NASA TECHNICAL MEMORANDUM

NASA TM X-73375

THE STRESS CORROSION RESISTANCE AND THE CRYOGENIC TEMPERATURE MECHANICAL PROPERTIES OF HOT ROLLED NITRONIC 32 BAR MATERIAL

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April 1977

NASA

George C. Marshall Space Flight Center
Marshall Space Flight Center, Alabama

TECHNICAL REPORT STANDARD TITLE PAGE

1. REPORT NO.	2. GOVERNMENT ACCESSION NO.	3. RECIPIENT'S CATALOG NO.
NASA TM X-73375		

4. TITLE AND SUBTITLE	5. REPORT DATE
The Stress Corrosion Resistance and The Cryogenic Temperature Mechanical Properties of Hot Rolled Nitronic 32 Bar Material	April 1977
	6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) J. W. Montano	8. PERFORMING ORGANIZATION REPORT #
9. PERFORMING ORGANIZATION NAME AND ADDRESS NASA - George C. Marshall Space Flight Center Marshall Space Flight Center, AL 35812	10. WORK UNIT NO.
	11. CONTRACT OR GRANT NO.
	13. TYPE OF REPORT & PERIOD COVERED Technical Memorandum
12. SPONSORING AGENCY NAME AND ADDRESS National Aeronautics and Space Administration Washington, D. C.	14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

Work performed by Materials and Processes Laboratory, Science and Engineering

16. ABSTRACT

This report presents the ambient and cryogenic temperature mechanical properties and the ambient temperature stress corrosion properties of hot rolled and centerless ground Nitronic 32 stainless steel bar material.

The mechanical properties of longitudinal specimens were evaluated at test temperatures from ambient to liquid hydrogen. The tensile test data indicated increasing smooth tensile strength with decreasing temperature to liquid hydrogen temperature. However, below -200°F (-129.0°C) the notched tensile strength decreased slightly and below -320°F (-196.0°C) the decrease was significant. The elongation and reduction of area decreased drastically at temperatures below -200°F (-129.0°C). The Charpy V-notched impact energy decreased steadily with decreasing test temperature.

Stress corrosion tests were performed on longitudinal tensile specimens stressed to 0, 75, and 90% of the 0.2% yield strength and on transverse "C"-ring specimens stressed to 75 and 90% of the yield strength and exposed to: alternate immersion in a 3.5% NaCl bath, humidity cabinet environment, and a 5% salt spray atmosphere. The longitudinal tensile specimens experienced no corrosive attack; however, the "C"-rings exposed to the alternate immersion and to the salt spray experienced some shallow etching and pitting, respectively. Small cracks appeared in two of the "C"-rings after one month exposure to the salt spray. Metallographic examination did not reveal the branching phenomenon associated with stress corrosion cracking.

17. KEY WORDS	18. DISTRIBUTION STATEMENT
Cryogenic Temperature Alternate Immersion Humidity Salt Spray Metallography	Unclassified - Unlimited

19. SECURITY CLASSIF. (of this report)	20. SECURITY CLASSIF. (of this page)	21. NO. OF PAGES	22. PRICE
Unclassified	Unclassified	22	NTIS

MSFC - Form 3292 (May 1969)

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SUMMARY

This report presents the ambient and cryogenic temperature mechanical properties and ambient temperature stress corrosion properties of hot rolled and centerless ground Nitronic 32 stainless steel bar material. Test specimens were manufactured from a 1.00-inch (2.54 cm) diameter bar.

The mechanical property tests were performed at temperatures of 75°F (23.9°C), 0°F (-17.8°C), -100°F (-73.0°C), -200°F (-129.0°C), -320°F (-196°C) and -423°F (-252.8°C). These tests included smooth tensile (ultimate, yield, modulus, elongation and reduction of area), V-notched tensile (notched tensile strength and notched/unnotched tensile ratio), and Charpy V-notched impact. The test data indicate an increase in smooth tensile properties with decreasing temperature. Below -200°F (-129.0°C) the notched tensile strength decreased moderately to liquid nitrogen temperature, then drastically between liquid nitrogen and liquid hydrogen temperatures. The elongation and reduction of area decreased drastically below -200°F (-129.0°C). The Charpy V-notched impact energy decreased steadily with decreasing test temperature decreasing to a minimum individual test value of 15 ft-lbs (20.3 Joules) at the lowest impact test temperature of -320°F (-196°C).

Results of the 180 day alternate immersion, salt spray and humidity tests on longitudinal tensile specimens (stressed to 0, 75, and 90% of the 0.2% yield strength) and transverse "C"-rings (stressed to 75, and 90% of the yield strength), indicate that the alloy has excellent resistance to stress corrosion cracking when tested in the longitudinal direction. The design of the "C"-ring specimens made them vulnerable to an end grain attack which caused some shallow etching and pitting of the specimens exposed to the alternate immersion and to the salt spray environments. Metallographic examination of the pits did not reveal the branching phenomenon associated with stress corrosion cracking.

INTRODUCTION

Nitronic 32 (formerly known as 18-2 Mn), an austenitic stainless steel developed by Armco Steel Company, is an alloy from a new family of stainless steels in which manganese and nitrogen are substituted for a portion of the usual nickel content. This Nitronic stainless was chosen for evaluation due to its unusually high yield strength in the hot rolled bar condition, its good corrosion resistance, and its excellent anti-galling properties. It is also lighter than most stainless steels and less costly when compured to type 304 stainless steel.

Nitronic 32 stainless steel is an iron base alloy containing approximately 18% chromium, 1.6% nickel, 12% manganese, 0.5% silicon, 0.10% carbon, and 0.34% nitrogen. The chemical composition of the 1.00-inch (2.54 cm) diameter bar material shown in Table I is from Armco Steel Company's heat number 536480. This alloy as supplied in the hot rolled and centerless ground condition is sold for marine applications such as propeller shafts, and is also designated as Aqua-Met 18.

EQUIPMENT AND MECHANICAL TEST SPECIMENS

The equipment used in the mechanical properties evaluation is described in a report by the author (Ref. 1). Tensile specimens, smooth and V-notched, are illustrated in Figures 1A and 1B , respectively. The Charpy V-notched specimen configuration was in accordance with Federal Test Method Standard No. 151A Method 222.1.

STRESS CORROSION TEST PROCEDURE AND TEST SPECIMENS

The equipment and the test procedure used in the alternate immersion (A.I.) stress corrosion test is described in a report by Humphries (Ref. 2). The A.I. bath is a 3.5% NaCl solution maintained at a pH of 6.5 - 7.2, a temperature of 80°F ± 2°F (27°C ± 1°C), and a water purity per ASTM-D-1193-7 Type II. The A.I. cycle is 10 minutes in solution and 50 minutes out of solution. The salt spray test utilized the procedures of ASTM-B-117-64, "Standard Method of Salt Spray (Fog) Testing," which specifies a 5% salt solution at a pH of 6.5 - 7.2 and a temperature of 95°F (35°C). The humidity test was conducted in a cabinet maintained at 98% relative humidity and a temperature of 95°F (35°C).

The longitudinal tensile specimens and the transverse "C" - rings illustrated in Figure 1C were degreased with acetone, stressed, then recleaned with acetone prior to the 180 day exposure in the corrosive environments. The stress applied to the tensile specimens was 0, 75, and 90% of the 0.2% yield strength while the "C" - ring specimens were stressed to 75 and 90% of the yield strength. Unstressed tensile specimens were also exposed to the same environments.

The stress corrosion testing schedule is outlined below:

Test Specimen	Applied Stress % of 0.2% Y.S.	Specimens Per Stress Level	Environments
Tensile	0, 75, 90	4	A.I., Salt Spray, Humidity
"C" - ring	75, 90	4	A.I., Salt Spray
"C" - ring	75, 90	3	Humidity

RESULTS AND DISCUSSION

1. Mechanical Properties Evaluation

The tensile test results of the ambient through cryogenic temperature mechanical properties evaluation and the Charpy V-notched impact data are tabulated in Tables II and III, respectively. These properties are also plotted in Figures 2-3.

Table II contains test data on hot rolled and centerless ground bar material tensile specimens. These tensile test data indicate an increase in ultimate tensile and 0.2% yield strengths with decreasing temperature. Below -200°F (-129.0°C) there is a drastic decrease in elongation (percent in 4 diameters) and reduction of area. The notch tensile strength (NTS) increased with decreasing test temperature to -200°F (-129.0°C). Below that temperature to liquid nitrogen temperature there was a moderate decrease in the NTS. Between liquid nitrogen and liquid hydrogen temperatures there was a drastic reduction of NTS resulting in a notched/unnotched tensile ratio of 0.53 at -423°F (-252.8°C).

Table III indicates a steady decrease in Charpy V-notched impact energy with decreasing temperature, dropping from an ambient temperature average impact energy of 155.0 ft-lbs (210.1 Joules) to a liquid nitrogen temperature average impact energy of 20.1 ft-lbs (27.3 Joules). The variation in impact energy within a given temperature range can be attributed to the hot working and centerless grinding of the bar.

2. Metallography of As Received Bar Material

Figure 4 shows the microstructure of the longitudinal and transverse directions of the hot rolled and centerless ground bar material. The grains are extremely small and are free from any precipitated carbides in the grain boundaries. The stringer material shown in the longitudinal microstructure is typical of the Nitronic stainless steels such as Nitronic 33 and Nitronic 60. Previous analysis of these nitronic steel stringers by Energy Dispersive Analysis of X-rays (EDAX) revealed them to contain the deoxidation additives, aluminum and calcium.

3. Stress Corrosion Evaluation

Table IV contains test data prior to and after 180 days exposure to the following environments:

(1) Alternate Immersion - 3.5% NaCl Bath, 80°F (27°C)

(2) Salt Spray Cabinet - 5.0% NaCl Fog, 95°F (35°C)

(3) Humidity Cabinet - 98% Relative Humidity, 95°F (35°C)

3. Stress Corrosion Evaluation (Cont'd)

These data indicate that the longitudinal tensile specimens were not susceptible to stress corrosion cracking, even when stressed to 90% of the 0.2% yield strength and exposed for 180 days to the environments listed above. However, after 180 days exposure to the various environments there was an increase in the mechanical properties of the 0% stressed specimens due, possibly, to aging.

These data in Table IV obtained from 0.1250- inch (0.3175 cm) diameter bar specimens also indicate the variable depth of hardening obtained by hot rolling. When the tensile test data in Table IV is compared with the tensile test results in Table II, obtained from 0.250- inch (0.635 cm) diameter bar specimens, the effects of hot rolling, specimen size, and specimen location become more evident. The variable strengths are reflected in the specimen size and specimen location as taken from the bar edge or center.

Figure 5 illustrates typical tensile and "C" - ring specimens stressed to 90% of the 0.2% yield strengths and exposed to the corrosive environments, listed above, for 180 days.

The "C" - ring specimens exposed to the alternate immersion experienced only superficial etching. After approximately four months exposure small shallow etching was observed on the specimens surface and after 180 days exposure shallow pits were present.

The "C" - ring specimens exposed to the salt spray experienced some pitting. Small cracks appeared in two of the "C" - ring specimens after one month exposure to the salt spray, however neither of these specimens failed in 180 days exposure.

Figure 6 illustrates the resultant corrosive attack caused by the end grain surface pitting. The "C" - ring specimen shown in Figure 6 was stressed to 75% of the 0.2% yield strength and exposed for 180 days to the salt spray. As previously mentioned minute cracks and pitting began in the "C" - ring after one month exposure.

The humidity cabinet environment produced no rusting, pitting, cracking, or failures in the stressed "C" - ring specimens.

CONCLUSIONS

Based upon the results of this evaluation of Nitronic 32 stainless steel hot rolled and centerless ground bar material specimens, the following conclusions are drawn:

(1) The ultimate tensile and 0.2% yield strengths of the longitudinal tensile specimens increased with decreasing temperature to liquid hydrogen temperature.

(2) The elongation (percent in 4 diameters) and reduction of area indicated excellent ductility from ambient temperature to -200°F (-129.0°C).

(3) The notched to unnotched tensile ratios (K_t = 5.8) remained above 1.00 from ambient to liquid nitrogen temperature.

(4) Charpy V-notched impact energy decreased with decreasing temperature, yet remained above 35.0 ft-lbs (47.4 Joules) at -200°F (-129.0°C).

(5) Considering the overall mechanical properties obtained in this evaluation, Nitronic 32 stainless steel alloy bar in the hot rolled and centerless ground condition could be utilized in tension applications from ambient temperature to -200°F (-129.0°C).

(6) Nitronic 32 stainless steel hot rolled and centerless ground bar material, as tested in this program, is not susceptible to stress corrosion cracking in the longitudinal direction, even when stressed to 90% of the 0.2% yield strength and exposed to 180 days of moisture and chloride environments.

(7) Transverse "C"-ring specimens exposed to alternate immersion and to the salt spray environments experienced shallow surface etching and pitting, respectively. If lengthy exposure to a chloride environment is anticipated, protection should be provided to prevent a corrosive end grain attack.

(8) Considering the overall stress corrosion data obtained in this evaluation, Nitronic 32 stainless steel alloy bars [1.00-inch (2.54 cm) diameter] in the hot rolled and centerless ground condition could be utilized in applications where 300 series stainless corrosion resistance is needed, yet additional strength is required.

REFERENCES

1. Montano, J. W.: "A Mechanical and Stress Corrosion Evaluation of Custom 455 Stainless Steel Alloy," TMX-64682, August 2, 1972.

2. Humphries, T. S.: "Procedures for Externally Loading and Corrosion Testing Stress Corrosion Specimens," TMX-53483, June 29, 1966.

TABLE I

CHEMICAL COMPOSITION OF NITRONIC 32 STAINLESS STEEL ALLOY BAR*

Analysis	Fe	Cr	Mn	Ni	Si	C	P	S	N	Other Elements
Nominal	Main	18.00	12.00	1.60	0.50	0.10	—	—	0.34	—
Armco	Main	17.86	12.24	1.50	0.57	0.10	0.019	0.005	—	0.38
MSFC	Main	17.7	12.2	1.6	0.50	0.10	0.015	0.007	0.33	—

* Armco Heat No. 536480

TABLE II

LOW TEMPERATURE MECHANICAL PROPERTIES OF NITRONIC 32 STAINLESS STEEL LONGITUDINAL TENSILE SPECIMENS
0.250 INCH (0.635 CM) DIAMETER - MACHINED FROM A 1.00 INCH (2.54 CM) DIA. HOT ROLLED AND CENTERLESS GROUND BAR

Test Temperature °F	(°C)	Ultimate Tensile Strength KSI	(GN/m²)	.2% Offset Yield Strength KSI	(GN/m²)	Elongation 1.00-In (2.54 cm) 4D%	Reduction of Area %	Fracture Strength KSI	(GN/m²)	Modulus X10⁻⁶ PSI	(GN/m²)	N/U* Tensile Ratio	No. of Tests
75	(+23.9)	141.2	(0.973)	93.5	(0.645)	51.0	71.2	334.8	(2.308)	26.1	(0.180)	1.60	3
0	(-17.8)	155.0	(1.069)	103.9	(0.716)	53.5	73.3	385.7	(2.659)	26.0	(0.179)	1.60	3
-100	(-73.0)	177.6	(1.224)	122.7	(0.846)	52.7	69.0	425.6	(2.934)	26.2	(0.181)	1.62	3
-200	(-129.0)	200.2	(1.380)	145.8	(1.005)	51.3	62.3	423.3	(2.918)	27.7	(0.191)	1.60	3
-320	(-196.0)	250.0	(1.724)	201.3	(1.388)	7.8	8.1	—	—	23.4	(0.196)	1.20	3
-423	(-252.8)	292.2	(2.015)	258.9	(1.785)	2.2	5.1	—	—	29.3	(0.202)	0.53	3

* Average Stress Concentration Factor $K_t = 5.8$

TABLE III

LOW TEMPERATURE IMPACT ENERGY OF NITRONIC 32 STAINLESS STEEL
CHARPY V-NOTCHED IMPACT SPECIMENS PER FEDERAL TEST METHOD STD. NO. 151
MACHINED FROM A 1.00 - INCH (2.54 CM) DIAMETER BAR

Test Temperature °F	(°C)	Charpy V-Notched Impact Energy Ft - Lbs	(Joules)
		180.0	244.0
75	(+23.9)	132.0	179.0
		141.0	191.2
		167.0	226.4
	Avg.	155.0	210.1
0	(-17.8)	108.5	147.1
		110.0	149.1
		114.5	155.2
		138.0	187.1
		156.0	211.5
	Avg.	125.4	170.0
-100	(-73.0)	70.5	95.6
		71.0	96.3
		85.5	115.9
		89.5	121.3
	Avg.	79.1	107.2
-200	(-129.0)	35.0	47.4
		38.0	51.5
		46.0	62.4
		46.5	63.0
	Avg.	41.4	56.1
-320	(-196.0)	16.0	21.7
		18.5	25.1
		21.0	28.5
		25.0	33.9
	Avg.	20.1	27.3

TABLE IV

MECHANICAL PROPERTIES OF NITRONIC 32 STAINLESS STEEL LONGITUDINAL TENSILE SPECIMENS
0.1250 INCH (0.3175 CM) DIAMETER - MACHINED FROM A 1.00 INCH (2.54 CM) DIA. HOT ROLLED AND CENTERLESS GROUND BAR
(STRESSED AND EXPOSED TO CORROSIVE ENVIRONMENTS FOR 180 DAYS)

Applied Stress Percent of Yield Strength	Ultimate Tensile Strength KSI	Ultimate Tensile Strength (GN/m^2)	0.2% Offset Yield Strength KSI	0.2% Offset Yield Strength (GN/m^2)	Elongation 0.5-In. (1.27 cm) 4D%	Reduction of Area %	Fracture Strength KSI	Fracture Strength (GN/m^2)	Modulus $X10^{-6}$ PSI	Modulus $X10^{-6}$ (GN/m^2)	Number of Tests
As Received Mechanical Properties[1]											
0	152.6	(1.052)	108.4	(0.747)	46.5	74.2	389.9	(2.688)	27.7	(0.191)	8
Alternate Immersion - 3.5 Percent NaCl Bath 80°F (27°C)											
0	156.7	(1.080)	118.6	(0.818)	43.0	74.4	400.5	(2.761)	28.0	(0.193)	4
75	155.6	(1.073)	119.8	(0.826)	43.2	74.2	397.6	(2.741)	28.3	(0.195)	4
90	155.2	(1.070)	123.0	(0.848)	43.0	74.8	399.1	(2.752)	28.8	(0.197)	4
Salt Spray Cabinet 95°F (35°C)											
0	154.5	(1.065)	115.6	(0.797)	43.2	72.8	395.5	(2.727)	28.0	(0.193)	4
75	149.6	(1.031)	107.6	(0.742)	48.2	74.8	400.5	(2.761)	28.3	(0.195)	4
90	157.0	(1.082)	127.6	(0.880)	41.9	72.8	388.9	(2.681)	28.7	(0.198)	4
Humidity Cabinet 95°F (35°C) 98% R.H.											
0	158.5	(1.093)	123.3	(0.850)	40.7	74.7	408.2	(2.814)	28.8	(0.197)	4
75	148.9	(1.027)	107.1	(0.738)	45.5	73.0	387.2	(2.670)	28.5	(0.196)	4
90	152.0	(1.048)	116.7	(0.805)	45.0	75.3	398.6	(2.748)	28.0	(0.193)	4

Armco Heat No. 536480

[1]As Received Mechanical Property determination made on 0% Stressed and 0% Exposed Specimens.

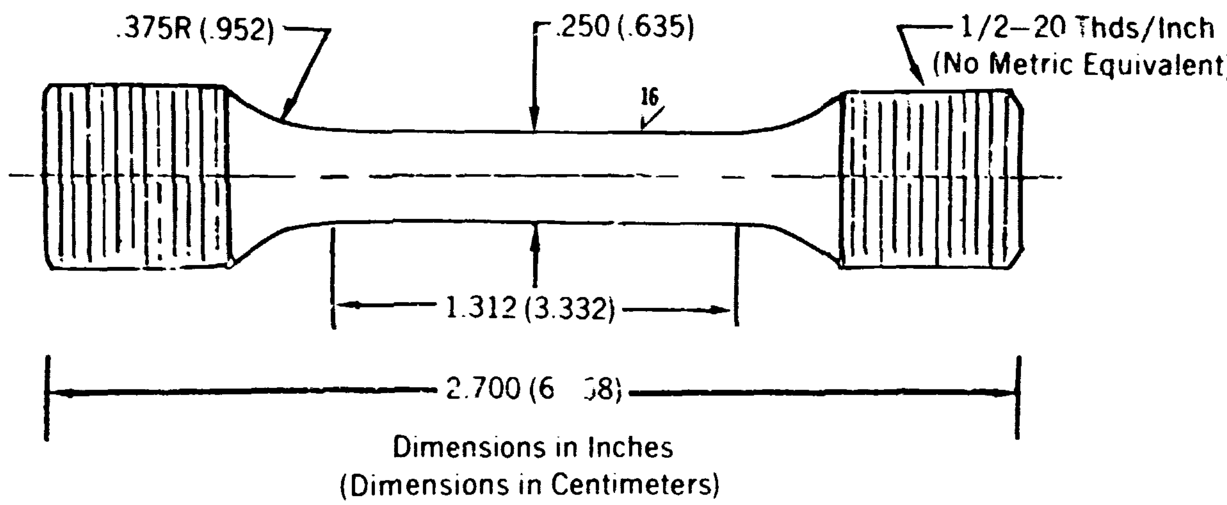


FIGURE 1A · SMOOTH TENSILE SPECIMEN CONFIGURATION

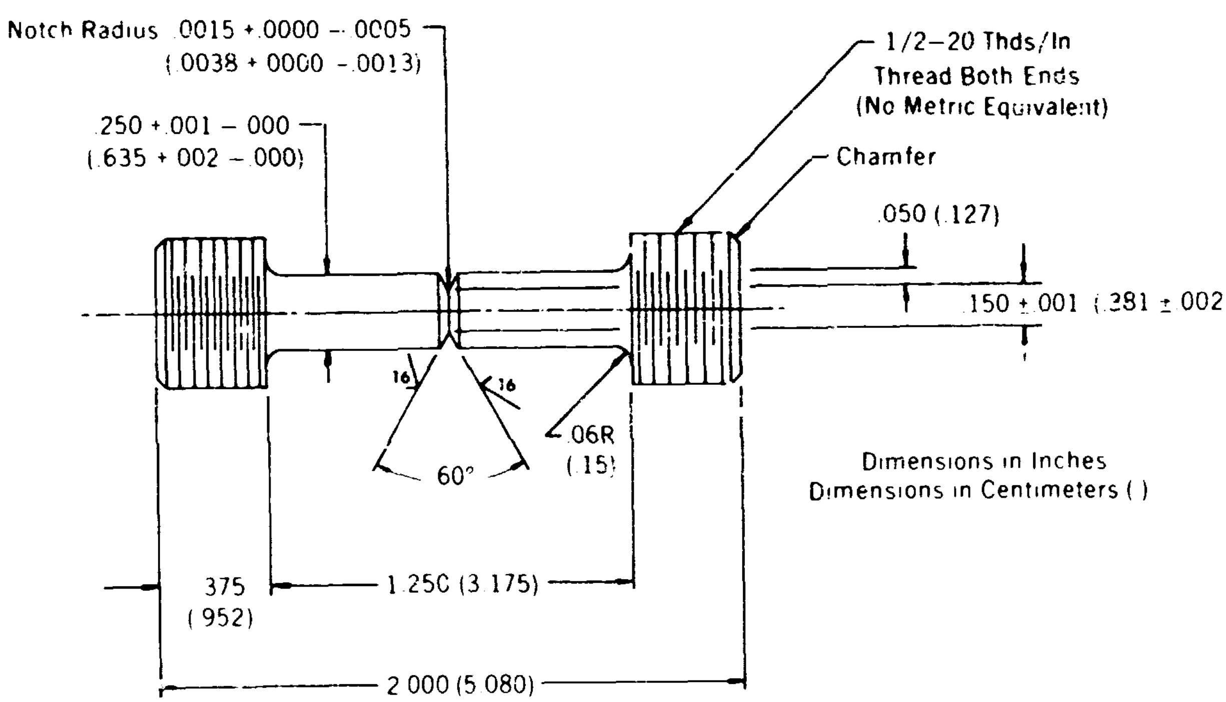


FIGURE 1B · V–NOTCHED TENSILE SPECIMEN CONFIGURATION

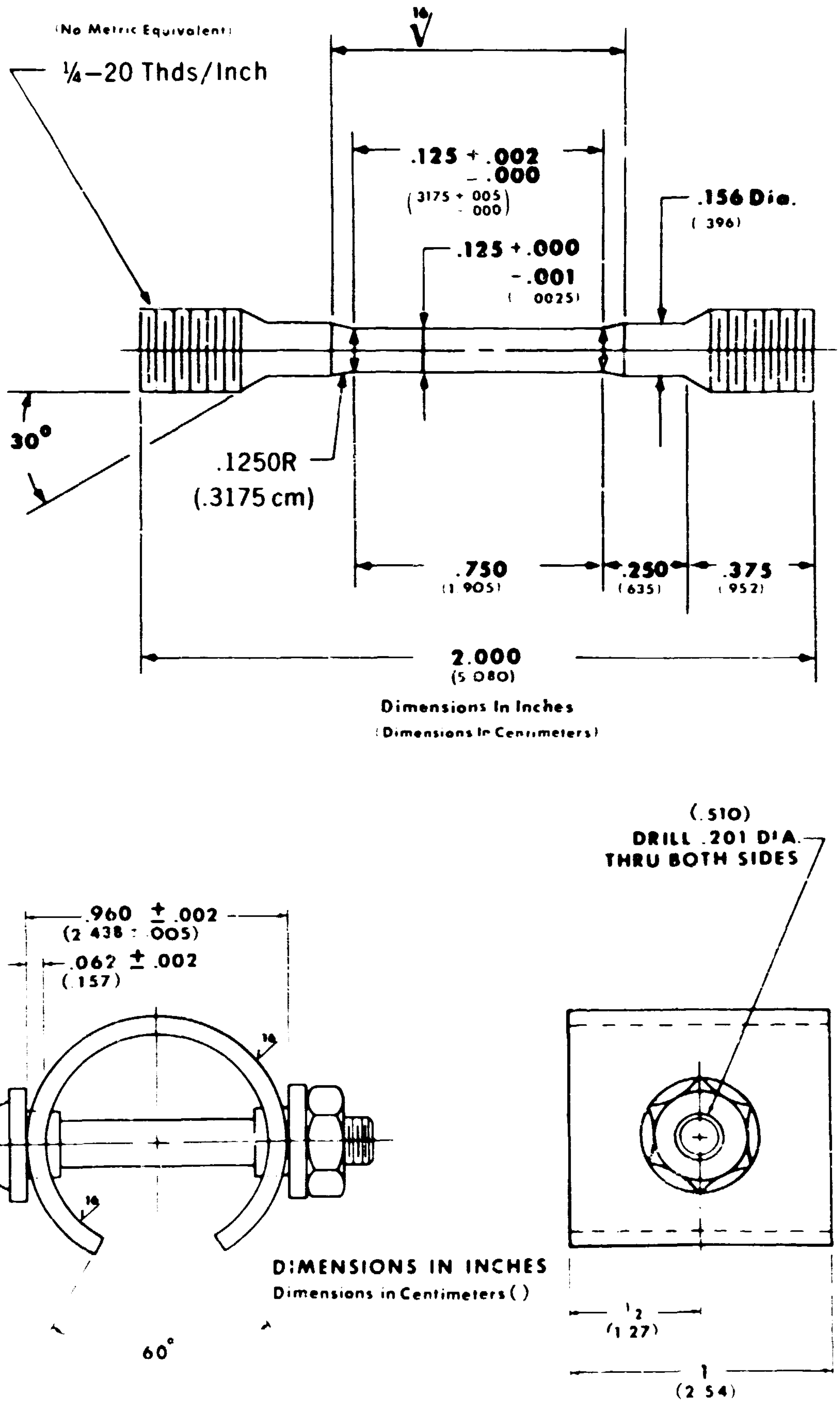


FIGURE 1C - STRESS CORROSION TEST SPECIMEN CONFIGURATIONS

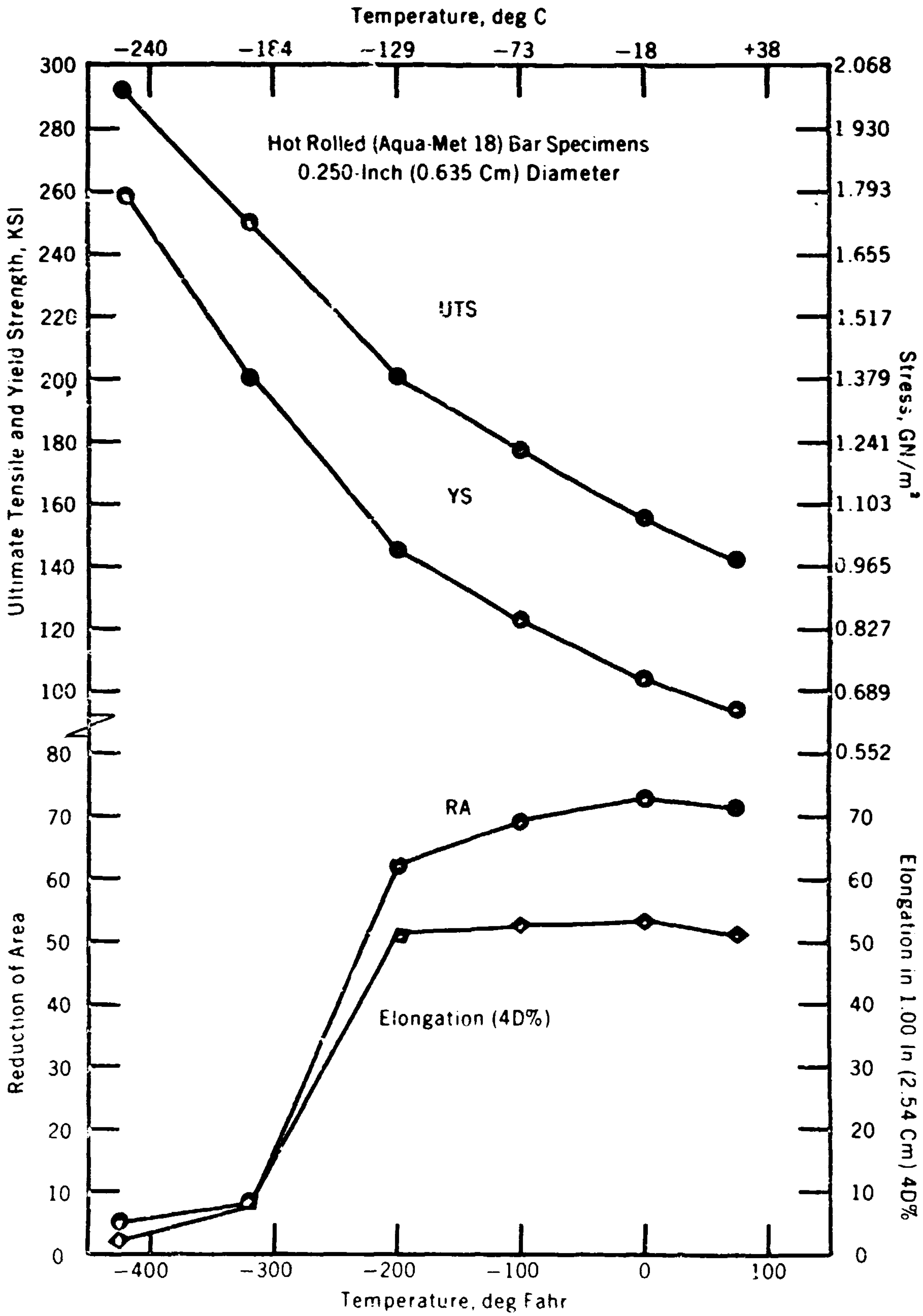


FIGURE 2 - LOW TEMPERATURE MECHANICAL PROPERTIES OF HOT ROLLED NITRONIC 32 STAINLESS STEEL SPECIMENS MACHINED FROM A 1.00 INCH (2.54 CM) DIAMETER BAR

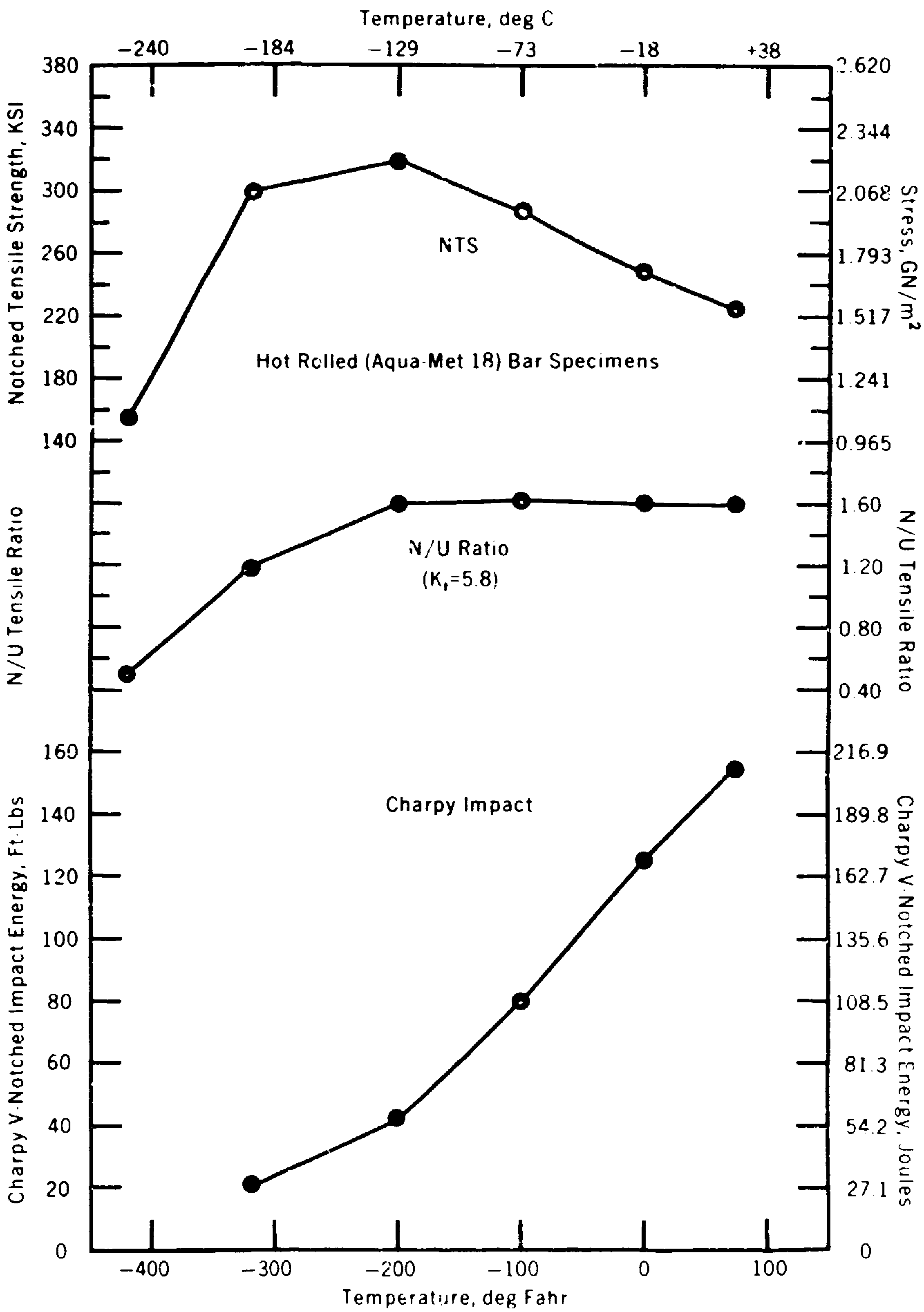
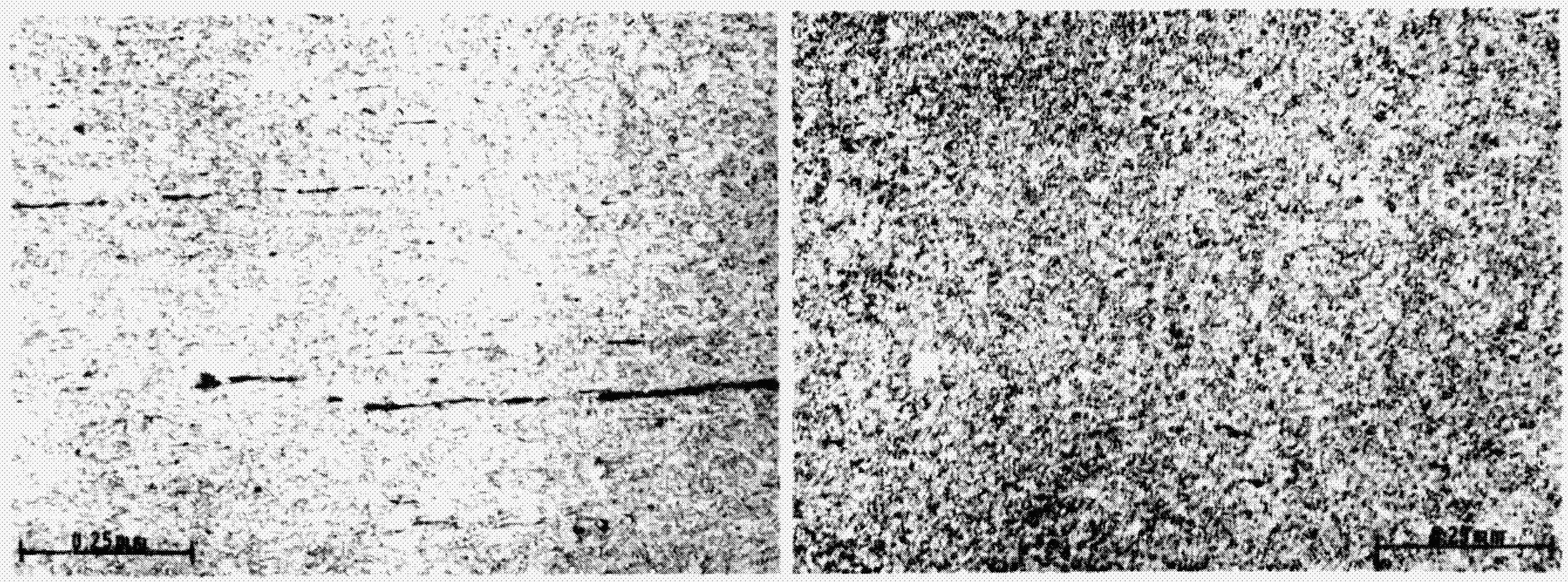


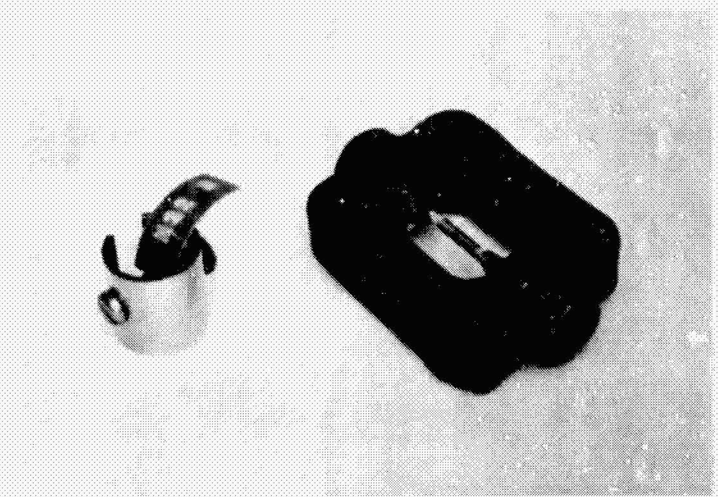
FIGURE 3 - LOW TEMPERATURE NOTCHED PROPERTIES OF HOT ROLLED NITRONIC 32 STAINLESS STEEL BAR SPECIMENS



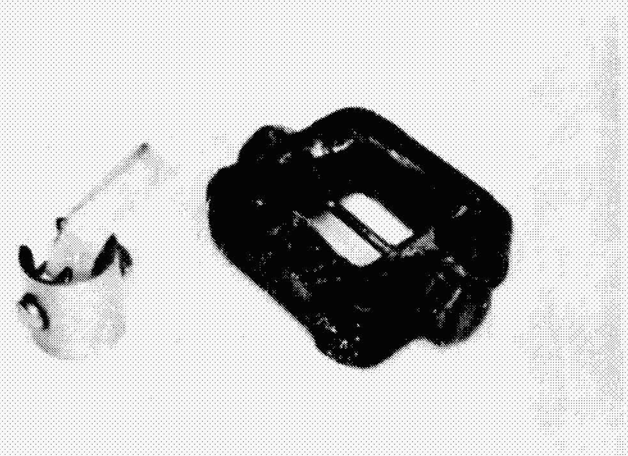
Longitudinal   Transverse

FIGURE 4 - MICROSTRUCTURE OF NITRONIC 32 STAINLESS STEEL ALLOY

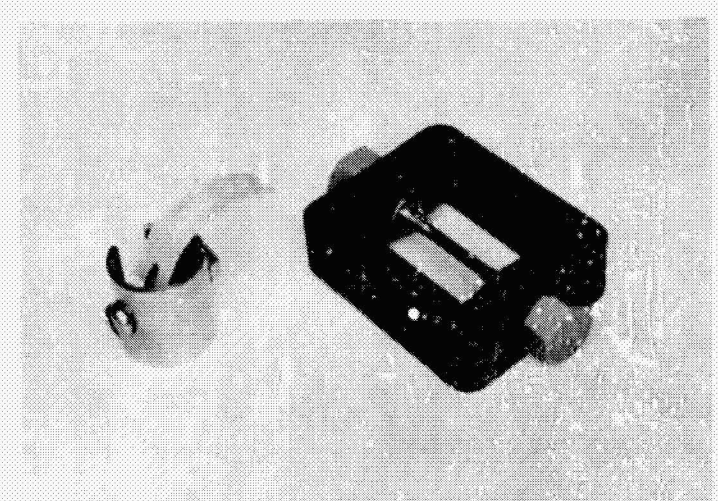
Etchant : Mixed Acids in Glycerol   Original Mag 100X



(A)

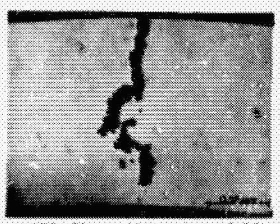


(B)

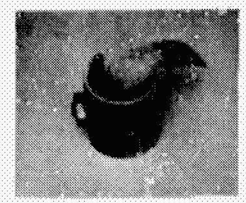


(C)

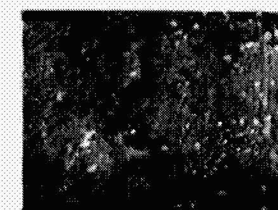
FIGURE 5 - NITRONIC 32 STAINLESS STEEL STRESS CORROSION SPECIMENS STRESSED TO 90% OF YIELD STRENGTH EXPOSED FOR 180 DAYS TO (A) ALTERNATE IMMERSION, (B) SALT SPRAY, (C) HUMIDITY ENVIRONMENTS



UNETCHED ORIGINAL MAG 50X



STRESSED TO 75% OF YIELD STRENGTH



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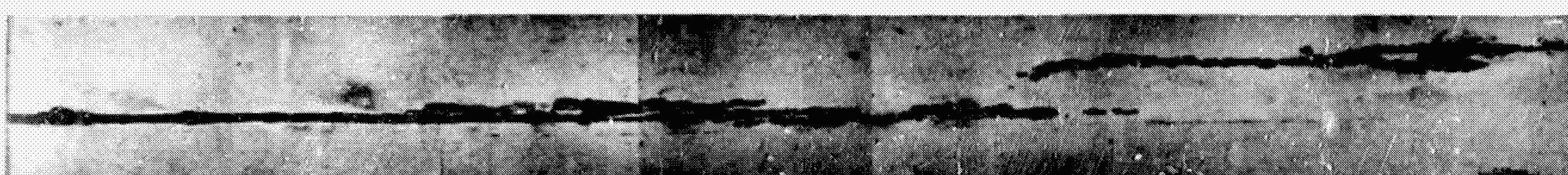

ETCHANT: MIXED ACIDS IN GLYCEROL

ORIGINAL MAG 50X

FIGURE 6 - NITRONIC 32 STAINLESS STEEL CRACKED 'C'-RING AND MICROSTRUCTURE AFTER 180 DAYS OF SALT SPRAY

APPROVAL

THE STRESS CORROSION RESISTANCE AND THE CRYOGENIC TEMPERATURE MECHANICAL PROPERTIES OF HOT ROLLED NITRONIC 32 BAR MATERIAL

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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