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**ALLOY EVALUATION FOR FOSSIL FUEL
PROCESS PLANTS (LIQUEFACTION)**

**Annual Report for
Period**

1 October 1976 through 30 September 1977

C. M. Woods and T. E. Scott

**Ames Laboratory
Iowa State University
Ames, Iowa 50011**

October 15, 1977

**PREPARED FOR
THE UNITED STATES DEPARTMENT OF ENERGY**

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FOREWORD

This report covers work performed during the period 1 October, 1976 through 30 September 1977. The work was administered by the Division of Materials and Exploratory Research with Dr. Thomas B. Cox as project manager. The report was prepared by Charles M. Woods and T. E. Scott of the Mechanical Properties Section in the Metallurgy and Ceramics Division at the DOE - Ames Laboratory, Ames, Iowa.

The work was performed under the direction of Dr. Scott as principal investigator assisted by: C. M. Woods, S. Shei, C. V. Owen and L. K. Reed.

ABSTRACT

ASTM mechanical property specification verification tests have been conducted on the 2 1/4 Cr - 1 Mo steel. The base properties have been determined for the steel at various temperatures and after exposure to various environments. Compression load versus deflection calibration curves have been determined for 316 SS loading rings. Thermal expansivity of both the 2 1/4 Cr - 1 Mo steel and 316 SS has been determined at 500°F and 900°F. Thermal expansion characteristics and time dependence of the deflection of ring-sample composites have been measured to provide information about the constancy of stress on samples loaded by pre-compressed rings. Results of all exposure tests, including samples under load during exposure, in inert gas reveal that no degradation of ambient temperature mechanical properties occurs.

OBJECTIVE AND SCOPE

The objective of this program is to evaluate the mechanical properties of liquefaction process plant "dissolver" vessel materials in a "dissolver" vessel environment including coal slurry and pressurized hydrogen gas at temperatures up to 900°F.

Specifically, the degradation of notched-bar and smooth bar tensile samples of 2 1/4 Cr - 1 Mo will be monitored as a function of exposure time and stress in the "dissolver" vessel environment.

PROGRESS SUMMARY

I. ASTM Mechanical Property Specification Verification Tests

ASTM mechanical property specification verification tests have been carried-out and the A387-74A-Gr.22 - Cl.2 steel has been found to comply to all the mechanical property specifications in the as-received condition. Composition and mill heat treatment supplied by the vendor are given in Table 1.

A. Procedure:

Smooth-bar and notched-bar tensile samples (Fig. 1 and Fig. 2 respectively) were cut from both the longitudinal (parallel to the rolling direction) and transverse (perpendicular to the rolling direction) sections of the plate. These samples were tested on a Baldwin-Southwark tensile test machine under ambient conditions at a constant strain rate, of 0.01 min^{-1} . Charpy V-notch samples (Fig. 3) were machined from both the longitudinal and transverse sections of the plate with the notch being milled parallel to the plate surface for both types of samples. The samples were tested over the temperature range -195.8°C to 25°C.

Three hardness readings were made on each of the 32 Charpy samples to check the hardness variation among locations in the plate. The tests were done on a Wilson Rockwell Hardness tester. Readings were taken across the notched face approximately 0.25 inches from the notch.

The microstructure of the as received material was elucidated by mechanically polishing and subsequently etching with 2% nital solution (2% HNO_3 in methanol) for ten seconds.

B. Results

Mechanical Properties investigated were the 0.2% yield stress, ultimate tensile strength, uniform elongation, total elongation, engineering fracture stress, true fracture stress, reduction in area, and notch tensile strength. The results for the longitudinal and transverse samples are given in Table 2 for smooth-bar samples and in Table 3 for notched-bar samples. As is apparent from the tables, the transverse properties differed from the longitudinal in the engineering fracture stress, notch-tensile strength, true fracture stress, uniform elongation (U.E.), and reduction in area (R.A.). The ductility in the longitudinal direction was slightly greater than that of the transverse direction as revealed by the reduction in area and uniform elongation.

Results of the Charpy V-notch test are given in Tables 4 and 5, and Fig. 4. It was found that the transverse samples had much lower impact properties than the longitudinal samples. One observation worth noting here is that the notch radius for the transverse samples was sharper (0.16 mm) than that of the longitudinal samples (0.24 mm) which would produce a reduction of the impact energy. However, the impact energy for any given temperature of the transverse samples was much lower than could be attributed to the notch sharpness alone.

Hardness data is present in Table 6 and 7. The values were averaged and the hardness found to be Rockwell "C" 15 ± 2 .

The microstructure appears to be mostly upper bainite with a small fraction of free ferrite. Inclusions were detected notably in the center of the thickness dimension of the plate. They appeared to be sulfide inclusions elongated in the direction of rolling.

II. Baseline Data Tests

A. Procedure:

Smooth-bar (Fig. 5) and notched-bar (Fig. 6) tensile samples were prepared from longitudinal sections of the plate. Testing was done on a TT-C Instron tensile machine at a constant crosshead rate of 0.05 in/min. All data were calculated from the stress-strain curves. Fiducial marks were used to measure the total elongation of the samples; however, it was found that the values obtained from the stress-strain curves at the point of fracture were within 1 percent of the values obtained by measurement of the fiducial marks before and after testing. Therefore it was decided to use the stress-strain curves for the total elongation. Cross-sectional areas and reduction in area at the neck were calculated by measuring across three diameters and averaging. All diameter measurements were made on a Gaertner model 2001 Toolmaker's microscope.

Smooth-bar and notched-bar tensile tests were carried out on the as-received material at room temperature, 500°F and 900°F. Similar tests were also carried out under ambient test conditions on smooth and notched samples which had been subjected to 168-hour exposures in high pressure (2000 and 4000 psig) inert gas (Argon) at 500 and 900°F. Also, smooth-bar and notched-bar samples were loaded in tension via precompressed loading rings during 168 hour exposure to

2000 psig Argon gas at 500°F; subsequently, these samples were tested under ambient conditions. Details of the stainless steel loading rings, Fig. 7, are discussed in a subsequent section of this report.

B. Results

Mechanical properties investigated include 0.2% yield stress, ultimate tensile strength, uniform elongation, total elongation, engineering fracture stress, true fracture stress, reduction in area, and notch tensile strength. The results for the as-received material tested at room temperature, 500°F and 900°F using smooth-bar and notch-bar samples are given in Tables 8 through 13. It is readily apparent that all the mechanical properties decrease with increasing temperature.

The results for the various exposure tests (168 hours at 2000 or 4000 psig Argon at 500 and 900°F, stressed and unstressed) are given in Tables 14-23: Their average values are summarized in Table 24. These values are statistical averages based on data certified by the 'Q' test at the 90% confidence level. It can be seen from Table 24 that the room temperature mechanical properties of A387-74A-Gr.22 - Cl.2 steel are not appreciably affected by prolonged (168 hour) exposures at temperatures of 500 and 900°F under pressures of 2000 and 4000 psig Argon. Furthermore, samples exposed for 168 hours in 2000 psig Argon at 500°F under an applied tensile stress of about 48 ksi did not reveal degradation in subsequent ambient condition tests. An examination of the microstructure after exposure (168 hours) to high pressure inert gas (2000 psig Argon) at 500°F and 900°F revealed no change from that of material

in the as-received condition. The A387-74A-Gr.22 - C1.2 steel seems to be stable and unaffected by the imposed exposure conditions employed to date.

III. Thermal Expansion, Ring Calibration, and Thermal Stability Tests

A. Procedure

Average thermal expansion coefficients for both the A387-74A-Gr.22 - C1.2 steel and 316 stainless steel were determined for the 72 to 500°F and 72 to 900°F temperature ranges using a capacitance gage having a resolution of 4×10^{-7} inches. The values are listed in Table 25. Calibration curves of compression load vs. deflection at 74°F, 500°F, and 900°F were run on diametrically loaded rings of 316 stainless steel (Fig. 8). These calibration curves are given in Fig. 9.

A thermal stability test was done at 900°F to monitor the stability of the 316 stainless steel rings over a period of 168 hours. The results are plotted in Fig. 10. The ring showed good stability as demonstrated by its constant diameter with time. The points of deviance from the horizontal line (constant diameter at 904°F) can be accounted for by thermal contraction and expansion of the ring with fluctuations in the ring temperature ($\pm 5^\circ\text{F}$).

Ring-sample composites (Fig. 7) were tested to determine the actual stress on the samples at temperature. The rings were loaded in compression at room temperature in a compression cage on the TT-C Instron machine. The load was transferred to a tensile sample spanning the diameter of the pre-compressed ring (Fig. 7) by screwing the sample into the threaded section of the ring at one end and tightening a nut at the other end. The diameter of the ring was measured before and after loading. Adjustments were made until the deflection of the ring matched that of a predetermined value from the room-

temperature load vs. deflection curve (Fig. 9). At this deflection, the ring and tensile sample are in static equilibrium. The composite was then placed in the thermal expansion apparatus and allowed to equilibrate at temperature (500°F). The expansion of the composite was measured over a period of 168 hours. The results for both the smooth and notched tensile sample-ring composites are given in Figs. 11 and 12 respectively. A small load relaxation was observed during the 168 hours as indicated by the slight upward slope of the ΔL vs. time curves of Figs. 11 and 12. The value for the time-dependent relaxation is approximately 3×10^{-5} inch in 168 hours.

Three ring-sample (smooth-bar) composites were tested at initial stress levels of 48 ksi, 36 ksi and 24 ksi, and held at 900°F for 168 hours to determine whether creep occurred in the samples. The creep was measured by machining two marks, one at each end of the gage section, and measuring the gage length before and after the exposure. No appreciable permanent strain was noted.

B. Results:

The load exerted on the sample by the ring at temperature was calculated in the following manner:

At Room Temperature:

$$\text{Diameter of Unloaded Ring } D_{u_0} = 2.6947 \pm .0001 \text{ inch}$$

$$\text{Diameter of Loaded Ring } D_{l_0} = 2.6884 \pm .0001 \text{ inch}$$

$$\text{Ring Deflection } \Delta D = .0063 \pm .0002 \text{ inch}$$

From the room temperature load vs. deflection curve (Fig. 9) this deflection corresponds to a value of 1535 ± 20 lbs load on the sample which translates to a stress of $43.5 \pm .6$ ksi.

Thermal expansion of the ring alone on heating from 73.5°F to 500°F:

$$\Delta L_R = \alpha_R L_R \Delta T$$

$$\Delta L_R = (9.090 \pm .046 \mu\text{in/in/}^\circ\text{F}) (2.6947 \pm .0001 \text{ inches}) (426.5 \pm 2^\circ\text{F})$$

$$\Delta L_R = (10.447 \pm .095) \times 10^{-3} \text{ inch}$$

Thermal expansion of the sample alone on heating from 73.5°F to 500°F:

$$\Delta L_S = \alpha_S L_S \Delta T$$

$$\Delta L_S = (7.400 \pm .035 \mu\text{in/in/}^\circ\text{F}) (2.6947 \pm .0001 \text{ inches}) (426.5 \pm 2^\circ\text{F})$$

$$\Delta L_S = (8.505 \pm .086) \times 10^{-3} \text{ inch}$$

The thermal expansion differential between the 316 SS and A387 accounts for slippage of the sample in the threaded sections at each end of the composite totalling .0002 inch. This, together with the thermal expansion of the sample, gives a system relaxation of $(8.705 \pm .086) \times 10^{-3}$ inch. If it is assumed that the sample is a perfectly rigid body which lengthens only by thermal expansion and slippage, then the ring will be restrained from expanding by:

$$\begin{aligned} \Delta L_R - \Delta L_{S_0} &= (.010447 \pm .000095) - (.008705 \pm .000086) \\ &= .00174 \pm .00018 \text{ inch} \end{aligned}$$

This is an increase over the room temperature deflection of the ring by $0.00174 \pm .00018$ inch. Consequently the deflection of the ring at 500°F is:

$$\Delta D_{RmT} + \text{Added constraint due to thermal expansion}$$

$$\text{or } \Delta D_{500 \text{ RIGID}} = \Delta D_{RmT} + (\Delta L_R - \Delta L_{S_0})$$

$$\Delta D_{500 \text{ RIGID}} = (.0063 \pm .0002) + (.00174 \pm .00018)$$

$$\Delta D_{500 \text{ RIGID}} = .0080 \pm .0004 \text{ inch}$$

The load vs. deflection curve for 500°F (Fig. 9) gives a load of 1775 ± 85 lbs corresponding to a stress of 50.3 ± 2.4 ksi or an increase of 6.8 ± 3.0 ksi over the room temperature stress.

Allowing the assumed rigid sample to strain elastically to accomodate the increase in stress:

$$\Delta \epsilon_s = \frac{\Delta \sigma_s}{E_s} \approx \frac{(6.8 \pm 3.0) \times 10^3}{(2.9 \pm .1) \times 10^7}$$

$$\Delta \epsilon_s = .00023 \pm .00011 \text{ in/in}$$

The increase in length of the sample due to the elastic strain, $\Delta \epsilon_s$, is:

$$\Delta L_{s\epsilon} = \Delta \epsilon_s L_\epsilon$$

where L_ϵ is the gage length of the sample increased by thermal expansion:

$$L_\epsilon = L_{\text{gage}} (1 + \alpha_s \Delta T)$$

$$L_\epsilon = (1.060 \pm .050 \text{ in}) [1 + (7.400 \pm .035 \mu\text{in/in/}^\circ\text{F}) (426.5 \pm 2^\circ\text{F})]$$

$$L_\epsilon = (1.063 \pm .050) \text{ inch}$$

$$\text{Therefore: } \Delta L_{s\epsilon} = .00024 \pm .00013 \text{ inch}$$

The deflection of the ring at temperature is given by:

$$\Delta D_{500} = \Delta D_{500 \text{ RIGID}} - \Delta L_{s\epsilon}$$

$$\text{or } (.0080 \pm .0004) - (.00024 \pm .00013)$$

$$\Delta D_{500} = .00776 \pm .00053 \text{ inch}$$

This deflection corresponds to a load of 1715 ± 100 lbs which gives a stress in the sample of 48.6 ± 3.0 ksi. This value represents the theoretical upper limit of the stress in the sample for an initial room temperature deflection of 0.0063 inch.

The actual thermal expansion of the ring-sample composite, Fig. 8, was experimentally determined by loading the ring at room temperature and measuring the actual thermal expansion on heating from 73.5°F to 500°F. For a ring loaded to a deflection of $0.0063 \pm .0001$ inch at room temperature, the ΔL due to thermal expansion was $9.000 \pm .004 \times 10^{-3}$ inch. It has already been shown that the unloaded ring would expand $(10.447 \pm .095) \times 10^{-3}$ inch, therefore the sample restrains the ring by $(1.45 \pm .10) \times 10^{-3}$ inch. This gives a total of $(7.75 \pm .20) \times 10^{-3}$ inches of ring deflection at 500°F. From Fig. 9, this corresponds to a load of 1715 ± 40 lbs. or a stress in the sample of 48.6 ± 1.1 ksi.

Therefore, the theoretical treatment gives a value of stress of 48.6 ± 3.0 ksi, and the experimental value is 48.6 ± 1.1 ksi. It is apparent that the theoretical value of stress is in good agreement with the experimentally determined value. The stress will be reported as the average of the theoretical and experimental values bounded by the deviation, i.e.

$$\sigma = 48.6 \pm 2.1 \text{ ksi}$$

During the course of 168 hours, the ring-sample composite diameter changes by approximately 3.0×10^{-5} inches (see Fig. 11). When the composite is cooled to room temperature the loaded diameter $D_{L_f} = D_{L_0}$, but the diameter of the ring when unloaded after 168 hours was $0.0008 \pm .0002$ inch smaller than the diameter of the ring in the unloaded condition at the beginning of the experiment. In other words,

$$D_{u_0} - D_{u_f} = 0.0008 \pm .0002 \text{ inch}$$

This means that the room temperature deflection has decreased in 168 hours to $0.0055 \pm .0002$ inch. This corresponds to a load of 1340 ± 20 lbs or a

stress in the sample of 38.0 ± 0.6 ksi, i.e.

$$\Delta D_{RmT_f} = 0.0055 \pm .0002 \text{ inch}$$

The implication of this reduced room temperature ring diameter is that the sample must have experienced some unloading at temperature. An estimate of the final stress in the sample at the end of the 168 hour exposure at temperature can be calculated as follows:

Thermal expansion of the slightly deformed ring alone on heating from 73.5°F to 500°F:

$$\Delta L_{R_f} = \alpha_R L_{R_f} \Delta T$$

where L_{R_f} = diameter of the unloaded ring after the 168 hour exposure
(This reflects a small amount of permanent set possibly due to creep of the outer fibers of the ring).

$$\Delta L_{R_f} = (9.090 \pm .046 \mu\text{in/in/}^\circ\text{F}) (2.6939 \pm .0001 \text{ inches}) (426.5 \pm 2.0^\circ\text{F})$$

$$\Delta L_{R_f} = (10.444 \pm .095) \times 10^{-3} \text{ inch}$$

Thermal expansion of the sample alone on heating from 73.5°F to 500°F.

$$\Delta L_{S_f} = \alpha_s L_{S_f} \Delta T$$

where L_{S_f} = length of the sample plus some elongation due to creep as indicated by the relaxation curve Fig. 11 ($\sim 3 \times 10^{-5}$ inch).

$$\text{so } L_{S_f} = (2.6947 \pm .0001 \text{ inch})$$

$$\Delta L_{S_f} = (7.400 \pm .035 \mu\text{in/in/}^\circ\text{F}) (2.6947 \pm .0001 \text{ inch}) (426.5^\circ\text{F} \pm 2.0^\circ\text{F})$$

$$\Delta L_{S_f} = (8.505 \pm .086) \times 10^{-3} \text{ inch}$$

Considering the .0002 inch of slippage in the threaded sections gives a total sample elongation of $(8.705 \pm .086) \times 10^{-3}$ in., or:

$$\Delta L_{s_{f_0}} = (8.705 \pm .086) \times 10^{-3} \text{ inch.}$$

If it is assumed that the sample is a perfectly rigid body which lengthens only by thermal expansion, then the ring will be restrained from expanding by:

$$\begin{aligned} \Delta L_{R_f} - \Delta L_{s_{f_0}} &= (.010444 \pm .000095) - (.008705 \pm .000086) \\ &= .00174 \pm .00018 \text{ inch} \end{aligned}$$

This is an increase over the room temperature deflection of the ring. Consequently, the deflection of the ring at 500°F is:

$$\begin{aligned} &\Delta D_{RmT_f} + \text{Added constraint due to thermal expansion} \\ \text{or } \Delta D_{500 \text{ RIGID}} &= \Delta D_{RmT_f} + (\Delta L_{R_f} - \Delta L_{s_{f_0}}) \\ \Delta D_{500 \text{ RIGID}} &= (.0055 \pm .0002) + (.00174 \pm .00018) \\ \Delta D_{500 \text{ RIGID}} &= .0072 \pm .0004 \text{ inch} \end{aligned}$$

The load vs. deflection curve for 500°F (Fig. 9) gives a load of 1590 ± 85 lbs corresponding to a stress of 45.0 ± 2.4 ksi or an increase of 7.0 ± 3.0 ksi over the room temperature stress.

Allowing the assumed rigid sample to strain elastically to accomodate the increase in stress:

$$\begin{aligned} \Delta \epsilon_s &= \frac{\Delta \sigma_s}{E_s} \approx \frac{(7.0 \pm 3.0) \times 10^3}{(2.9 \pm .1) \times 10^7} \\ \Delta \epsilon_s &= .00024 \pm .00011 \text{ in/in} \end{aligned}$$

The increase in length of the sample due to the elastic strain, $\Delta \epsilon_s$, is:

$$\Delta L_{s\epsilon} = \Delta \epsilon_s L_\epsilon$$

where L_ϵ is the gage length of the crept sample increased by thermal expansion. Since the deformation (possible creep) is very small compared to the length of the sample, it will be neglected:

$$L_\epsilon = L_{\text{gage}} (1 + \alpha_s \Delta T)$$

$$L_\epsilon = (1.060 \pm .050 \text{ in}) [1 + (7.400 \pm .035 \mu\text{in/in/}^\circ\text{F}) (426.5 \pm 2.0^\circ\text{F})]$$

$$L_\epsilon = 1.063 \pm .050 \text{ in.}$$

Therefore: $\Delta L_{s\epsilon} = .00026 \pm .00013 \text{ inch}$

The deflection of the ring at temperature is given by:

$$\Delta D_{500} = \Delta D_{500 \text{ RIGID}} - \Delta L_{s\epsilon}$$

$$\text{or } \Delta D_{500} = (.0072 \pm .0004) - (.00026 \pm .00013)$$

$$\Delta D_{500} = .00694 \pm .00053 \text{ inch.}$$

This deflection corresponds to a load of $1535 \pm 100 \text{ lbs}$ which gives a stress in the sample of $43.5 \pm 3.0 \text{ ksi}$. This value represents the theoretical upper limit of the stress in the sample at the end of the 168 hour exposure. The ring dimensional change and composite diameter stated above, are the statistical averages of ten sample runs.

During the course of the 168 hour exposure to 500°F , 2000 Psig Argon gas, the theoretically calculated stress has diminished from $48.6 \pm 3.0 \text{ ksi}$ to $43.5 \pm 3.0 \text{ ksi}$.

A previous comparison of the theoretically calculated stress at the start of the run at temperature with the experimentally determined stress showed them to be the same. Assuming them to be the same at the end of the exposure, the theoretical final stress gives a reasonable estimate of the actual stress in the sample at the end of the run at temperature: The value is 43.5 ± 3.0 ksi. This will be termed the experimentally determined stress at the end of the 168 hour exposure and will be considered as the lower limit of the stress in the sample.

Therefore it is safe to say, that the stress in the sample is maintained somewhere in the region of 43.5 ± 3.0 ksi to 48.6 ± 3.0 ksi for the duration of the exposures, or 46.1 ± 6.0 ksi.

WORK FORECAST

At the time this report was written tests conditions 1 through 20 (200 samples) of Table 24 have been completed in accordance with the Revised Milestone Chart, Fig. 13. Test conditions 20 and 21 (20 samples) as indicated in Table 26, will be completed within the next three weeks, also on schedule.

Static autoclaves have not been received although delivery has now been promised by October 17, 1977. Safety modules for housing the pressure vessels are under construction and space for the pressure vessels should be ready by the time they are delivered. This puts equipment receipt, installation and check-out about one quarter behind the Revised Milestone Chart schedule. However, because testing is somewhat ahead of schedule efforts can be devoted, in the first two quarters of FY 1978, to readying the pressure vessels, tensile testing equipment and stress-rupture testing equipment. Consequently, it is possible, despite the equipment delays, that all the test conditions indicated in the FY 1978 Test Matrix, Table 27, will be completed on schedule.

TABLE #1

A387-74A GRADE 22 CLASS 2

ELEMENTAL COMPOSITION AND HEAT TREATMENT

ELEMENT	wt. %
Cr	2.41
Mo	0.93
C	0.115
S	0.029
Mn	0.42
Si	0.17

HEAT TREATMENT:

NORMALIZED, 1650°-1700°F, HELD 1 HOUR PER INCH MINIMUM AND AIR COOLED, THEN TEMPERED 1350°F, HELD 3/4 HOUR PER INCH MINIMUM AND AIR COOLED.

TABLE #2

ASTM SMOOTH BAR TENSILE SAMPLE DATA

STRAIN RATE = $\dot{\epsilon}$ = .01 in/in/min

Sample #	0.2% YS (ksi)	UTS (ksi)	Engineering Fracture Stress (ksi)	True Fract. Stress (ksi)	Uniform Elongation (%)	RA (%)
1L*	79.1	94.3	55.0	192.5	9.75%	72
2L	78.3	94.4	53.0	193.4	9.75	73
3L	78.0	93.9	54.0	200.8	9.0	73.5
4L	78.1	93.9	53.7	183.0	9.5	72
5L	78.2	94.4	54.5	192.5	8.5	72
6T**	78.1	94.1	64.5	162.0	9.5	61
7T	82.9	94.3	65.2	166.0	7.5	61.5
8T	78.3	95.2	64.8	165.0	9.0	61.5
9T	77.5	94.4	63.7	156.0	9.0	60

* L-refers to Longitudinal Sample

** T-refers to Transverse Samples

TABLE #3

ASTM NOTCHED BAR TENSILE SAMPLE DATA

 $\dot{\epsilon} = .01 \text{ in/in/min}$

Sample #	Notch Area (in ²)	Notch Radius (in)	Notch Angle (°)	Notch Tensile Strength (ksi)
1T	.2032	<.001	63.5°	137.8
2T	.2042	.001	65	139.1
3T	.2013	.001	67	139.6
4T	.2017	<.001	66	138.8
5L**	.1982	.001	66	145.3
6L	.1986	.00125	66	144.7
7L	.1996	.001	66	143.8
8L	.2007	.001	66	144.3
9L	.200	.0015	67	144.9

* T-refers to Transverse samples

** L-refers to Longitudinal samples

TABLE #4

CHARPY V-NOTCH LONGITUDINAL SAMPLES

Sample #	Test Temperature (°C)	Impact Energy (ft-lbs)	Area at Base of Notch (in ²)	Notch Radius (mm)	Notch Angle (°)
CL1	25°	>120	-	0.24	45
CL2	-78.5	5.5	.122	0.24	45
CL3	-195.8	-	.121	0.24	45
CL4	0	>120	.122	0.24	45
CL5	0	>120	.124	0.24	45
CL6	-25	78.5	.123	0.24	45
CL7	-25	70	.125	0.24	45
CL8	-50	21	.124	0.24	45
CL9	-50	17	.122	0.24	45
CL10	-75	18	.122	0.24	45
CL11	-60	27	.122	0.24	45
CL12	-195.8	2	.125	0.24	45

TABLE #5

CHARPY V-NOTCH TRANSVERSE SAMPLES

Sample #	Test Temp. (°C)	Impact Energy (ft-lbs)	Area at Base Notch (in ²)	Notch Radius (mm)	Notch Angle (°)
CT1	23°C	58.5	.125	.16 (mm)	45°
CT2	23	42	.123	.16	45
CT3	0	26.5	.124	.16	45
CT4	0	37	.123	.16	45
CT5	-25	22.5	.121	.16	45
CT6	-25	14	.124	.16	45
CT7	-25	18.5	.125	.16	45
CT8	-40	14	.122	.16	45
CT9	-40	18.5	.122	.16	45
CT10	-50	11.5	.124	.16	45
CT11	-50	20	.123	.16	45
CT12	-70	3	.125	.16	45
CT13	-70	6	.123	.16	45
CT14	-195.8	1.5	.125	.16	45
CT15	-195.8	2	.124	.16	45

TABLE #6

ROCKWELL 'C' HARDNESS

Sample #	1st	2nd	3rd	4th	Avg.
CL1	13	14	14	14	14
CL2	11	14	15	14.5	14
CL3	14	14	14.5		14
CL4	12	14.5	15.5		14
CL5	13.5	14.5	14.5		14
CL6	13	14.5	14.5		14
CL7	14	14	15		14.5
CL8	11	15	15		14
CL9	14.5	15	14.0		14.5
CL10	14.5	15	14.5		15
CL11	14	15.5	15		15
CL12	14.5	15.5	15	15	15

Overall Average = 14.5

TABLE #7

ROCKWELL 'C' HARDNESS

Sample #	1st	2nd	3rd	Avg.
CT1	12.5	16	16.5	15
CT2	15	17	17	16.5
CT3	13	16	16	15
CT4	15.5	17	17	16.5
CT5	14	16.5	16	15.5
CT6	14	17		15.5
CT7	14	16		15
CT8	13.5	15		14.5
CT9	11	15	15.5	14
CT10	15.5	16		16
CT11	15	16		15.5
CT12	16	17		16.5
CT13	15	16.5		16
CT14	14	17		15.5
CT15	12	16	15.5	14.5
CT16	13.5	16		15
CT17	14	15.5		15
CT18	14	15		14.5
CT19	16	16		16
CT20	13.5	16	16.5	15.5

Overall Average = 15.5

TABLE #8

Test 1 T=72°F P=1ATM AIR $\dot{\epsilon}$ =.05 in/in/min

HISTORY: MATERIAL IN AS RECEIVED CONDITION

SMOOTH BAR TENSILE SAMPLES

Sample #	Gage Area (in ²)	0.2% YS (ksi)	UTS (ksi)	Total Elongation (%)	Uniform Elong. (%)	Engr. Fracture Stress (ksi)	Reduction Area (%)	True Fracture Stress (ksi)
TS11	.0356	80.1	96.9	24.9	14.2	54.8	75.2	221.0
TS12	.0355	80.3	97.2	23.7	13.1	54.9	75.1	221.0
TS13	.0346	79.3	96.0	25.1	14.1	53.5	75.9	222.0
TS14	.0361	78.3	95.3	24.7	14.3	52.6	75.5	215.3
TS15	.0352	78.1	94.3	25.7	14.9	52.6	75.9	217.8
TS16	.0351	78.6	95.4	24.5	14	52.7	75.8	217.8
TS17	.0361	78.3	95.0	25.7	15.1	52.6	76	219.4
TS18	.0352	78.1	95.2	24	14.4	52.6	75.4	213.7
TS19	.0349	78.8	96.0	23.8	13.9	55.2	74.7	218.1
TS20	.0359	77.3	94.7	24.9	14.2	52.2	75.4	212.5

TABLE #9

Test 2 T=72°F P=1ATM AIR $\dot{\epsilon}$ =.05 in/in/min

HISTORY: MATERIAL IN AS RECEIVED CONDITION

NOTCHED BAR TENSILE SAMPLES

Sample #	Notch Area (in ²)	Notch Radius (in)	Notch Angle (°)	Notch Tensile Stress (ksi)	~ Area At Fracture (in ²)	~ Reduction in Area (%)
NS11	.0350	.00125	67	147.1	.0256	27
NS12	.0353	.00125	67.5	146.7	.0265	25
NS13	.0346	.00125	67	149.7	.0259	25
NS14	.0346	.001	67.5	148.0		
NS15	.0350	.00125	68	148.6		
NS16	.0343	.001	68.5	149.9		
NS17	.0346	.001	68.5	148.6		
NS18	.0350	.001	67.5	146.9		
NS19	.0346	.00125	67.5	148.6		
NS20	.0350	.001	68	148.3		

TABLE #10

Test 3 T=500°F P=1ATM AIR $\dot{\epsilon}=.05$ in/in/min

HISTORY: MATERIAL IN AS RECEIVED CONDITION

SMOOTH BAR TENSILE SAMPLES

Sample #	Gage Area (in ²)	0.2% YS (ksi)	UTS (ksi)	Total Elongation (%)	Uniform Elong. (%)	Engr. Fracture Stress (ksi)	Reduction Area (%)	True Fracture Stress (ksi)
TS31	.0349	68.1	84.0	20.9	12	51.6	73.8	196.5
TS32	.0348	69.0	83.9	21	11.7	50.3	74.2	194.6
TS33	.0354	69.9	85.0	20.6	11.3	50.8	74.6	200.2
TS34	.0353	70.1	85.0	20.5	11.3	52.4	73.1	194.7
TS35	.0355	69.7	85.2	21.4	12	51.3	74.2	198.7
TS36	.0339	68.6	84.1	21.2	11.8	50.1	74.5	196.3
TS37	.0353	68.6	83.9	22	12.2	48.9	74.0	188.3
TS38	.0351	69.5	84.8	20.9	11.4	50.7	74.4	198.0
TS39	.0356	68.8	84.3	21.7	11.7	51.1	74.3	198.7
TS40	.0345	69.6	84.9	20.5	11.3	50.7	74.4	198.3

TABLE #11

Test 4 T=500°F P=1ATM AIR $\dot{\epsilon}=.05$ in/in/min

HISTORY: MATERIAL IN AS RECEIVED CONDITION

NOTCHED BAR TENSILE SAMPLES

Sample #	Notch Area (in ²)	Notch Radius (in)	Notch Angle (°)	Notch Tensile Stress (ksi)	~ Area At Fracture (in ²)	~ Reduction in Area (%)
NS31	.0350	.00125	68	129.3	.0264	24
NS32	.0353	.00125	67	129.6	.0276	22
NS33	.0346	.00125	67.5	130.1	.0268	23
NS34	.0350	.001	68	130.0		
NS35	.0350	.001	68	129.3		
NS36	.0350	.00125	67.5	130.3		
NS37	.0343	.001	68	129.7		
NS38	.0350	.001	67.5	128.0		
NS39	.0350	.00125	68	129.7		
NS40	.0248	.001	68	129.6		

TABLE #12

Test 5 T=900°F P=1ATM Argon $\dot{\epsilon}$ =.05 in/in/min

HISTORY: MATERIAL IN AS RECEIVED CONDITION

SMOOTH BAR TENSILE SAMPLES

Sample #	Gage Area (in ²)	0.2% YS (ksi)	UTS (ksi)	Total Elongation (%)	Uniform Elong. (%)	Engr. Fracture Stress (ksi)	Reduction Area (%)	True Fracture Stress (ksi)
TS41	.0354	65.0	80.2	21.5	11.3	45.2	72.2	162.4
TS42	.0361	63.0	75.5	21.3	10.5	40.9	71.2	142.0
TS43	.0354	65.0	78.4	20.2	10.5	45.2	70.7	154.0
TS44	.0351	64.1	79.2	20.8	11.1	50.6	67.8	156.9
TS45	.0360	64.6	79.2	20.9	11.2	49.3	70.6	168.0
TS46	.0355	64.8	73.9	21.6	11.2	44.2	72.7	162.2
TS47	.0363	65.0	73.8	21.8	11	44.1	71.4	154.0
TS48	.0354	63.8	77.7	20.6	10.3	43.8	71.7	154.6
TS49	.035	63.6	77.9	21.5	10.8	42.9	72.4	155.0
TS50	.0354	64.1	78.5	21	11	44.5	70.7	151.6

TABLE #13

Test 6 T=900°F P=1ATM Argon $\dot{\epsilon}=.05$ in/in/min

HISTORY: MATERIAL IN AS RECEIVED CONDITION

NOTCHED BAR TENSILE SAMPLES

Sample #	Notch Area (in ²)	Notch Radius (in)	Notch Angle (°)	Notch Tensile Stress (ksi)	~ Area At Fracture (in ²)	~ Reduction in Area (%)
NS41	.0346	.00125	68	123.1	.0283	18%
NS42	.0346	.001	68	121.4	.0267	23%
NS43	.0348	<.001	67.5	122.1	.025	28%
NS44	.0350	.001	67.5	121.7		
NS45	.0346	.001	66.5	121.4		
NS46	.0348	.00125	66.5	119.8		
NS47	.0346	.001	67	119.9		
NS48	.0353	.00125	67	119.7		
NS49	.0348	.001	69.5	120.7		
NS50	.0351	.00125	67.5	122.8		

TABLE #14

Test 7 T=72°F P=1ATM AIR $\dot{\epsilon}$ =.05 in/in/min

HISTORY: MATERIAL EXPOSED FOR 168 HOURS AT 500°F AND 2000 psi Argon

SMOOTH BAR TENSILE SAMPLES

Sample #	Gage Area (in ²)	0.2% YS (ksi)	UTS (ksi)	Total Elongation (%)	Uniform Elong. (%)	Engr. Fracture Stress (ksi)	Reduction Area (%)	True Fracture Stress (ksi)
TS1	.0348	80.2	96.8	25	14.5	54.6	75.6	223.7
TS2	.0353	79.3	96.3	25.6	14.7	53.1	76.4	225.0
TS3	.0363	79.2	96.4	23.6	14	55.1	75.7	226.6
TS4	.0354	80.2	96.0	24.3	14	54.4	75.1	218.1
TS5	.0362	79.4	96.0	24.8	14.6	56.6	76.1	236.7
TS6	.0357	79.8	96.4	24.6	14.2	54.6	76.2	229.6
TS7	.0344	79.5	95.2	24.2	14.7	55.2	75.3	223.7
TS8	.0353	80.0	96.0	23.1	13.5	54.5	75.9	226.6
TS9	.0354	79.4	96.3	24.9	14.2	53.7	76.0	223.7
TS10	.0356	80.1	96.1	24.7	14	54.1	76.1	226.6

TABLE #15

Test 8 T=72°F P=1ATM AIR $\dot{\epsilon}=.05$ in/in/min

HISTORY: MATERIAL EXPOSED FOR 168 HOURS AT 500°F AND 2000 psi Argon

NOTCHED BAR TENSILE SAMPLES

Sample #	Notch Area (in ²)	Notch Radius (in)	Notch Angle (°)	Notch Tensile Stress (ksi)	~ Area At Fracture (in ²)	~ Reduction in Area (%)
NS1	.0346	.00125	67.5	150.3	.0263	24
NS2	.0346	.00125	67.5	148.8	.0263	24
NS3	.0343	.00125	67.5	151.6	.0253	26
NS4	.0346	.00125	68.5	149.4		
NS5	.0350	.00125	67.5	148.6		
NS6	.0353	.00125	68.5	148.7		
NS7	.0350	.00125	67.5	148.6		
NS8	.0350	.00125	68	145.7		
NS9	.0346	.00125	67	147.4		
NS10	.0353	.00125	68	147.3		

TABLE #16

Test 9 T=72°F P=1ATM AIR $\dot{\epsilon}$ =.05 in/in/min

HISTORY: MATERIAL EXPOSED FOR 168 HOURS AT 900°F AND 2000 psi Argon

SMOOTH BAR TENSILE SAMPLES

Sample #	Gage Area (in ²)	0.2% YS (ksi)	UTS (ksi)	Total Elongation (%)	Uniform Elong. (%)	Engr. Fracture Stress (ksi)	Reduction Area (%)	True Fracture Stress (ksi)
TS21	.0359	78.7	96.4	24.4	14	54.3	75.8	225.2
TS22	.0352	79.0	96.3	23.9	13.7	55.4	74.0	212.9
TS23	.0352	78.1	95.9	24.5	14.1	54.0	74.9	215.3
TS24	.0350	77.9	95.0	23.8	13.7	54.3	74.7	215.3
TS25	.0353	78.5	95.8	23.5	13.6	56.7	74	218.3
TS26	.0355	78.2	95.8	24.5	14.1	54.6	74.7	215.7
TS27	.0350	77.2	94.7	24.6	14.2	53.9	75.9	224.0
TS28	.0356	77.9	95.5	24.2	14.2	55.3	75.2	223.2
TS29	.0353	78.6	95.8	24.6	14.7	54.4	75	217.6
TS30	.0366	77.9	95.6	24.8	14.1	54.1	75.9	224.4

TABLE #17

Test 10 T=72°F P=1ATM AIR $\dot{\epsilon}=.05$ in/in/min

HISTORY: MATERIAL EXPOSED FOR 168 HOURS AT 900°F AND 2000 psi Argon

NOTCHED BAR TENSILE SAMPLES

Sample #	Notch Area (in ²)	Notch Radius (in)	Notch Angle (°)	Notch Tensile Stress (ksi)	~ Area At Fracture (in ²)	~ Reduction in Area (%)
NS21	.0350	.00125	67	148.6	.0250	29
NS22	.0346	<.00125	67.5	149.4	.0249	28
NS23	.0350	.00125	67	147.7	.027	23
NS24	.0350	.00125	68	146.3		
NS25	.0350	.00125	68	148.6		
NS26	.0350	.001	68	148.6		
NS27	.0350	.00125	68	146.0		
NS28	.0350	.001	67	147.7		
NS29	.0343	.001	66.5	148.7		
NS30	.0350	.00125	67	147.1		

TABLE #18

Test 11 T=72°F P=1ATM AIR $\dot{\epsilon}=.05 \text{ min.}^{-1}$

HISTORY: MATERIAL EXPOSED FOR 168 HOURS AT 500°F AND 4000 psi Argon

SMOOTH BAR TENSILE SAMPLES

Sample #	Gage Area (in ²)	.2% YS (ksi)	UTS (ksi)	Total Elongation (%)	Uniform Elong. (%)	Engr. Fracture Stress (ksi)	Reduction Area (%)	True Fracture Stress (ksi)
TS51	.0346	79.5	96.3	24.3	13.9	53.5	75.1	215.1
TS52	.0343	80.8	97.7	22.8	13.0	56.3	74.3	219.3
TS53	.035	78.9	95.4	24.6	14.3	52.9	76.3	222.9
TS54	.035	79.1	96.0	23.8	13.6	52.6	75.7	216.5
TS55	.0346	80.3	97.1	24.0	13.8	53.2	76.0	221.7
TS56	.0353	79.3	96.3	24.8	14.7	53.8	75.6	220.9
TS57	.0340	81.6	97.9	22.8	12.9	54.1	73.5	204.4
TS58	.035	79.3	96.3	23.1	13.2	55.0	74.3	213.9
TS59	.0346	79.5	96.1	24.6	14.0	53.2	75.7	219.0
TS60	.0343	81.9	98.5	22.0	12.8	58.3	73.2	217.4

TABLE #19

Test 12: T=72°F P=1ATM AIR $\dot{\epsilon}$ -.05 min.⁻¹

HISTORY: MATERIAL EXPOSED FOR 168 HOURS AT 500°F AND 4000 psi Argon

NOTCHED BAR TENSILE SAMPLES

Sample #	Notch Area (in ²)	Notch Radius (in)	Notch Angle (°)	Notch Tensile Stress (ksi)
NS51	.036	<.001	66.5	145.8
NS52	.0363	<.001	67.5	147.4
NS53	.0356	<.001	66	146.9
NS54	.0356	<.001	67	147.5
NS55	.0363	<.001	66.5	145.7
NS56	.036	<.001	66	145.1
NS57	.0356	<.001	67	145.8
NS58	.0356	<.001	67	148.0
NS59	.0353	<.001	67.5	147.3
NS60	.0363	<.001	66.5	144.6

TABLE #20

Test 13 T=72°F P=1ATM AIR $\dot{\epsilon}$ -.05 min.⁻¹

HISTORY: MATERIAL EXPOSED FOR 168 HOURS AT 900°F and 4000 psi Argon

SMOOTH BAR TENSILE SAMPLES

Sample #	Gage Area (in ²)	.2% YS (ksi)	UTS (ksi)	Total Elongation (%)	Uniform Elong. (%)	Engr. Fracture Stress (ksi)	Reduction Area (%)	True Fracture Stress (ksi)
TS61	.0346	79.2	96.8	24.2	13.1	53.2	75.0	212.5
TS62	.0356	79.8	97.6	22.5	12.5	55.5	74.3	215.6
TS63	.0353	79.3	97.5	23.8	13.4	55.2	74.5	216.9
TS64	.0363	79.9	97.8	24.1	13.6	55.1	74.3	214.3
TS65	.0353	79.3	97.5	23.2	12.8	55.2	74.0	212.9
TS66	.0356	79.4	97.5	23.8	12.6	52.7	75.2	212.5
TS67	.036	79.4	97.2	22.1	12.2	54.2	75.0	216.9
TS68	.0343	78.4	96.5	24.0	13.3	53.9	74.8	213.7
TS69	.0353	79.0	96.9	24.2	13.0	53.8	75.0	215.3
TS70	.0356	78.7	96.9	23.4	12.6	54.1	74.7	214.1

TABLE #21

Test 14: T=72°F P=1ATM AIR $\dot{\epsilon}=.05 \text{ min.}^{-1}$

HISTORY: MATERIAL EXPOSED FOR 168 HOURS AT 900°F AND 4000 psi Argon

NOTCHED BAR TENSILE SAMPLES

Sample #	Notch Area (in ²)	Notch Radius (in)	Notch Angle (°)	Notch Tensile Stress (ksi)
NS61	.0353	.00175	65.5	146.0
NS62	.0356	.00175	65.5	146.8
NS63	.0356	.00175	65.5	146.1
NS64	.035	.00175	65.5	147.3
NS65	.0356	.00175	65.5	147.3
NS66	.036	.00175	65.5	146.5
NS67	.0356	.00175	65.5	146.8
NS68	.035	.00175	65.5	146.0
NS69	.0356	.00175	64.5	146.8
NS70	.0353	.00175	64	146.3

TABLE #22

Test 15 T=72°F P=1ATM AIR $\dot{\epsilon}=.05 \text{ min.}^{-1}$

HISTORY: MATERIAL EXPOSED FOR 168 HOURS AT 500°F, 2000 psi Argon

AND STRESS = $46.1 \pm 6.0 \text{ ksi}$

SMOOTH BAR TENSILE SAMPLES

Sample #	Gage Area (in ²)	.2% YS (ksi)	UTS (ksi)	Total Elongation (%)	Uniform Elong. (%)	Engr. Fracture Stress (ksi)	Reduction Area (%)	True Fracture Stress (ksi)
TS71	.035	80.7	95.7	23.9	13.5	53.6	74.3	208.5
TS72	.0346	79.8	96.2	22.5	13.2	54.9	74.5	215.3
TS73	.035	79.3	95.1	23.5	13.6	54.3	73.8	207.4
TS74	.0348	79.7	95.5	20.8	12.0	54.6	74.6	215.3
TS75	.0346	79.5	96.5	23.7	13.3	53.5	75.0	213.7
TS76	.0346	78.8	96.1	21.5	12.4	54.9	74.0	211.3
TS77	.035	78.6	95.0	21.8	12.4	54.3	75.3	219.4
TS78	.035	78.6	95.4	25.2	14.0	52.9	74.8	209.6
TS79	.0346	79.5	96.1	22.2	12.9	54.2	75.0	216.5
TS80	.035	79.3	96.3	23.7	13.6	55.0	75.3	222.3

TABLE #23

Test 16: T=72°F P=ATM AIR $\dot{\epsilon}=.05 \text{ min.}^{-1}$

HISTORY: MATERIAL EXPOSED FOR 168 HOURS AT 500°F, 2000 psi Argon

AND STRESS = $46.1 \pm 6.0 \text{ ksi}$

NOTCHED BAR TENSILE SAMPLES

Sample #	Notch Area (in ²)	Notch Radius (in)	Notch Angle (°)	Notch Tensile Stress (ksi)
NS71	.0346	.0005	65	148.8
NS72	.0348	.0005	64.5	147.3
NS73	.0358	.0005	65	145.3
NS74	.0346	.0005	65	148.8
NS75	.0353	.0005	65	148.0
NS76	.0351	.0005	63.5	146.7
NS77	.036	.0005	64	145.8
NS78	.0356	.0005	65	146.1
NS79	.0353	.0005	64.5	145.9
NS80	.0351	.0005	64.5	147.4

TABLE #24

Comparison of Room Temperature Tensile Properties of A387-74A-Gr. 22-C1. 2

	From Table	0.2% YS (ksi)	UTS (ksi)	Total Elongation (%)	Uniform Elongation (%)	RA (%)	Notch Tensile (ksi) Strength
ASTM Code Specifications		45.0 min.	75.0 to 100.0	22% min.	-	45 min.	-
ASTM Specification Verification Tests (Longitudinal)	{#2 & #3}	78.3 (5)*	94.2 (5)	>22.5 (5)	9.3 (5)	72.5 (5)	146.0 (5)
ASTM Specification Verification Tests (Transverse)	{#2 & #3}	79.2 (4)	94.5 (4)	>22.5 (4)	8.8 (4)	61.0 (4)	138.8 (4)
Base Data Tests	{#8 & #9}	78.7 (10)	95.6 (10)	24.7 (10)	14.2 (10)	75.5 (10)	148.2 (10)
Exposed Sample Tests (500°F, 2000 Psig Argon)	{#14 & #15}	79.6 (10)	96.4 (9)	24.5 (10)	14.3 (10)	75.8 (10)	148.6 (10)
Exposed Sample Tests (900°F, 2000 Psig Argon)	{#16 & #17}	78.2 (10)	95.7 (10)	24.3 (10)	14.0 (10)	75.0 (10)	147.9 (10)
Exposed Sample Tests (500°F, 4000 Psig Argon)	{#18 & #19}	80.0 (10)	96.8 (10)	23.7 (10)	13.6 (10)	75.0 (10)	146.4 (10)
Exposed Sample Tests (900°F, 4000 Psig Argon)	{#20 & #21}	79.2 (10)	97.2 (10)	23.5 (10)	12.9 (10)	74.7 (10)	146.6 (10)
Stress Exposed Sample Tests (500°F, 2000 Psig, Argon, 46.1 ± 6.0 ksi).	{#22 & #23}	79.2 (9)	95.8 (10)	22.9 (10)	13.1 (10)	74.7 (10)	147.0 (10)

*The number in () following each value indicates the number of samples averaged.

TABLE #25

Thermal Expansion Data

<u>Temperature Range (°F)</u>	<u>Material</u>	<u>Thermal Expansion Coefficient (μin/in/°F)</u>
72-500	A387	7.40 $\pm$.035
72-900	A387	7.89 $\pm$.013
72-500	316 SS	9.09 $\pm$.046
72-900	316 SS	9.38 $\pm$.011

TABLE #26

FY 1977 TEST MATRIX

Test	Type	Exposure Conditions			Time (HRS.)	Exposure Stress ^A (KSI)	Test Conditions ^{A,B}			Number of samples
		Temp. (F°)	Pressure (Psig)	Envir- onment			Temp. (F°)	Pressure (Psig)	Envir- onment	
1	Smooth	-	-	-	-	-	Ambient	Ambient	Air	10
2	Notched	-	-	-	-	-	Ambient	Ambient	Air	10
3	Smooth	-	-	-	-	-	500	Ambient	Air	10
4	Notched	-	-	-	-	-	500	Ambient	Air	10
5	Smooth	-	-	-	-	-	900	Ambient	Argon	10
6	Notched	-	-	-	-	-	900	Ambient	Argon	10
7	Smooth	500	2000	Argon	168	0	Ambient	Ambient	Air	10
8	Notched	500	2000	Argon	168	0	Ambient	Ambient	Air	10
9	Smooth	900	2000	Argon	168	0	Ambient	Ambient	Air	10
10	Notched	900	2000	Argon	168	0	Ambient	Ambient	Air	10
11	Smooth	500	4000	Argon	168	0	Ambient	Ambient	Air	10
12	Notched	500	4000	Argon	168	0	Ambient	Ambient	Air	10
13	Smooth	900	4000	Argon	168	0	Ambient	Ambient	Air	10
14	Notched	900	4000	Argon	168	0	Ambient	Ambient	Air	10
15	Smooth	500	2000	Argon	168	48 ^C	Ambient	Ambient	Air	10
16	Notched	500	2000	Argon	168	40 ^C	Ambient	Ambient	Air	10
17	Smooth	900	2000	Argon	168	25 ^C	Ambient	Ambient	Air	10
18	Notched	900	2000	Argon	168	25 ^C	Ambient	Ambient	Air	10
19	Smooth	500	4000	Argon	168	48 ^C	Ambient	Ambient	Air	10
20	Notched	500	4000	Argon	168	48 ^C	Ambient	Ambient	Air	10
21	Smooth	900	4000	Argon	168	25 ^C	Ambient	Ambient	Air	10
22	Notched	900	4000	Argon	168	25 ^C	Ambient	Ambient	Air	10

A All loading is in tension

B Constant cross-head rate of 0.05 inch/min.

C Loading via precompressed rings

TABLE #27

FY 1978 TEST MATRIX

Test	Type	Exposure Conditions				Exposure ^A Stress (KSI)	Test Conditions ^{A,B}			
		Temp. (°F)	Pressure (Psig)	Envir- onment	Time (HRS)		Temp. (°F)	Pressure (Psig)	Envir- onment	Number of samples
23	Smooth	500	2000	Slurry-H ₂	1	-	500	2000	Slurry-H ₂	10
24	Notched	500	2000	Slurry-H ₂	1	-	500	2000	Slurry-H ₂	10
25	Smooth	900	2000	Slurry-H ₂	1	-	900	2000	Slurry-H ₂	10
26	Notched	900	2000	Slurry-H ₂	1	-	900	2000	Slurry-H ₂	10
27	Smooth	500	2000	Argon	1	-	500	2000	Argon	10
28	Notched	500	2000	Argon	1	-	500	2000	Argon	10
29	Smooth	900	2000	Argon	1	-	900	2000	Argon	10
30	Notched	900	2000	Argon	1	-	900	2000	Argon	10
31	Smooth	500	4000	Argon	1	-	500	4000	Argon	10
32	Notched	500	4000	Argon	1	-	500	4000	Argon	10
33	Smooth	900	4000	Argon	1	-	900	4000	Argon	10
34	Notched	900	4000	Argon	1	-	900	4000	Argon	10
35	Smooth	500	4000	Slurry-H ₂	1	-	500	4000	Slurry-H ₂	10
36	Notched	500	4000	Slurry-H ₂	1	-	500	4000	Slurry-H ₂	10
37	Smooth	900	4000	Slurry-H ₂	1	-	900	4000	Slurry-H ₂	10
38	Notched	900	4000	Slurry-H ₂	1	-	900	4000	Slurry-H ₂	10
39	Smooth	500	2000	Slurry-H ₂	168	0	Ambient	Ambient	Air	10
40	Notched	500	2000	Slurry-H ₂	168	0	Ambient	Ambient	Air	10
41	Smooth	900	2000	Slurry-H ₂	168	0	Ambient	Ambient	Air	10
42	Notched	900	2000	Slurry-H ₂	168	0	Ambient	Ambient	Air	10
43	Smooth	500	4000	Slurry-H ₂	168	0	Ambient	Ambient	Air	10
44	Notched	500	4000	Slurry-H ₂	168	0	Ambient	Ambient	Air	10
45	Smooth	900	4000	Slurry-H ₂	168	0	Ambient	Ambient	Air	10
46	Notched	900	4000	Slurry-H ₂	168	0	Ambient	Ambient	Air	10
47	Smooth	500	2000	Slurry-H ₂	168	25 ^C	Ambient	Ambient	Air	10
48	Notched	500	2000	Slurry-H ₂	168	25 ^C	Ambient	Ambient	Air	10
49	Smooth	900	2000	Slurry-H ₂	168	25 ^C	Ambient	Ambient	Air	10
50	Notched	900	2000	Slurry-H ₂	168	25 ^C	Ambient	Ambient	Air	10
51	Smooth	500	4000	Slurry-H ₂	168	25 ^C	Ambient	Ambient	Air	10
52	Notched	500	4000	Slurry-H ₂	168	25 ^C	Ambient	Ambient	Air	10
53	Smooth	900	4000	Slurry-H ₂	168	25 ^C	Ambient	Ambient	Air	10
54	Notched	900	4000	Slurry-H ₂	168	25 ^C	Ambient	Ambient	Air	10
55	Smooth	500	4000	Argon	Failure ^D	Various	-	-	-	12 ^E
56	Notched	500	4000	Argon	Failure ^D	Various	-	-	-	12 ^E
57	Smooth	900	4000	Argon	Failure ^D	Various	-	-	-	12 ^E
58	Notched	900	4000	Argon	Failure ^D	Various	-	-	-	12 ^E
59	Smooth	500	4000	Slurry-H ₂	Failure ^D	Various	-	-	-	12 ^E
60	Notched	500	4000	Slurry-H ₂	Failure ^D	Various	-	-	-	12 ^E
61	Smooth	900	4000	Slurry-H ₂	Failure ^D	Various	-	-	-	12 ^E
62	Notched	900	4000	Slurry-H ₂	Failure ^D	Various	-	-	-	12 ^E

A All loading is in tension

B Constant cross-head rate of 0.05 inch/min.

C Loading via precompressed rings

D Stress-rupture tests: Until failure or 1000 Hours whichever comes first

E Two samples at each of 6 different stress levels

Fig. 1: ASTM Standard Sample for Mechanical Properties Specification Verification Tests.

NOTCH RADIUS; ($R \leq 0.0007"$)
 SCALE: 1" = 1"

Fig. 2: ASTM Standard Notch Sample for Mechanical Properties Specification Verification Tests.

Fig. 3: Charpy V-Notch Sample

Fig. 4: Charpy Impact Energy vs. Temperature plots for A387-74A-Grade 22-Class 2 steel.

Fig. 5: Base Property Determination Smooth Tensile Sample.

SCALE: 2"=1"

Fig. 6: Base Property Determination Notched Tensile Sample.

Fig. 7: Ring-sample composites for 168 hour, stressed exposures.

MATERIAL : 316 S.S.

I.D. = 2.070"

Fig. 8: 316 S.S. ring for loading tensile samples in tension for 168 hour exposure tests.

Fig. 9: 316 S.S. ring deflection vs. compression load calibration curves.

Fig. 10: 316 S.S. ring, thermal expansion vs. time isothermal stability plot. Scatter bands represent furnace temperature fluctuations.

Fig. 11: Ring-smooth-tensile-sample-composite thermal expansion vs. time isothermal relaxation curve.

Fig. 12: Ring-notched-tensile-sample-composite thermal expansion vs. time isothermal relaxation curve.

Fig. 13. REVISED MILESTONE CHART*

*With concurrence of Dr. T. B. Cox on July 21, 1977.

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