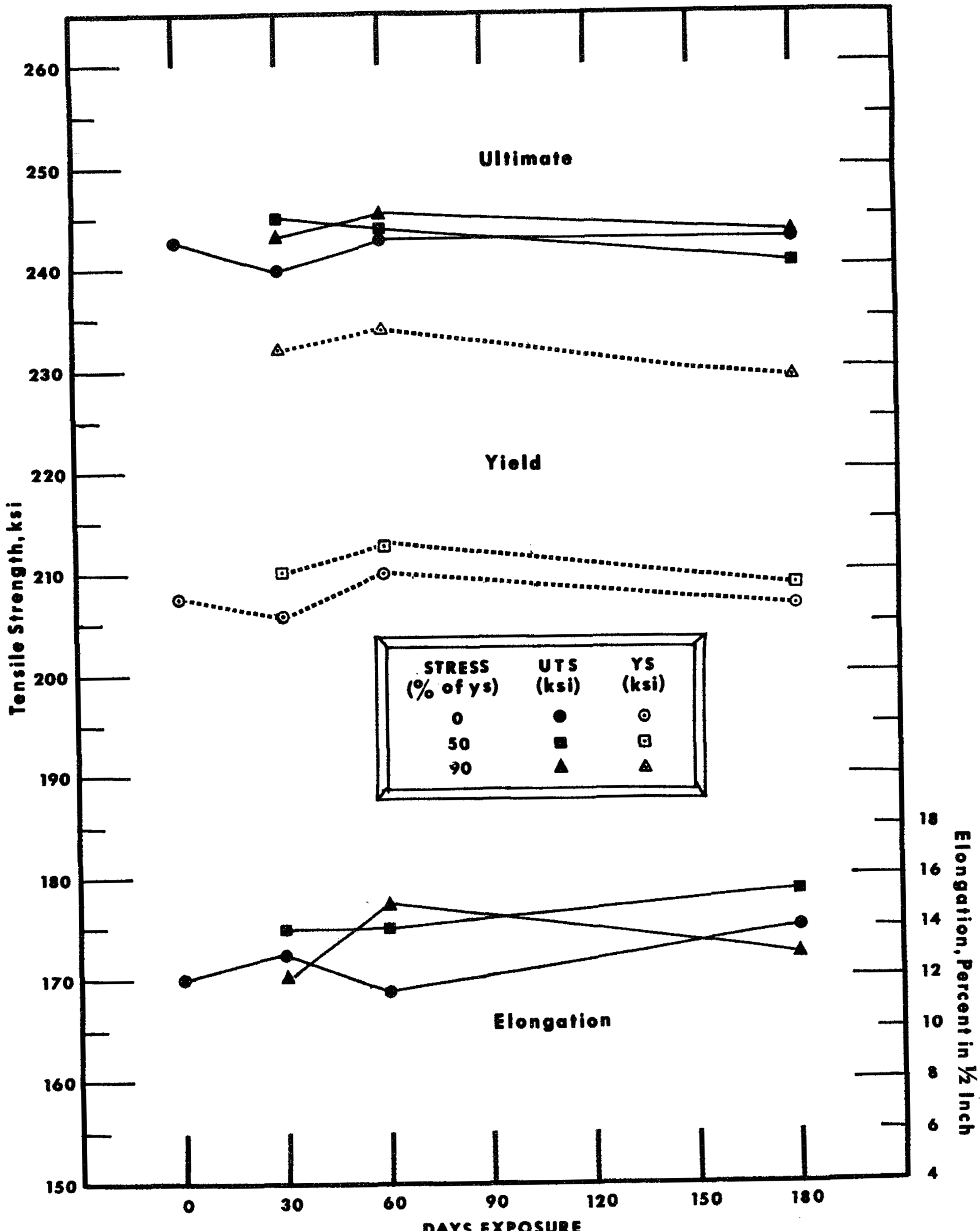


FIGURE 2. - MECHANICAL PROPERTIES OF STRESSED NICKEL-CADMIUM PLATED H-11 AlloY STEEL EXPOSED TO A 3.5 % NACL A.I. BATH

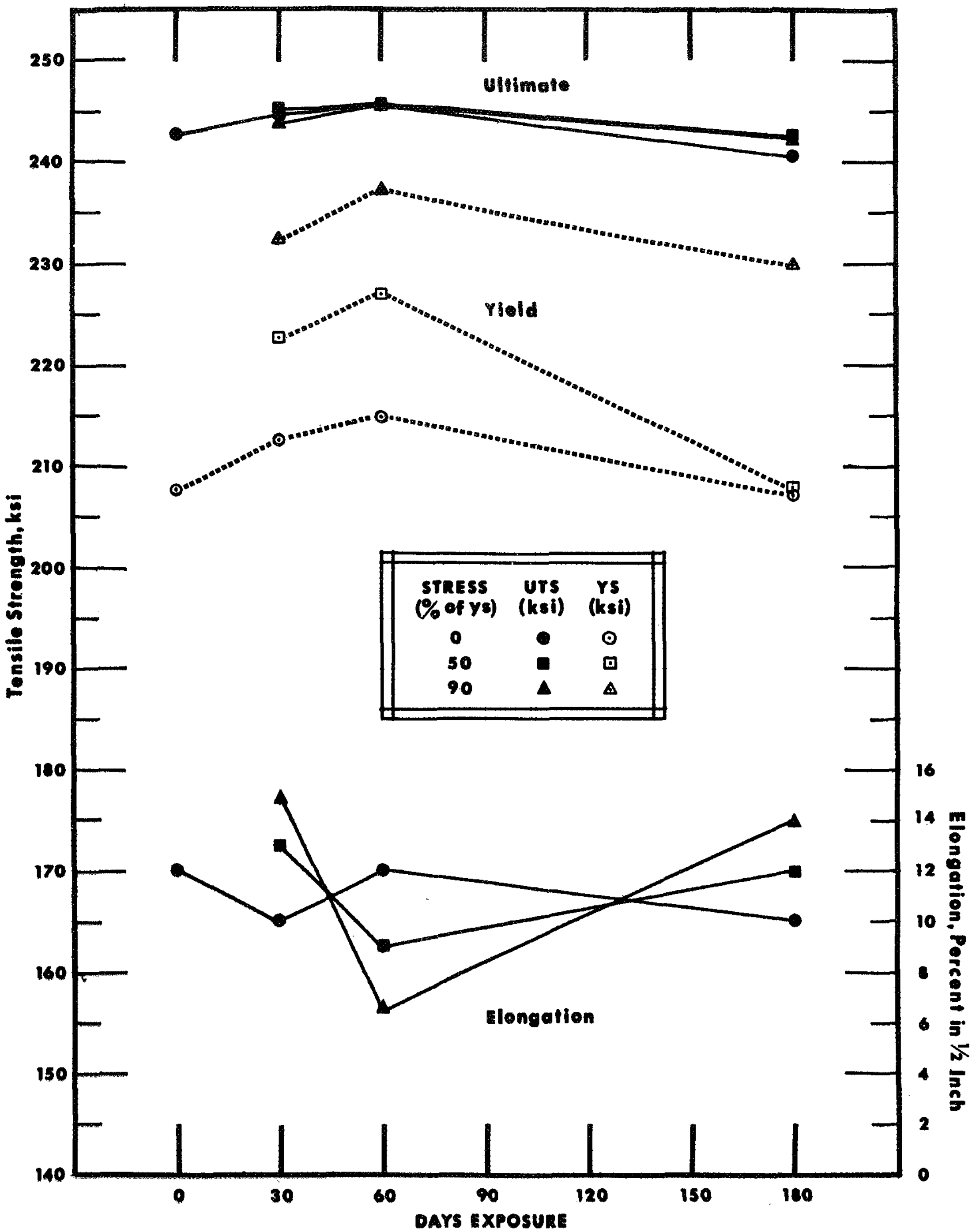


FIGURE 3.- MECHANICAL PROPERTIES OF STRESSED NICKEL-CADMIUM PLATED H-11 ALLOY STEEL EXPOSED TO THE M.S.F.C. ATMOSPHERE

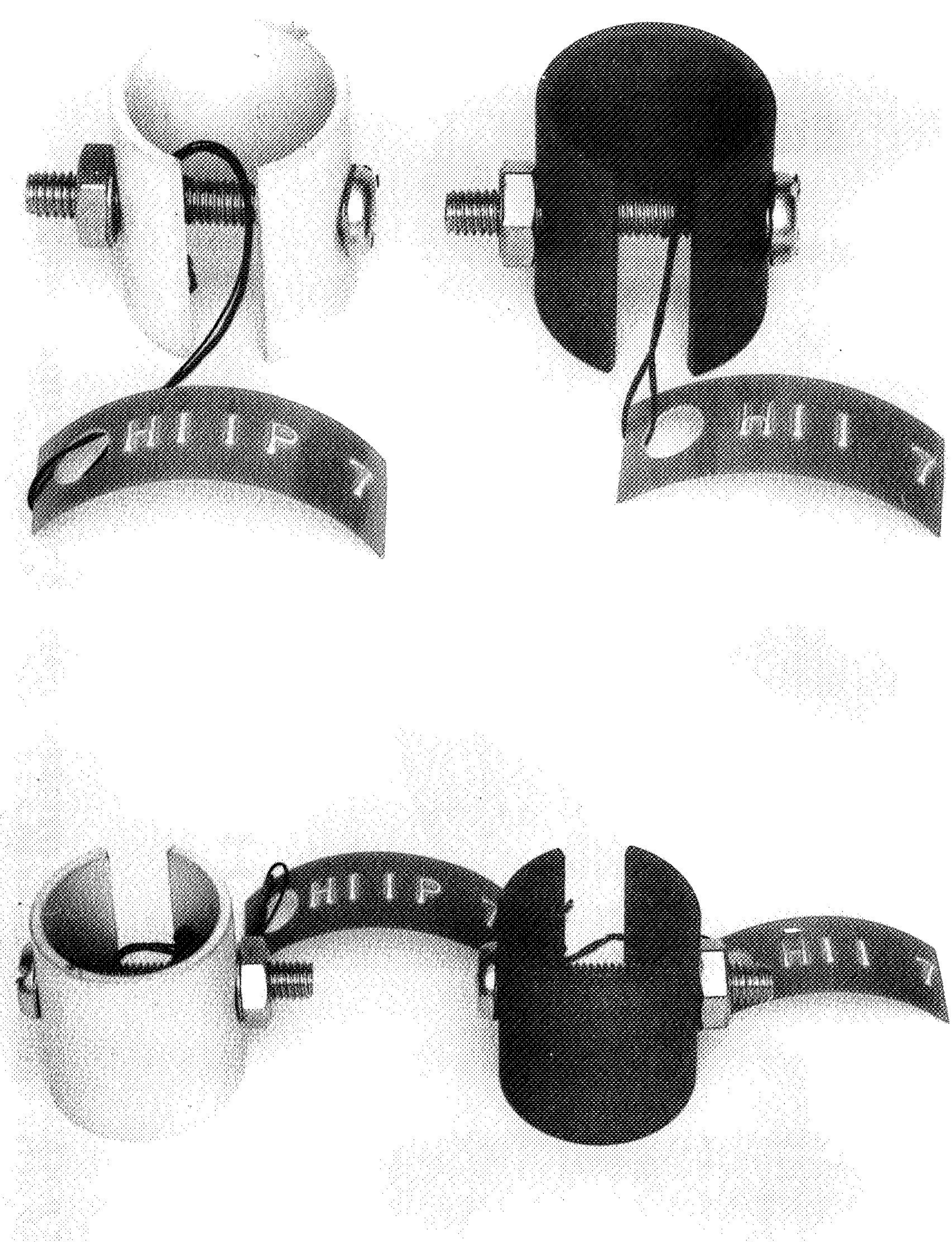


FIGURE 4 - BARE AND NICKEL–CAD PLATED H-11 ALLOY STEEL 'C'-RING SPECIMENS STRESSED TO 90% OF YIELD STRENGTH–PRIOR TO A.I. TESTING

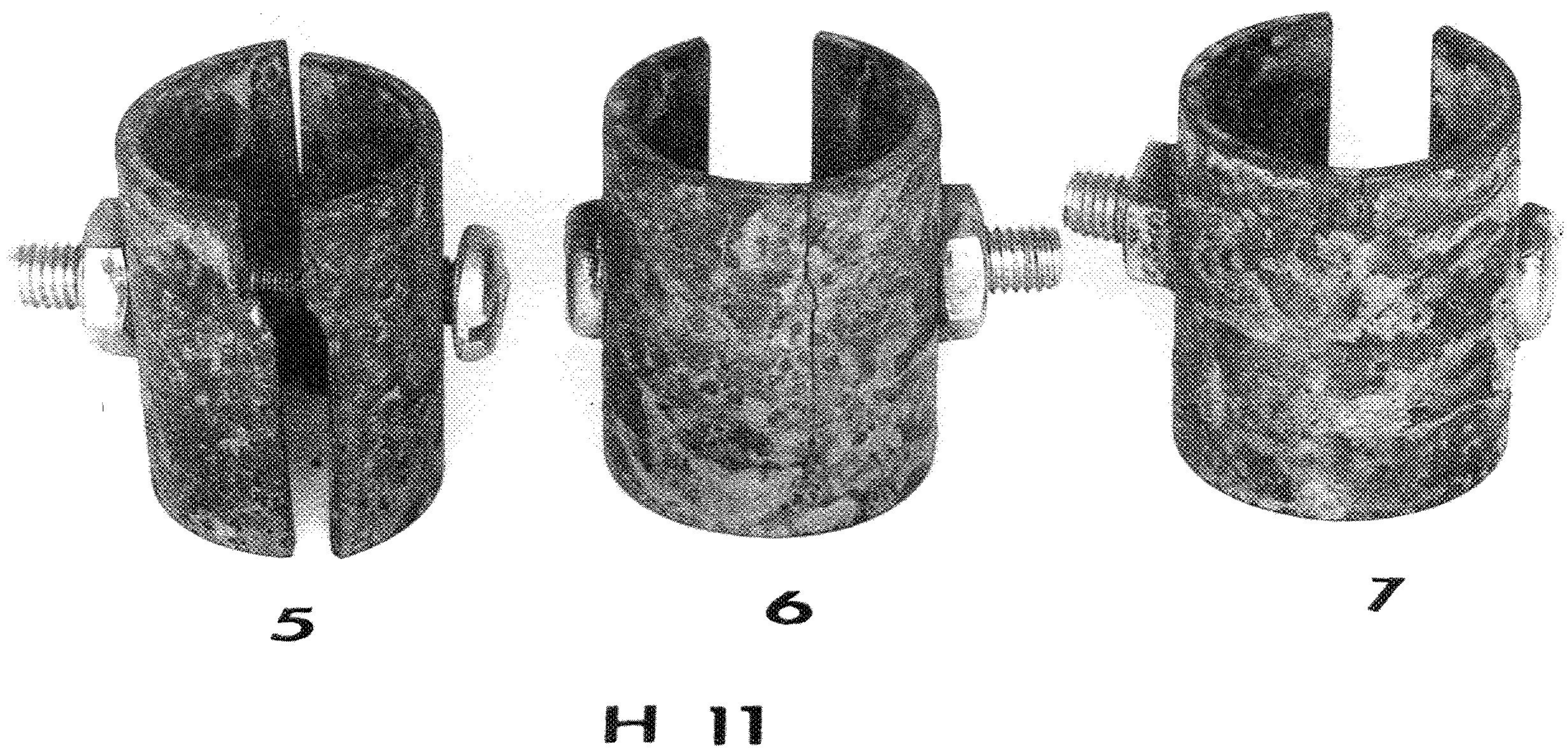
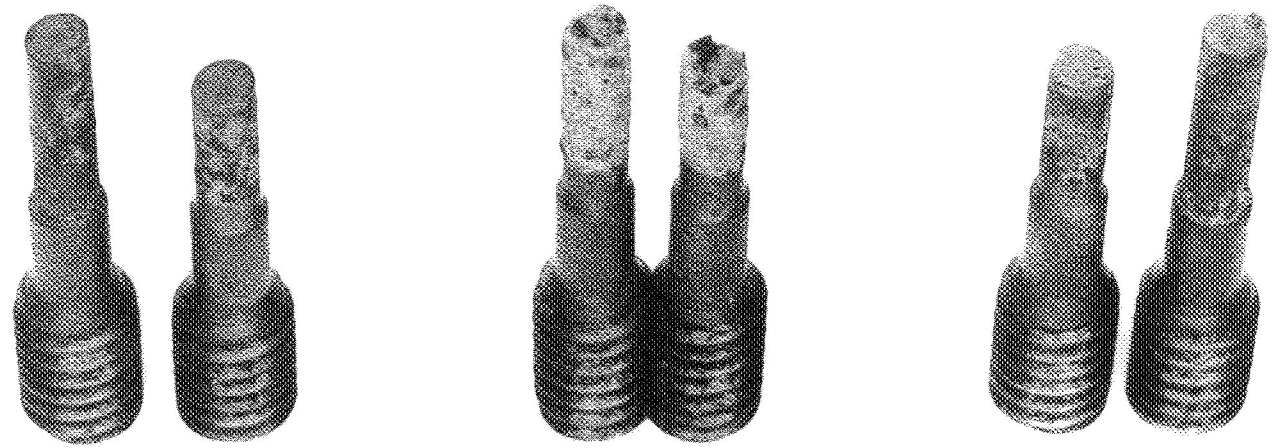


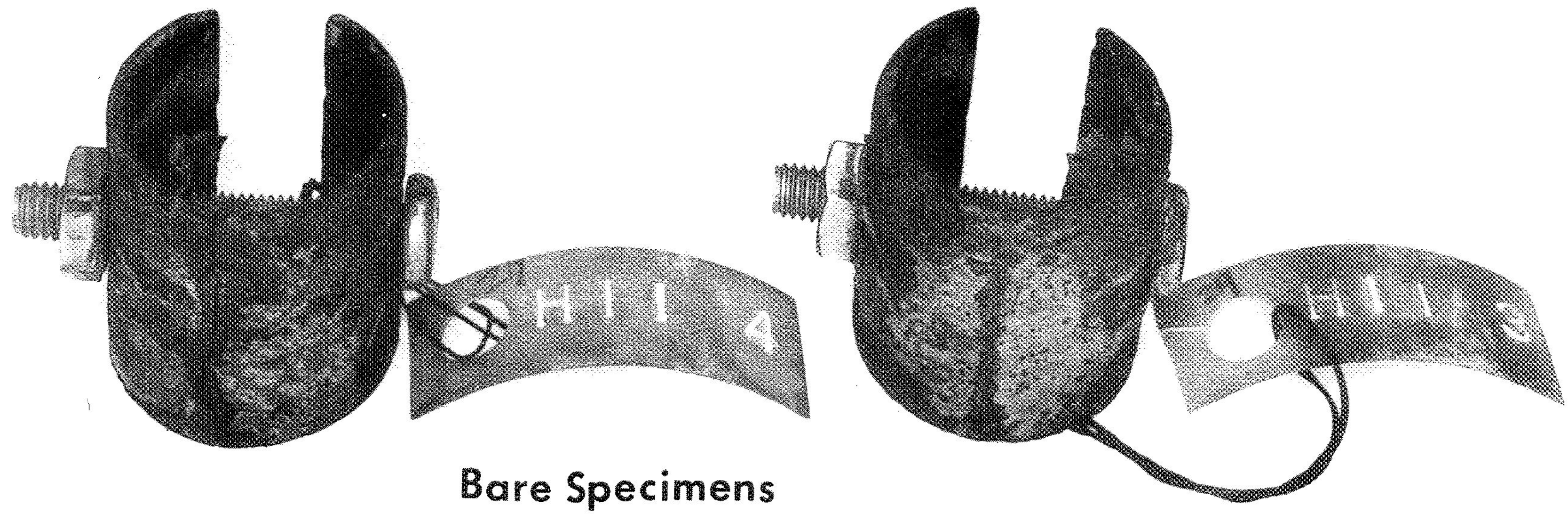
FIGURE 5 - BARE H-11 ALLOY STEEL 'C'-RING SPECIMENS STRESSED TO 90% OF YIELD STRENGTH FAILED AFTER 2 DAYS EXPOSURE TO A 3.5% NACL A.I. BATH



Bare Specimens

H-11 ALLOY STEEL 240 KSI UTS
STRESSED TO 90 % OF .2% YS
FAILED AFTER 7,8,&9 DAYS OF
ALTERNATE IMMERSION TESTING

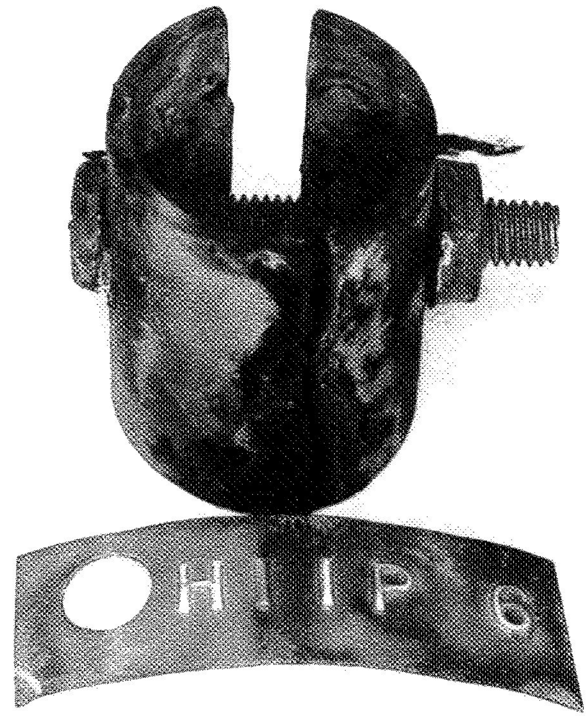
FIGURE 6



Bare Specimens

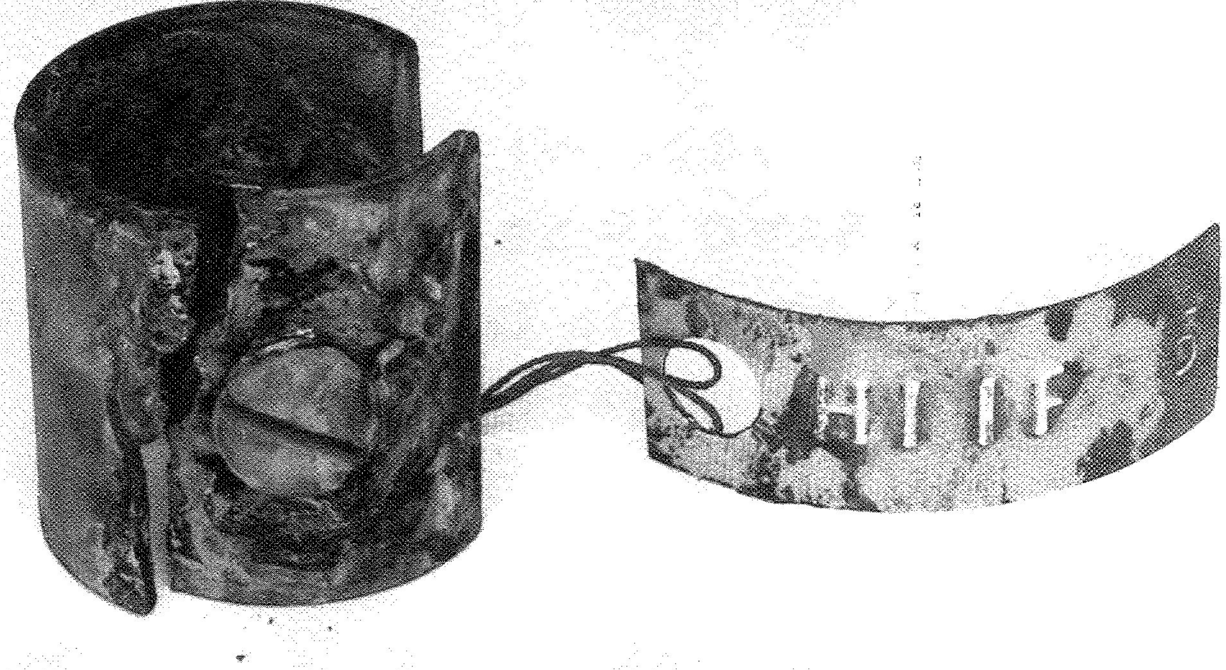
H-II ALLOY STEEL 240 KSI UTS STRESSED TO 50 % OF .2% YS FAILED AFTER 27 & 29 DAYS OF ALTERNATE IMMERSION TESTING

FIGURE 7



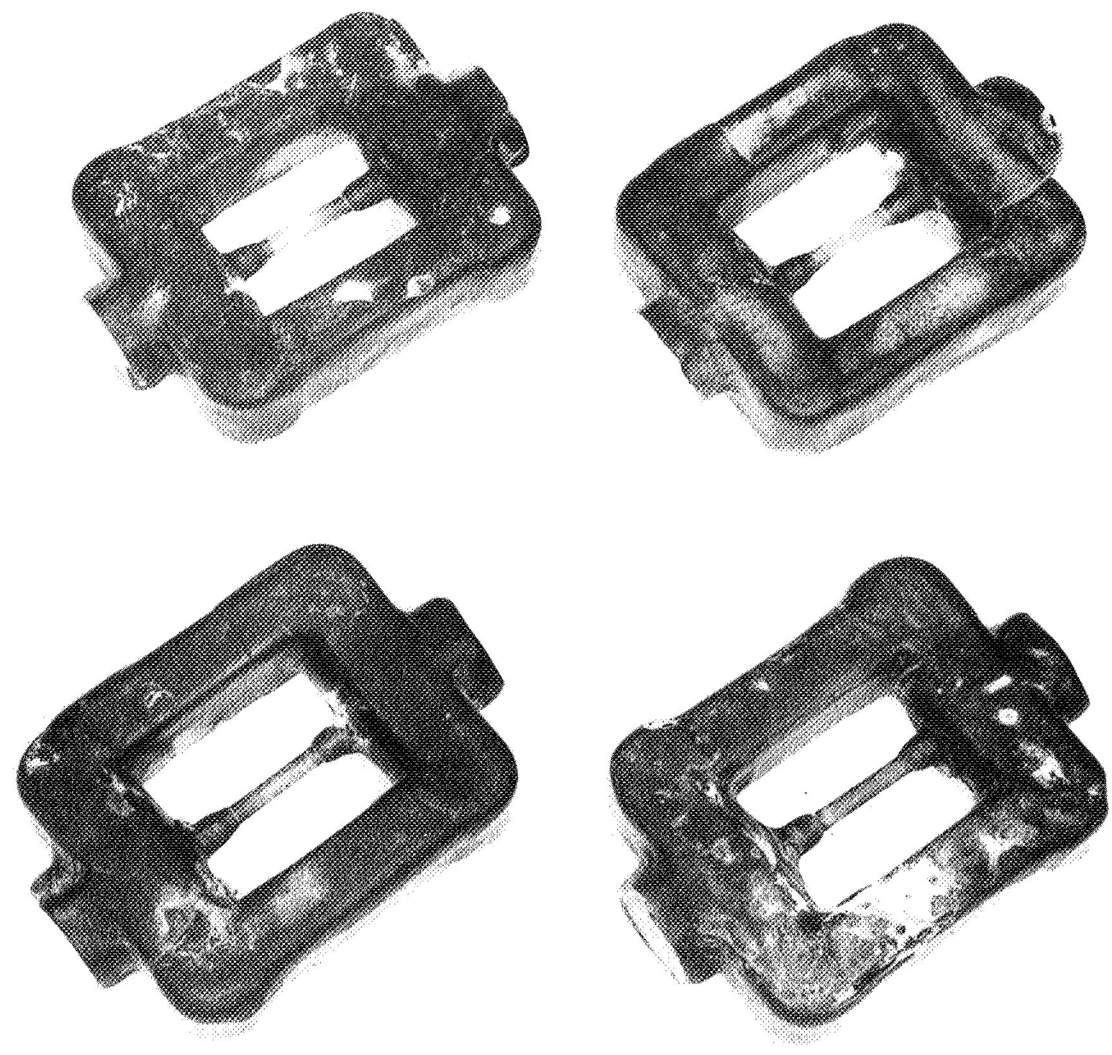
NICKEL–CADMIUM PLATED
H-11 ALLOY STEEL 240 KSI UTS
STRESSED TO 90 % OF .2% YS
FAILED AFTER 67 DAYS OF
ALTERNATE IMMERSION TESTING

FIGURE 8



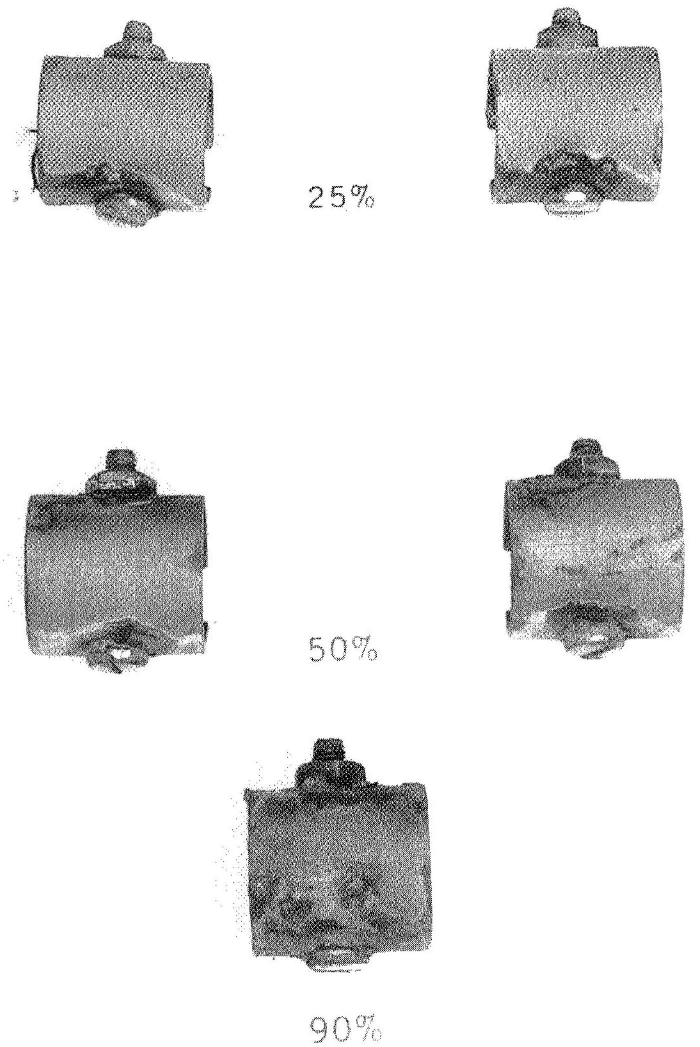
NICKEL-CADMIUM PLATED
H-11 ALLOY STEEL 240 KSI UTS
STRESSED TO 90 % OF .2% YS
FAILED AFTER 161 DAYS OF
ALTERNATE IMMERSION TESTING

FIGURE 9



H-11 ALLOY STEEL ULTIMATE TENSILE STRENGTH 240 KSI
NICKEL CADMIUM PLATED LONGITUDINAL TENSILE SPECIMENS
STRESSED TO 50, & 90% OF THE 0.2% YIELD STRENGTH
EXPOSED TO 180 DAYS OF ALTERNATE IMMERSION TESTING

FIGURE 10



H-11 ALLOY STEEL ULTIMATE TENSILE STRENGTH 240 KSI
NICKEL CADMIUM PLATED "C" - RING SPECIMENS
STRESSED TO 25, 50, & 90% OF THE 0.2% YIELD STRENGTH
EXPOSED TO 180 DAYS OF ALTERNATE IMMERSION TESTING

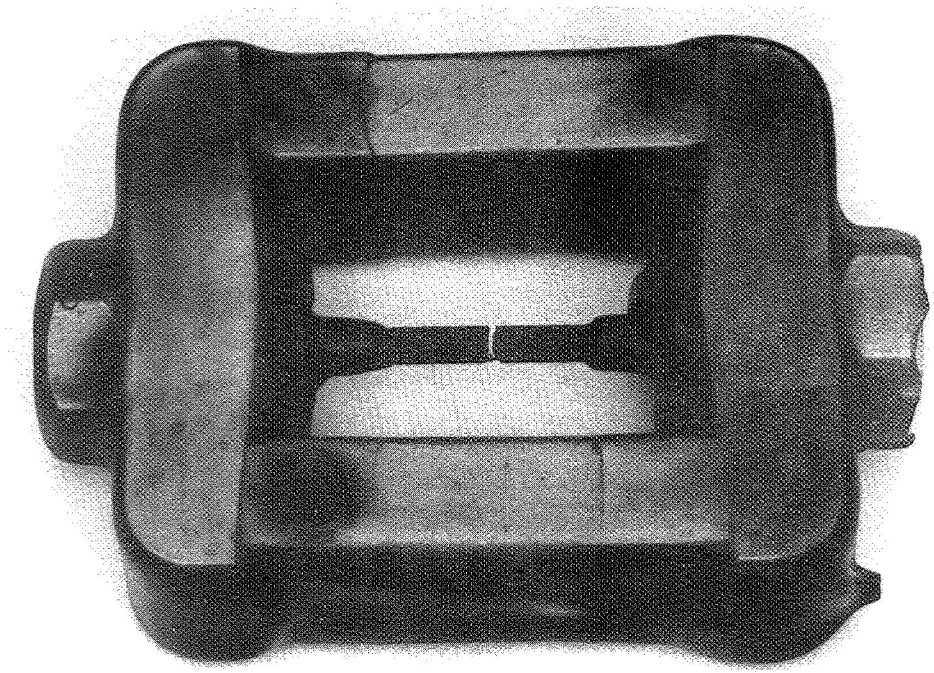
FIGURE 11

H-11 ALLOY STEEL ULTIMATE TENSILE STRENGTH 240 KSI
BARE "C" - RING SPECIMENS

STRESSED TO 25% OF THE 0.2% YIELD STRENGTH

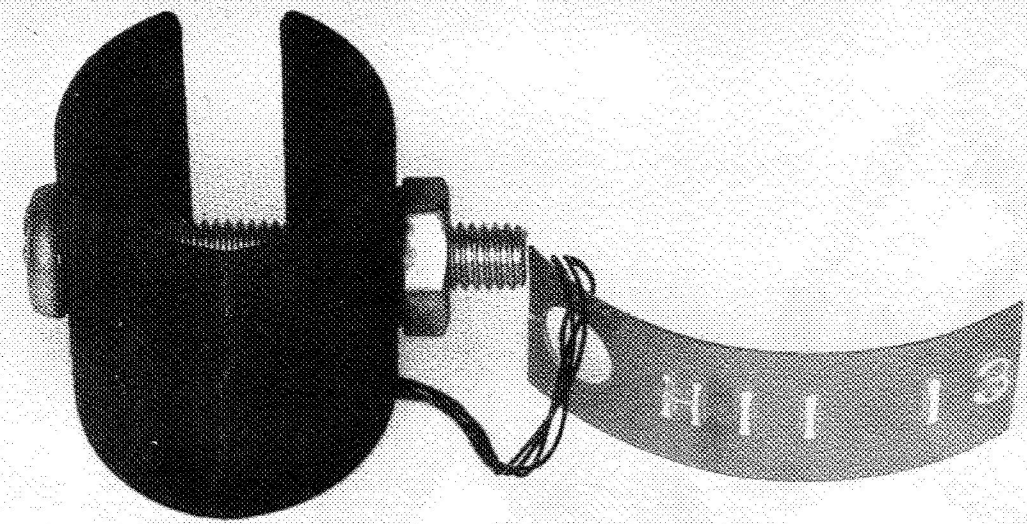
EXPOSED TO 180 DAYS OF ALTERNATE IMMERSION TESTING

FIGURE 12



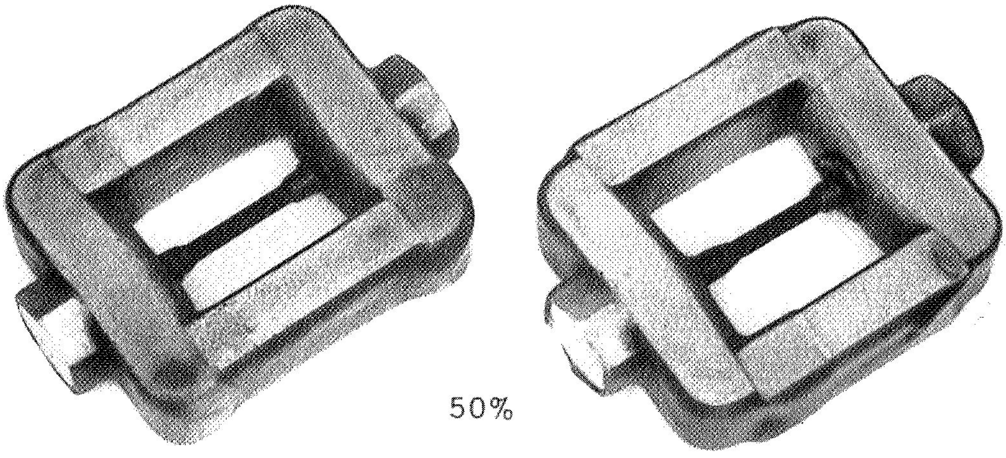
BARE LONGITUDINAL SPECIMEN
H-11 ALLOY STEEL 240 KSI UTS
STRESSED TO 90 % OF .2% YS
FAILED AFTER 141 DAYS OF
MSFC ATMOSPHERIC TESTING

FIGURE 13

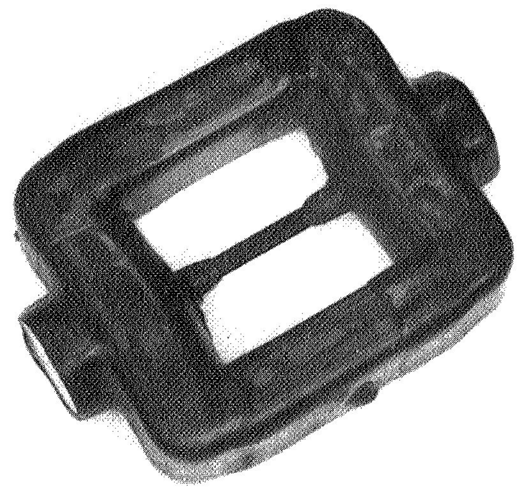


BARE 'C'-RING SPECIMEN
H-11 ALLOY STEEL 240KSI UTS
STRESSED TO 90% OF .2% YS
FAILED AFTER 167DAYS OF
MSFC ATMOSPHERIC TESTING

FIGURE 14



50%



90%

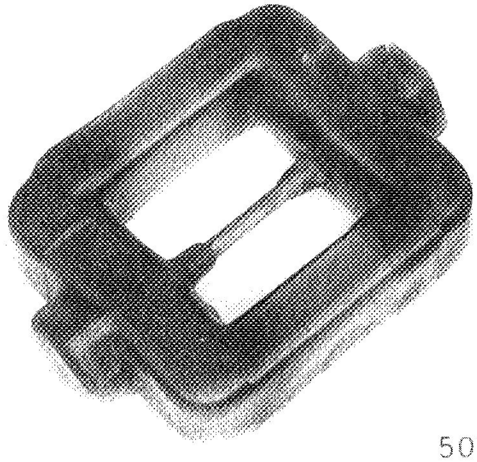
H-11 ALLOY STEEL ULTIMATE TENSILE STRENGTH 240 KSI

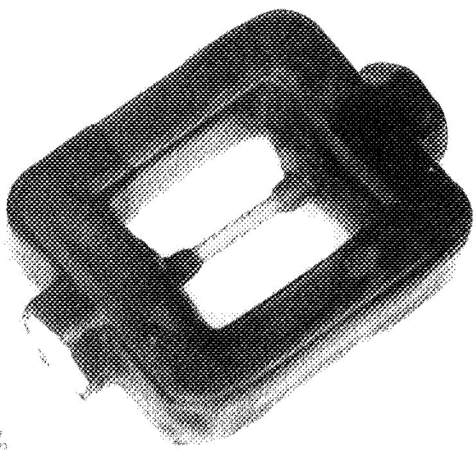
BARE LONGITUDINAL TENSILE SPECIMENS

STRESSED TO 50 & 90% OF THE 0.2% YIELD STRENGTH

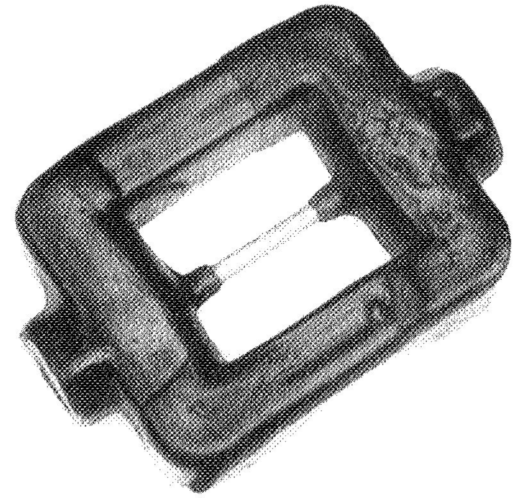
EXPOSED TO 180 DAYS OF MSFC ATMOSPHERIC TESTING

FIGURE 15





50%



90%

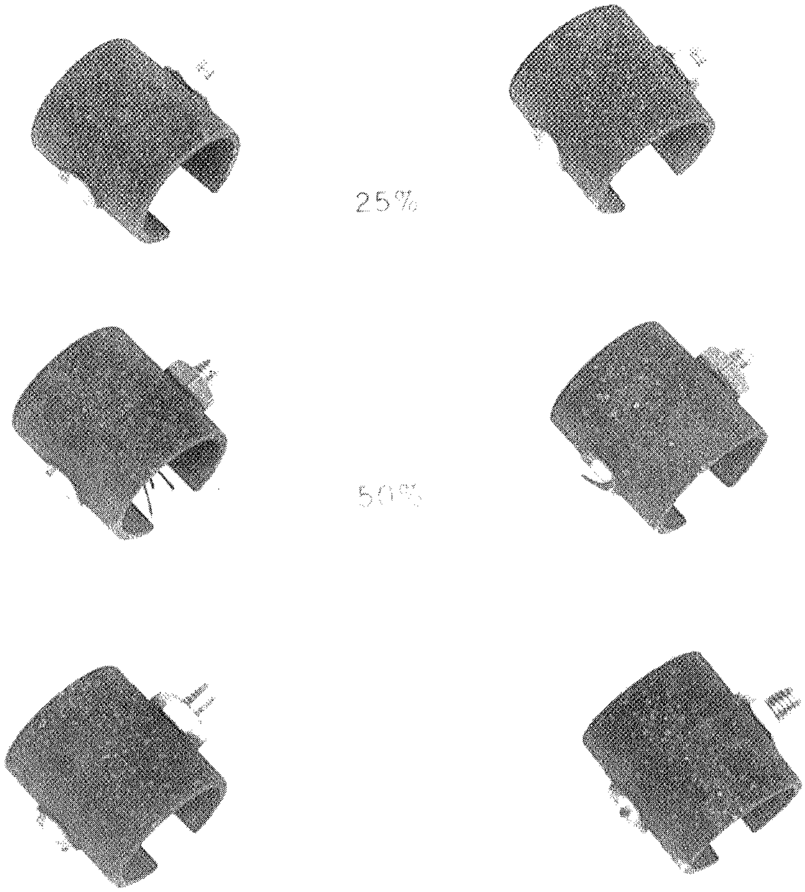
H-11 ALLOY STEEL ULTIMATE TENSILE STRENGTH 240 KSI

NICKEL CADMIUM PLATED LONGITUDINAL TENSILE SPECIMENS

STRESSED TO 50 & 90% OF THE 0.2% YIELD STRENGTH

EXPOSED TO 180 DAYS OF MSFC ATMOSPHERIC TESTING

FIGURE 16



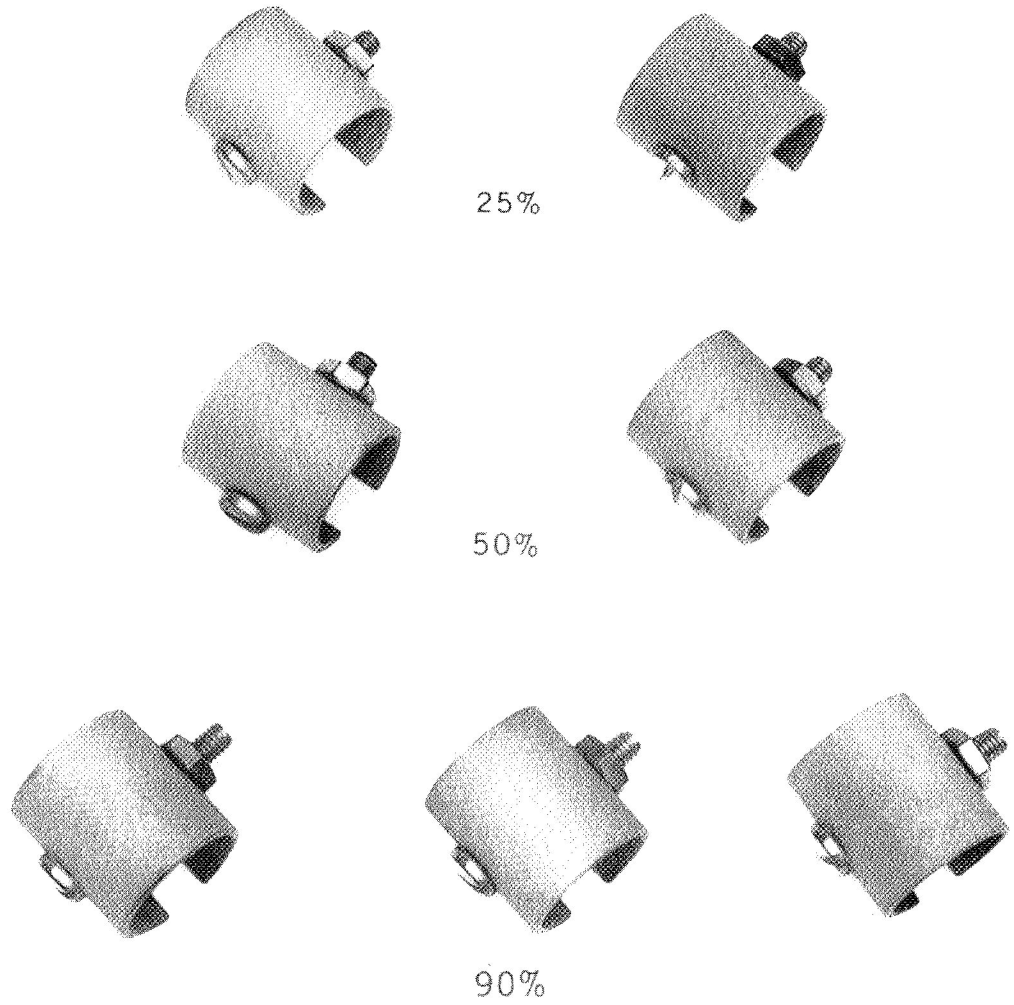
H-11 ALLOY STEEL ULTIMATE TENSILE STRENGTH 240 KSI

BARE "C" - RING SPECIMENS

STRESSED TO 25, 50, & 90% OF THE 0.2% YIELD STRENGTH

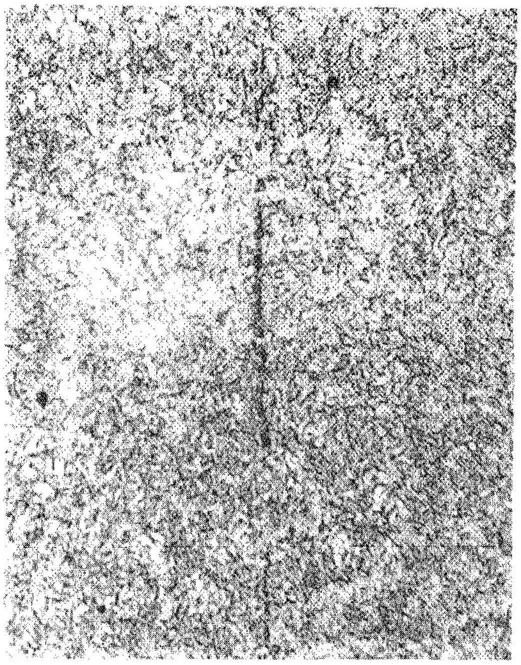
EXPOSED TO 180 DAYS OF MSFC ATMOSPHERIC TESTING

FIGURE 17

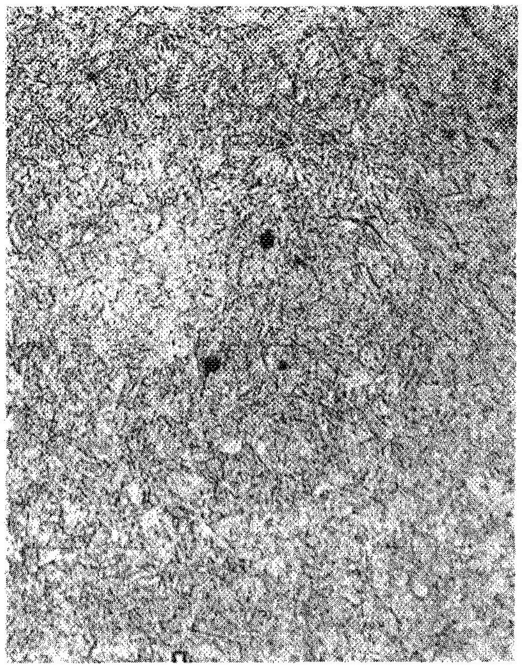


H-11 ALLOY STEEL ULTIMATE TENSILE STRENGTH 240 KSI
NICKEL CADMIUM PLATED "C" - RING SPECIMENS
STRESSED TO 25, 50, & 90% OF THE 0.2% YIELD STRENGTH
EXPOSED TO 180 DAYS OF MSFC ATMOSPHERIC TESTING

FIGURE 18

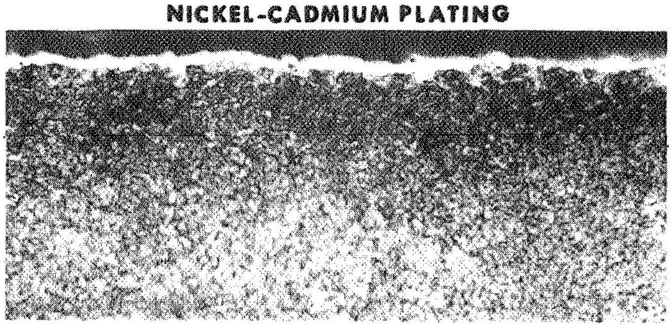


Longitudinal



Transverse

NICKEL-CADMIUM PLATING



Transverse

FIGURE 19-MICROSTRUCTURE OF H-11 ALLOY STEEL
Nital Etch 425X Mag

APPROVAL NASA TM X-64510

A STRESS CORROSION EVALUATION OF AISI - H-11 ALLOY STEEL PLATED WITH NICKEL - CADMIUM COATING

By

J. W. Montano

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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