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

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16. ABSTRACT

This report presents a preliminary mechanical property and stress corrosion evaluation of double melted [vacuum induction melted (VIM), and vacuum arc remelted (VAR)], solution treated, work strengthened and direct aged Inconel 718 alloy bar [5.50 in. (13.97 cm) diameter] processed by Wyman Gordon.

Two sets of tensile specimens, one direct single aged and the other direct double aged, were tested at ambient temperature in both the longitudinal and transverse directions. Longitudinal tensile and yield strengths in excess of 200 ksi (1378.96 MPa) and 168 ksi (1158.33 MPa) respectively, were realized at ambient temperature, for the direct double aged specimens.

No failures occurred in the single or double aged longitudinal and 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.

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

SUMMARY

This report presents the mechanical properties and the stress corrosion resistance of double melted [vacuum induction melted (VIM) and vacuum arc remelted (VAR)] solution treated, work strengthened and direct aged Inconel 718 alloy bar [5.50 in. (13.97 cm) diameter] processed by Wyman Gordon.

Tensile test data generated by the Marshall Space Flight Center's (MSFC) Materials and Processes (M&P) Laboratory and by Wyman Gordon are tabulated for comparison.

The moderately 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°C).

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 preliminary investigation indicates a breakthrough by Wyman Gordon in processing large diameter bars of Inconel 718 alloy. Their processing of 5.50 in. (13.97 cm) diameter bar has resulted in increased yield strengths, elongation, and reduction of area and a significant reduction in grain size.

The preliminary investigation of moderately work strengthened and direct single and double aged material, as reported in this paper, resulted in a second evaluation of Wyman Gordon's work strengthened material with higher yield and ultimate strengths. The results of that investigation were published in NASA Technical Paper 2634 [1]. Based on that test data generated by Wyman and 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 Report, "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 (A) and (B) configuration specimens were determined by using a Tinius Olsen (DS-30) Servohydraulic Testing Machine. The locations for the tensile specimen are shown in Figures 2 through 8. The specimen blanks were sectioned from these locations by the MSFC M&P Laboratory.

MATERIAL PROCESSING

The chemical composition of the as received material used in the investigation is shown in Table I. This material was purchased in the solution treated, work strengthened, and direct single aged condition from Wyman Gordon. The material supplier to Wyman Gordon press converted a vacuum induction melted (VIM) vacuum arc remelted (VAR) 20 in. (50.8 cm) diameter ingot to 12 in. (30.5 cm) diameter round billets.

Wyman Gordon converted the billets on a cogging press to 10 in. (25.4 cm) diameter round billets using a semi-fine grain conversion practice. The billets were then press formed on a cogging press in two operations to yield 6 in. (15.2 cm) rough round bars. The bars were then special processed to 5.50 in. (13.97 cm) diameters and single aged at 1325°F (718°C) for 10 hours – furnace cooled to 1150°F (621°C) – hold for a total single aging time of 20 hours (repeat for double aging). The processing and heat treatment are documented in the Wyman Gordon report, "Product Test Report No. 362" [2].

The bar ends received by MSFC were sectioned and identified as shown in Figures 2 through 8. Some of the tensile specimens from these locations were given a second aging treatment.

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 the [5.50 in. (13.97 cm) diameter] bar is tabulated in Table II. 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 12 longitudinal and 8 transverse specimens to evaluate the bar.

The ultimate tensile strength and the 0.2 percent yield strength in the longitudinal direction were slightly higher than those obtained for the transverse direction, regardless of single or double aging. The elongation and reduction of area were significantly different between the longitudinal and transverse directions. Table II represents the MSFC condensed tabulation of Wyman Gordon data, which they have thoroughly documented in a Wyman Gordon "Product Test Report No. 362" [2]. MSFC test data is also plotted in Table II for comparison purposes.

b. MSFC Test Data

The complete results of the tensile tests conducted at MSFC are tabulated in Tables II through VI. Figures 2 through 8 show the specimen locations and orientations within the bar.

Figure 9 illustrates the transverse microstructure at 100x magnifications taken from four locations identified in Figures 3 and 6. Microhardness readings (D.P.H. values converted to Rockwell C) are also shown in Figure 9. These hardness values were consistent for all four locations and averaged Rockwell C -45+.

The material processing employed by Wyman Gordon using a semi-fine grain conversion practice, when converting the billets from 12 in. (30.5 cm) to 10 in. (25.4 cm) diameter, resulted in a grain size varying from approximately ASTM size 6 to 8.

A fine grain conversion technique, used later in the production of higher strength large diameter Inconel 718 bar material, resulted in a grain size of ASTM 10 and smaller, as reported in References 1 and 2.

Tables III and IV show the mechanical property evaluation of *single* aged longitudinal and transverse tensile specimens. Although there was an insignificant difference between the longitudinal and transverse yield and ultimate tensile strengths, there was a noticable increase in elongation and reduction of area in the longitudinal direction.

Tables V and VI show the mechanical property evaluation of *double* aged longitudinal and transverse tensile specimens. Once again, there was a noticeable increase in elongation and reduction of area in the longitudinal direction. The double aging treatment indicated a slight increase in strength in both testing directions without any loss in ductility as compared to the single aged mechanical properties. For this reason a double aging treatment was later chosen for the evaluation of higher work strengthened material evaluated and reported in Reference 1.

2. Salt Fog – Stress Corrosion Tests

The stress corrosion test specimen configuration is shown in Figure 1(A). Section 2 of Figure 4 was split into two equal thicknesses to facilitate the removal of sufficient transverse tensile specimens to evaluate the stress corrosion resistance of single aged (Section 2A) and double aged (Section 2B) material removed from almost identical locations. Table VII lists the mechanical properties for both the single and double aged longitudinal and transverse tensile specimens prior to and after 180 days exposure to the salt fog environment.

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 transverse ultimate tensile and yield strengths of the stressed specimens, a phenomenon attributed to additional work strengthening of the Inconel 718 alloy.

CONCLUSIONS

Based upon our preliminary investigation of moderately work strengthened and direct single and double aged Inconel 718 alloy material processed by Wyman Gordon 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. Montano, J. W.: A Mechanical Property and Stress Corrosion Evaluation of VIM-ESR-VAR Work Strengthened and Direct Double Aged Inconel 718 Bar Material. NASA Technical Paper 2634, September 1986.

2. Wyman Gordon Product Test Report No. 362, dated January 28, 1985, Hand Forgings-Alloy Inco 718, NASA Space Shuttle, Prepared by Senior Product Metallurgist Ken Kohlstrom, assisted by Metallurgical Technician Peter Rice.

TABLE I

CHEMICAL COMPOSITION OF 5.50 in. (13.97 cm) DIAMETER DOUBLE MELTED (VIM-VAR) 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
W G Analysis															
Bar 1B3	18.78	0.045	0.10	0.12	0.003	0.001	17.66	52.54	2.92	5.32(Cb) 0.03(Ta)	1.04	0.59	0.30	0.0053	0.07
Bar 6T1	18.59	0.045	0.11	0.12	0.003	0.001	17.70	52.74	2.86	5.28(Cb) 0.03(Ta)	1.03	0.57	0.27	0.0053	0.07
MSFC Analysis															
Specimen 3L	19.11	0.047	0.13	0.10	0.004	0.003	17.48	52.82	2.90	5.26(Cb)	0.85	0.47	0.34	<0.005	0.05

Notes: Photometric Analysis For Boron & Phosphorus (MSFC Analysis)

X-ray Fluorescence Spectrometry & Combustion Analyses For Remaining Elements (MSFC Analysis)

TABLE II

MECHANICAL PROPERTIES OF INCONEL 718 ALLOY WORK STRENGTHENED AND DIRECT SINGLE AGED BAR PROCESSED BY WYMAAN GORDON FROM ALLVAC HEAT E 56 (MSFC vs WYMAN GORDAN DATA)

AGED COND.	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 SPEC.	DATA
SINGLE	LONG.	166.5-171.6	168.5	204.2-207.7	205.9	17.0-22.0	38.6-44.1	29.1-29.9	6	MSFC
DOUBLE	LONG.	168.4-173.8	170.7	205.9-209.2	207.5	21.0-21.0	37.5-42.5	29.3-29.7	5	MSFC
DOUBLE *	LONG.	169.5-174.7	171.5	206.4-208.6	207.2	19.0-22.0	39.8-42.7	28.1-30.8	5	MSFC
SINGLE	LONG.	173.7-178.0	175.5	200.0-207.2	203.0	20.0-22.0	45.0-47.0	--	6	WG
DOUBLE	LONG.	172-8-181.8	176.4	200.8-208.0	204.6	22.0-25.0	44.0-46.0	--	6	WG
SINGLE	TRANS.	162.4-176.7	169.3	197.8-207.3	200.4	12.0-16.0	19.2-27.4	28.9-30.1	7	MSFC
DOUBLE	TRANS.	171.1-180.1	175.2	201.0-205.5	202.1	13.0-18.0	21.2-28.9	28.9-30.2	7	MSFC
DOUBLE *	TRANS.	172.7-178.3	175.3	203.8-206.5	205.0	14.0-16.5	25.1-31.4	28.6-29.3	9	MSFC
SINGLE	TRANS.	170.0-171.6	170.9	195.2-200.8	198.2	19.0-19.0	30.0-34.0	--	4	WG
DOUBLE	TRANS.	172.8-180.0	176.4	202.0-205.6	203.4	19.0-21.0	30.0-33.0	--	4	WG

NOTES:

MSFC - Longitudinal & Transverse (Radial) Specimens - 0.1250 inch (.3175cm) Gage Diameter.
* - Longitudinal & Transverse Stress Corrosion - 0.2500 inch (.6350cm) Gage Diameter.

WG - Longitudinal Specimens - 0.252 inch (0.640cm) Gage Diameter.
- Transverse (Radial) Specimens - 0.178 inch (0.452cm) Gage Diameter.

1000 psi = 1 KSi = 6.8948 Mn/m^2 = 6.8948 MPa

TABLE III

MECHANICAL PROPERTIES OF INCONEL 718 ALLOY WORK STRENGTHENED AND DIRECT SINGLE AGED BAR PROCESSED BY WYMAN GORDON FROM ALLVAC HEAT E 563

LONGITUDINAL TENSILE SPECIMENS

SPECIMEN NUMBER	NOMINAL GAGE DIA. INCHES	(CM)	YIELD STRENGTH KSI	(MPa)	ULTIMATE TENSILE STRENGTH KSI	(MPa)	MODULUS X 10-6 PSI	(MPa)	ELONG 4D%	RA %
1L	0.125	(0.318)	167.7	(1156.2)	204.2	(1407.9)	29.3	(0.2020)	18.0	40.0
7LA	0.125	(0.318)	169.2	(1166.6)	205.5	(1416.9)	29.1	(0.2006)	19.0	42.6
15LA	0.125	(0.318)	166.5	(1148.0)	205.8	(1418.9)	29.1	(0.2006)	22.0	45.0
24LA	0.125	(0.318)	166.5	(1148.0)	207.7	(1432.0)	29.9	(0.2061)	22.0	42.6
33LA	0.125	(0.318)	169.5	(1168.7)	207.2	(1428.6)	29.7	(0.2048)	18.0	44.1
39L	0.125	(0.318)	171.6	(1183.1)	204.9	(1412.7)	29.9	(0.2061)	18.0	42.6
AVERAGE			168.5	(1161.8)	205.9	(1419.6)	29.5	(0.2034)	19.5	42.8
1 *	0.125	(0.318)	173.2	(1194.2)	212.8	(1467.2)	30.2	(0.2082)	18.0	42.0
2 *	0.125	(0.318)	178.2	(1228.6)	212.9	(1467.9)	30.8	(0.2123)	21.0	44.1
6 *	0.125	(0.318)	170.0	(1172.1)	209.9	(1447.2)	29.4	(0.2027)	20.0	44.2
9 *	0.125	(0.318)	169.8	(1170.7)	210.7	(1452.7)	29.7	(0.2048)	22.0	43.8
AVERAGE			172.8	(1191.4)	211.6	(1458.9)	30.0	(0.2070)	20.2	43.5

NOTES: * Stress Corrosion Specimens Stressed to 100% of Y.S. - Tensile tested after 180 day exposure to salt fog.

1000 psi = 1 KSi = 6.8948 Mn/m^2 = 6.8948 MPa

TABLE IV

MECHANICAL PROPERTIES OF INCONEL 718 ALLOY WORK STRENGTHENED AND DIRECT SINGLE AGED BAR PROCESSED BY WYMEN GORDON FROM ALLVAC HEAT E 563

TRANSVERSE TENSILE SPECIMENS

SPECIMEN NUMBER	NOMINAL GAGE DIA. INCHES	(CM)	YIELD STRENGTH KSi	(MPa)	ULTIMATE TENSILE STRENGTH KSi	(MPa)	MODULUS X 10^{-6} KSi	(MPa)	ELONG 4D%	RA %
1A	0.125	(0.318)	167.2	(1152.8)	200.2	(1380.3)	28.9	(0.1992)	16.0	25.0
2A	0.125	(0.318)	171.3	(1181.1)	199.0	(1372.1)	29.8	(0.2055)	16.0	27.3
3A	0.125	(0.318)	168.0	(1158.3)	197.8	(1363.8)	29.1	(0.2006)	16.0	27.0
4A	0.125	(0.318)	170.6	(1176.2)	199.7	(1376.9)	30.1	(0.2075)	14.0	27.4
5A	0.125	(0.318)	164.2	(1132.1)	198.1	(1365.8)	29.8	(0.2055)	14.0	23.3
6A	0.125	(0.318)	167.0	(1151.4)	200.6	(1383.1)	30.0	(0.2068)	16.0	25.8
7A	0.125	(0.318)	176.7	(1218.3)	207.3	(1429.3)	30.0	(0.2068)	12.0	22.4
AVERAGE			169.3	(1167.3)	200.4	(1381.7)	29.7	(0.2048)	14.9	25.5
8A *	0.125	(0.318)	171.2	(1180.4)	199.2	(1373.4)	30.8	(0.2123)	16.0	24.6
9A *	0.125	(0.318)	178.5	(1230.7)	209.8	(1446.5)	30.6	(0.2110)	15.0	24.6
10A*	0.125	(0.318)	167.1	(1152.1)	200.1	(1379.6)	30.7	(0.2117)	18.0	27.7
11A*	0.125	(0.318)	169.7	(1170.0)	199.7	(1376.9)	30.4	(0.2096)	15.0	28.6
12A*	0.125	(0.318)	167.0	(1151.4)	201.3	(1387.9)	29.2	(0.2020)	16.0	24.9
13A*	0.125	(0.318)	171.1	(1179.7)	201.5	(1389.3)	30.4	(0.2096)	16.0	26.8
14A*	0.125	(0.318)	171.4	(1181.8)	202.5	(1396.2)	29.9	(0.2061)	14.0	26.8
AVERAGE			170.8	(1177.6)	202.0	(1392.7)	30.3	(0.2089)	15.7	26.2
T1	0.250	(1.724)	166.5	(1148.0)	202.4	(1395.5)	29.3	(0.2020)	14.5	30.6
T2	0.250	(1.724)	170.1	(1172.8)	204.3	(1408.6)	31.2	(0.2151)	15.0	29.8
T3	0.250	(1.724)	168.3	(1160.4)	202.0	(1392.7)	29.1	(0.2006)	15.5	24.3
T4	0.250	(1.724)	170.3	(1174.2)	201.3	(1387.9)	29.3	(0.2020)	16.0	24.7
T5	0.250	(1.724)	168.4	(1161.1)	203.7	(1404.5)	30.7	(0.2117)	15.0	22.3
T6	0.250	(1.724)	174.4	(1202.4)	206.9	(1426.5)	29.8	)0.2055)	13.5	23.8
T7	0.250	(1.724)	170.6	(1176.2)	204.3	(1408.6)	31.0	(0.2137)	12.5	23.3
T8	0.250	(1.724)	168.7	(1163.1)	203.4	(1402.4)	29.8	(0.2055)	14.5	27.1
T9	0.250	(1.724)	171.4	(1181.8)	203.6	(1403.8)	29.7	(0.2048)	13.5	26.8
AVERAGE			169.9	(1171.4)	203.5	(1403.1)	30.0	(0.2068)	14.4	25.9

NOTES: * Corrosion Specimens Stressed to 75 & 100% of Y.S. - Tensile Tested after 180 days exposure to salt fog.

TABLE V

MECHANICAL PROPERTIES OF INCONEL 718 ALLOY WORK STRENGTHENED AND DIRECT DOUBLE AGED BAR PROCESSED BY WYMAN GORDON FROM ALLVAC HEAT E 563

LONGITUDINAL TENSILE SPECIMENS

SPECIMEN NUMBER	NOMINAL GAGE DIA. INCHES	(CM)	YIELD STRENGTH KSI	(MPa)	ULTIMATE TENSILE STRENGTH KSI	(MPa)	MODULUS X 10-6 PSI	(MPa)	ELONG 4D%	RA %
18LA	0.125	(0.318)	170.6	(1176.2)	208.8	(1439.6)	29.5	(0.2034)	20.0	44.6
22LA	0.125	(0.318)	173.8	(1198.3)	205.9	(1419.6)	29.3	(0.2020)	18.0	42.1
27LA	0.125	(0.318)	168.4	(1161.1)	207.3	(1429.3)	29.7	(0.2048)	20.0	43.7
36LA	0.125	(0.318)	170.3	(1174.2)	209.2	(1442.4)	29.4	(0.2027)	20.0	45.5
37LA	0.125	(0.318)	170.5	(1175.6)	206.2	(1421.7)	29.4	(0.2027)	18.0	44.2
AVERAGE			170.7	(1177.1)	208.4	(1436.9)	29.5	(0.2034)	19.2	44.0
18LB *	0.125	(0.318)	178.0	(1227.3)	213.4	(1471.3)	29.8	(0.2055)	20.0	45.3
22LB *	0.125	(0.318)	183.6	(1265.9)	213.9	(1474.8)	30.0	(0.2068)	18.0	44.1
27LB *	0.125	(0.318)	175.2	(1265.9)	212.8	(1467.2)	30.4	(0.2096)	20.0	44.9
36LB *	0.125	(0.318)	178.8	(1232.8)	212.7	(1466.5)	29.2	(0.2013)	20.0	43.6
37LB *	0.125	(0.318)	173.9	(1199.0)	214.1	(1476.2)	29.7	(0.2048)	18.0	44.1
AVERAGE			177.9	(1226.1)	213.4	(1471.2)	29.8	(0.2056)	19.2	44.4
9L	0.250	(0.635)	174.6	(1203.8)	208.6	(1438.2)	29.4	(0.2027)	20.5	42.4
17L	0.250	(0.635)	169.5	(1168.7)	206.4	(1423.1)	28.1	(0.1937)	19.5	41.4
26L	0.250	(0.635)	169.8	(1170.7)	206.5	(1423.8)	30.8	(0.2124)	19.0	41.9
35L	0.250	(0.635)	171.2	(1180.4)	207.7	(1432.0)	29.4	(0.2027)	18.0	41.6
42L	0.250	(0.635)	172.4	(1188.7)	206.9	(1426.5)	30.4	(0.2096)	19.0	43.1
AVERAGE			171.5	(1182.4)	207.2	(1428.7)	29.6	(0.2042)	19.0	42.1

NOTES: * 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

TABLE VI

MECHANICAL PROPERTIES OF INCONEL 718 ALLOY WORK STRENGTHENED AND DIRECT DOUBLE AGED BAR PROCESSED BY WYMEN GORDON FROM ALLVAC HEAT E 563

TRANSVERSE TENSILE SPECIMENS

SPECIMEN NUMBER	NOMINAL GAGE DIA.		YIELD STRENGTH		ULTIMATE TENSILE STRENGTH		MODULUS X 10-6		ELONG 4D%	RA %
	INCHES	(CM)	KSI	(MPa)	KSI	(MPa)	PSI	(MPa)		
1B	0.125	(0.318)	176.2	(1214.9)	202.4	(1395.5)	30.2	(0.2082)	18.0	21.8
2B	0.125	(0.318)	172.8	(1191.4)	201.0	(1385.8)	29.6	(0.2041)	16.0	28.9
3B	0.125	(0.318)	174.9	(1205.9)	201.0	(1385.8)	29.7	(0.2048)	16.0	21.3
4B	0.125	(0.318)	178.0	(1227.3)	202.2	(1394.1)	30.1	(0.2075)	16.0	21.2
5B	0.125	(0.318)	173.2	(1194.2)	201.0	(1385.8)	30.2	(0.2082)	16.0	23.2
6B	0.125	(0.318)	171.0	(1179.7)	201.7	(1390.7)	28.9	(0.1992)	16.0	22.7
7B	0.125	(0.318)	180.1	(1241.7)	205.5	(1416.9)	29.8	(0.2055)	13.0	25.6
AVERAGE			175.2	(1207.9)	202.1	(1393.4)	29.8	(0.2055)	15.8	23.5
8B *	0.125	(0.318)	180.2	(1242.4)	205.7	(1418.3)	30.3	(0.2089)	14.0	26.8
9B *	0.125	(0.318)	177.7	(1225.2)	206.2	(1421.7)	29.9	(0.2061)	14.0	25.3
10B*	0.125	(0.318)	178.6	(1231.4)	207.9	(1433.3)	30.5	(0.2103)	16.0	27.3
11B*	0.125	(0.318)	181.2	(1249.3)	209.0	(1441.0)	30.9	(0.2130)	16.0	24.9
12B**	0.125	(0.318)	177.2	(1221.7)	206.8	(1425.8)	30.5	(0.2103)	16.0	24.8
13B**	0.125	(0.318)	176.0	(1213.5)	204.4	(1409.3)	29.8	(0.2055)	16.0	28.3
14B**	0.125	(0.318)	178.4	(1230.0)	205.8	(1418.9)	29.1	(0.2006)	14.0	26.8
AVERAGE			178.5	(1230.4)	206.5	(1424.1)	30.1	(0.2078)	15.1	26.3
T10	0.250	(0.635)	175.7	(1211.4)	205.0	(1413.4)	28.7	(0.2048)	14.5	32.6
T11	0.250	(0.635)	178.3	(1229.3)	206.5	(1423.8)	28.6	(0.1972)	16.0	29.1
T12	0.250	(0.354)	176.0	(1213.5)	204.7	(1411.4)	29.0	(0.1999)	16.5	25.1
T13	0.250	(0.635)	176.0	(1213.5)	203.8	(1405.2)	28.7	(0.1979)	16.5	25.8
T14	0.250	(0.635)	174.9	(1205.9)	205.0	(1413.4)	28.8	(0.1986)	16.5	26.4
T15	0.250	(0.635)	175.4	(1209.3)	205.8	(1418.9)	29.3	)0.2020)	14.5	26.9
T16	0.250	(0.635)	174.7	(1204.5)	204.7	(1411.4)	28.9	(0.1992)	14.0	28.9
T17	0.250	(0.635)	172.7	(1190.7)	205.0	(1413.4)	28.7	(0.1979)	16.0	28.9
T18	0.250	(0.635)	174.1	(1200.4)	204.4	(1409.3)	28.6	(0.1972)	16.0	31.4
AVERAGE			175.3	(1208.7)	205.0	(1413.3)	28.8	(0.1986)	15.6	28.3

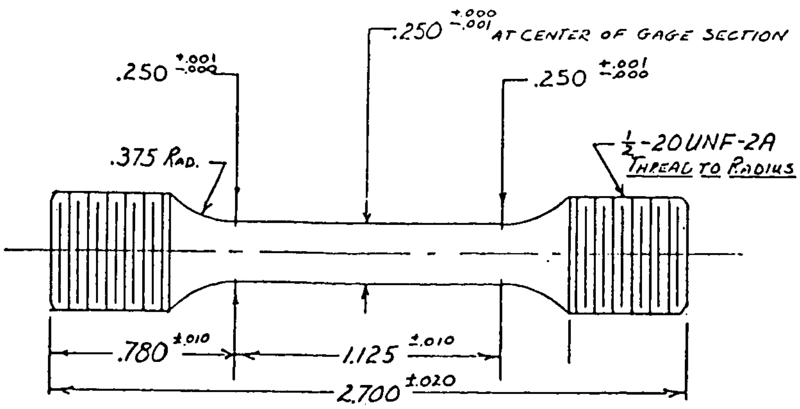
NOTES: * Stress Corrosion Specimens Stressed to 100% of Y.S. - Tensile Tested after 180 days exposure to salt fog.
** " " " " " 75% " " " " " " " " " " .
1000 psi = 1KSi = 6.8948 Mn/m^2 = 6.8948 MPa

TABLE VII

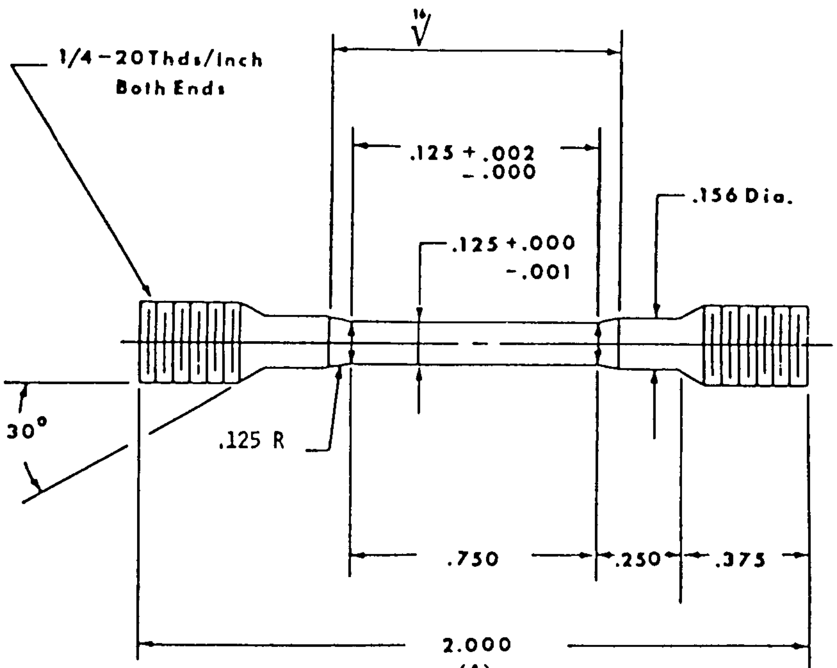
SUMMARY OF TENSILE TESTS PERFORMED ON WORK STRENGTHENED AND DIRECT AGED INCONEL 718 ALLOY BAR AFTER 180 DAYS EXPOSURE TO A 5% NaCL FOG ENVIRONMENT

EXPOSURE TIME DAYS	APPLIED STRESS PERCENT OF YIELD STRENGTH	.2% OFFSET Y.S. KSi	.2% OFFSET Y.S. (MPa)	U.T.S KSi	U.T.S (MPa)	ELONG 4D%	REDUCTION OF AREA	SPECIMEN DIRECTION	NO. OF TESTS	AGED CONDITION
0	0	168.5	(1161.8)	205.9	(1419.6)	19.5	42.8	Long	6	Single
180	100	172.8	(1191.4)	211.6	(1458.9)	20.2	43.5	Long	6	Single
0	0	169.3	(1167.3)	200.4	(1381.7)	14.9	25.5	Trans	7	Single
180	75&100*	170.8	(1177.6)	202.0	(1392.7)	15.7	26.2	Trans	7	Single
0	0	170.7	(1177.1)	208.4	(1436.9	19.2	44.0	Long	5	Double
180	100	171.5	(1182.4)	207.2	(1428.7)	19.0	42.1	Long	5	Double
0	0	175.2	(1207.9)	202.1	(1393.4)	15.8	23.5	Trans	7	Double
180	75	177.2	(1221.7)	205.7	(1418.3)	15.3	26.6	Trans	3	Double
180	100	179.4	(1236.9)	207.2	(1428.6)	15.0	26.1	Trans	4	Double

NOTES: * Specimens mixed prior to tensile tests - see Table iv for consistency of mechanical properties
Stress corrosion tensile specimens 0.1250 inch (0.3175 cm) gage diameter
1000 psi = 1 KSi = 6.8948 Mn/m^2 = 6.8948 MPa



(B)



(A)

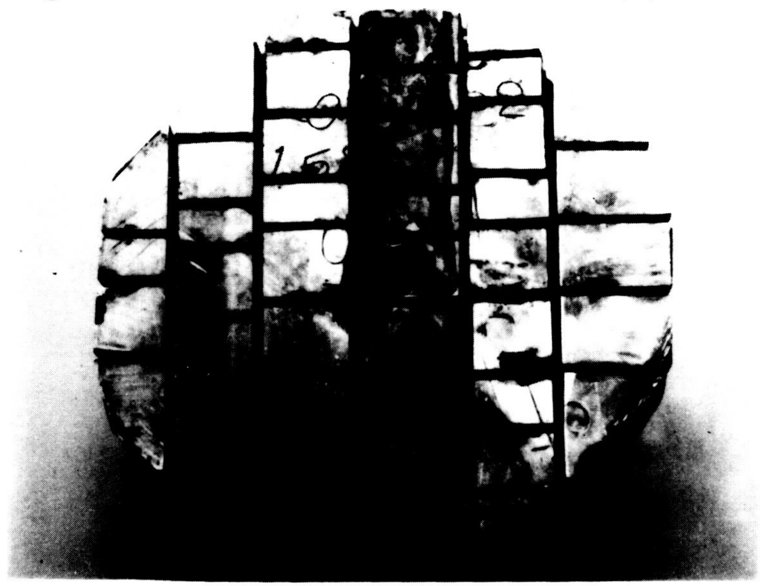
NOTES:

1. Gage Section to be concentric with axis within .002" TIR, and Parallel
2. Gage Section Finish 16-32 RMS.
3. No File Marks or Nicks Permitted within Gage Section.
4. No undercutting will be permitted at Tangency Point of Gage Section and .125" & .375" Radii.

Figure 1. MSFC Tensile Test Specimen Configurations.

(A) Initial Sectioning

(B) Secondary Sectioning – Top View



(C) Secondary Sectioning – Bottom View

Figure 2. Views of Sectioned, Solution Treated, Work Strengthened and Direct Aged Inconel 718 Alloy.

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Large & Small No's Indicate Sizes — 0.250 In. (0.635 Cm.) & 0.125 In. (0.317 Cm.) Dia.

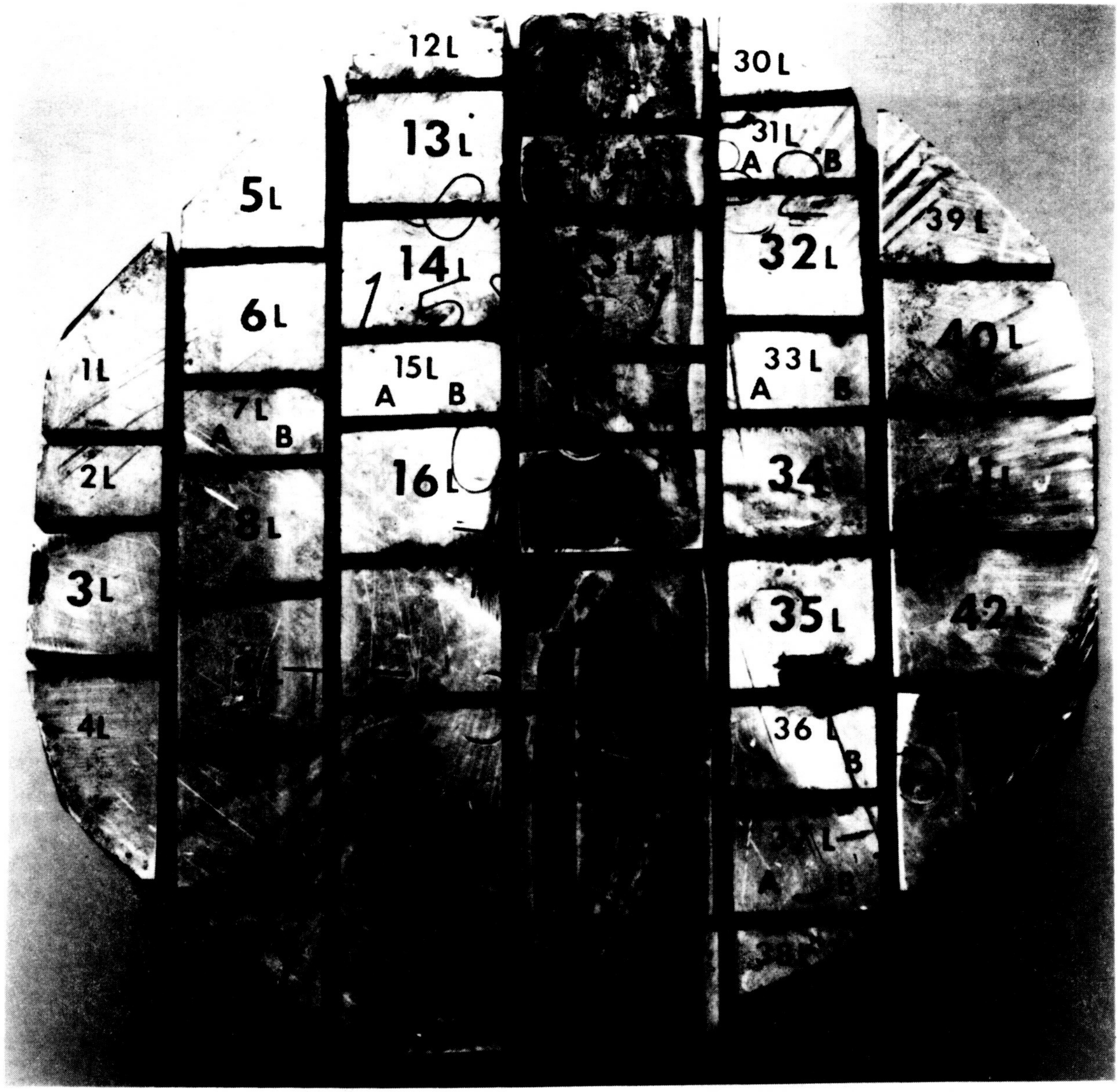

Figure 3. Enlarged View of Figure 2(C) Showing Longitudinal Specimen Locations.

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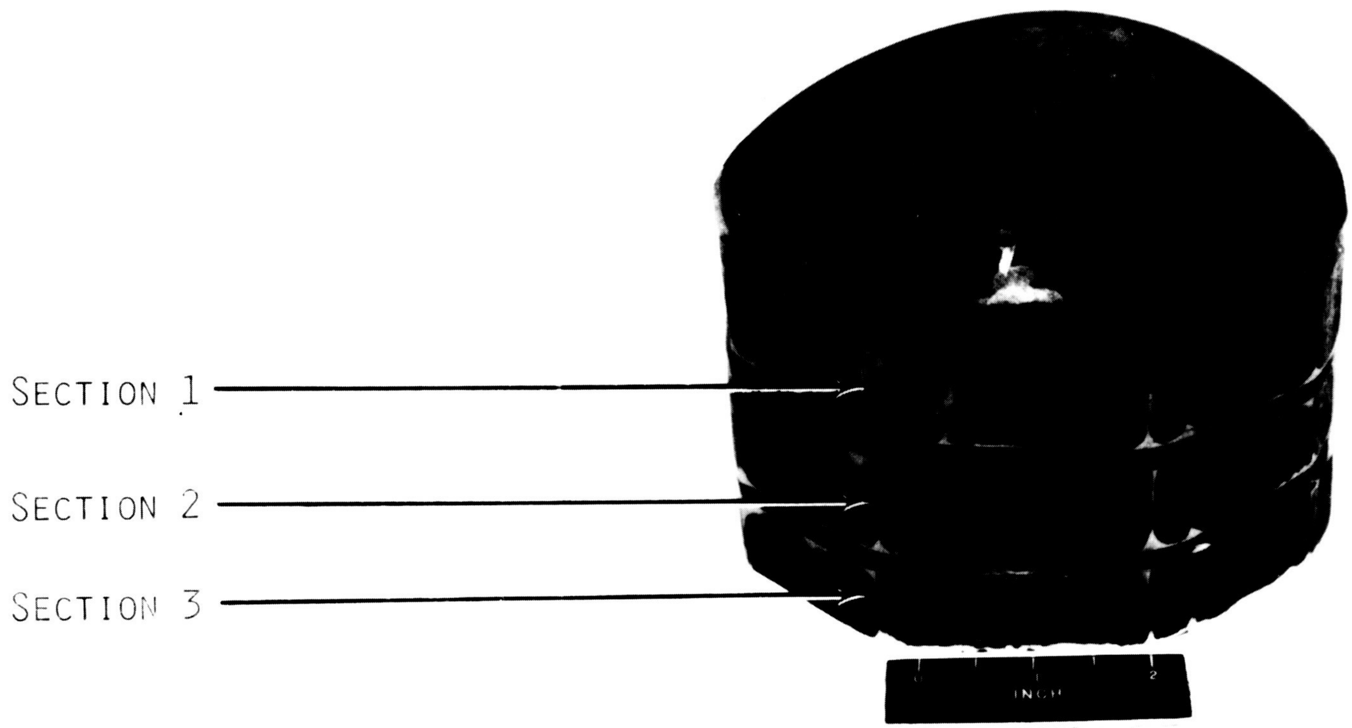

Figure 4. Sectioned View of Solution Treated, Work Strengthened and Direct Aged Inconel 718 Bar Used for Evaluation of Transverse Specimens of Wyman Gordon Processed Material.

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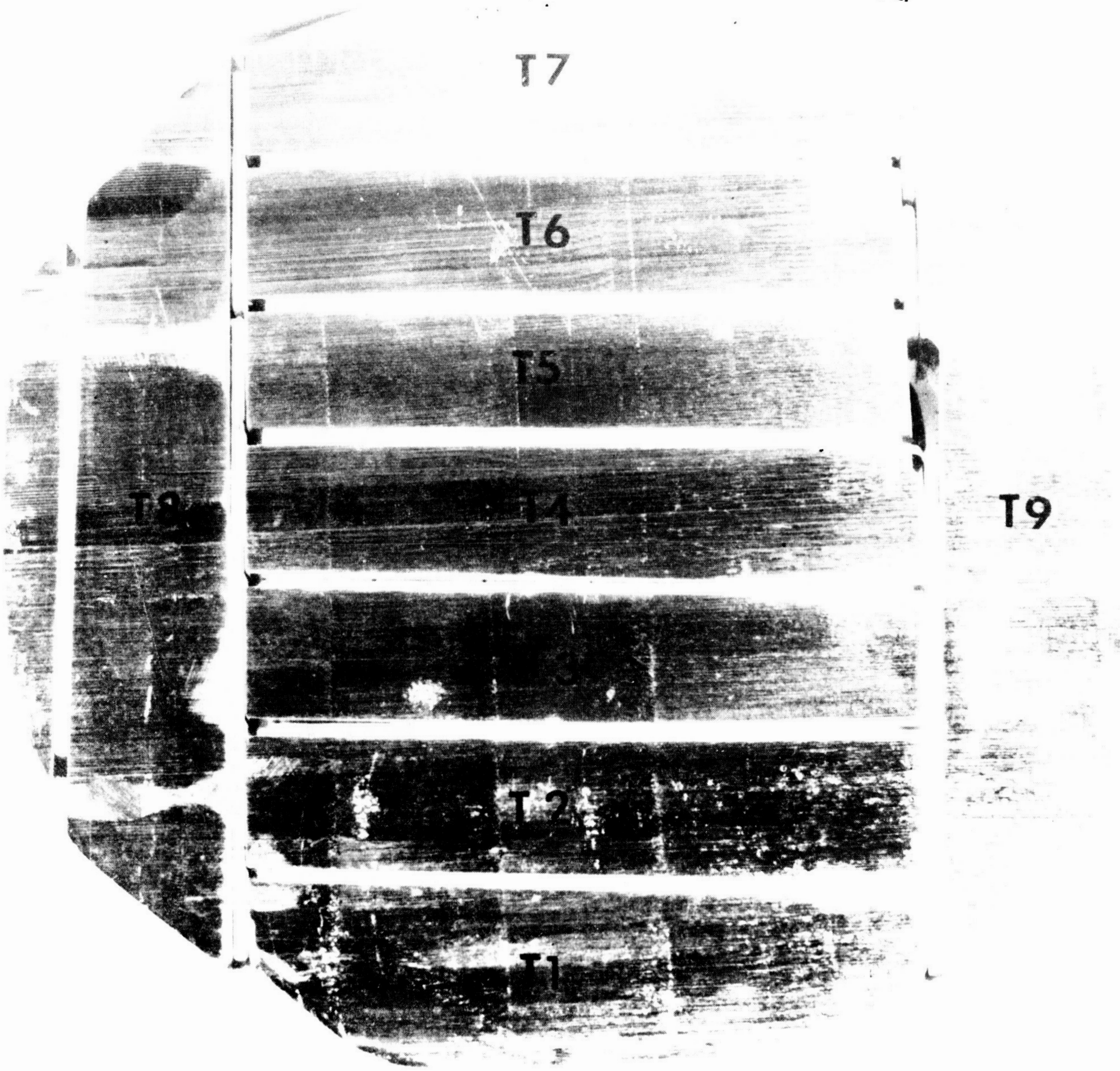

Figure 5. Transverse Specimen Locations and Identification Numbers in Section 1 of Figure 4 Wyman Gordon's Solution Treated, Work Strengthened and Direct Aged Inconel 718 Bar.

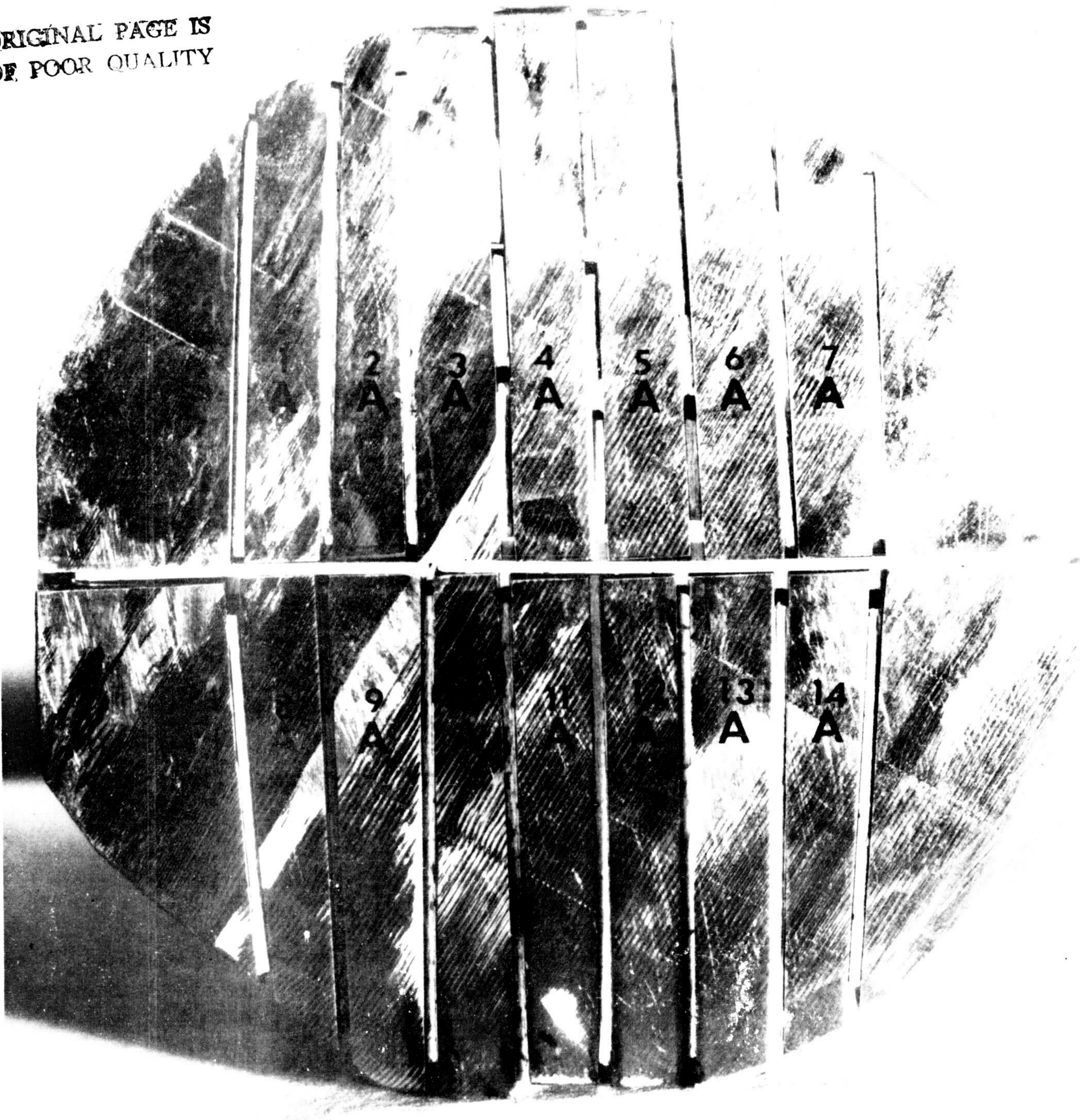

Figure 6. Transverse Specimen Locations and Identification Numbers in Section 2(A) of Figure 4
Wyman Gordon's Solution Treated, Work Strengthened and Direct Aged Inconel 718 Bar.

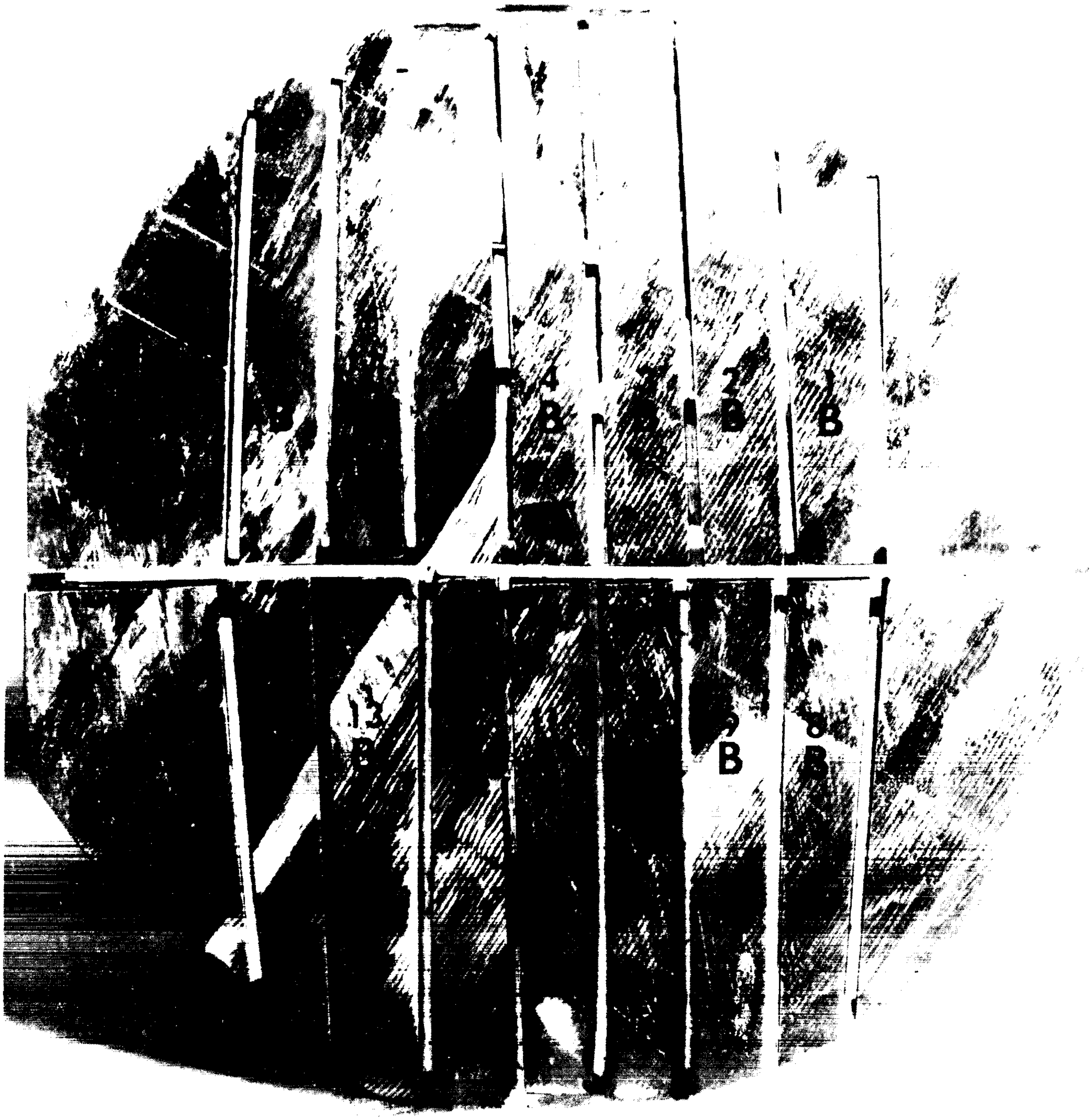

Figure 7. Transverse Specimen Loctions and Identification Numbers in Section 2(B) of Figure 4 Wyman Gordon's Solution Treated, Work Strengthened and Direct Aged Inconel 718 Bar.

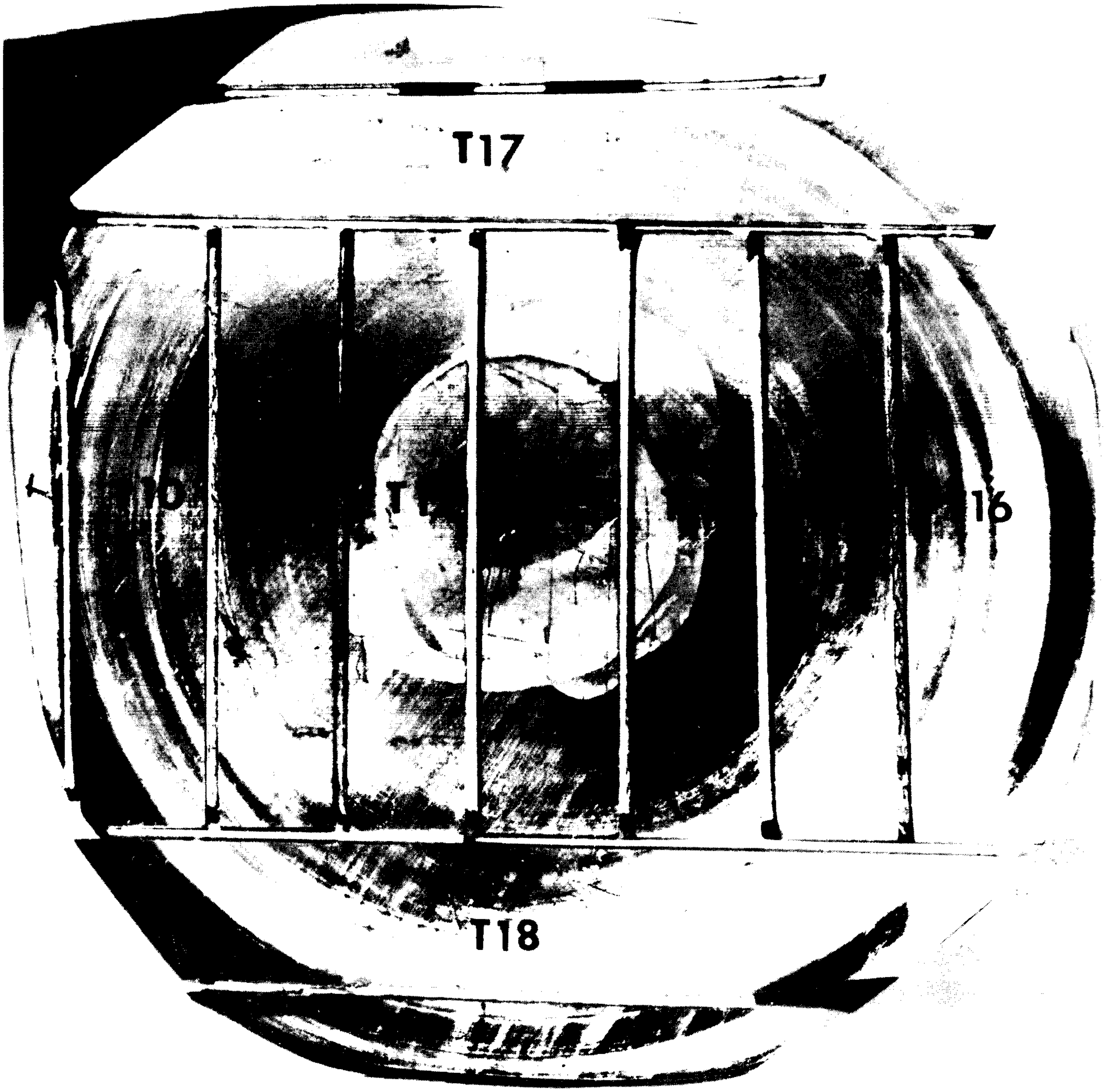

Figure 8. Transverse Specimen Locations and Identification Numbers in Section 3 of Figure 4
Wyman Gordon's Solution Treated, Work Strengthened and Direct Aged Inconel 718 Bar.

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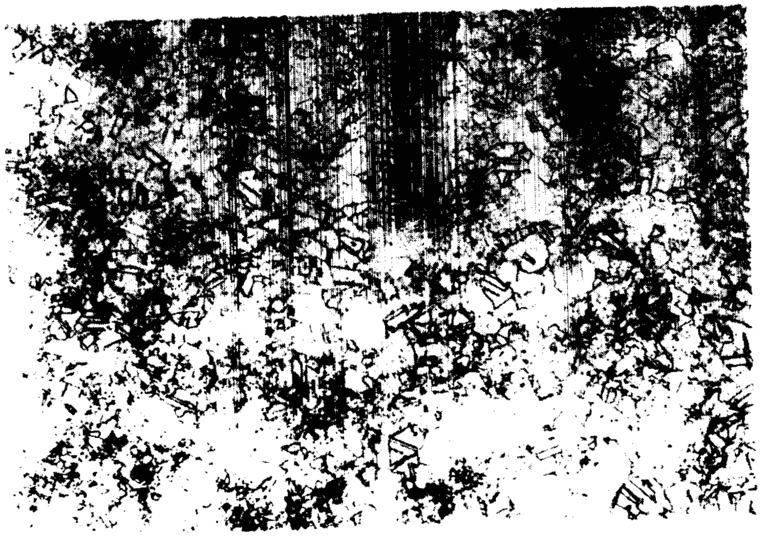
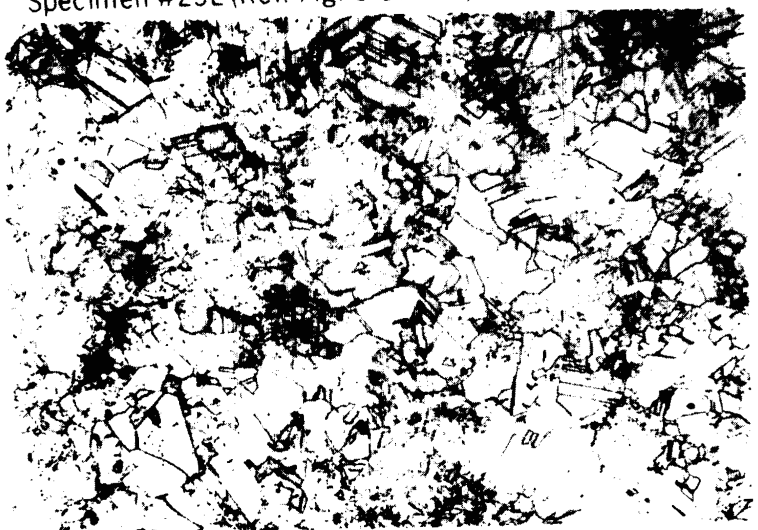
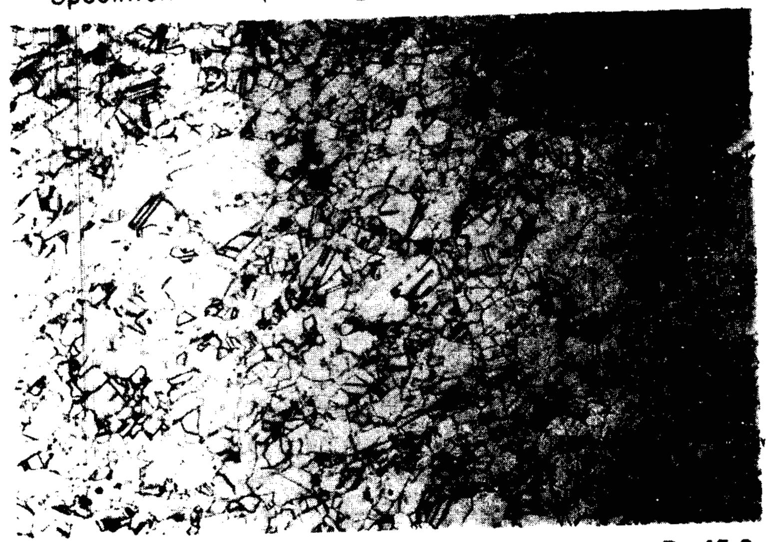


Specimen #25L (Ref: Fig. 3 Center) Hardness Rc 45.4

Specimen #41L (Ref: Fig. 3 O.D.) Hardness Rc 45.6



Specimen #4A (Ref: Fig. 6 Center) Hardness Rc 45.4



Specimen #8A (Ref: Fig. 6 Mid Radius) Hardness Rc 45.0

Kalling's Etchant   Mag. 100X

Figure 9. Transverse Microstructure of Work Strengthened Inconel 718 Bar Processed by Wyman Gordon.

APPROVAL

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

By Joseph W. Montano

The information in this report has been reviewed for technical content. Review of any information concerning Department of Defense or nuclear energy activities or programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

R. J. SCHWINGHAMER
Director
Materials and Processes Laboratory

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