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A MECHANICAL PROPERTY AND STRESS CORROSION EVALUATION OF MP 35N MULTIPHASE ALLOY

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Astronautics Laboratory

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16. ABSTRACT

This report presents the mechanical properties of solution treated, work strengthened, and age hardened, MP35N Multiphase alloy bar stock manufactured by the Latrobe Steel Company under license from the Standard Pressed Steel Company. Test specimens manufactured from approximately 1.0 inch (2.54 cm) diameter bar stock were tested at temperatures of 75°F (23.9°C) to -423°F (-253°C). The test data indicated excellent tensile strength, ductility, and impact properties.

Results of the alternate immersion stress corrosion tests on stressed and unstressed tensile specimens 0.125-inch (.3175 cm) diameter and transverse "C"-ring specimens machined from 1.0 inch (2.54 cm) diameter bar indicated that the material is unsusceptible to stress corrosion cracking when tested in 3.5 percent NaCl solution for 180 days.

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Alternate Immersion

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Photography

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Photography

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A MECHANICAL PROPERTY AND STRESS CORROSION EVALUATION OF MP35N MULTIPHASE ALLOY

SUMMARY

The mechanical properties of solution treated, worked strengthened, and age hardened, MP35N Multiphase bar stock were determined for the temperature range of 75°F (23.9°C) to -423°F (-252.8°C). The ultimate tensile and yield strengths of the material increased with decreasing temperatures, as did the elongation values. The percent reduction in area changed very little with decreasing temperature to -200°F (-129°C) and then gradually decreased in value to liquid hydrogen temperature.

Results of the alternate immersion stress corrosion tests on stressed and unstressed longitudinal tensile specimens [0.125-inch (.3175 cm) diameter] and transverse "C"-ring specimens machined from approximately 1.0 inch (2.54 cm) diameter bar indicated that the material is unsusceptible to stress corrosion cracking when tested in a 3.5 percent NaCl solution for 180 days.

INTRODUCTION

MP35N is a relatively new alloy belonging to a family called Multiphase. These alloys were originally developed by E. I. du Pont de Nemours and Company, Inc., and are now being manufactured by Latrobe Steel Company under license from the Standard Pressed Steel Company.

The metallurgy of the Multiphase alloy system is as unusual as its combination of high strength and corrosion resistance. MP35N with 35 percent nickel, 35 percent cobalt, 20 percent chromium and 10 percent molybdenum,is a comparatively simple composition, intentionally melted with the minimum amount of carbon and other elements commonly added to most engineering alloys. The Multiphase alloys incorporate both phase transformation and aging reactions to attain their strength, even though iron, carbon, titanium and aluminum, usually associated with either martensite transformation or age hardening reactions, are only present as residual impurities. MP35N, as a simple quaternary alloy, can be strengthened to above 260,000 psi (1.793 GN/m^2) tensile strength with good ductility, by combining a phase transformation that is induced with cold work and an aging reaction. Because both of these strengthening reactions are dependent only on the interfactions of Ni, Co, Cr, and Mo, MP35N has a unique combination of mechanical strength, physical properties, corrosion and stress corrosion resistance (Ref. 1).

The Materials Division of MSFC, Astronautics Laboratory, in a continuing search for new and stronger alloys with resistance to stress corrosion cracking and desirable low temperature properties, performed an evaluation of MP35N Multiphase alloy.

The Standard Pressed Steel Company (SPS) furnished the Materials Division with ten feet of one-inch diameter MP35N Multiphase alloy for evaluation purposes.

The bar, provided by Latrobe Steel Company, at the SPS Company's request, was in the solution treated, work strengthened and centerless ground condition, capable of meeting 265 ksi minimum ultimate tensile strength after aging at 1100°F (593°C) for four hours and air cooling. Under contract from MSFC, the SPS Company machined the bar into test specimens, completed the aging treatment, aged at 1200°F (650°C) and returned the specimens to MSFC for evaluation testing.

EQUIPMENT AND TEST SPECIMENS

The equipment used in this evaluation is described in reports by Miller (Ref. 2) and Williamson (Ref. 3). Test specimen configurations appear in Figures 1A and 1B and the chemical composition of the test material is shown in Table I.

Longitudinal tensile specimens [0.125-inch (.3175 cm) diameter], and [0.250-inch (.635 cm) diameter], longitudinal V-notched tensile specimens (Kt=5.5), transverse "C"-ring specimens [1.00-inch (2.54 cm) diameter], and charpy V-notched impact specimens (Per Federal Standard 151) were machined from the solution treated and 49 percent work strengthened bar stock. The specimens were age hardened at 1200°F (650°C) for 4 hours and air cooled. This aging treatment gave a more desirable ultimate tensile strength of approximately 280 ksi (1.930 GN/m^2) as compared to the 1100°F (593°C) aging treatment which would produce an approximate ultimate tensile strength of 300 ksi (2.068 GN/m^2).

The stressed "C"-ring specimens and the stressed tensile specimens are shown in Figures 2 and 3, respectively. The "C"-ring specimens stressed by the constant deflection method, explained in Appendix 1, were stressed in the transverse direction to 50, 75, and 100 percent of the 0.2 percent offset longitudinal yield strength. The tensile specimens were stressed to 0, 50, 75, and 100 percent of the 0.2 percent offset longitudinal yield strength. Both types of specimens were exposed to 180 days of alternate immersion (A.I.) testing (10 minutes in solution, 50 minutes above solution) in a 3.5 percent sodium chloride solution.

RESULTS AND DISCUSSION

The tensile test results of the ambient through cryogenic temperature mechanical properties evaluation are tabulated in Tables II and III and these properties are plotted in Figures 4-6.

Table II contains test data on 0.250-inch (0.635 cm) diameter specimens. The 0.2 percent offset yield load was acquired by use of a low temperature extensometer. Table III contains test data on 0.125-inch (0.3175 cm) diameter specimens which were tensile tested utilizing a deflectometer to record the yield load. The deflectometer, which was attached to the crosshead of the testing machine, measured not only the strain in the test specimen but also the adjustment in the mechanical linkage of the test set-up. The cryogenic extensometer produced an appreciably higher yield load because it functioned to record strain only in the active gage portion of the specimen.

Table IV contains charpy V-notched impact test data. These low temperature tests utilized a special cover for the impact tester specimen holder, which enabled the specimen to be cooled down to the test temperatures of -100°F (-73.0°C), and -200°F (-129.0°C) with liquid nitrogen (LN_2) vapor. The test set-up also utilized a recorder-controller actuated by a thermocouple attached to the V-notch in the test specimen. A second thermocouple was also attached to the V-notch and potentiometer readings were made for temperature accuracy checks. For LN_2 temperatures the specimens were pre-soaked in LN_2, prior to testing, and the test specimen holder was pre-cooled with LN_2. For the lowest test temperature, between liquid helium and LN_2 temperatures, the impact specimens and the test fixture specimen holder were pre-cooled with LN_2 and liquid helium was sprayed directly on the test specimen, cooling it to approximately liquid hydrogen temperature.

For comparison purposes, the low temperature mechanical properties of MP35N Multiphase alloy and high strength A-286 alloy are plotted in Figure 6. The MP35N alloy, which was cold worked 49 percent prior to aging, has a distinct advantage in ultimate tensile and yield strength over the high strength A-286 alloy which had a minimum of 40 percent cold work prior to aging. The A-286 alloy has a slight advantage in elongation properties; however, its reduction in area is approximately identical to the MP35N alloy. Additional data on the properties of cold worked A-286 alloy are contained in Reference 4.

There were no failures in the alternate immersion tensile or "C"-ring specimens indicating excellent resistance to stress corrosion cracking under the test conditions of this program. Tensile test performed on the stress corrosion test specimens, after 180 days of alternate immersion exposure, are tabulated in Table V. These test data indicate no degradation of mechanical properties.

The microstructure of the test material illustrated in Figures 7 and 8, indicates the effects of cold work. The MP35N alloy is difficult to etch when it is in the cold worked and aged condition. Electrolytic etching techniques and swabbing or immersion techniques utilizing various etchants were employed to bring out the grain structure. Microhardness readings indicated a hardness of Rockwell C-50 (converted from DPH).

Fractographs taken at 3150X magnification were made on smooth and V-notched tensile specimens and charpy V-notched impact specimens of MP35N alloy tested at temperatures from ambient to liquid hydrogen temperature. These fractographs illustrated in Figures 9-11 illustrate the ductility of the alloy at all testing temperatures employed in this evaluation.

CONCLUSIONS

Based upon the results of this evaluation, MP35N Multiphase alloy (solution treated, work strengthened, and aged) properties such as ultimate tensile and yield strength and notched tensile strength are shown to increase with decreasing temperatures. Elongation values remain fairly constant while reduction in area, and charpy V-notched impact values decrease somewhat with decreasing temperature. However, these values are within acceptable limits when compared with other high strength materials used for cryogenic applications.

The stress corrosion resistance of MP35N Multiphase, as determined by alternate immersion testing in a 3.5 percent NaCl solution for 180 days, is not affected by work strengthening up to 49 percent reduction followed by a 1200°F (650°C) aging treatment, even when the material is stressed to 100 percent of the 0.2 percent offset longitudinal yield strength, prior to exposure.

This evaluation indicates that MP35N Multiphase alloy bar stock (solution treated, work strengthened, and aged) as tested in this program is suitable for cryogenic applications and is resistant to stress corrosion in a chloride environment.

For additional data on the mechanical and corrosion properties of MP35N Multiphase several other sources are listed in Appendix II.

REFERENCES

1. Latrobe Steel Company, MP35N Technical Data Book

2. Miller, P.C.: "Low Temperature Mechanical Properties of Several Aluminum Alloys and Their Weldments," MTP-S&M-M-61-16, October 1961.

3. Williamson; J. G.: "Stress Corrosion Studies of AM-355 Stainless Steel," NASA TMX-53317, August 1961.

4. Montano, J. W.: "A Mechanical and Stress Corrosion Property Evaluation of Cold Worked A-286 Alloy," NASA TMX-64569, February 1971.

Additional Sources of MP35N Multiphase Data are listed in Appendix II.

APPENDIX I

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:

$$OD_f = OD - \Delta$$

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

where
- Δ = Change of OD giving desired stress, inches
- f = Desired stress, psi
- OD = Outside diameter, inches
- t = Wall thickness, inches
- D = Mean diameter ($OD-t$), inches
- E = Modulus of elasticity
- Z = Constant (function of ring D/t)
- OD_f = Final outside diameter of stress "C"-ring, inches

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

APPENDIX II

ADDITIONAL SOURCES OF MP35N MULTIPHASE DATA

1. Battelle Memorial Institute
   Columbus, OH
   Mr. Omar Deal

   Test Data - Tensile - Fracture Toughness

2. Climax-Moly Research Lab.
   Ann Arbor, MI

   Test Data - Stress Corrosion and General Corrosion

3. Institut - Dr. Ing. Reinhard Stramann
   Waldenberg, Switzerland
   Mr. Pierre Marechal

   Test Data - Watch Spring Wire

4. International Nickel Company
   Pittsburgh PA
   Mr. Harry Weil

   Test Data - Corrosion Fatigue

5. Latrobe Steel Company
   Latrobe, PA
   Mr. Jerry Stalnaker - Marketing
   Mr. Jim Stroup - Product Researcher
   Mr. John Slaney - Research

   Test Data - Tensile testing study of cold drawing and aging characteristics

6. Maryland Specialty Wire, Inc.
   Cockeysville, MD
   Mr. Frank Rittenshouse - Vice President

   Test Data - Experience in Spring Wire Manufacturing Technique

7. Medtronics
   Minneapolis, MN
   Mr. Bod Krafska - Metallurgist

   Test Data - Fatigue and Corrosion tests to determine suitability for use in heart pacers

APPENDIX II (Continued)

8. Naval Research Laboratory
Washington, D.C.
Dr. Floyd Brown - Head-Physical Metallurgy Division - Wash. D.C.
Mr. F. R. Stonesifer - Ocean Tech. Division
Mr. H. L. Smith - Ocean Tech. Division
Mr. H. E. Romine - Naval Weapons Lab - Dahlgren, VA

<u>Test Data</u> - KI scc and KIc - Fracture Toughness Test in Sea Water

9. Standard Pressed Steel Company
Jenkintown, PA.
Mr. Ken Kulju - Applications Engineer
Mr. Thomas Roach - Research

<u>Test Data</u> - Tensile-Fatigue-Stress Corrosion-Thermal-cryogenic-material and fastener evaluation

10. Pratt & Whitney, Division of United Aircraft Company
West Palm Beach, FL
Mr. Buch Van Wanderham

<u>Test Data</u> - Tensile & Notched Tests in high pressure hydrogen

11. U. S. Steel - Research Laboratory
Monroeville, PA
Mr. Alex Loginaw
Mr. Nick Phelps

<u>Test Data</u> - Specific Corrosion Tests and Stress Corrosion Cracking Tests

12. Xylem
Minneapolis, MN
Mr. Russel Johnston, Sr.

<u>Test Data</u> - Fatigue and other tests on coiled springs

TABLE I

CHEMICAL COMPOSITION OF MP35N MULTIPHASE ALLOY BAR STOCK

Co	Ni	Cr	Fe	C	Si	Mn	S	P	O_2	N_2	Mo
*35.11	35.24	19.48	0.15	0.015	0.04	0.02	0.003	0.004	24 ppm	98 ppm	9.61
**34.79	35.25	19.57	0.15	0.014	0.06	0.003	0.003	0.003	-	-	9.86

* Latrobe Steel Company Analysis - Heat. No. 51010

** MSFC Analysis - Heat No. 51010

TABLE II

LOW TEMPERATURE MECHANICAL PROPERTIES OF MP35N MULTIPHASE TENSILE SPECIMENS
[.250-INCH (.635cm) DIAMETER] WORK STRENGTHENED 49 PERCENT AND AGED

Test Temp °F (°C)	U.T.S. ksi (GN/M^2)	.2% Offset Y.S. * ksi (GN/m^2)	Elongation 1.0 Inch (2.54cm) (4D%)	Reduction In Area (%)	Modulus X 10^{-6} psi (N/m^2)	N.T.S. Kt=5.5 ksi (GN/m^2)	N/U Ratio	No. of Tests
75 (+23.9)	279.3 (1.926)	274.1 (1.890)	9.8	46.8	34.8 (239.9)	356.5 (2.458)	1.28	3
0 (-17.8)	286.0 (1.972)	282.7 (1.949)	10.0	48.6	34.1 (234.4)	- -	-	1
-100 (-73.0)	300.6 (2.072)	295.9 (2.040)	10.0	45.0	34.4 (237.2)	413.1 (2.848)	1.37	2
-200 (-129.0)	314.3 (2.167)	308.0 (2.123)	10.3	46.6	35.5 (244.8)	446.5 (3.078)	1.42	3
-320 (-196.0)	336.7 (2.321)	326.5 (2.251)	11.0	39.5	35.6 (245.4)	478.7 (3.300)	1.42	3
-423 (-252.8)	359.8 (2.481)	344.3 (2.374)	11.8	36.1	36.8 (253.7)	501.4 (3.457)	1.39	3

* Yield Load Obtained by use of a Cryogenic Extensometer.

TABLE III

LOW TEMPERATURE MECHANICAL PROPERTIES OF MP35N MULTIPHASE TENSILE SPECIMENS [.125-INCH (.3175 cm) DIAMETER] WORK STRENGTHENED 49 PERCENT AND AGED

Test Temp °F (°C)	U.T.S. ksi (GN/m^2)	.2% Offset Y.S. * ksi (GN/m^2)	Elongation 1/2-Inch (1.27cm) (4D%)	Reduction In Area (%)	No. of Tests
75 (+23.9)	280.3 (1.933)	266.5 (1.837)	11.0	53.6	4
0 (-17.8)	296.2 (2.042)	275.2 (1.897)	9.5	52.2	4
-100 (-73.0)	313.3 (2.160)	284.5 (1.961)	11.2	52.0	4
-200 (-129.0)	320.1 (2.207)	295.5 (2.037)	12.0	48.6	4
-320 (-196.0)	352.5 (2.430)	317.5 (2.189)	12.8	43.6	4
-423 (-252.8)	376.6 (2.596)	336.8 (2.322)	9.2	42.6	5

* Yield Load Obtained by use of a Deflectometer.

TABLE IV

CHARPY V-NOTCHED IMPACT TEST DATA FOR COLD-WORKED MP35N BAR

Test Temp °F	(°C)	Average Impact Energy Ft-Lb	(Joules)	Impact Energy Range Ft-Lb	(Joules)	Number of Tests
75	(+23.9)	18.90	(25.62)	15.50-23.00	(21.01-31.18)	3
-100	(-73.0)	17.10	(23.18)	14.75-19.25	(20.00-26.10)	3
-200	(-129.0)	15.25	(20.68)	15.00-15.50	(20.34-21.01)	2
-320	(-196.0)	16.10	(21.83)	14.00-18.25	(18.98-24.74)	2
-423	(-252.8)	13.50	(18.30)	13.50-13.50	(18-30-18.30)	2

TABLE V

MECHANICAL PROPERTIES OF MP35N MULTIPHASE ALLOY LONGITUDINAL TENSILE SPECIMENS [.125-INCH (.3175 cm) DIAMETER] WORK STRENGTHENED 49 PERCENT, AGED, STRESSED AND EXPOSED TO ALTERNATE IMMERSION TESTING IN A 3.5 PERCENT NaCl BATH

Exposure Time Days	Applied Stress Percent of Yield Strength	U.T.S. ksi (GN/m^2)	.2% Offset Y.S. ksi (GN/m^2)	Elongation 1/2 Inch (1.27cm) (4D%)	Reduction In Area (%)	No. of Tests
0	0	280.3 (1.933)	266.5 (1.837)	11.0	53.6	4
180	0	284.7 (1.963)	268.7 (1.853)	10.3	54.0	4
180	50	284.4 (1.961)	270.6 (1.866)	11.3	51.9	4
180	75	281.2 (1.939)	264.4 (1.823)	11.0	52.7	3
180	100	281.4 (1.941)	273.2 (1.884)	11.0	53.3	4

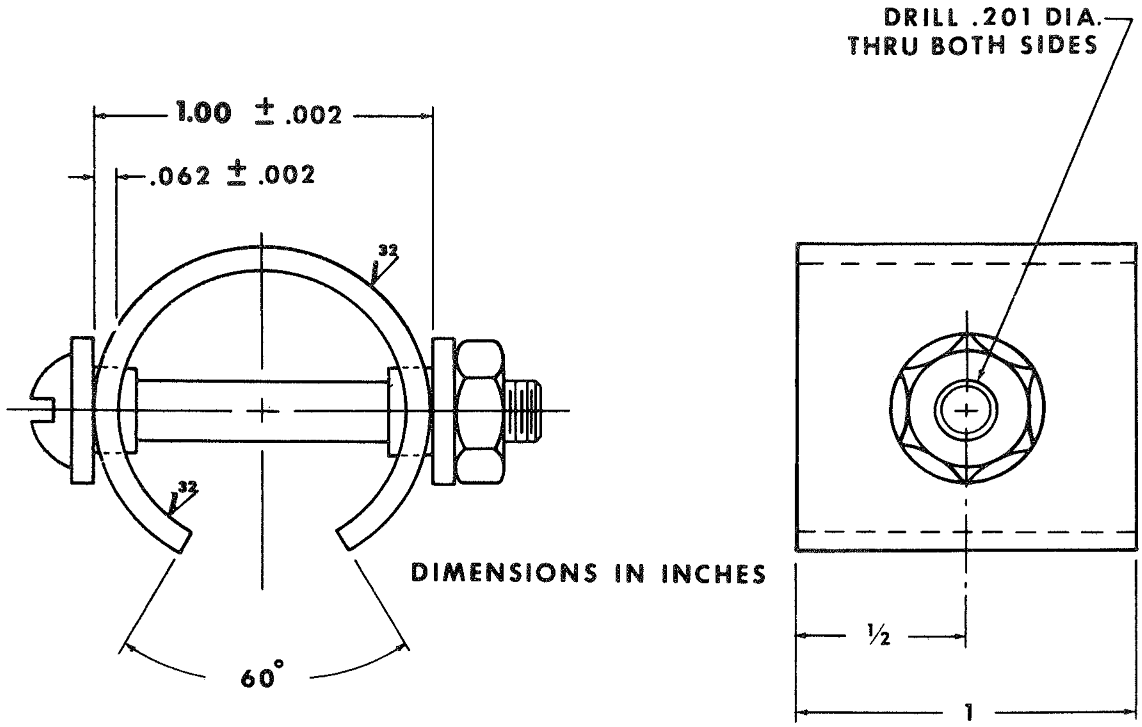


FIGURE 1B - STRESS CORROSION 'C' - RING SPECIMEN

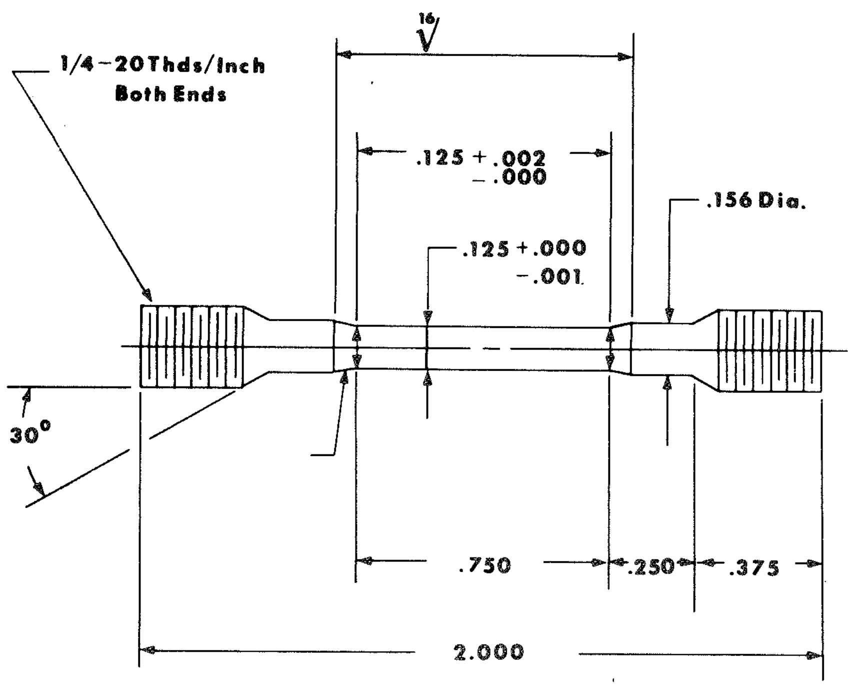
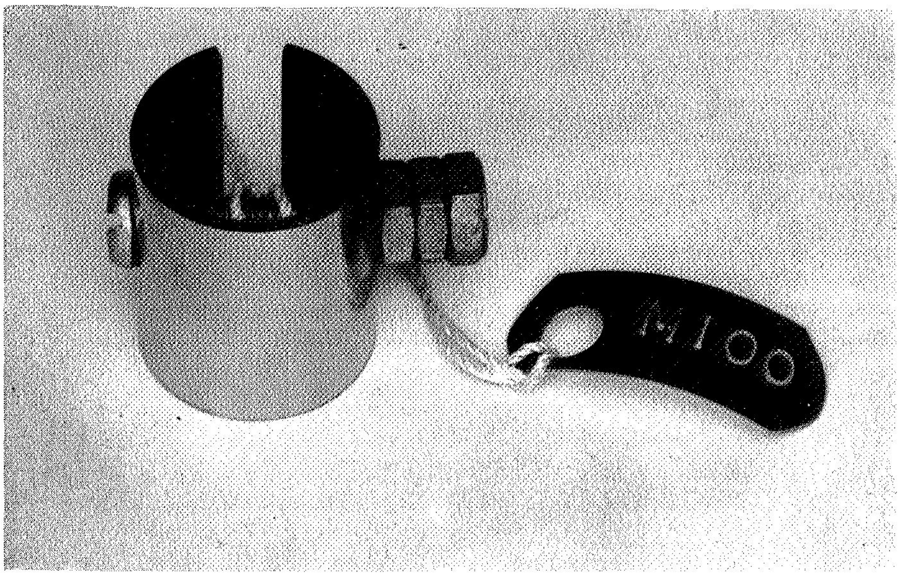
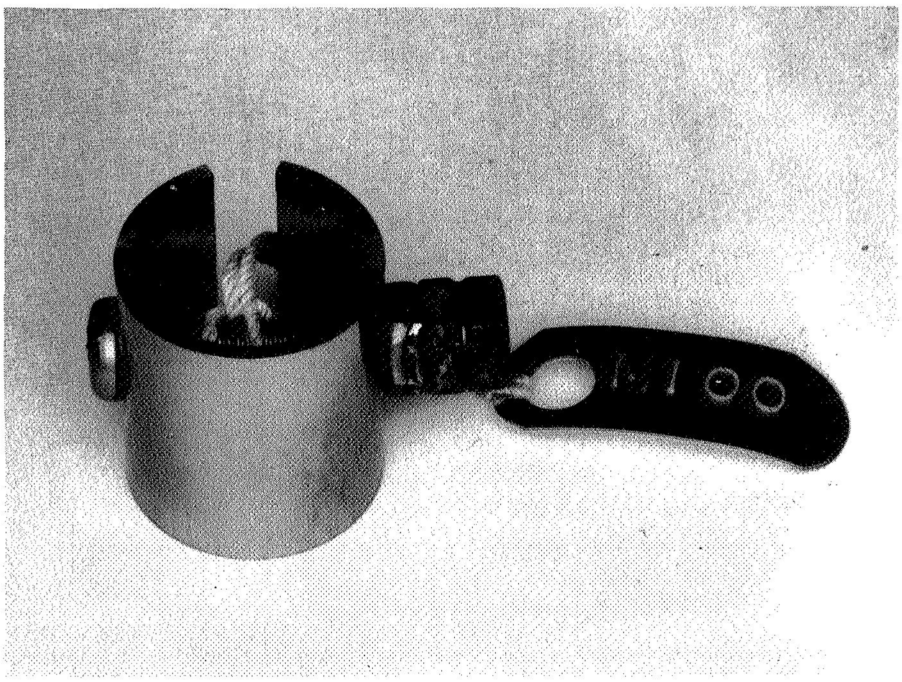


FIGURE 1A - STRESS CORROSION TENSILE SPECIMEN

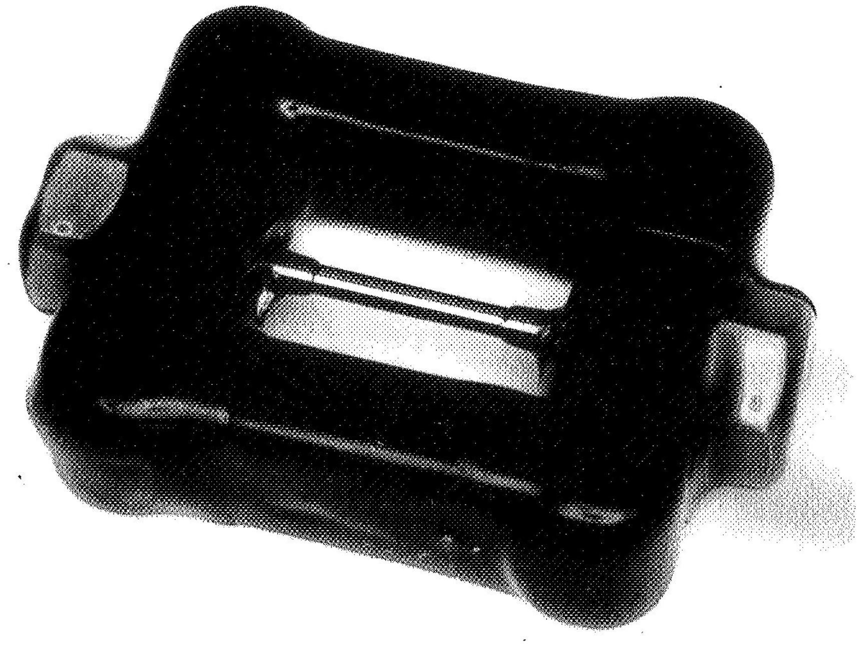


PRIOR TO TESTING

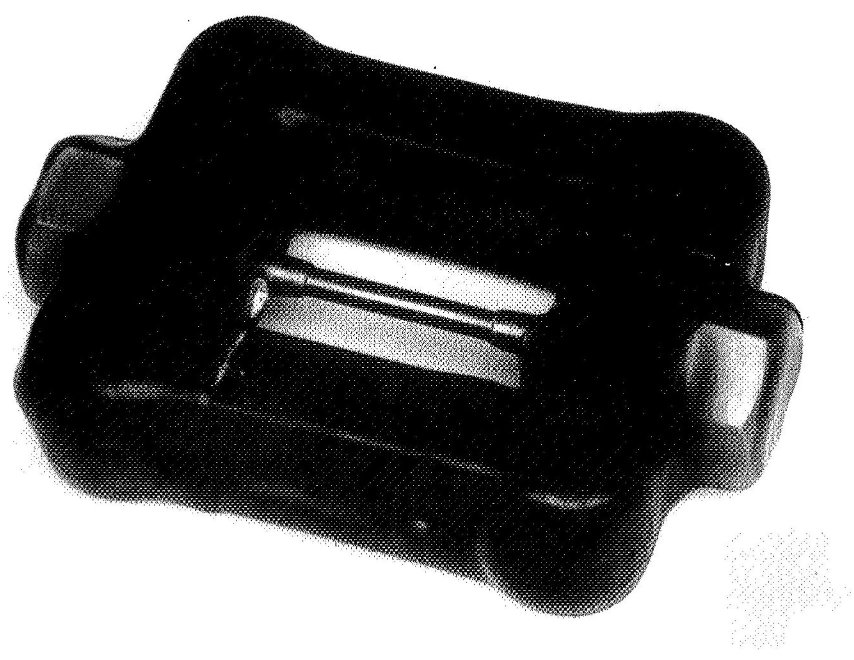


AFTER 180 DAY TEST

FIGURE 2 - MP-35N MULTIPHASE C-RING SPECIMEN M-100 STRESSED TO 100% OF YIELD STRENGTH



PRIOR TO TESTING



AFTER 180 DAY TEST

FIGURE 3 - MP-35N MULTIPHASE LONGITUDINAL TENSILE SPECIMEN STRESSED TO 100% OF YIELD STRENGTH

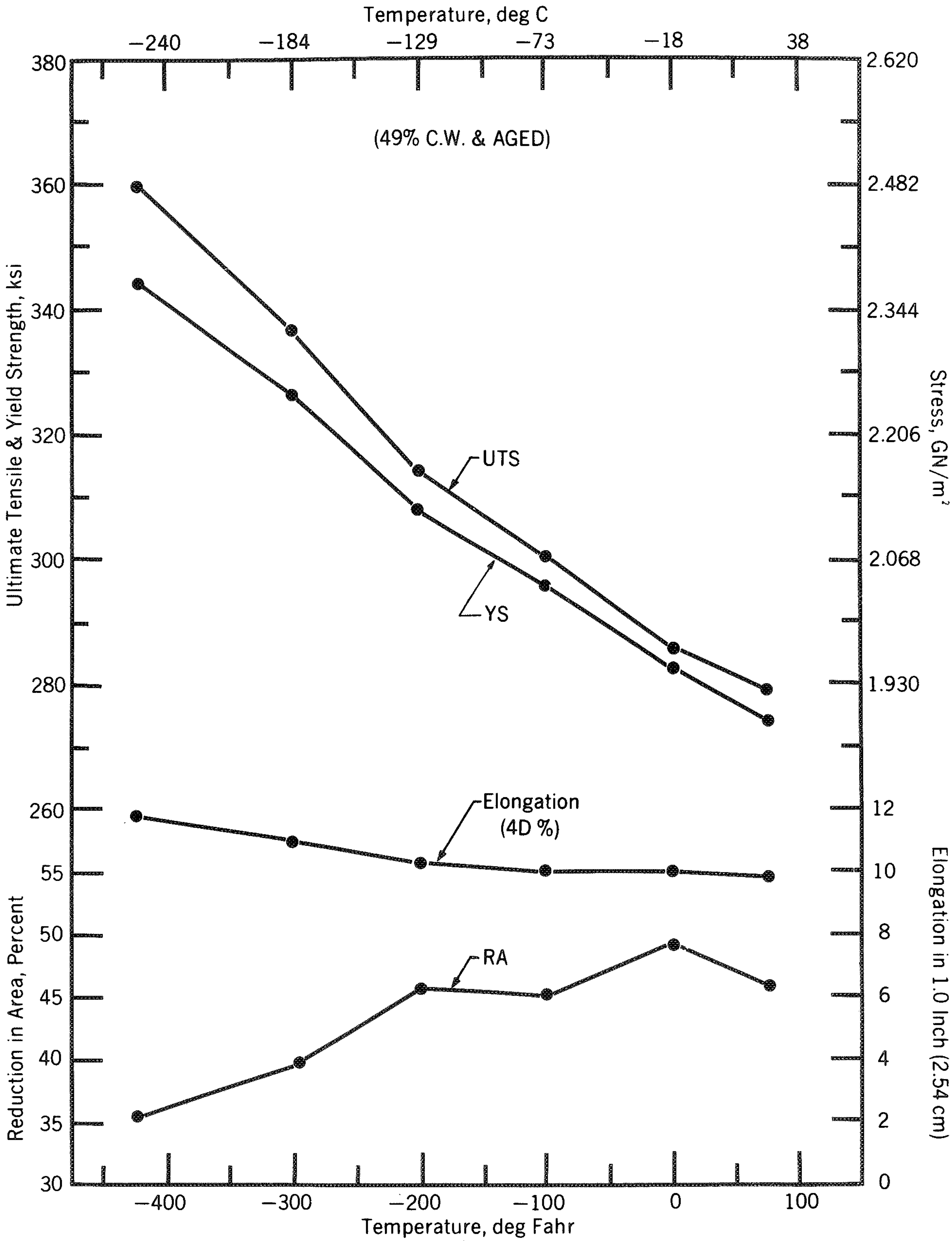


FIGURE 4 - LOW TEMPERATURE MECHANICAL PROPERTIES OF MP35N MULTIPHASE ALLOY LONGITUDINAL TENSILE SPECIMENS .250-INCH (.635 CM) DIAMETER

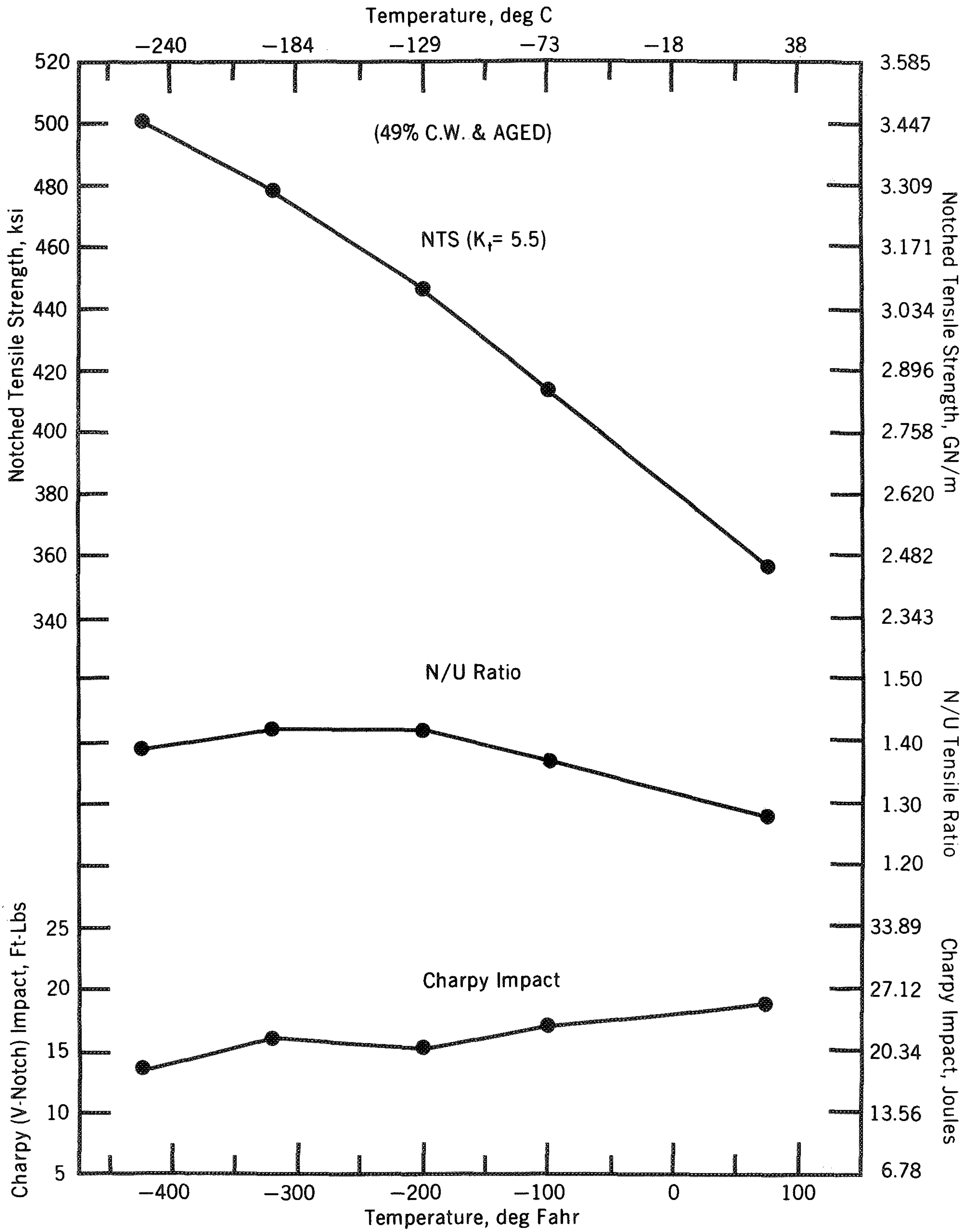


FIGURE 5 - LOW TEMPERATURE NOTCHED PROPERTIES OF MP35N MULTIPHASE ALLOY LONGITUDINAL TENSILE SPECIMENS AND CHARPY IMPACT SPECIMENS

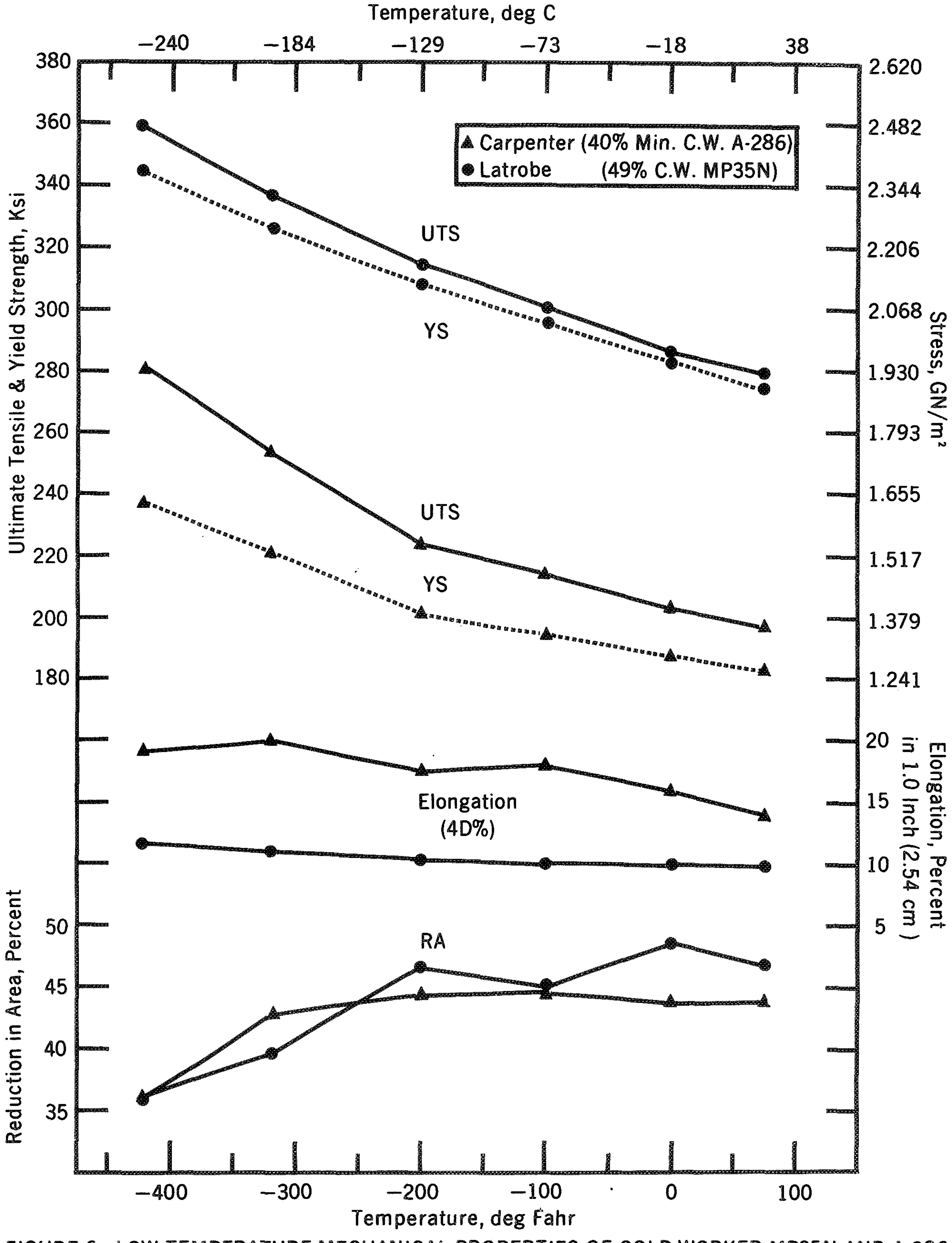


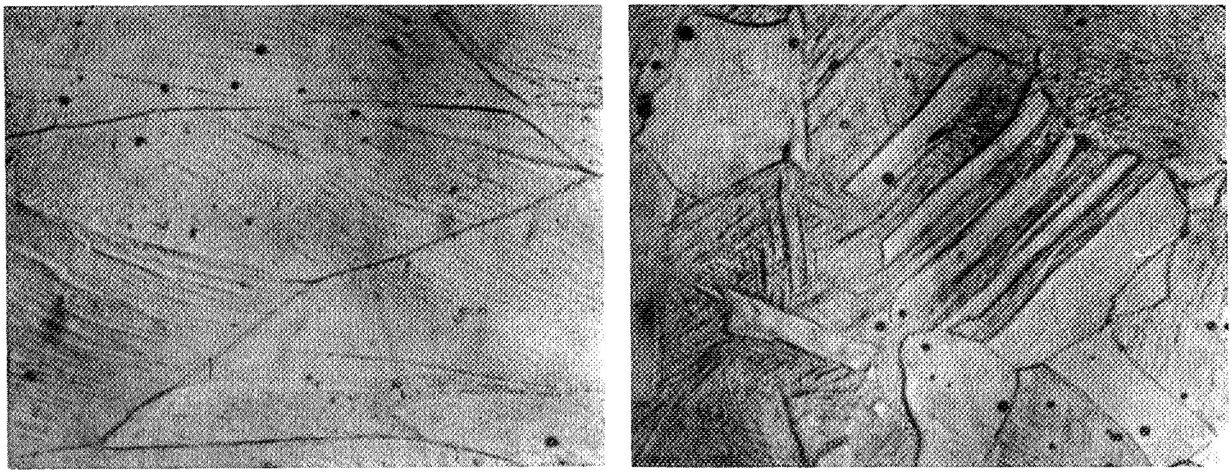
FIGURE 6 - LOW TEMPERATURE MECHANICAL PROPERTIES OF COLD WORKED MP35N AND A-286 LONGITUDINAL TENSILE SPECIMENS .250-INCH (.635 CM) DIAMETER

500 X LONGITUDINAL 1000 X

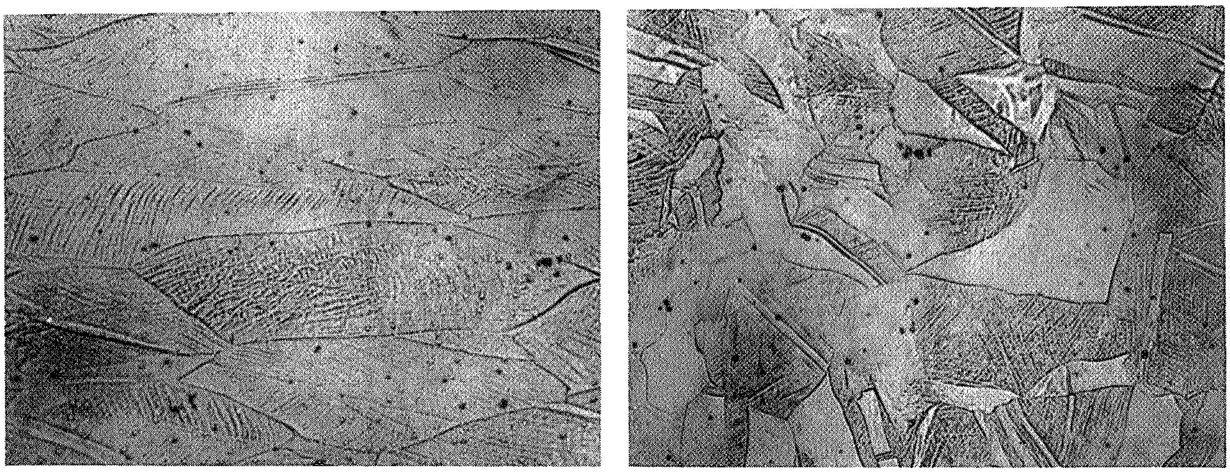
500 X TRANSVERSE 1000 X

FIGURE 7 - MICROSTRUCTURE OF MP35N MULTIPHASE ALLOY (49% C.W. & AGED)
1.0 - INCH DIAMETER BAR

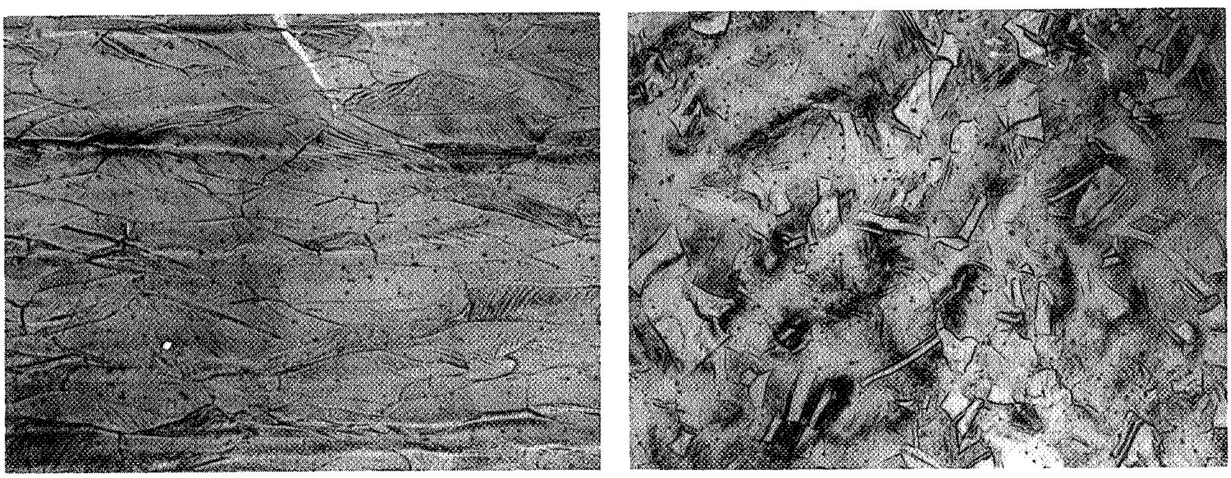
ELECTROLYTIC CHROMIC ACID ETCH



1000 X



500 X



LONGITUNAL 200 X TRANSVERSE

FIGURE 8 - MICROSTRUCTURE OF MP35N MULTIPHASE ALLOY (49% C.W. & AGED) 1.0-INCH DIAMETER BAR

92% HCL, 5% HNO_3, 3% HF-ETCH

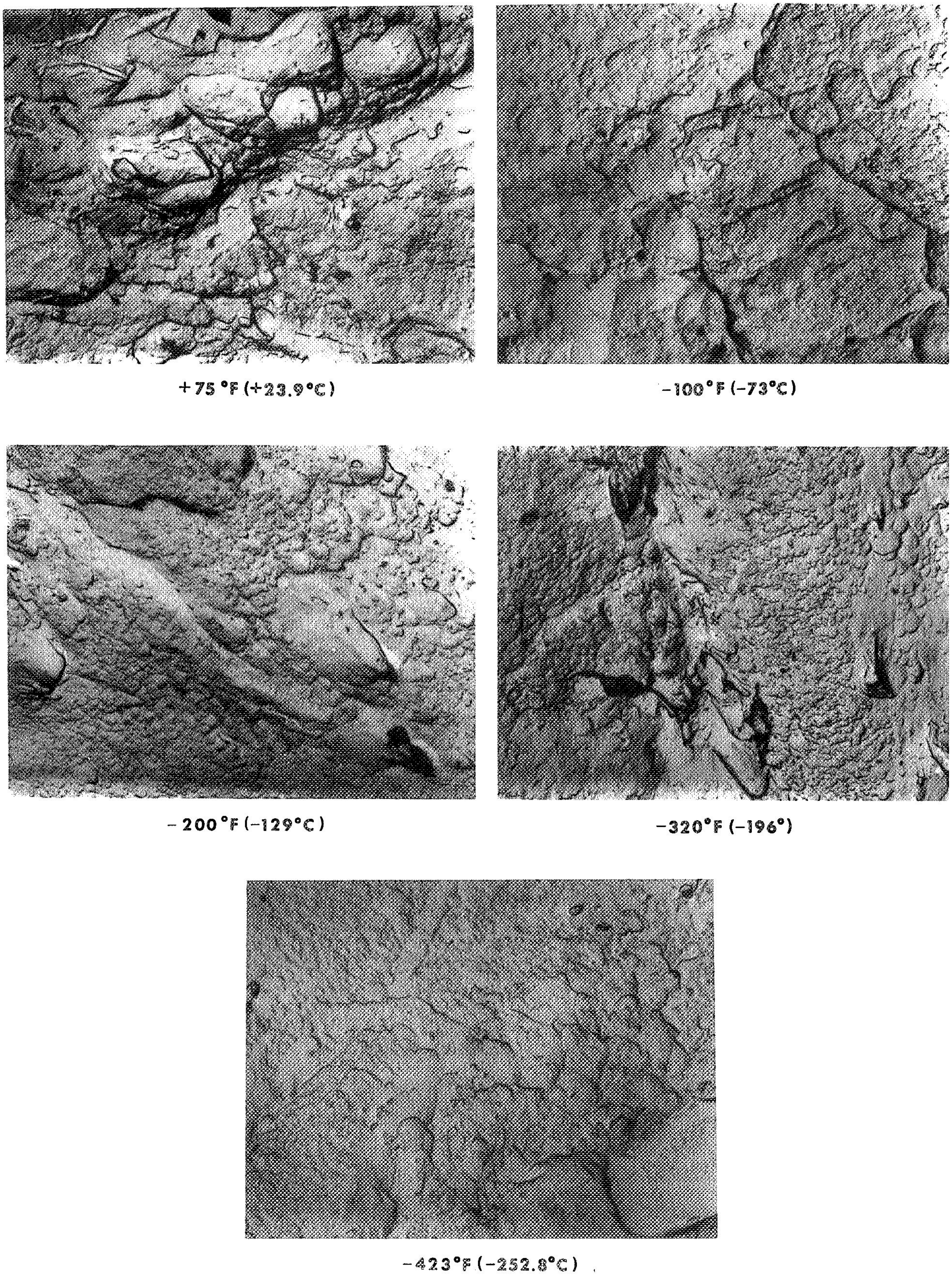
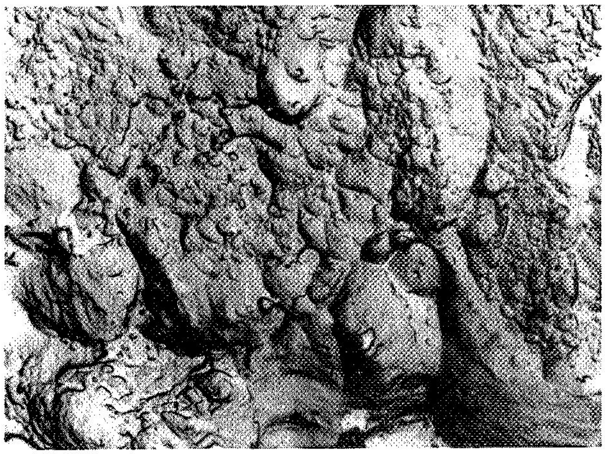
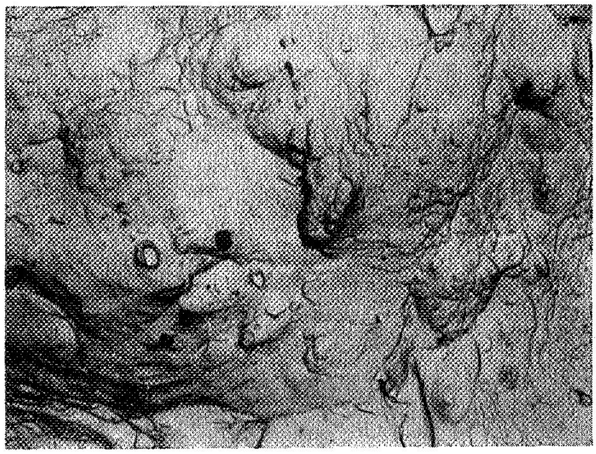


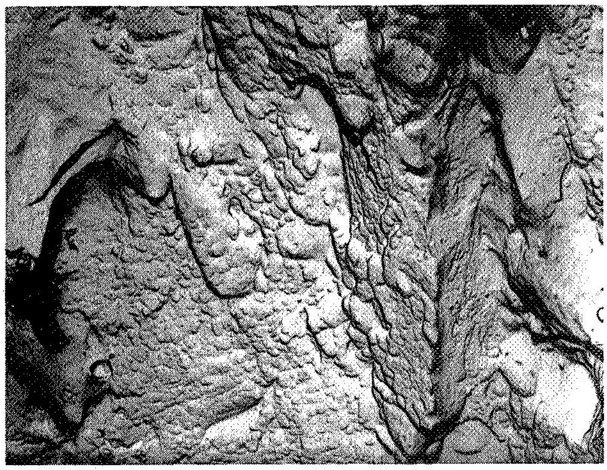
FIGURE 9 - FRACTOGRAPHS OF MP35N MULTIPHASE ALLOY (49% C.W. & AGED)
SMOOTH TENSILE FRACTURES 3150X Mag



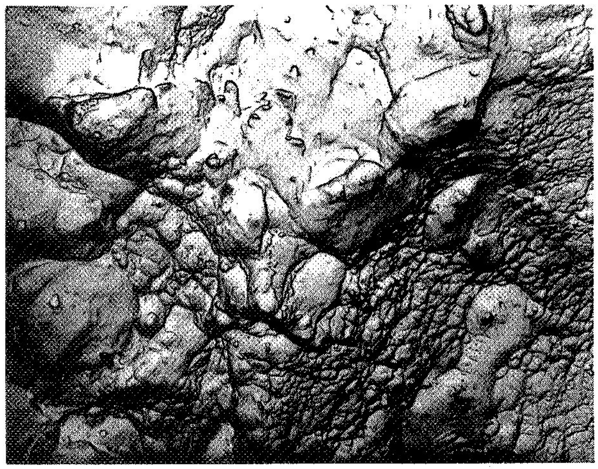
+75°F (+23.9°C)



-100°F (-73°C)



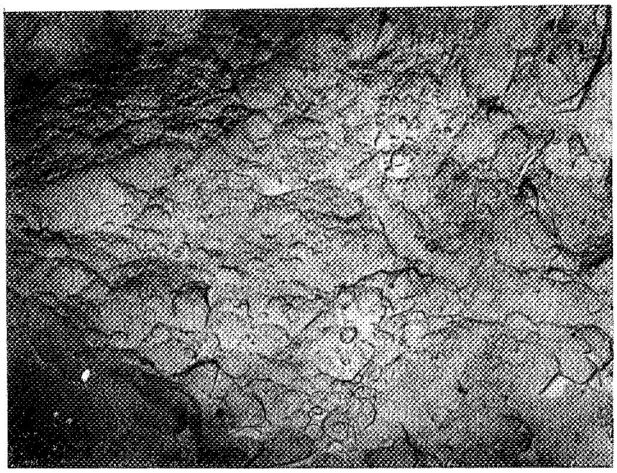
-200°F (-129°C)



-320°F (-196°C)

- 423°F (-252.8°C)

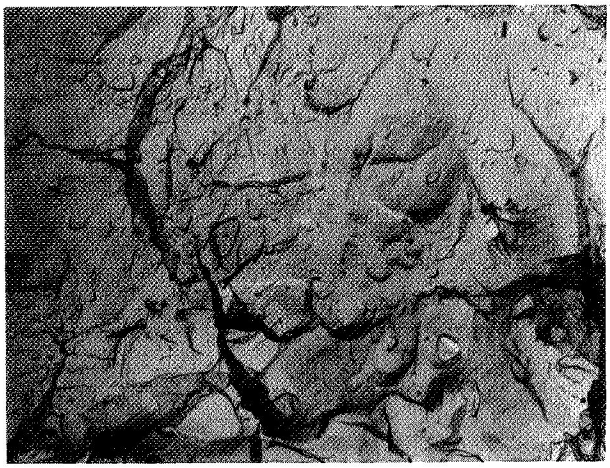
FIGURE 10 - FRACTOGRAPHS OF MP35N MULTIPHASE ALLOY (49% C.W. & AGED) TENSILE V-NOTCH SPECIMEN FRACTURES 3150X Mag



+75°F (+23.9°C)

-100°F (-73°C)

-200°F (-129°C)



320°F (-196°C)

-423°F (-252.8°C)

FIGURE 11 - FRACTOGRAPHS OF MP35N MULTIPHASE ALLOY (49% C.W. & AGED) CHARPY V-NOTCHED IMPACT SPECIMEN FRACTURES 3150X Mag

APPROVAL

A MECHANICAL PROPERTY AND STRESS CORROSION EVALUATION
OF MP35N MULTIPHASE ALLOY

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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