NASA
Technical
Paper
2634

September 1986

A Mechanical Property and Stress Corrosion Evaluation of VIM-ESR-VAR Work Strengthened and Direct Double Aged Inconel 718 Bar Material

J. W. Montano

(NASA-TP-2634) A MECHANICAL PROPERTY AND STRESS CORROSION EVALUATION OF VIM-ESR-VAR WORK STRENGTHENED AND DIRECT DOUBLE AGED INCONEL 718 BAR MATERIAL (NASA) 37 p CSCL 11F H1/15

N86-30753

Unclas
43487

NASA

NASA
Technical
Paper
2634

1986

A Mechanical Property and Stress Corrosion Evaluation of VIM-ESR-VAR Work Strengthened and Direct Double Aged Inconel 718 Bar Material

J. W. Montano

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

NASA

National Aeronautics
and Space Administration

Scientific and Technical
Information Branch

ACKNOWLEDGMENT

Mr. Ken Kohlstrom, Wyman Gordon – Sr. Product Metallurgist – Consultation and independent mechanical property evaluation.

Mr. Peter Rice, Wyman Gordon – Metallurgical Technician – Specimen blank layouts and bar sectioning.

Messrs. Carl Wood and Bill McMahan – NASA/MSFC-M&P Laboratory– Special Tables and Figures.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF ILLUSTRATIONS

TECHNICAL PAPER

A MECHANICAL PROPERTY AND STRESS CORROSION EVALUATION OF VIM-ESR-VAR WORK STRENGTHENED AND DIRECT DOUBLE AGED INCONEL 718 BAR MATERIAL

SUMMARY

This report presents the mechanical properties and the stress corrosion resistance of triple melted [vacuum induction melted (VIM), electroslag remelted (ESR), and vacuum arm remelted (VAR)] solution treated, work strengthened and direct double aged Inconel 718 alloy bars [4.00 in. (10.16 cm) and 5.75 in. (14.60 cm) diameter] processed by Wyman Gordon.

Tensile test data generated by the Marshall Space Flight Center's (MSFC) Materials and Processes Laboratory and by Wyman Gordon are tabulated for comparison purposes. Additional MSFC fracture toughness and charpy impact test data at ambient temperature and -100°F (–73°C) is also presented. There appears to be very little, if any, degradation in the material's toughness with decreasing temperature, within the limits of our testing program.

The work strengthened Inconel 718 alloy showed excellent resistance to stress corrosion as evidenced by the mechanical properties of stressed specimens after 180 days exposure to a salt fog environment.

INTRODUCTION

Inconel 718 is a nickel base austenitic precipitation hardenable alloy which was developed by the International Nickel Company in the late 1950's. The alloy possesses high strength, excellent corrosion resistance and is used over the temperature range of –423°F (–252.8°C) to +1300°F (704°F).

The alloy is currently being used in the solution treated and aged condition at Kennedy Space Center (KSC) for the solid rocket booster (SRB) holddown studs which are approximately 3.5 in. (8.9 cm) diameter and 31.5 in. (80.0 cm) length. The Inconel 718 alloy is also used as the mating frangible nuts on the holddown studs.

At MSFC the alloy has found use as high strength fasteners, limited to relatively small diameters due to cold working and hot heading restrictions. Large diameter bar material use has also been restricted to the solution treated and aged condition due to the limitation of cold work. The normal penalties associated with cold working are loss in reduction of area, loss in elongation, and increased grain size.

Our investigation indicates a breakthrough by Wyman Gordon in processing large diameter bars of Inconel 718 alloy. Their processing of 4.0 in. (10.16 cm) and 5.75 in. (14.60 cm) diameter bars has resulted in greatly increased yield strength, elongation, and reduction of area and a significant reduction in grain size.

A preliminary investigation was performed at MSFC's Materials and Processes Laboratory on moderately work strengthened and direct single and double aged material processed by Wyman Gordon. The results of that investigation are tentatively scheduled for publication at a later date. This preliminary investigation indicated that large diameter material could be work strengthened without the loss of ductility or elongation or increase in grain size. The investigation also proved the alloy's excellent resistance to stress corrosion cracking in a chloride environment is not impaired by work strengthening.

Based on the test data generated by Wyman Gordon and MSFC, the solution treated work strengthened and direct aged material is being used at KSC in the Biach Industries tensioner which applies the tension load to the SRB holddown studs. This application is reported in the January 1986 *Metals Progress* – "86 Technology Forecast for Superalloys." Biach Industries has also supplied Vandenberg Air Force Base with tensioners for SRB holddown application.

EQUIPMENT AND TEST SPECIMENS

The tensile properties for Figure 1 configuration specimens were determined by using a Tinius Olsen (DS-30) Servohydraulic Testing Machine. Charpy v-notched impact specimens, made to the configuration shown in Figure 2, were tested at ambient and cryogenic temperature with a Tinius Olsen Impact Machine. Fracture toughness compact tension specimen configurations, shown in Figure 3 were precracked and tensile tested at ambient and cryogenic temperature on a Model 812.21 Material Test System (MTS) 10,000 lb (4540 kg) capacity servohydraulic testing machine.

Fluke Digital Comparators (Model 2162A) were used to control the upper and lower limits for the cryogenic tests on the charpy impact and the compact tension test specimens. A Fluke Digital Thermometer (Model 2165A) indicated the test temperature of –100°F (–73°C). Liquid nitrogen vapors were utilized to maintain the cryogenic temperature.

The locations for the tensile, charpy, and fracture toughness specimens are shown in Figures 1A and B, 2A, and 3A and B, respectively. The specimen blanks were sectioned for these locations by Wyman Gordon.

MATERIAL PROCESSING

The chemical composition of the as received material used in the investigation is shown in Table 1. This material was purchased in the solution treated, work strengthened, and direct double aged condition from Wyman Gordon. The material supplier to Wyman Gordon press converted a vacuum induction melted (VIM)-electro-slag remelted (ESR)-vacuum arc remelted (VAR) 25 in. (63.5 cm) diameter ingot to 12 in. (30.5 cm) diameter round billets.

Wyman Gordon converted the billets (identified as WG39735) on a cogging press to 10 in. (25.4 cm) diameter round billets using a fine grain conversion practice. The billets were then press forged on a cogging press in two operations to yield 6 in. (15.2 cm) round corner squares approximately 120 in. (304.8 cm) long. These configurations were sheared into three 40 in. (101.6 cm) long bars, which were drawn by four draw operations to 100 in. (254 cm)-113 in. (287.0 cm) lengths by approximately 4.25 in. (10.8 cm) diameters. The bars were then special processed to 4.0 in. (10.2 cm) diameters and double aged at 1325°F (718°C) for 10 hours-furnace cooled to 1150°F-hold for a total single aging time of 20 hours (repeat).

Almost identical processing was performed to achieve the 5.75 in. (14.6 cm) diameter bars except that the supplier converted a 20 in. (50.8 cm) diameter ingot to 12 in. (30.5 cm) diameter round billets (identified as WG39736). Wyman Gordon used a five draw operation (as opposed to the four draw operation used for the smaller diameter material) to achieve a 6.25 in. (15.9 cm) diameter by 127 in. (322.6 cm) length.

The processing and heat treatment are documented in the Wyman Gordon "Product Test Report No. 362" [Ref. 1].

STRESS CORROSION TEST PROCEDURE

A 180 day salt fog exposure test was performed on tensile specimens manufactured to the Figure 1 configuration. The test specimens were stressed to 75 percent and 100 percent of the transverse 0.2 percent yield strength prior to exposure to the chloride environment.

The salt fog test followed the procedures of ASTM-B-117-64, "Standard Method of Salt Fog (FOG) Testing," which specifies a 5 percent salt solution at a pH of 6.5 to 7.2 and a temperature of 95°F (35°C).

RESULTS AND DISCUSSION

1. Tensile Tests

a. Wyman Gordon Test Data

The Wyman Gordon mechanical property evaluation of bars WG39735 [4.00 in. (10.16 cm) dia.] and WG39736 [5.75 in. (14.60 cm) dia.] shown in Table II, is tabulated in Table III. The tensile test specimen gage diameters were 0.252 in. (0.640 cm) and 0.178 in. (0.452 cm) for the longitudinal and transverse directions, respectively. Wyman Gordon used 40 longitudinal and 16 transverse specimens to evaluate the WG39735 bar and 8 longitudinal and 4 transverse specimens to evaluate the WG39736 bar.

The ultimate tensile strength and the 0.2 percent yield strength in the longitudinal and transverse directions were practically identical when specimen data were compared for the same bar segments, the exception being the S/N K2997 segment. The elongation and reduction of area were significantly different between the longitudinal and transverse directions within a given bar. The WG397535 longitudinal specimen data indicated an average 8.5 percent to 14.5 percent (Max. to Min.) greater elongation than the transverse specimen data and an average of 24.7 percent to 30.8 percent (Max. to Min.) greater reduction of area. The WG39736 longitudinal specimen data indicated an average 29.4 percent to 25.0 percent (Max. to Min.) greater elongation and an average 36.4 percent to 31.9 percent (Max. to Min.) greater reduction of area than the transverse specimen data.

A yield strength difference was detected within the WG39735 bars. WG segment S/N K2989 longitudinal specimen yield strength values ranged from 195.6 ksi (1348.6 MPa) to 200.6 ksi (1383.1 MPa) as compared to WG segment S/N K2997 with a range of 177.0 ksi (1220.4 MPa) to 192.6 ksi (1327.9 MPa). A more significant yield strength difference was noted in the transverse directions of the two segments as indicated in Tables III A-D. The longitudinal mechanical property ranges for the WG39735 [4.00 in. (10.16 cm) dia.] bars are plotted in Tables III A and B, respectively. Table III C and D illustrate the transverse mechanical property range. The above described Tables represent the MSFC evaluation of Wyman Gordon data, which they have thoroughly documented in a Wyman Gordon "Product Test Report No. 362" [Ref. 1].

b. MSFC Test Data

The complete results of the tensile tests conducted at MSFC on specimens removed from bar WG39735 locations S/N K2989 and S/N K2992, illustrated in Table II, are tabulated in Table IV. Figures 1A and B show the specimen orientation within the bar locations.

These data indicate low elongation and reduction of area for the transverse specimens removed from location S/N K2989. A comparison of the MSFC data with Wyman Gordon data is shown in Table V. The difference in properties can be explained by the near proximity of the small gage diameter [0.1250 in. (0.3175 cm)] MSFC specimens to the end of the bar. The Wyman Gordon specimen containing larger gage diameters were removed closer to the adjacent segment S/N K2990, which is toward the center of the bar.

In the MSFC investigation the differences in elongation and reduction of area of the transverse specimens from S/N K2992 as compared with specimens from S/N K2989 prompted a metallographic examination. Tensile samples T14 from section S/N K2989 and T23 from S/N K2993 were cross sectioned, mounted, polished and etched for microstructural examination. The resulting microstructures are shown in Figure 1C and D. Specimen T23, which has twice the elongation and reduction of area as the T14 specimen, also has a significantly smaller grain size.

2. Charpy V-Notched Impact Tests

Table VI lists the average impact values for ambient temperature and -100°F (-73°C) tests on longitudinal and transverse charpy v-notched impact specimens. These specimens were removed from segment S/N K3006 of the WG39736 [5.75 in. (14.60 cm) dia.] bar. The specimen configuration and locations are shown in Figure 2 and 2A, respectively, and the impact values are plotted in Figure 2B. Notice that there is an approximate 94 percent and 89 percent retention of the ambient temperature impact strength at -100°F (-73°C) in the longitudinal and transverse directions, respectively. For comparison purposes the average ambient temperature longitudinal and transverse tensile properties on the S/N K3006 segment, as determined by Wyman Gordon, are also shown in Table IV.

3. Compact Tension Fracture Toughness Tests

Table VII lists the fracture toughness values for ambient temperature and -100°F (-73°C) tests on LC and C-L direction specimens. These specimens were removed from segment S/N K2998 of the WG39736 [5.75 in. (14.60 cm) dia.] bar. The specimen configuration and locations are shown in Figure 3, 3A and 3B, respectively, and the fracture toughness values are plotted in Figure 3C. Notice that there is no loss in the fracture toughness strength of the LC direction specimens at -100°F (-73°C) and that there is a 95 percent retention of ambient temperature fracture toughness strength at -100°F (-73°C) in the C-L direction specimens. For comparison purposes the average ambient temperature longitudinal and transverse tensile properties on the S/N K2998 segment, as determined by Wyman Gordon, are also shown in Table VII.

4. Salt Fog – Stress Corrosion Tests

The stress corrosion test specimen configuration is shown in Figure 1 and the location and orientation illustrated in Table II and Figure 1A and B, respectively. The specimens were removed from the WG39735 [4.00 in. (10.16 cm) diameter] bar segments S/N K2989 and K2992.

Table VIII lists the average tensile properties of longitudinal and transverse specimens stressed to 0, 75, and 100 percent of their respective yield strength and exposed to 0 and 180 days of salt fog exposure. There were no tensile failures or loss in mechanical properties after 180 days of stress and exposure. There was, however, an increase in the longitudinal and the transverse yield strengths of the 100 percent stressed specimens, a phenomenon attributed to additional work strengthening of the Inconel 718 alloy. Figures 4 and 5 illustrate the stressed specimens prior to and after 180 days, respectively.

CONCLUSIONS

Based upon our preliminary investigation of moderately work strengthened and direct single and double aged Inconel 718 alloy material processed by Wyman Gordon and the results of the evaluation described in this report the following conclusions are drawn:

1. A significant increase in ultimate tensile and yield strength can be achieved in large diameter bars of Inconel 718 alloy by the Wyman Gordon work strengthening process without the sacrifice of grain size, elongation, or reduction of area.

2. The Inconel 718 alloy's excellent resistance to stress corrosion cracking in a chloride environment was not impaired by the Wyman Gordon work strengthening process.

REFERENCES

1. Wyman Gordon Product Test Report No. 362, dated 1-28-85, Hand Forgings–Alloy Inco 718, NASA Space Shuttle, Prepared by Sr. Product Metallurgist Ken Kohlstrom, assisted by Metallurgical Technician Peter Rice.

TABLE I

Chemical Composition of 4.00 in. (10.16 cm) and 5.75 in. (14.60 cm) Diameter Triple Melted (VIM-ESR-VAR) Double Aged Bars Processed by Wyman Gordon

NOMINAL	Fe	C	Mn	Si	P	S	Cr	Ni	Mo	Cb+Ta	Ti	Al	Co	B	Cu
AMS 5644	--- BAL	(MAX) 0.080	(MAX) 0.35	(MAX) 0.35	(MAX) 0.015	(MAX) 0.0150	(RANGE) 17/21.00	(RANGE) 50/55.00	(RANGE) 2.8/3.30	(RANGE) 4.75/5.50	(RANGE) 0.65/1.15	(RANGE) 0.20/0.80	(MAX) 1.00	(MAX) 0.006	(MAX) 0.30
MSFC ANALYSIS WG 39735	BAL	0.053	0.13	0.09	-----	0.0004	18.46	53.04	2.92	5.14 (Cb)	0.84	0.48	0.43	-----	0.06
WG ANALYSIS	18.59	0.034	0.13	0.08	0.008	0.0010	18.06	53.22	3.03	5.33 (Cb) 0.03 (Ta)	1.10	0.46	0.33	0.0048	0.07
MSFC ANALYSIS WG 39736	BAL	0.043	0.14	0.11	0.001	0.0005	18.17	52.44	2.97	5.27 (Cb)	0.98	0.50	0.41	0.005	0.06
WG ANALYSIS	18.51	0.038	0.11	0.08	0.008	0.0010	17.95	52.94	2.99	5.34 (Cb) 0.03 (Ta)	1.07	0.47	0.33	0.0047	0.07

NOTES: Photometric Analysis for Boron & Phosphorus (MSFC Analysis)
X-Ray Fluorescence Spectroscopy & Combustion Analyses for Remaining Elements (MSFC Analysis)

WG 39735 - Tensile Specimen #1 - S/N K2989 - Located at End of 4.00 Inch (10.16 cm) Bar - Outer Diameter

WG 39736 - Charpy Specimen #33 - S/N K3006 - Located at End of 5.75 Inch (14.60 cm) Bar - Center of Diameter

TABLE II

Inconel 718 Alloy Work Strengthened and Direct Double Aged Bars Processed By Wyman Gordon From Triple Melted (VIM-ESR-VAR) Universal Cyclops Heat No. 605948

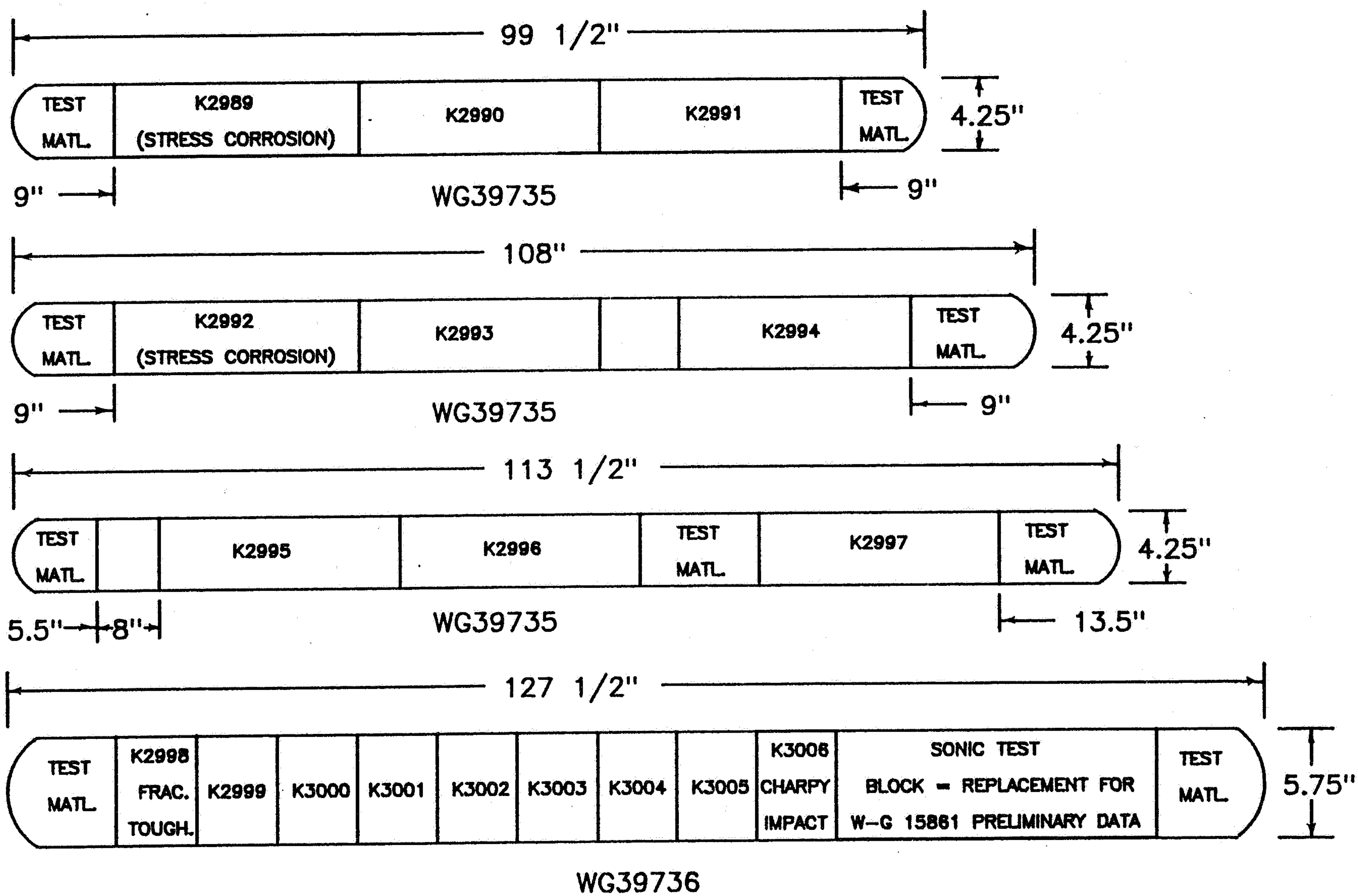


TABLE III

Mechanical Properties of Inconel 718 Alloy Work Strengthened and Double Aged Bar Specimens Processed by Wyman Gordon

SPECIMEN DIRECTION	RANGE YIELD STRENGTH KSI	AVG. Y.S. KSI	RANGE U.T.S. KSI	AVG. U.T.S. KSI	RANGE ELONG. 4D%	RANGE R.A. %	NO. OF SPECIMENS	WG S/N IDENT.	SPEC. LOCATION IN BAR
LONG.	195.6-200.6	198.6	219.8-223.2	221.4	14.0-16.0	34.0-35.0	5	K2989	END
TRANS.	198.4-200.8	199.6	216.8-218.4	217.6	12.0-12.0	23.0-26.0	2	K2989	END
LONG.	196.2-202.2	199.7	219.6-224.8	222.0	14.0-16.0	32.0-35.0	5	K2991	END
TRANS.	192.8-196.0	194.4	218.0-218.0	218.0	12.0-12.0	24.0-24.0	2	K2991	END
LONG.	182.8-190.2	186.6	215.0-216.6	215.5	18.0-20.0	35.0-38.0	5	K2992	END
TRANS.	190.0-196.0	193.0	218.0-218.4	218.2	14.0-15.0	24.0-25.0	2	K2992	END
LONG.	186.0-190.8	188.9	212.4-217.6	215.5	17.0-18.0	34-0.39.0	5	K2993	MIDDLE
TRANS.	196.0-196.4	196.2	217.2-218.0	217.6	15.0-16.0	25.0-26.0	2	K2993	MIDDLE
LONG.	193.6-199.0	195.1	218.0-222.0	219.7	16.0-16.0	33.0-37.0	5	K2994	END
TRANS.	188.8-192.0	190.4	212.0-214.0	213.0	14.0-16.0	24.0-26.0	2	K2994	END
LONG.	187.0-194.0	189.2	213.2-217.6	215.1	17.0-19.0	34.0-40.0	5	K2995	END
TRANS.	188.0-188.8	188.4	212.0-212.4	212.8	17.0-17.0	26.0-28.0	2	K2995	END
LONG.	185.6-189.8	187.2	211.8-216.4	213.8	18.0-19.0	34.0-41.0	5	K2996	MIDDLE
TRANS.	192.0-192.0	192.0	216.4-217.2	216.8	18.0-18.0	26.0-28.0	2	K2996	MIDDLE
LONG.	177.0-192.6	186.4	210.0-219.0	215.5	16.0-21.0	27.0-40.0	5	K2997	END
TRANS.	178.0-180.0	179.0	212.0-214.0	213.0	17.0-18.0	26.0-28.0	2	K2997	END
LONG.	185.6-188.8	187.2	213.2-216.8	214.6	18.0-18.0	34.0-37.0	4	K2998	END
TRANS.	185.0-186.0	185.5	212.0-212.6	212.3	12.0-13.0	20.0-25.0	2	K2998	END
LONG.	187.8-191.8	190.0	214.8-218.2	216.7	16.0-18.0	32.0-35.0	4	K3006	END
TRANS.	186.9-188.0	187.4	210.2-213.6	211.9	12.0-14.0	22.0-24.0	2	K3006	END

NOTES:

WG S/N Ident. K2989-91, K2992-93-94, K2995-96-97 Specimens from 4.00 Inch Dia. Bar (VIM-ESR-VAR Melted)

WG S/N Ident. K2998-3006 Specimens from 5 3/4 Inch Dia. Bar (VIM-ESR-VAR Melted)

1 KSI = 6.8948 Mega Newtons/m^2 = 6.8948 Mega Pascals/m^2

1 Inch = 2.54 cm

TABLE IIIA

Longitudinal Tensile and Yield Strength in Inconel 718 Alloy Bar WG39735

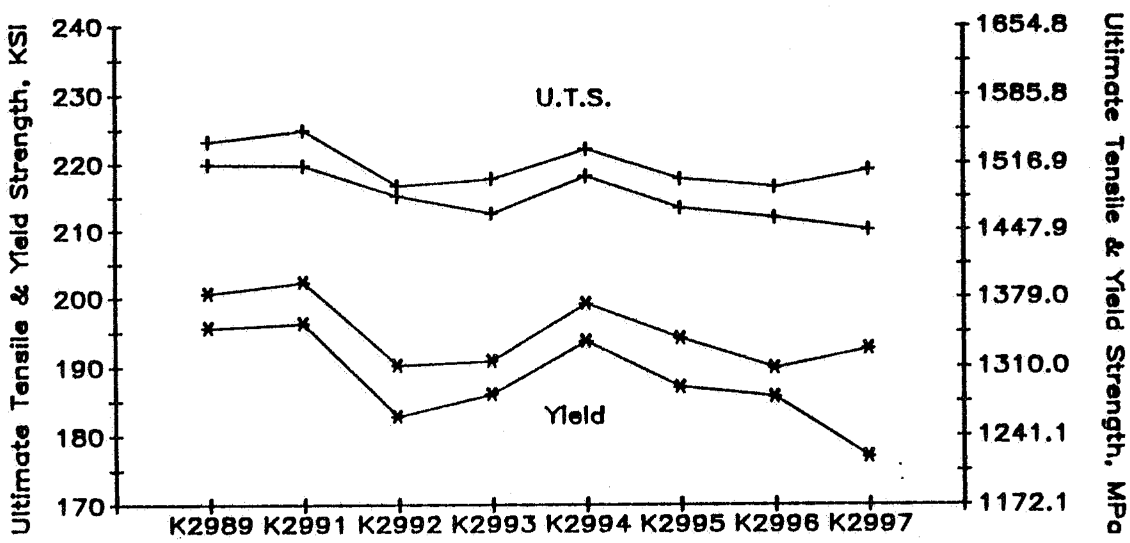
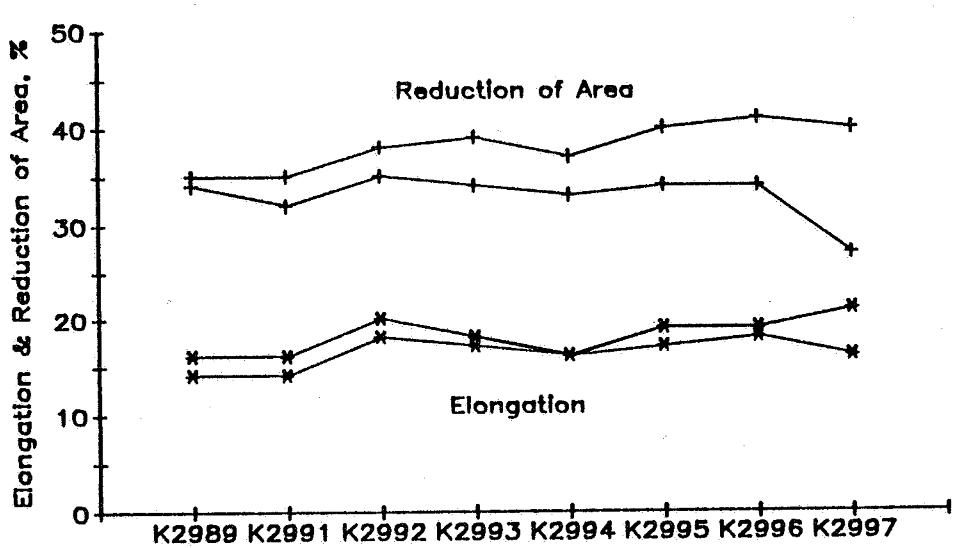


TABLE IIIB

Longitudinal Elongation and Reduction of Area in Inconel 718 Alloy Bar WG39735



NOTE:

1. Reference Table III Values [4.00 In. (10.16 cm) Dia. Bar]
2. Data Furnished By Wyman Gordon

TABLE IIIC

Transverse Tensile and Yield Strength in Inconel 718 Bar WG39735

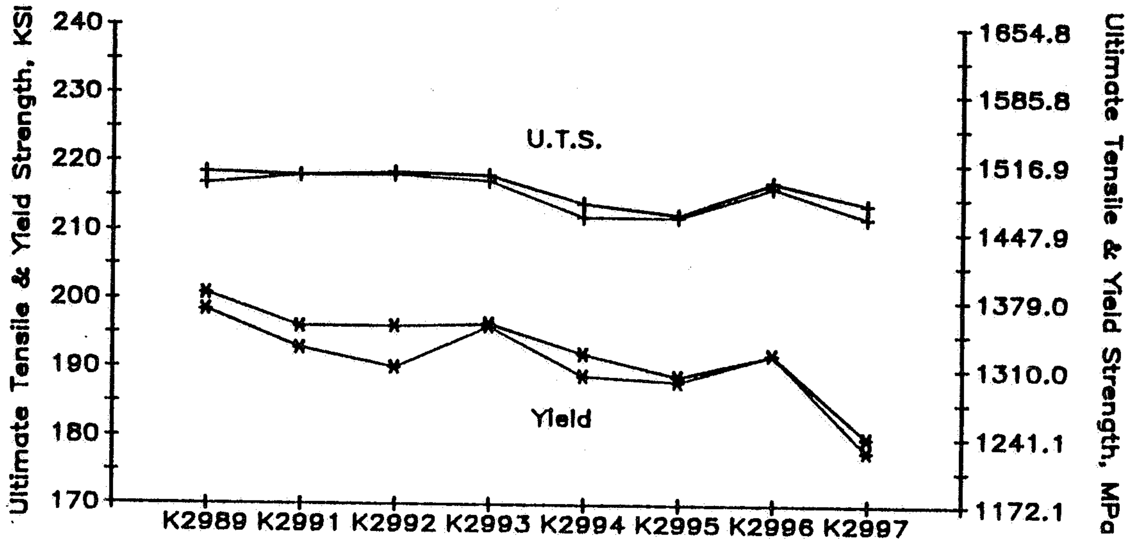
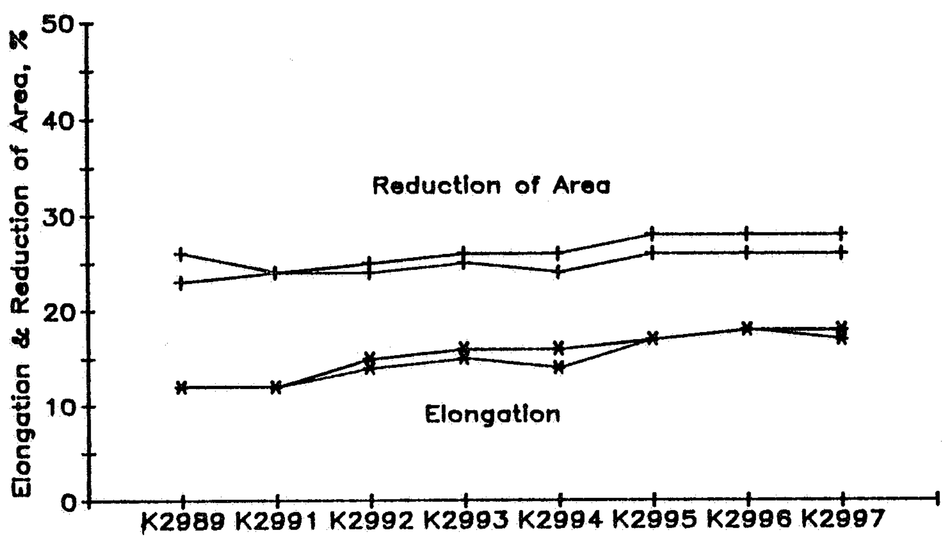


TABLE IIID

Transverse Elongation and Reduction of Area in Inconel 718 Alloy Bar WG39735



NOTE:

1. Reference Table III Values [4.00 in. (10.16 cm) Dia. Bar]
2. Data Furnished By Wyman Gordon

TABLE IV

Mechanical Properties of Inconel 718 Alloy Work Strengthened and Direct Double Aged Bars Processed by Wyman Gordon from Triple Melted (VIM-ESR-VAR) Universal Cyclops Heat No. 605948

[MSFC TEST DATA FROM 0.1250 INCH (0.3175cm) DIAMETER SPECIMENS]

Specimen Number	Specimen Direction	U.T.S. ksi	U.T.S. (MPa)	Y.S. ksi	Y.S. (MPa)	Modulus X 10^{-6} psi	Modulus X 10^{-6} (MPa)	Frac. Strength ksi	Frac. Strength (MPa)	Elong. 4D%	RA %	WG Ident.
L1	Long.	224.2	(1545.8)	204.2	(1407.9)	29.6	(.2041)	288.7	(1990.5)	12.5	32.8	K2989
L3	Long.	230.0	(1585.8)	208.7	(1438.9)	29.9	(.2061)	307.9	(2122.9)	13.0	35.8	K2989
L4	Long.	235.1	(1621.0)	216.7	(1494.1)	29.1	(.2006)	330.0	(2275.3)	13.0	37.5	K2989
L6	Long.	230.2	(1587.2)	207.7	(1432.0)	30.2	(.2082)	304.8	(2101.5)	13.2	34.4	K2989
L2*	Long.	231.4	(1595.4)	214.4	(1478.2)	31.0	(.2137)	323.2	(2228.4)	12.5	34.7	K2989
L5*	Long.	227.9	(1571.3)	208.5	(1437.6)	31.3	(.2158)	317.8	(2191.2)	12.5	35.0	K2989
L7*	Long.	227.3	(1567.2)	206.2	(1421.7)	31.5	(.2172)	317.6	(2189.8)	12.5	35.3	K2989
L8**	Long.	238.2	(1642.3)	236.6	(1631.3)	30.0	(.2068)	321.0	(2213.2)	9.5	32.2	K2989
L9**	Long.	224.9	(1550.6)	214.8	(1481.0)	29.6	(.2041)	323.9	(2233.2)	13.0	37.4	K2989
L10**	Long.	227.7	(1569.9)	214.0	(1475.5)	31.5	(.2172)	317.1	(2186.3)	12.2	34.7	K2989
T13	Trans.	224.2	(1546.5)	205.7	(1418.3)	31.0	(.2137)	230.6	(1589.9)	8.0	8.5	K2989
T14	Trans.	223.2	(1538.9)	208.7	(1438.9)	30.5	(.2103)	245.3	(1691.3)	6.0	10.1	K2989
T15	Trans.	224.8	(1549.9)	208.2	(1435.5)	30.9	(.2130)	255.4	(1760.9)	7.2	13.4	K2989
T16	Trans.	227.6	(1569.2)	210.0	(1447.9)	30.6	(.2110)	245.2	(1690.6)	8.7	12.6	K2989
T18	Trans.	220.7	(1521.7)	184.5	(1272.1)	30.4	(.2096)	245.7	(1694.0)	12.0	21.0	K2992
T19	Trans.	224.4	(1547.2)	190.1	(1310.7)	30.5	(.2103)	256.2	(1766.4)	11.0	19.3	K2992
T23	Trans.	223.6	(1541.7)	190.6	(1314.1)	30.4	(.2096)	265.5	(1830.6)	12.0	22.7	K2992
T17*	Trans.	222.4	(1533.4)	190.5	(1313.4)	31.9	(.2199)	273.2	(1883.6)	11.7	22.2	K2992
T20*	Trans.	223.2	(1538.9)	190.3	(1312.1)	31.5	(.2172)	290.6	(2003.6)	12.5	25.1	K2992
T21**	Trans.	223.3	(1539.6)	194.4	(1340.3)	31.7	(.2186)	283.5	(1954.7)	12.5	23.3	K2992
T22**	Trans.	221.9	(1530.0)	194.4	(1340.3)	31.6	(.2179)	280.3	(1932.6)	12.5	21.6	K2992
T24**	Trans.	222.8	(1536.2)	199.2	(1373.4)	31.2	(.2151)	278.6	(1920.9)	12.5	20.2	K2992

Notes: *Stress Corrosion Specimens Stressed to 75% of Y.S.-Tensile Tested After 180 Days Exposure to Salt Fog
**Stress Corrosion Specimens Stressed to 100% of Y.S.-Tensile Tested After 180 Days Exposure to Salt Fog
1000 psi = 1 ksi = 6.8948 Mn/m^2 = 6.8948 MPa
Fracture Strength - Breaking Load Divided by Fracture Area
Figure 1A Indicates the Locations of Longitudinal Specimens L1 Thru L10 and Transverse Specimens T13 Thru T16
Figure 1B Illustrates the Locations of Transverse Specimens T17 Thru T24

TABLE V

Comparison of Mechanical Properties of Inconel 718 Alloy Work Strengthened and Direct Double Aged Bars Processed by Wyman Gordon from Triple Melted (VIM-ESR-VAR) Universal Cyclops Heat No. 605948

[MSFC VS. WYMAN GORDON DATA]

Data	Specimen Direction	RANGE Yield Strength ksi	AVG. Y.S. ksi	RANGE U.T.S. ksi	AVG. U.T.S. ksi	RANGE Elong. 4D%	RANGE R.A. %	RANGE Modulus $X10^{-6}$ psi	No. of Tests	WG S/N Ident.
MSFC	Long.	204.2-216.7	209.4	224.2-235.1	229.9	12.5-13.2	32.8-37.5	29.1-30.2	4	K2989
WG	Long.	195.6-200.6	198.6	219.8-223.2	221.4	14.0-16.0	34.0-35.0	---------	5	K2989
MSFC	Trans.	205.7-210.0	208.2	223.2-227.6	225.0	6.0-8.7	8.5-13.4	30.5-31.0	4	K3989
WG	Trans.	198.4-200.8	199.6	216.8-218.4	217.6	12.0-12.0	23.0-26.0	---------	2	K2989
WG	Long.	182.8-190.2	186.6	215.0-216.6	215.5	18.0-20.0	35.0-38.0	---------	5	K2992
WG	Trans.	190.0-196.0	193.0	218.0-218.4	218.2	14.0-15.0	24.0-25.0	---------	2	K2992
MSFC	Trans.	184.5-190.6	188.4	220.7-224.4	222.9	11.0-12.0	19.3-22.7	30.4-30.5	3	K2992

NOTES: 1000 psi = 1 ksi = 6.8948 Mn/m^2 = 6.8948 MPa

MSFC Tensile Specimens 0.1250 Inch (0.3175cm) Diameter

WG Longitudinal Specimens 0.252 Inch (0.640cm) Diameter

WG Transverse Specimens 0.178 Inch (0.452cm) Diameter

TABLE VI

Charpy V-Notched Impact Strength for 5.75 in. (14.60 cm) Diameter Inconel 718 Triple Melted (VIM-ESR-VAR) Double Aged Bar Processed by Wyman Gordon*

Test Temperature		Average Impact Energy		Impact Energy Range		Specimen Direction	No. of Tests
°F	°C	Ft.-Lb.	(Joules)	Ft.-Lb.	(Joules)		
80	(+26.7)	14.1	(19.1)	12.5-15.0	(16.9-20.3)	Longitudinal	4
-100	(-73.0)	13.2	(17.9)	12.0-14.0	(16.3-19.0)	Longitudinal	3
80	(+26.7)	7.3	(9.9)	6.5 - 8.0	(8.0-10.8)	Transverse	4
-100	(-73.0)	6.5	(8.8)	6.5 - 6.5	(8.8 - 8.8)	Transverse	2

AVG. MECHANICAL PROPERTIES OF 5.75 INCH (14.60cm) DIA. BAR USED FOR CHARPY SPECIMENS

Specimen Direction	U.T.S.		Y.S.		Elong. Range	RA Range	Avg. ASTM Grain Size	No. of Tests
	ksi	(MPa)	ksi	(MPa)	%	%		
Long.	216.7	(1494.1)	190.0	(1310.0)	16.0-18.0	32.0-35.0	-	4
Trans.	211.9	(1461.0)	187.4	(1292.1)	12.0-14.0	22.0-24.0	10	2

NOTE: *WG 39736 Serial No. K3006

TABLE VII

Fracture Toughness Strength of 0.75 in. (1.90 cm) Thick Specimens Taken from 5.75 in. (14.60 cm) Diameter Inconel 718 Triple Melted (VIM-ESR-VAR) Double Aged Bar Processed by Wyman Gordon*

Test Temperature °F	°C	Specimen No. & Direction	Fracture Toughness K_{IC} ksi $\sqrt{in.}$	MPa $\sqrt{m}$	Specimen No. & Direction	Fracture Toughness K_{IC} ksi $\sqrt{in.}$	MPa $\sqrt{m}$
80	(+26.7)	39LC	80.03	87.94	47C-L	73.47	80.73
		40LC	80.37	88.31	48C-L	73.64	80.92
		42LC	82.55	90.71	49C-L	72.05	79.17
		43LC	79.54	87.40	50C-L	75.22	82.65
		41LC	(KQ77.92)	(KQ85.62)	46C-L	(KQ68.65)	(KQ75.44)
-100	(-73.0)	44LC	83.14	91.36	51C-L	72.76	79.95
-100		45LC	80.50	88.46	52C-L	66.71	73.30

AVG. MECHANICAL PROPERTIES OF 5.75 INCH (14.60cm) DIA. BAR USED FOR FRACTURE TOUGHNESS SPECIMENS

Specimen Direction	U.T.S. ksi	(MPa)	Y.S. ksi	(MPa)	Elong. Range %	RA Range %	Avg. ASTM Grain Size	No. of Tests
Long.	214.6	(1479.6)	187.2	(1290.7)	18.0-18.0	34.0-37.0	-	4
Trans.	212.3	(1463.7)	185.5	(1279.0)	12.0-13.0	20.0-25.0	10	2

NOTE: *WG 39736 Serial No. K2998 end of 127.50 Inch (323.85cm) Bar
Universal Cyclops Heat #605948

TABLE VIII

Mechanical Properties of Inconel 718 Alloy Work Strengthened and Direct Double Aged Bars Processed by Wyman Gordon from Triple Melted (VIM-ESR-VAR) Universal Cyclops Heat No. 605948

[0.1250 Inch (0.3175cm) Diameter Specimens Stressed and Exposed to a 5% Salt Fog Environment]

Exposure Time Days	Applied Stress Percent of Yield Strength	U.T.S. ksi	U.T.S. (MPa)	.2% Offset Y.S. ksi	.2% Offset Y.S. (MPa)	Elong. 4D%	Reduction of Area %	Specimen Direction	No. of Tests	WG S/N Ident.
0	0	229.9	(1585.1)	209.4	(1443.8)	12.9	35.1	Long.	4	K2989
180	75	228.9	(1578.2)	209.7	(1445.8)	12.5	35.0	Long.	3	K2989
180	100	230.3	(1587.9)	221.9	(1530.0)	11.5	34.7	Long.	3	K2989
0	0	222.9	(1536.8)	188.4	(1299.0)	11.7	21.0	Trans.	3	K2992
180	75	222.8	(1536.2)	189.9	(1309.3)	12.1	23.7	Trans.	2	K2992
180	100	222.7	(1535.5)	196.0	(1351.4)	12.5	21.7	Trans.	3	K2992

NOTES: 1000 psi = 1 ksi = 6.8948 Mn/m^2 = 6.8948 MPa

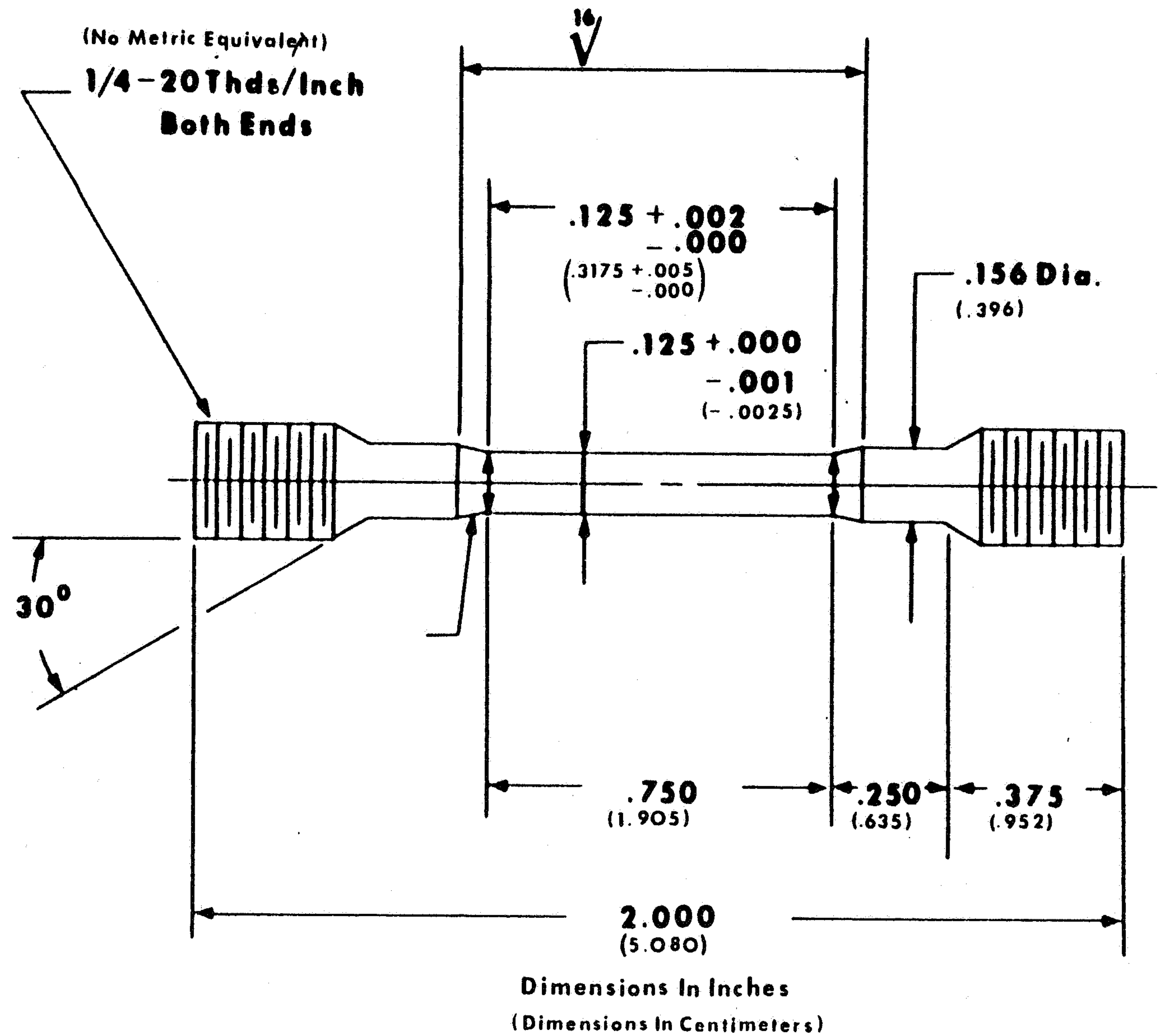
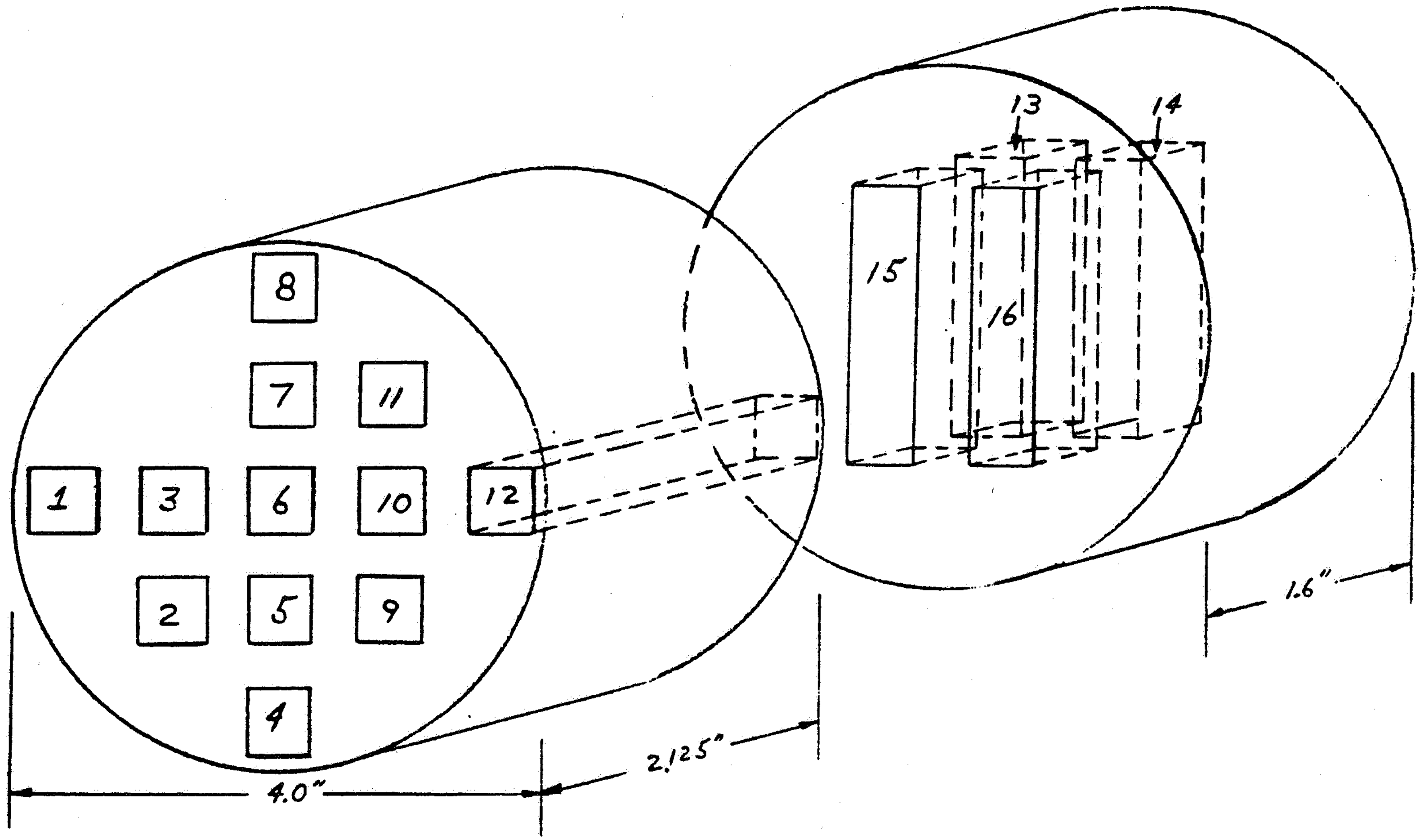
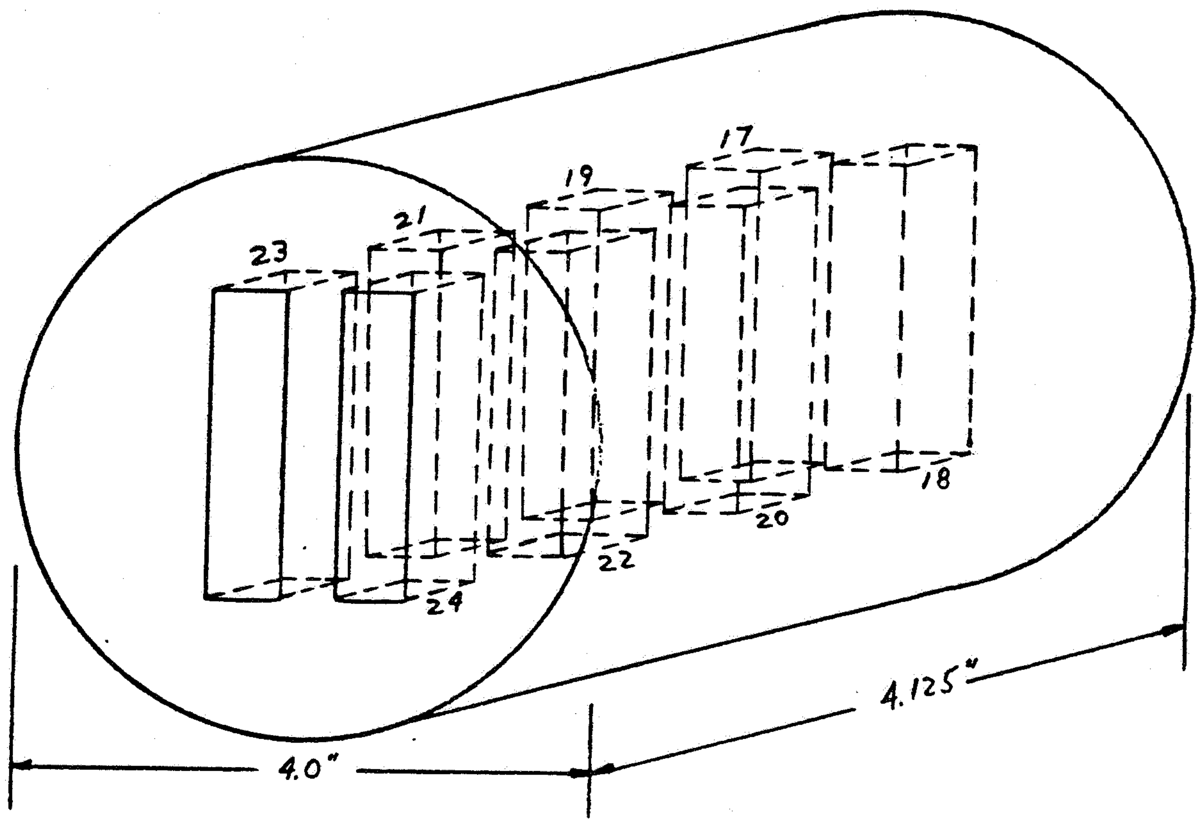


Figure 1. Round Tensile Specimen Configuration for Stress Corrosion and Mechanical Property Tests.



Bar 39735 S/N K2989
Long. Blanks 1-12
Trans. Blanks 13-16

Figure 1A. Location of 0.1250 in. (0.3175 cm) Diameter Longitudinal and Transverse Stress Corrosion Specimens In Work Strengthened and Direct Double Aged Inconel 718 Alloy Bar Processed by Wyman Gordon.



Bar 39735 S/N K2992

Figure 1B. Locations of 0.1250 in. (0.3175 cm) Diameter Transverse Stress Corrosion Specimens In Work Strengthened and Direct Double Aged Inconel 718 Alloy Bar Processed by Wyman Gordon.

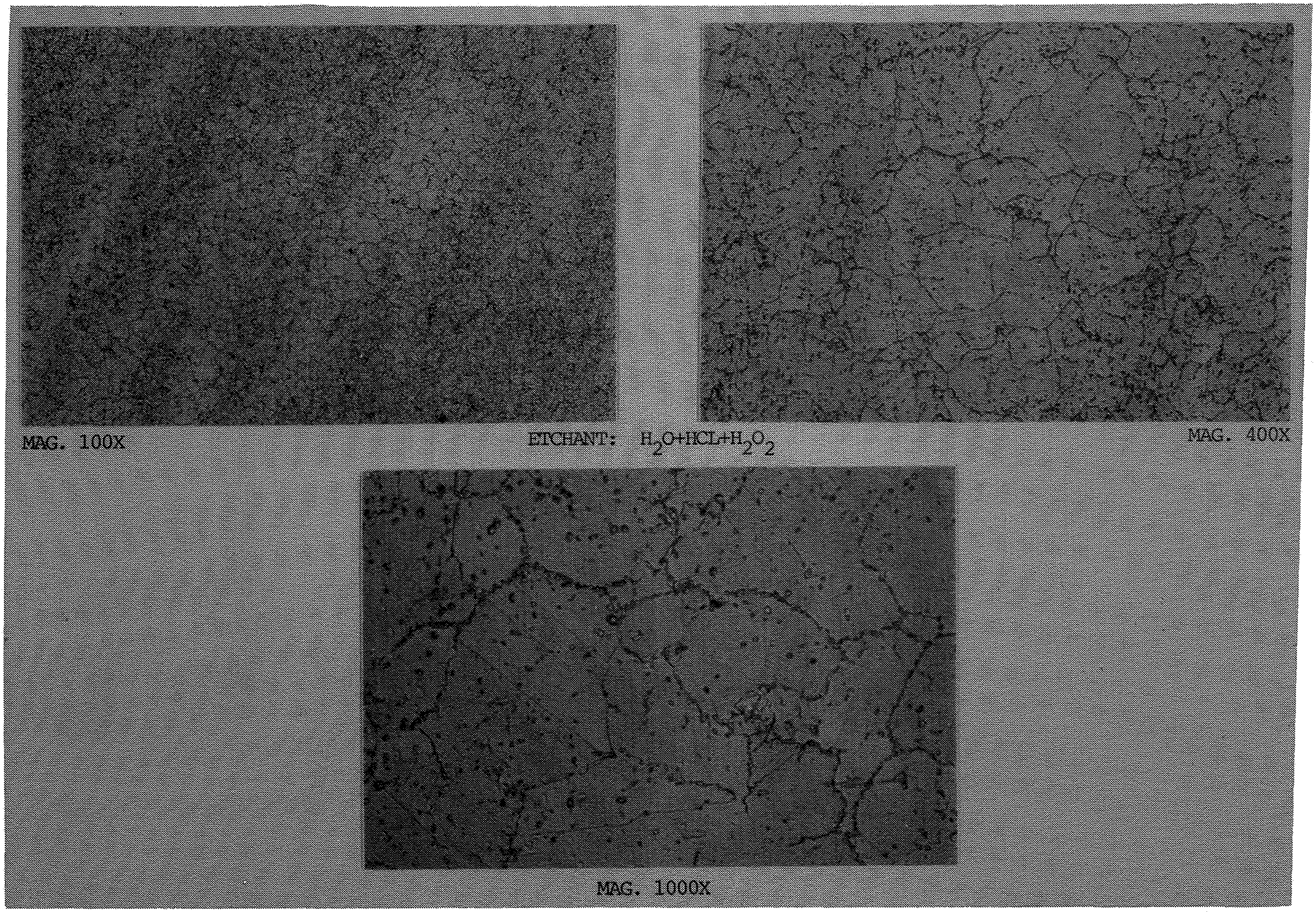


Figure 1C. Inconel 718 Alloy Work Strengthened and Direct Double Aged Bar Processed by Wyman Gordon
Specimen No. T14 (6.0 Percent Elong. and 10.1% RA) Microstructure
[Reference: S/N K2989 and Table IV]

ORIGINAL PAGE IS
OF POOR QUALITY

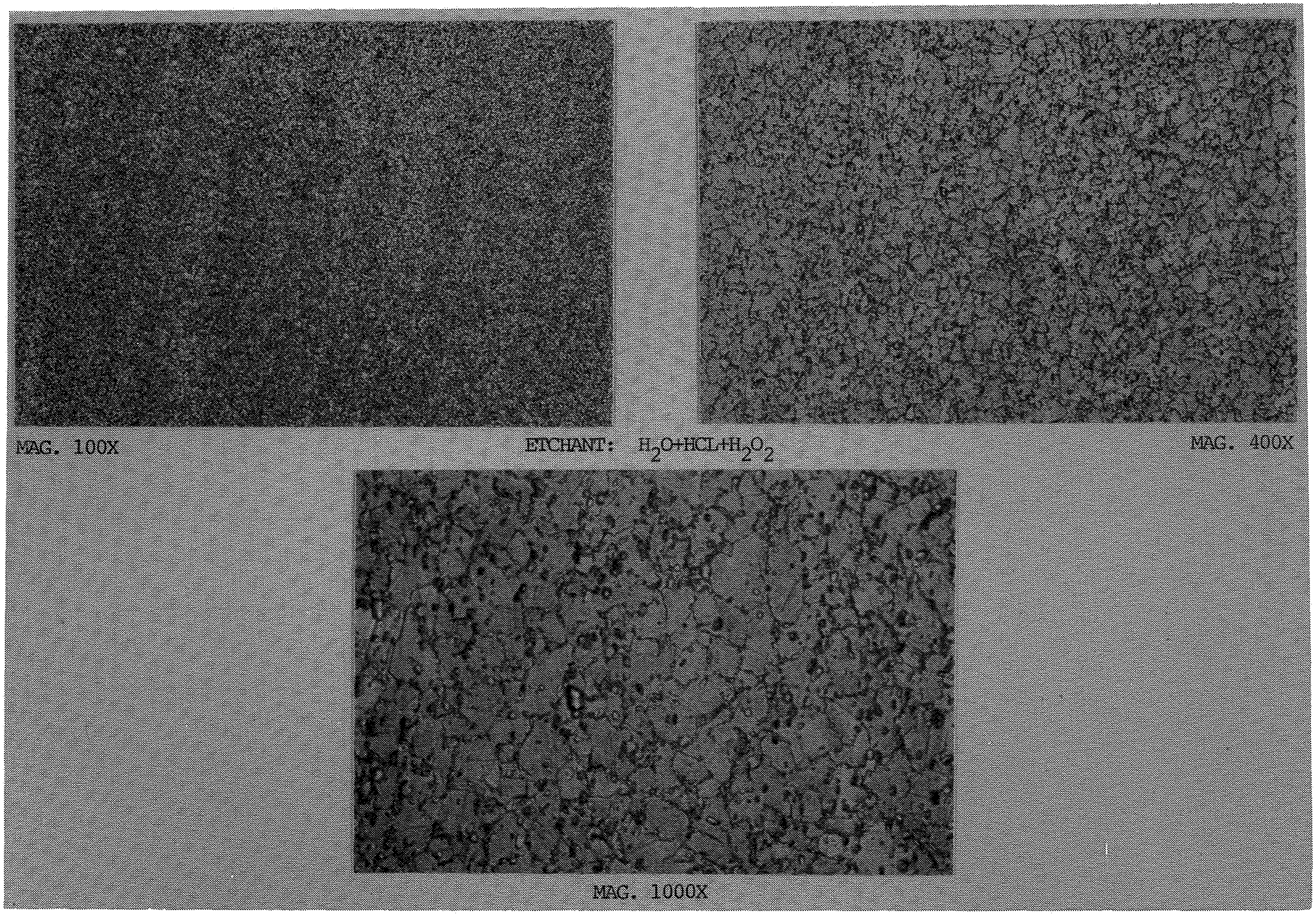
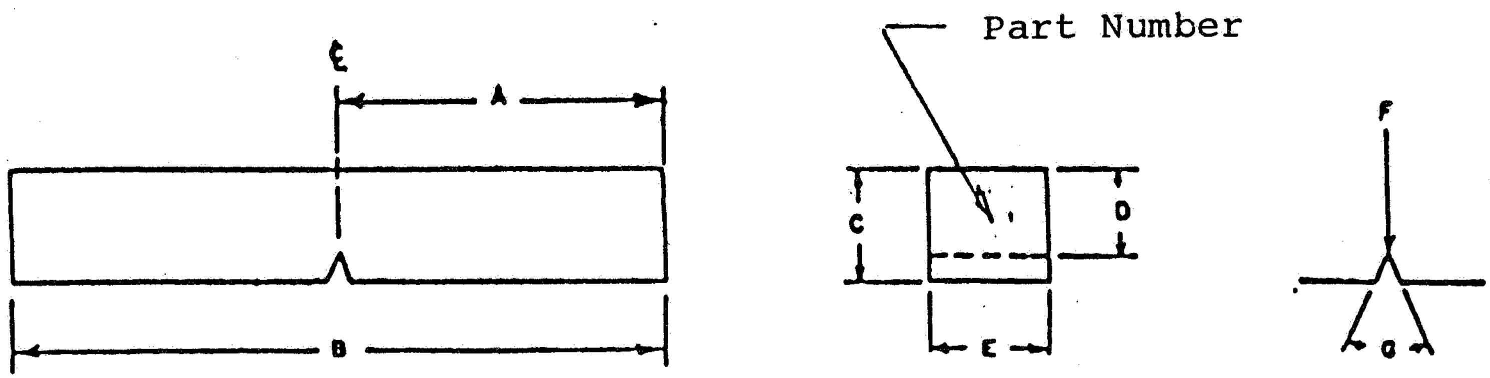


Figure 1D. Inconel 718 Alloy Work Strengthened and Direct Double Aged Bar Processed by Wyman Gordon Specimen No. T23 (12.0 Percent Elong. and 22.7 Percent RA) Microstructure [Reference: S/N K2992 and Table IV]

ORIGINAL PAGE IS
OF POOR QUALITY



DIMENSION	MM.	TOLERANCE (MM.) +	TOLERANCE (MM.) −	INCHES	TOLERANCE (INCHES) +	TOLERANCE (INCHES) −
A — CENTER TO END	1/2 B		—	1/2 B[1]		—
B — LENGTH	55.000	0	−2.50	2.165	0	.100
C — CROSS SECTION (DEPTH)	10.000	.025	.025	.394	.001	.001
D — NOTCH TO BASE	8.000	.025	.025	.315	.001	.001
E — CROSS SECTION (WIDTH)	10.000	.025	.025	.394	.001	.001
F — RADIUS OF NOTCH	.250	.025	.025	.010	.001	.001
G — ANGLE OF NOTCH	45° PLUS OR MINUS 1°					
OUT OF SQUARE (OF CROSS SECTION)	0.001 INCH IN 0.394 INCH OR 0.15° (9 MINUTES)					

1. NOT OVER 1.085 INCHES FOR LONGEST END.
2. FINISH ALL OVER, EXCEPT ENDS, 32 RMS.
3. MARK PART NUMBER WITH ELECTRO-ETCH PROCESS

Figure 2. Charpy V-Notched Impact-Specimen Configuration.

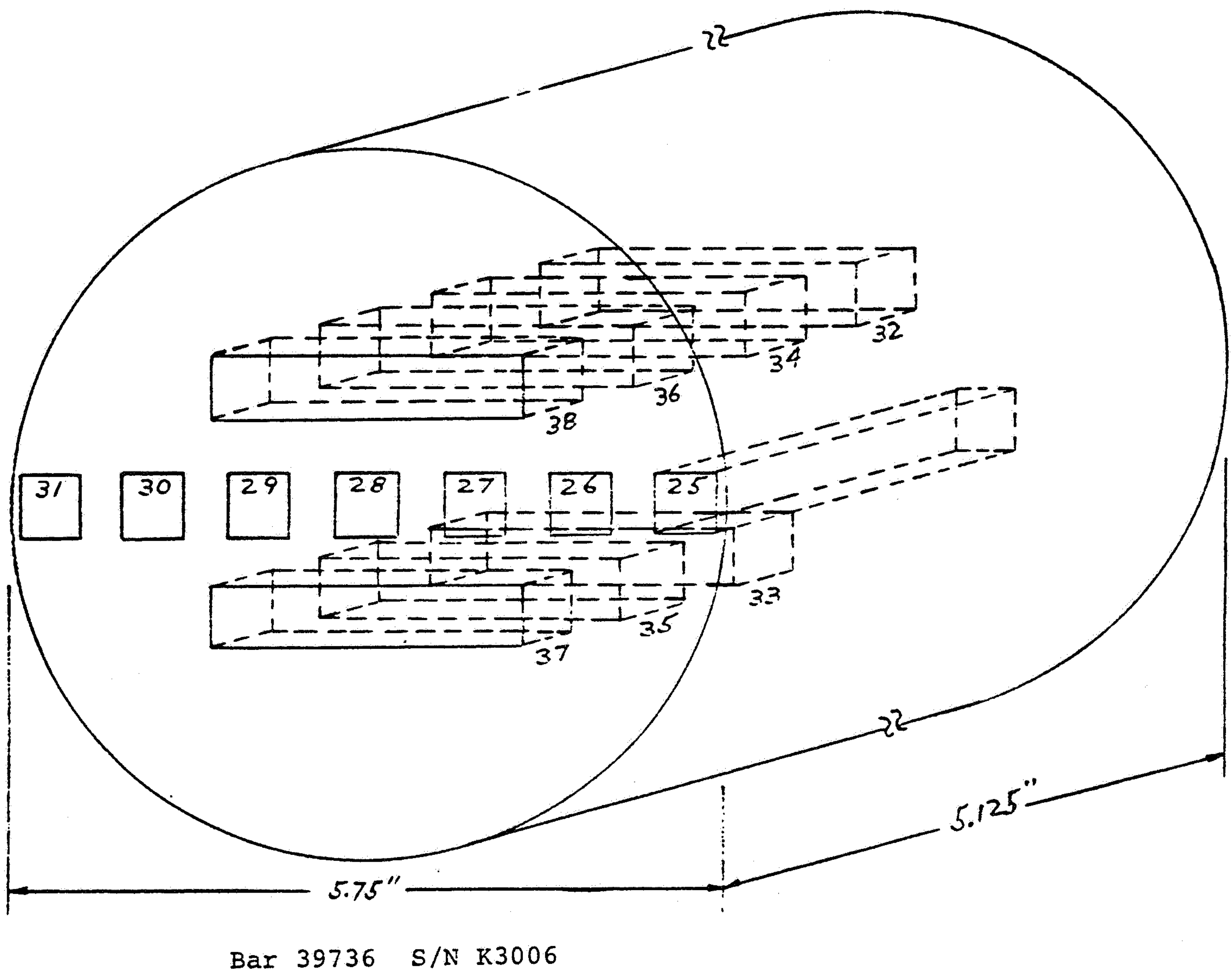
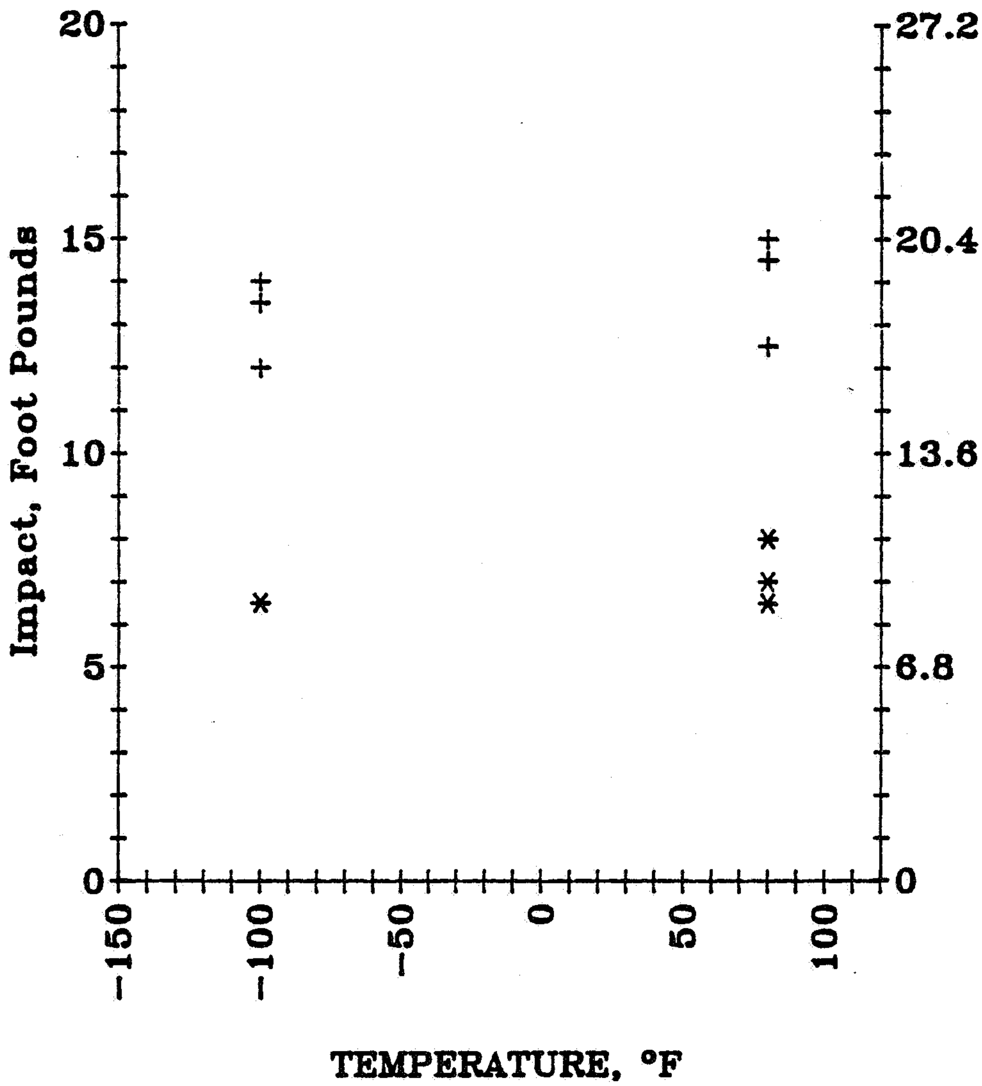


Figure 2A. Locations of 2.165 in. (5.499 cm) Length Charpy V-Notched Impact Specimens In Work Strengthened and Direct Double Aged Inconel Bar Processed by Wyman Gordon.



NOTE: S.T., Work Strengthened & Direct Double Aged

Data:	−100°F (−73°C)	80°F (26.7°C)
+ Longitudinal	12,13.5,14	12.5,14.5,14.5,15
* Transverse	6.5,6.5	6.5,7,8,8

Figure 2B. Charpy V-Notched Impact Strength of Work Strengthened and Direct Double Aged Inconel 718 Alloy Bar.

ORIGINAL PAGE IS
OF POOR QUALITY

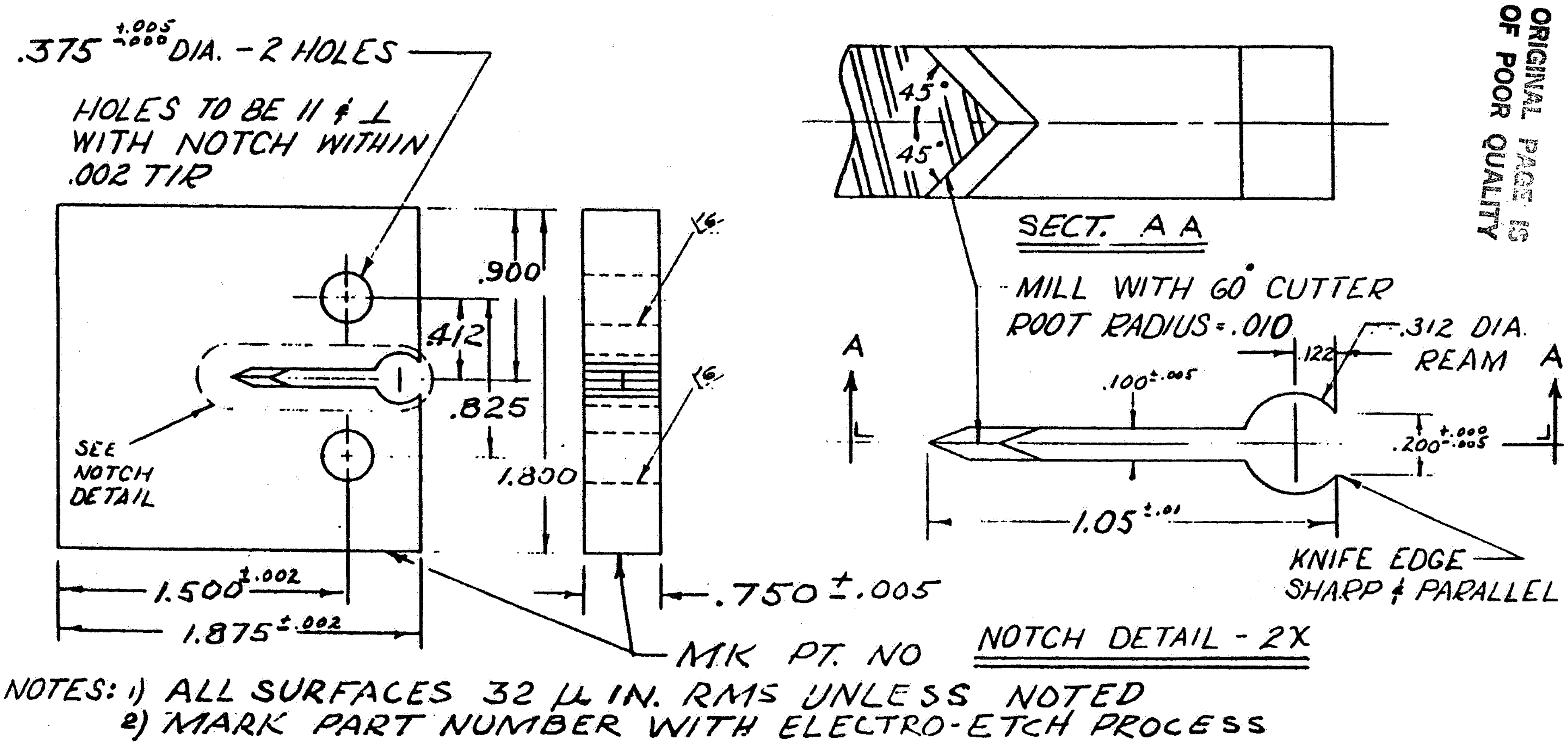
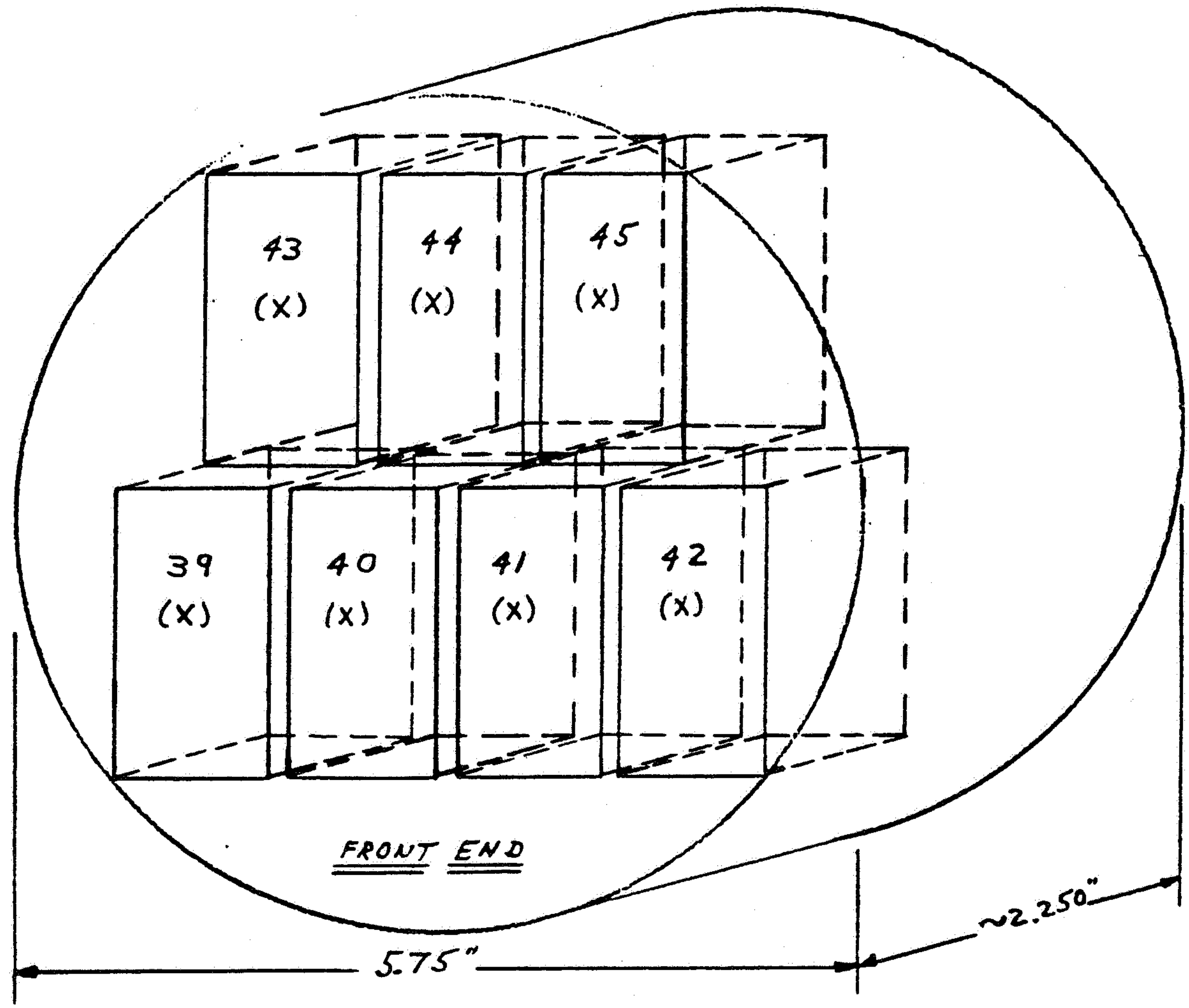
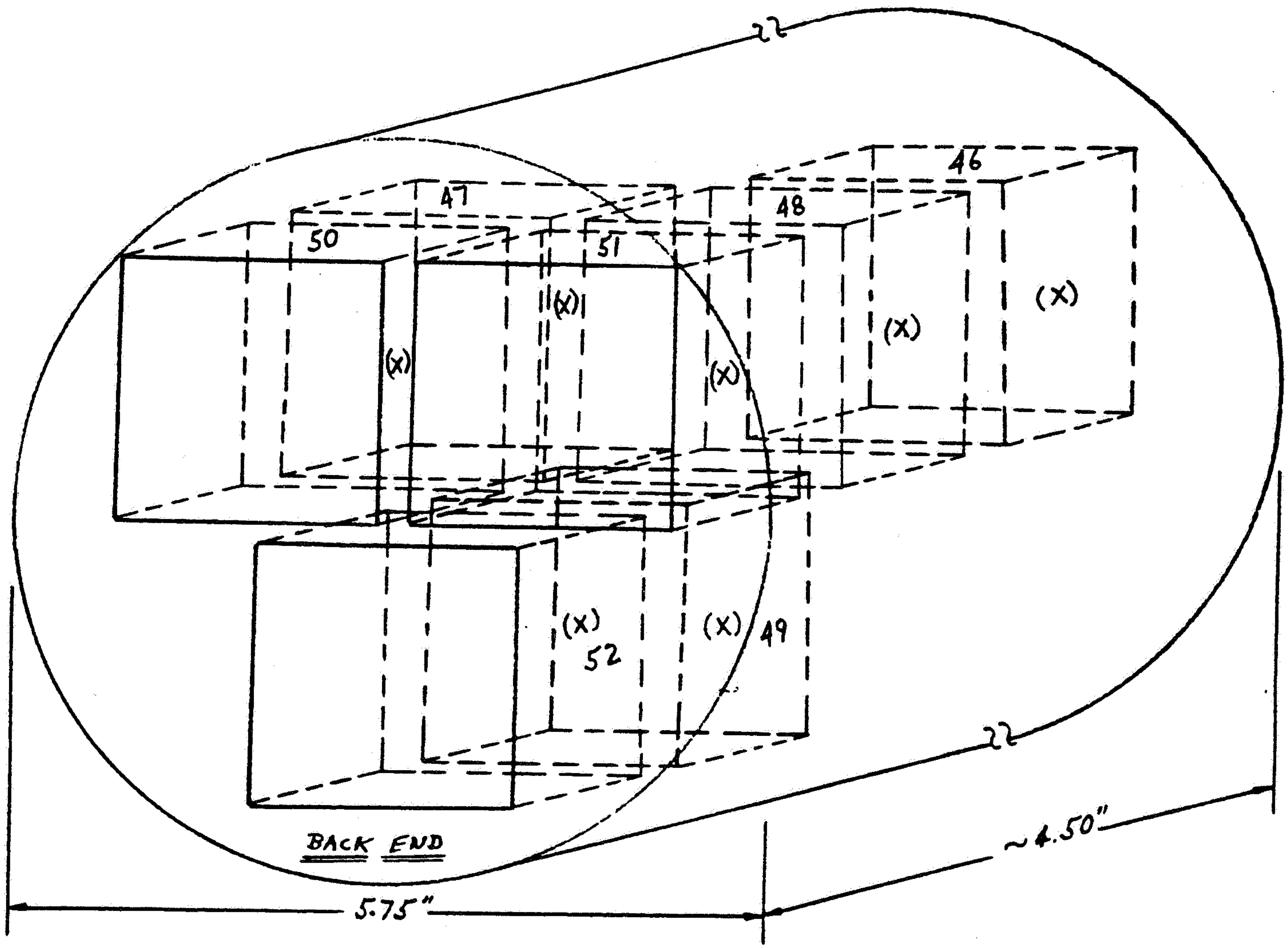


Figure 3. Compact Tension Fracture Toughness Specimen Configuration.



Bar 39736 S/N K2998

Figure 3A. Locations of 0.750 in. (1.905 cm) Thick LC Direction Compact Tension Specimens In Work Strengthened and Direct Double Aged Inconel 718 Alloy Bar Processed by Wyman Gordon.



Bar 39736 S/N K2998

Figure 3B. Locations of 0.750 in. (1.905 cm) Thick C-L Direction Compact Tension Specimens In Work Strengthened and Direct Double Aged Inconel 718 Alloy Bar Processed by Wyman Gordon.

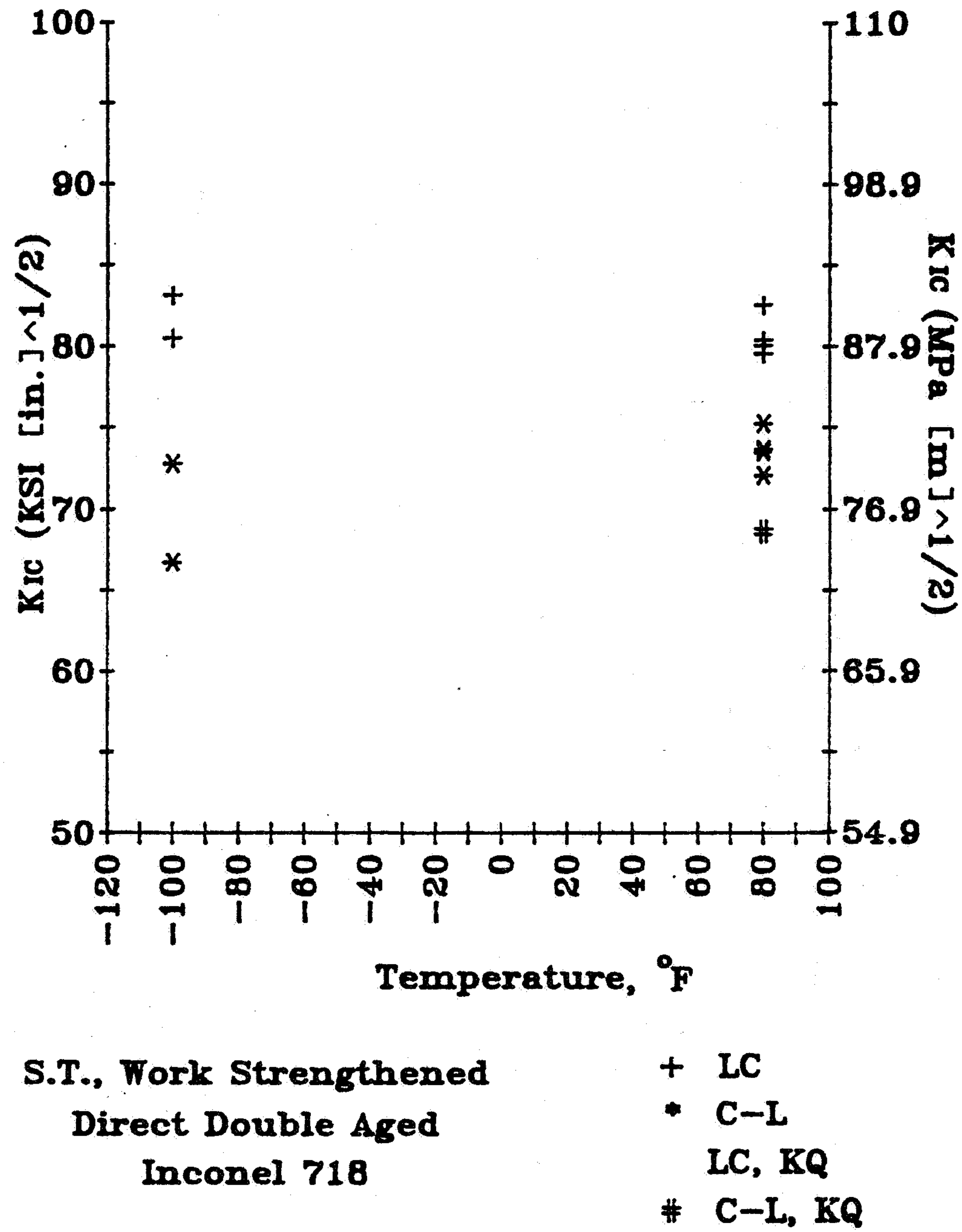


Figure 3C. Fracture Toughness of Work Strengthened and Direct Double Aged Inconel 718 Alloy Bars.

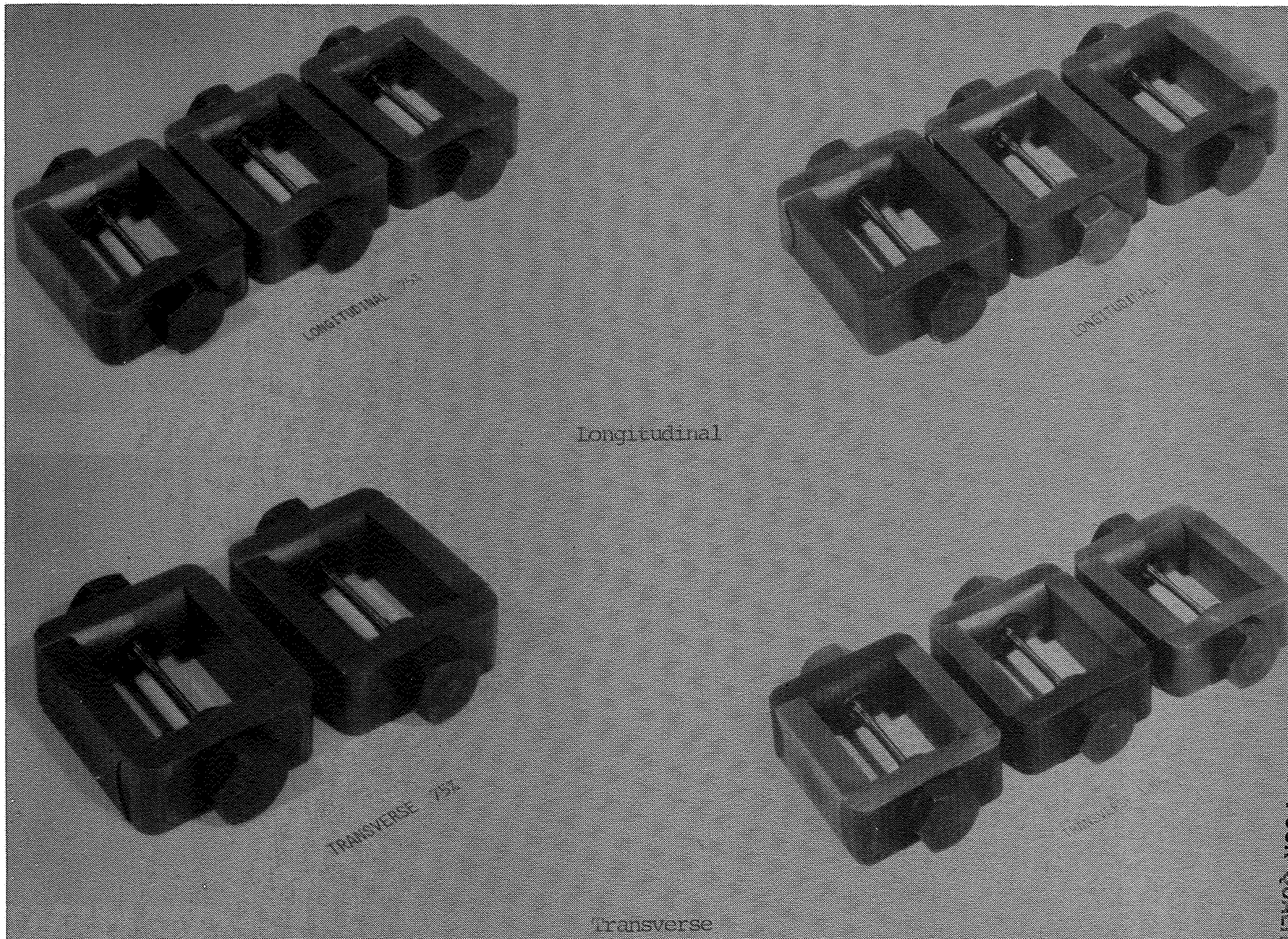


Figure 4. Inconel 718 Alloy Work Strengthened and Direct Double Aged Bar Processed by Wyman Gordon Longitudinal and Transverse Specimens Stressed to 75 and 100 Percent of Yield Strength Prior to Salt Fog Exposure.

ORIGINAL PAGE IS OF POOR QUALITY

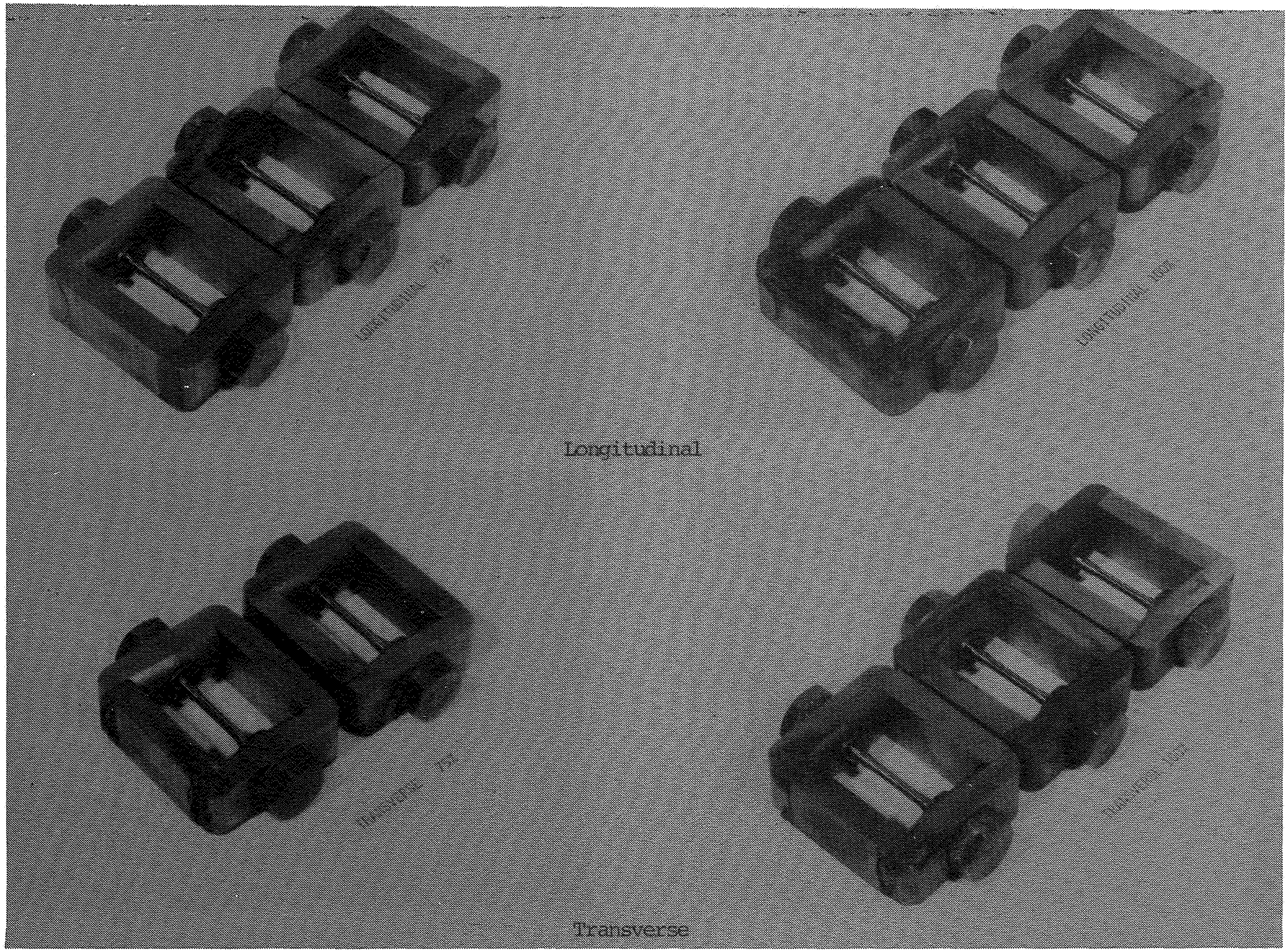


Figure 5. Inconel 718 Alloy Work Strengthened and Direct Double Aged Bar Processed by Wyman Gordon Longitudinal and Transverse Specimens After 180 Days Exposure to a Salt Fog Environment.

ORIGINAL PAGE IS
OF POOR QUALITY

1. REPORT NO. NASA TP-2634	2. GOVERNMENT ACCESSION NO.	3. RECIPIENT'S CATALOG NO.
4. TITLE AND SUBTITLE A Mechanical Property and Stress Corrosion Evaluation of VIM-ESR-VAR Work Strengthened and Direct Double Aged Inconel 718 Bar Material		5. REPORT DATE September 1986
		6. PERFORMING ORGANIZATION CODE EH22
7. AUTHOR(S) J. W. Montano		8. PERFORMING ORGANIZATION REPORT #
9. PERFORMING ORGANIZATION NAME AND ADDRESS George C. Marshall Space Flight Center Marshall Space Flight Center, Alabama 35812		10. WORK UNIT NO. M-535
		11. CONTRACT OR GRANT NO.
12. SPONSORING AGENCY NAME AND ADDRESS National Aeronautics and Space Administration Washington, D.C. 20546		13. TYPE OF REPORT & PERIOD COVERED Technical Paper
		14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

Prepared by Materials and Processes Laboratory, Science and Engineering Directorate.

16. ABSTRACT

This report presents the mechanical properties and the stress corrosion resistance of triple melted [vacuum induction melted (VIM), electro-slag remelted (ESR), and vacuum arc remelted (VAR)], solution treated, work strengthened and direct double aged Inconel 718 alloy bars [4.00 in. (10.16 cm) and 5.75 in. (14.60 cm) diameter] processed by Wyman Gordon.

Tensile, charpy v-notched impact, and compact tension specimens were tested at ambient temperature in both the longitudinal and transverse directions. Longitudinal tensile and yield strengths in excess of 220 ksi (1516.85 MPa) and 200 ksi (1378.00 MPa) respectively, were realized at ambient temperature.

Additional charpy impact and compact tension tests were performed at −100°F (−73°C). Longitudinal charpy impact strength equalled or exceeded 12.0 ft-lbs (16.3 Joules) at ambient and at −100°F (−73°C) while longitudinal (LC) compact tension fracture toughness strength remained above 79 ksi$\sqrt{\text{in.}}$ (86.80 MPa $\sqrt{\text{m}}$) at ambient and at −100°F (−73°C) temperatures.

No failures occurred in the longitudinal or transverse tensile specimens stressed to 75 and 100 percent of their respective yield strengths and exposed to a salt fog environment for 180 days. Tensile tests performed after the stress corrosion test indicated no mechanical property degradation.

17. KEY WORDS Vacuum Induction Melted (VIM) Electro-Slag Remelted (ESR) Vacuum Arc Remelted (VAR) Work Strengthened and Direct Double Aged Charpy V-Notched Impact Compact Tension Fracture Toughness Stress Corrorion		18. DISTRIBUTION STATEMENT Unclassified – Unlimited Subject Category 15	
19. SECURITY CLASSIF. (of this report) Unclassified	20. SECURITY CLASSIF. (of this page) Unclassified	21. NO. OF PAGES 36	22. PRICE A03

For sale by National Technical Information Service, Springfield, Virginia 22161

NASA-Langley, 1986