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

Quarterly Report

1 October 1977 through 31 December 1977

C.M. Woods and T. E. Scott

**Work performed Under Contract
No. W-7405-eng-82**

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

U. S. DEPARTMENT OF ENERGY

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✓ January 15, 1978

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FOREWORD

This report covers work performed during the period 1 October, 1977 through 31 December 1977. The work was administered by the Division of Materials and Exploratory Research with Mr. Wate Bakker 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

Base properties have been determined for A387-74A-Gr. 22-C1. 2 steel at various temperatures in inert environments. Tests have been completed to monitor the actual stress level as a function of exposure time in tensile samples loaded in pre-compressed rings. Samples were exposed under various stress levels at 900°F to determine the amount of creep during the 168 hour exposures. Results of all exposure tests (including samples under load during exposure with and without creep, in inert gas) revealed that no degradation of ambient temperature mechanical properties occurred.

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. Baseline Date Tests

A. Procedure:

Smooth-bar (Fig. 1) and notched-bar (Fig. 2) tensile samples were prepared from longitudinal (parallel to the rolling direction) 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. 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 under ambient test conditions on samples which had been subjected to 168 hour exposures at stresses of 48 ksi or 20 ksi in 900°F, 2000 psig Argon gas. Similar tests were run on notched-bar and smooth-bar samples subjected to 168 hour exposures in 500°F, 4000 psig Argon gas, at a stress of 48 ksi. Finally, tests were run on smooth-bar and notched-bar tensile samples subjected to

168 hours under a stress of 20 ksi, at 900°F in 4000 psig Argon gas. All samples were loaded in tension via precompressed loading rings (Figs. 3 & 4).

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 of the various exposure tests are given in Tables 1-8. Their average values are summarized and compared with the previously determined room temperature tensile properties (Report #FE-7318-4) in Table 9. These values are statistical averages based on data certified by the 'Q' test at the 90% confidence level. It can be seen from Table 9 that the room temperature mechanical properties of A387-74A-Gr. 22-C1. 2 steel are not appreciably affected by prolonged (168 hour) stressed exposures to high temperature (500°F & 900°F), high pressure (2000 & 4000 psig) inert gas (Argon).

It must be noted here that samples loaded to 48 ksi and exposed for 168 hours at 900°F in 2000 psig Argon gas crept $\approx 0.32\%$. This creep may have resulted in the slight increase of the 0.2% yield stress of the samples, and a slight lowering of the uniform elongation. These values do not differ appreciably from the statistical variance of a test of this nature; however, there appears to be a significant trend in the lowering of the uniform elongation due to the slight creep extension.

II. Thermal Stability Tests

A. Procedure

Smooth-bar tensile samples (Fig. 1) were loaded via precompressed loading rings (Figs. 3 & 4) to three initial stress levels (48.6 ksi, 22.5 ksi, and 20 ksi) and allowed to equilibrate at 900°F in a dilatometer rig designed to monitor the ring-sample composite diameter as a function of time. Fiducial

marks were machined in each end of the sample gage sections and the distance between the marks was measured before and after a 168 hour stability run at 900°F. The ring-sample composite diameter was measured with a micrometer before and after the run. The fiducial marks were measured with the Gaertner Toolmaker's Microscope.

B. Results:

The actual stress in the sample was calculated in the following manner:

The ring-sample composite diameter was measured at room temperature at the start of the run. This will be signified as D_{L_0} . This composite diameter reflects a known amount of ring deflection imparted by compressing the ring in a compression cage on the Instron and then tightening the nut on the end of the sample (Fig. 4) in order to transfer the load to the sample. The ring-sample composite is thus at static equilibrium with the ring exerting a known load on the sample as given by the room temperature load vs deflection ring calibration curve (Fig. 5). The deflection is given by:

$$D_0 - D_{L_0} = \Delta D \quad \text{where } \Delta D \text{ is the deflection}$$

and D_0 is the unloaded ring diameter.

The ring-sample composite is placed in the dilatometer rig and the initial temperature (T_0) and the initial dilatometer reading (L_0) are recorded.

The furnace is then turned on and the ring-sample composite is allowed to equilibrate at 900°F. The temperature (T_1) and the new dilatometer reading (L_1) are recorded. The change in the diameter of the composite (ΔL) is given by:

$$\Delta L = L_1 - L_0$$

This value reflects the increase in the diameter due to thermal expansion of the composite. Since the sample has a smaller thermal expansion coefficient

than the ring (Table 10) it will constrain the ring from expanding fully thereby increasing the amount of ring deflection over that at room temperature. The increase in deflection is given by the difference between the thermal expansion of the ring alone (ΔL_R), and the actual measurement of the composite diameter change (ΔL) due to thermal equilibration. Thermal expansion of the ring alone is given by:

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

$$\text{where } \Delta T = T_1 - T_o$$

$$D_o = \text{ring diameter}$$

$$\alpha_R = \text{ring material thermal expansion coefficient}$$

The thermally induced deflection then, is given by:

$$\Delta L_R - \Delta L = \Delta D_{Th}$$

The actual deflection of the ring at 900°F is thus given by the deflection at room temperature (ΔD) plus the thermally induced deflection (ΔD_{Th}).

$$\Delta D_{Total} = \Delta D + \Delta D_{Th}$$

The 900°F ring-sample composite static equilibrium load can thus be obtained from the 900°F load vs. deflection ring calibration curve (Fig. 5) making it possible to calculate the stress in the sample.

Temperature and dilatometer readings are taken at random intervals during the 168 hour exposure run and the actual stress in the sample can be known at any time during the exposure.

The base property tests run at 500°F and 48 ksi show no indication of sample creep, therefore the stress is deemed constant throughout the course of the run. The 900°F tests, however, show considerable creep in the sample

at the 48 ksi level. This creep results in a time dependent unloading of the sample. The stress vs. time of exposure plots for the 48 ksi, 22 ksi, and 20 ksi tests are given in Figs. 6, 7 and 8 respectively.

Creep in the samples was measured three ways.

1. The difference in the ring-sample composite diameter as seen by the dilatometer from start to finish at room temperature.
2. The ring-sample composites were measured before and after the test using a micrometer at room temperature.
3. Fiducial marks were machined at the ends of the gage sections of the samples, and the distance between the marks measured before and after the run.

All three measurements were in very good agreement. For the 48 ksi test, the dilatometer gave a difference of 3.1 mils, the micrometer gave 3.2 mils and measurement of the fiducial marks gave 3.1 mils. The fiducial marks give the best indication of creep, since that is the only way the spacing between them can change. For the 22 ksi test, the dilatometer gave 0.7 mils, the micrometer gave 0.8 mils, and measurement of the fiducial marks gave 0.6 mils. The discrepancy could lie in the fact that the micrometer reading is $0.8 \pm .1$ or there could be some slippage in the threaded segments of the ring-sample composite. For the 20 ksi test, the dilatometer gave 0.55 mils, the micrometer gave 0.5 mils, and measurement of the fiducial marks gave 0.5 mils. Due to the small amount of creep, 20 ksi was chosen as the stress for the 900°F, stressed exposure tests.

It was reported in FE-7318-4 that the loading rings changed dimension during the course of the exposure runs. This was the case for the first two runs; however, the rings have not undergone any dimensional changes in any of the subsequent exposure runs.

Work Forecast

All the tests conditions 1 through 22 (Table 11) including duplicate tests 17A and 18A at 48 ksi have been completed in accordance with Revised Milestone Chart, Fig. 9.

Static autoclaves have been received and preparation for their installation and operation are now being made. Installation and checkout are about one quarter behind the Revised Milestone Chart schedule. However, because testing is somewhat ahead of schedule, efforts can be devoted in the next quarter to readying the pressure vessels, the tensile testing equipment and the stress-rupture testing equipment. Consequently, it is possible, despite the equipment delays, that all test conditions indicated in the FY 1978 test matrix, Table 12, will be completed on schedule.

TABLE #1

Test 17: T=72°F P=1ATM AIR $\dot{\epsilon}=.05 \text{ min.}^{-1}$

HISTORY: MATERIAL EXPOSED FOR 168 HOURS AT 900°F, 2000 psig Argon

AND STRESS = $19.1 \pm 1.3 \text{ ksi}$

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)
TS81	.0346	78.8	96.1	22.6	13.1	54.9	74.5	215.3
TS82	.0351	78.1	94.9	23.5	14.3	54.1	74.9	215.3
TS83	.0350	78.1	95.7	23.2	13.7	54.3	75.3	219.4
TS84	.0341	79.2	96.2	22.0	12.7	55.7	73.1	207.4
TS85	.0353	79.3	96.9	23.0	13.8	55.9	74.0	215.6
TS86	.0350	78.3	95.7	22.9	13.5	55.7	73.8	212.9
TS87	.0350	77.9	96.0	23.1	13.6	55.0	75.7	226.6
TS88	.0345	77.5	94.5	21.7	13.2	56.5	70.9	194.4
TS89	.0348	77.6	94.8	22.3	13.2	54.6	74.2	211.3
TS90	.0353	77.6	94.9	23.2	14.1	55.2	74.5	216.9

TABLE # 2

Test 17A: T=72°F P=1ATM AIR $\dot{\epsilon}=.05 \text{ min.}^{-1}$

HISTORY: MATERIAL EXPOSED FOR 168 HOURS AT 900°F, 2000 psig Argon

AND STRESS = $41.4 \pm 7.2 \text{ ksi}$

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)
TS81A	.0350	82.9	97.7	22.2	12.5	57.9	72.8	213.1
TS82A	.0346	81.6	95.7	22.2	11.4	52.7	74.5	206.8
TS83A	.0350	80.7	95.1	22.8	12.1	54.3	74.8	215.3
TS84A	.0350	80.0	95.1	22.1	12.5	53.6	72.4	193.8
TS85A	.0351	80.5	95.2	21.0	11.7	55.6	72.4	201.5
TS86A	.0351	82.6	95.4	22.2	11.9	54.8	74.9	218.1
TS87A	.0350	82.9	95.0	23.5	11.8	50.7	75.7	208.9
TS88A	.0353	79.3	94.9	22.2	12.2	53.1	75.0	212.5
TS89A	.0343	80.9	94.8	22.2	11.6	52.5	73.8	200.2
TS90A	.0351	81.9	95.7	22.6	12.2	53.4	72.9	197.3

TABLE #3

Test 18: T=72°F. P=1ATM AIR $\dot{\epsilon}=.05 \text{ min}^{-1}$

HISTORY: MATERIAL EXPOSED FOR 168 HOURS AT 900°F, 2000 psig Argon

AND STRESS = $19.1 \pm 1.3 \text{ ksi}$

NOTCHED BAR TENSILE SAMPLES

Sample #	Notch Area (in ²)	Notch Radius (in)	Notch Angle (°)	Notch Tensile Stress (ksi)
NS81	.0359	.001	65	149.0
NS82	.0351	.00175	65	150.7
NS83	.0359	.001	65.5	147.6
NS84	.0358	.001	65	146.9
NS85	.0362	.001	66	146.4
NS86	.0360	.001	65	146.9
NS87	.0351	.001	66	148.1
NS88	.0360	.001	65	147.2
NS89	.0349	.00175	65	148.7
NS90	.0360	.001	66	146.5

TABLE #4

Test 18A: T=72°F P=1ATM AIR $\dot{\epsilon}=.05 \text{ min.}^{-1}$

HISTORY: MATERIAL EXPOSED FOR 168 HOURS AT 900°F, 2000 psig, Argon

AND STRESS = $41.4 \pm 7.2 \text{ ksi}$

NOTCHED BAR TENSILE SAMPLES

Sample #	Notch Area (in ²)	Notch Radius (in)	Notch Angle (°)	Notch Tensile Stress (ksi)
NSB1A	.0353	.00025	65	149.4
NS32A	.0353	.0005	63.5	149.4
NS33A	.0346	.0005	63	149.6
NS84A	.0353	.0005	64	148.7
NS85A	.0356	.0005	66	148.1
NS86A	.0346	.0005	63	151.7
NS87A	.0350	.0005	63.5	150.0
NS88A	.0350	.0005	64	---
NS89A	.0353	.0005	65	147.3
NS90A	.0351	.00075	63	148.9

TABLE # 5

Test 19: T=72°F P=1ATM AIR $\dot{\epsilon} = .05 \text{ min.}^{-1}$

HISTORY: MATERIAL EXPOSED FOR 168 HOUR AT 500°F. 4000 psig Argon

AND STRESS = 48.6 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)
TS91	.0351	83.5	96.9	25.7%	13.6%	53.4	73.9	204.7
TS92	.0346	79.5	95.4	21.5	12.3	54.2	72.5	197.3
TS93	.0351	79.8	93.3	21.7	11.8	52.0	74.9	206.8
TS94	.0343	81.0	94.8	21.4	11.0	51.9	75.2	209.5
TS95	.0351	78.9	95.2	23.6	13.0	53.4	74.9	212.5
TS96	.0341	81.4	95.0	19.9	10.7	53.5	75.6	219.0
TS97	.0346	78.8	91.8	19.2	10.1	52.0	75.4	211.9
TS98	.0346	79.5	95.4	23.3	12.9	52.7	75.0	210.8
TS99	.0350	83.6	95.1	22.4	12.1	52.9	75.3	213.7
TS100	.0350	80.9	93.6	22.4	11.9	52.1	75.3	210.8

TABLE #6

Test 20: T=72°F P=1ATM AIR $\dot{\epsilon}=.05 \text{ min.}^{-1}$

HISTORY: MATERIAL EXPOSED FOR 168 HOURS AT 500°F. 4000 psig Argon

AND STRESS = 48.6 ksi

NOTCHED BAR TENSILE SAMPLES

Sample #	Notch Area (in ²)	Notch Radius (in)	Notch Angle (°)	Notch Tensile Stress (ksi)
NS91	.0353	.00075	65	148.7
NS92	.0351	.00075	65	149.6
NS93	.0351	.00075	64	148.1
NS94	.0351	.001	63	148.9
NS95	.0351	.00075	64	148.1
NS96	.0351	.00075	63	148.1
NS97	.0355	.00075	65	146.5
NS98	.0355	.001	63	146.8
NS99	.0353	.001	61	147.3
NS100	.0353	.001	65	147.6

TABLE #7

Test 21: T=72°F P-1ATM AIR $\dot{\epsilon}=.05 \text{ min}^{-1}$

HISTORY: MATERIAL EXPOSED FOR 168 HOURS AT 900°F, 4000 psig Argon

AND STRESS = $19.1 \pm 1.3 \text{ ksi}$

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)
TS101	.0350	78.6	96.3	23.0	13.5	55.7	74.3	216.9
TS102	.0350	78.6	95.7	23.6	14.4	55.7	74.3	216.9
TS103	.0348	77.6	94.8	22.9	13.6	54.6	74.2	211.3
TS104	.0351	76.9	94.6	25.3	14.4	52.7	75.3	213.7
TS105	.0350	77.7	95.0	23.5	13.8	55.0	74.8	218.1
TS106	.0353	76.5	93.5	24.6	14.6	53.8	74.0	207.4
TS107	.0350	76.6	93.6	23.4	13.9	54.3	74.8	215.3
TS108	.0348	76.2	93.4	22.7	12.9	53.2	74.6	209.6
TS109	.0350	76.0	93.1	24.0	14.2	52.9	74.3	205.7
TS110	.0348	76.2	92.5	23.0	13.4	53.2	75.1	213.7

TABLE #8

Test 22: T=72°F P=1ATM AIR $\dot{\epsilon}=.05 \text{ min}^{-1}$

HISTORY: MATERIAL EXPOSED FOR 168 HOURS AT 900°F, 4000 psig Argon

AND STRESS + 19.1 $\pm$ 1.3 ksi

NOTCHED BAR TENSILE SAMPLES

Sample #	Notch Area (in ²)	Notch Radius (in)	Notch Angle (°)	Notch Tensile Stress (ksi)
NS101	.0359	.001	65	144.8
NS102	.0352	.001	65.5	145.6
NS103	.0357	.00075	65	145.0
NS104	.0356	.001	65	146.1
NS105	.0352	.00075	64	145.6
NS106	.0358	.001	65.5	145.0
NS107	.0354	.00075	63	144.8
NS108	.0363	.00125	64.5	144.6
NS109	.0356	.00075	64.5	144.0
NS110	.0360	.00125	65	144.4

TABLE #9

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

	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)	78.3 (5)*	94.2 (5)	>22.5 (5)	9.3 (5)	72.5 (5)	146.0 (5)
ASTM Specification Verification Tests (Transverse)	79.2 (4)	94.5 (4)	>22.5 (4)	8.8 (4)	61.0 (4)	138.8 (4)
Base Data Tests	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)	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)	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)	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)	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)	79.2 (9)	95.8 (10)	22.9 (10)	13.1 (10)	74.7 (10)	147.0 (10)
Stress Exposed Sample Tests (900°F, 2000 Psig Argon, 19.1 ± 1.3 ksi)	78.2 (10)	94.6 (10)	22.8 (10)	13.5 (10)	74.4 (9)	147.8 (10)
Stress Exposed Sample Tests (900°F, 2000 Psig Argon, 41.4 ± 7.2 ksi)	81.3 (10)	95.2 (9)	22.4 (9)	12.0 (10)	73.9 (10)	149.2 (9)
Stress Exposed Sample Tests (500°F, 4000 Psig Argon, 48.6 ksi)	80.7 (10)	94.7 (10)	22.1 (10)	11.9 (10)	75.1 (9)	148.0 (10)
Stress Exposed Sample Tests (900°F, 4000 Psig Argon, 19.1 ± 1.3 ksi)	77.1 (10)	94.3 (10)	23.6 (10)	13.9 (10)	74.6 (10)	145.0 (10)

TABLE #10

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 #11

FY 1977 TEST MATRIX

Test	Type	Exposure Conditions			Time (HRS.)	Exposure ^A Stress (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	48 ^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 #12

FY 1978 TEST MATRIX

Exposure Conditions							Test Conditions A,B			
Test	Type	Temp. (°F)	Pressure (Psig)	Environ-ment	Time (HRS)	Exposure ^A Stress (KSI)	Temp. (°F)	Pressure (Psig)	Environ-ment	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: Base Property Determination Smooth Tensile Sample.

SCALE: 2"=1"

Fig. 2: Base Property Determination Notched Tensile Sample.

MATERIAL : 316 S.S.

I.D. = 2.070"

Fig. 3 : 316 S.S. ring for loading tensile samples in tension for 168 hour exposure tests.

Fig. 4: Ring-sample composites for 168 hour, stressed exposures.

Fig. 5: 316 S.S. ring deflection vs. compression load calibration curves.

Fig. 6: Sample Stress vs. Time of Exposure for 900°F,
41.4 ± 7.2 ksi Tests.

Fig. 7: Sample Stress vs. Time of Exposure for 900°F,
21.4 $\pm$ 1.1 ksi Test.

Fig. 8: Sample Stress vs. Time of Exposure for 900°F,
 19.1 ± 1.3 ksi Tests.

Fig. 9 . REVISED MILESTONE CHART*

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

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