TID/5NA -- 2217

15p.

1 December 1971

NOV

METALLURGY SECTION
ADVANCED TECHNOLOGY
AEROJET SOLID PROPULSION COMPANY

MONTHLY PROGRESS REPORT - NOVEMBER 1971

DESIGN OF STRESS CORROSION SPECIMEN FOR DETERMINATION OF
 K_{Isc} IN PRESSURIZED GASEOUS HYDROGEN EXPOSED TO IRRADIATION

MASTER

I. INTRODUCTION

Department 4830 has been requested to determine if a synergistic effect will result when Inconel 718, A-286, SAE 9310 and Ti-5Al-2.5Sn are exposed to 1000 psi gaseous hydrogen and a nuclear reactor. The criterion used to determine any synergistic effect will be to measure the susceptibility of each test material to slow crack growth, crack growth rate and/or apparent K_{Isc} , when exposed to the nuclear environment with and without 1000 psi gaseous hydrogen. The reactor environment will include a fast neutron fluence of about 10^{20} and a specimen temperature in the range between 155 and 200°F.

The specimen development and calibration are to be conducted in three phases where Phase 1 is to design and evaluate a test specimen for Phases 2 and 3. Phase 2 will consist solely of a reactor test to determine the noise characteristics as detected by acoustic emission. This test will be conducted to determine the applicability of using acoustic emission to detect slow crack growth in a reactor environment. Phase 3 will involve in-reactor testing to determine the combined effects of 1500 psi GH_2 and the nuclear environment.

II. CURRENT STATUS SUMMARY

The preliminary program outlining objectives and procedures has been submitted.

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Energy Research and Development Administration, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

DISTRIBUTION OF THIS DOCUMENT UNLIMITED

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

A. SPECIMEN CONFIGURATION

1. Stress Corrosion Specimen

Sketches for modified WOL specimen, 1-1/2 and 2.0-in.-thick compact tension (CT) specimen, and encapsulated specimen designs have been evaluated. Minor dimensional changes to existing 1.0-in.-thick CT specimen were also made. A tentative design for the stress corrosion specimen has been completed, see Figures 1 and 2. The final design will depend on the thermal analysis being conducted by NERVA.

2. Encapsulated Specimen

Preliminary stress analysis has been completed for the specimen in Figure 1 and indicates that the encapsulation device had little effect on the stress at the crack tip. Consequently, the encapsulation design shown in Figure 1 will be used for this specimen.

B. INSTRUMENTATION FOR DETECTION OF SLOW CRACK GROWTH

Instrumentation is required to ascertain whether slow crack growth had initiated and arrested during the limited time in the reactor. Without such information, accurate comparisons could not be made between effects due to pressurized hydrogen and those in helium in a reactor environment. Since it will be necessary only to detect crack arrest, a very high system sensitivity may not be required. Two types of instrumentation, acoustic emission and strain gages, are being investigated for this purpose. Several tests have been conducted in water at 94°C but the test conditions employed have not resulted in slow crack growth so that a relative evaluation of the two test methods has not been possible.

1. Stress Wave Analysis Technique (SWAT)

a. Sensors

Preliminary information concerning stress wave emission sensors that could be used in the reactor has been obtained. Comparison test data between a possible sensor (Endevco P-15) for use in the reactor tests and the sensor (Endevco 2213E) presently being used for data collection by ASPC has been obtained. Both sensors (P-15 and 2213E) were connected to voltage amplifiers and the P-15 results compared very favorably to the results obtained using the 2213 sensor. The major problem associated with the P-15

type sensors is low capacitance (on the order of 50 pf). A second sensor fabricated from a P-14 crystal appears to be suitable because it has a higher capacitance (on the order of 300 pf). Tests have not been made on the P-14 sensor to determine its sensitivity as compared to the P-15 or the 2213, but tests at Endevco have found the P-14 to be approximately 20% as sensitive as the P-15. However, the P-14 sensor is less sensitive to the cable capacitance than the P-15 sensor so that with 15 feet of cable, it is thought that the P-15 sensor would be twice as sensitive as the P-14 unit. Both sensors and cables have been ordered to evaluate the combined sensor-cable sensitivity.

Gulton Industries have supplied ASPC with a sensor so sensitivity measurements could be compared with the P-14 and P-15. The Gulton Industries' sensor has been received and comparison tests are scheduled for next month.

A hard-line triaxial cable has been selected for the tests because of a lower noise level. As the sensors will be exposed to water, it has also been decided to fabricate the cable and sensor as an integral unit in order to eliminate fittings which could be a source of leakage. A supplier for line drivers (preamplifier) that will withstand exposure to radiation and water has been found.

2. Alternate Approaches to Detect Slow Crack Growth

a. Instrumentated Tup

An instrumentated tup suitable for use in water at 200°F has been fabricated but slow crack growth has not occurred in the tests performed to date using this instrumentation. However, during these tests difficulties were encountered due to eventual water penetration of the insulation which resulted in a continuously changing zero shift. These difficulties have not been eliminated although an additional test is now in progress.

Welded strain gages with integral cables have been mounted to the tup (see Figure 1) and preliminary tests made which indicated much less drift than previously observed using waterproofing agents. Additional tests are planned.

b. Strain Gages

Strain gages can be placed along the path of slow crack growth but difficulties are anticipated in the design of an acceptable entrance port through the encapsulation device for the lead wires. An alternate approach would be to mount the strain gages on the edge of the encapsulation device, offset from the path of slow crack growth, although the sensitivity attainable using this approach requires definition. Another alternate approach would be to mount the strain gage on the backside of the specimen, opposite the COD gage, and measure the change in load by monitoring the change in strain at this location. This approach would be applicable to the modified WOL specimen, but may not be useful for the 6-in. long specimen anticipated for our tests. No tests have been run to determine the sensitivity of the strain gages as a method for detecting slow crack growth; such tests are planned during the next reporting period.

III. ACTIVITIES DURING THE REPORTING PERIOD

PHASE I - DESIGN AND EVALUATION

A. TESTING

A fatigue-precracked, SAE 9310, modified WOL specimen was loaded to successively higher loads and placed in deionized water; the results obtained to date and shown in Table I indicate no measureable crack growth. The crack length (a) was based on an average of two surface measurements and the specimen has not been failed and will be used for further testing. The differences observed between the initial and final Δ COD could be the result of crack growth, corrosion products, or plastic deformation. Although there was no slow crack growth observed from surface measurements, internal crack growth (tunneling) could have occurred but not be physically observed unless the specimen was fractured and the fracture face examined. Also, considerable rust was observed in the crack which could tend to act as a cushion and reduce the final COD reading resulting in a reduction of Δ COD. Obviously, the problems associated with rust will not be encountered in the pressurized gaseous hydrogen tests.

B. SLOW CRACK GROWTH DETECTION

1. Instrumentated Tup

Weldable strain gages and integral cables were also mounted on both sides of the 9310 specimen as shown in Figure 1. The specimen was placed in hot water (75°C) and the output signal monitored by the strip chart recorder. Slight drift was observed for 16 hours at which time erratic behavior was observed. Later examination of the system revealed that an amplifier had malfunctioned and was replaced.

2. Acoustic Emission

There has been no crack growth detected by acoustic emission in any of the tests performed to date. This result substantiates the crack length measurements made on the specimen surface. There have been false signals detected by the acoustic emission system that were attributed to air bubbles in the water impinging on the specimen. By placing the specimen in agitated water with the inlet tube located below the water surface the false SWE were eliminated. False SWE due to bubble impingement will not be encountered during the in reactor tests since deionized water is used for those tests. As indicated in Table I, a ground loop problem was encountered between the strain gage and the acoustic emission sensor which was eliminated in our tests by removing the strain gage. For future tests, an insulated stud on the sensor will be used and will eliminate any ground loop problems.

C. ENCAPSULATION DEVICE

No change.

D. STRESS ANALYSIS OF SPECIMEN-ENCAPSULATION DEVICE

Recent test modifications indicate it may be necessary to insert the specimen into a 2-1/2 in. diameter pipe for testing in the reactor. Consequently, a stress analysis was initiated using a specimen height of 1.8 (H = .9) and 2.0 (H = 1.0) in. to determine the effect of the reduced specimen size on the stress gradients in the specimen at anticipated loads. As a first approximation, 20 kip was selected as the maximum load supplied by the loading bolt and an analysis made for each specimen height to determine areas of localized yielding. Figures 3 and 4 are sketches of the specimen showing

regions which would be exposed to stresses above the yield strength. It was obvious that the 1.8 in. specimen would not be acceptable because of the extensive amount of yielding; therefore, the 2.0 in. specimen was selected for the next phase of the design program.

A thermal analysis made by NERVA on the specimen design indicated the temperature in the center of the specimen would be excessive. In order to lower the temperature, the possible use of side grooves to reduce the specimen volume and provide more efficient cooling was considered provided the test results are not seriously affected. As a first approximation, two groove sizes were selected (see Figure 5). Note that there appears to be about a 10% reduction in load for the same COD opening or conversely about a 10% greater COD value for the same load. The boundary conditions are shown in Figure 5 and assume a point load of 20,000 lbs applied at location 166 with a uniform pressure of 40,000 psi applied at locations 79, 61 and 80. Using the COD values shown in Figure 5, at 20.0 kip load, additional computer runs were

made to determine the load on the bolt after various increments of crack growth. The boundary conditions used for the analysis are shown in Table II along with the summary of the computer printout. The boundary conditions refer to those points on the specimen that were fixed and could not move. The variation in load at the bolt is a result of the different boundary conditions, but upon completion of tests of specimens in Figures 1 and 2 it will be possible to determine which of the boundary conditions is the more correct one.

Table II also shows the stress intensity (K_I) values and indicate that at 20 kip, $K_I = 130 \text{ ksi-in.}^{1/2}$. This value is greater than $K_q = 120, 90$ or $93 \text{ ksi-in.}^{1/2}$ for SAE 9310, A-286, and Inconel 718, respectively, so slow crack growth should occur using this specimen design and load. After about 1-in. of crack growth, the K_I value has decreased to about 1/2 the original value.

There may be some question as to the interaction of the stress from the corner of the groove on the crack tip, see Figure 2. It is anticipated that the error introduced by the groove would be minimal as this region is generally exposed to a compressive stress. Since the purpose of this program is to ascertain if a synergistic effect exists, the existing specimens would suffice but it would be of additional value if the mathematical analysis would be complete enough to obtain quantitative results.

The specimen design shown in Figure 2 has been given to NERVA for thermal analysis to determine if the maximum temperature is acceptable.

PHASE II - INITIAL SPECIMEN TESTING AT PLUMBROOK REACTOR

Tests are planned at ASPC to investigate the noise from water flow in a 2-1/2-in. diameter pipe preliminary to the in-reactor noise tests. The test at ASPC will be conducted to determine the extent and frequency of noise generated by water flowing around the test specimen and its effect on the SWAT data collection. The test system has been designed so a water flow of 15 to 25 ft./sec. can be obtained and the specimen placed in a fixture that will fit into the 2-1/2-in. diameter pipe. It is anticipated that the fixture will be quite similar to that needed for the reactor test.

PHASE III - TESTING THE COMBINED EFFECT OF 1000 PSI H_2 AND THE NUCLEAR REACTOR

Dependent upon completion of Phase I and II.

IV. ANTICIPATED ACTIVITIES DURING THE NEXT REPORTING PERIOD

1. A Modified WOL specimen (SAE 9310) will be loaded to $K_1 > 110$ ksi-in. and placed in a salt water solution at 90°C. This will be done in an attempt to grow a crack so that the comparative sensitivities of acoustic emission and the welded tup in detecting crack growth and subsequent arrest can be evaluated.

2. Testing of specimens exposed to pressurized gaseous hydrogen. Machined specimens are scheduled to be fatigue cracked at the end of this week and have the tubes welded, for containing the hydrogen, the following week. Testing is scheduled, about December 15, in the hydrogen environment to determine the sensitivity of detecting slow crack growth.

3. An alternate approach of detecting slow crack growth with strain gages will be investigated. The strain gage will be mounted on the back side, opposite the COD opening, and the change in strain monitored with a change in load.

4. Due to the expense of the acoustic emission sensor, the possibility of using an 8 foot long wave guide on which the sensor could be mounted will be considered. In the past, we have found that the wave guide shape and material type have an effect on the signal attenuation; therefore, tests will be conducted

using 3/16 and 5/16 stainless steel and 3/16, 5/16 and 1/2-in. diameter aluminum guides. The tests will consist of using a pulser mounted on a specimen and observe the output detected by the sensor mounted on wave guides of varying length and diameter. The pulser is a device that can be programmed to give any desired constant signal, and closely simulates the type of signal generated by a growing crack. The sensor from Gulton Industries will be tested at the same time, which will allow for comparisons to be made between sensors as well as wave guide length and material.

5. Preliminary to Phase II, tests will be performed to investigate the frequency and extent of noise generated by water flowing past the specimen and sensor, mounted on the wave guide. The completion of fabrication of the test fixture is scheduled for the end of this week or the first of next week and testing will be conducted during December.

6. Continue mathematical analysis of the grooved specimen, after receipt of the NERVA thermal analysis data.

Prepared by

W. G. Reuter

Approved by

P. P. Crimmins, Manager
Metallurgy Section

Figure 2. Schematic of Grooved Specimen

Figure 3. Stress Analysis for 1.8-in. High Specimen Loaded to 20 kip

Figure 4. Stress Analysis for 2.0-in. High Specimen Loaded to 20 kip

CROSS SECTION

Non Grooved

Grooved Specimen

Load Input = 20 kip @ Null Point #166

Pressure Input = 40 ksi @ Null Point 79, 61 & 80

See Figures 3 & 4

Figure 5. Radial Stress and COD Opening for Various Depths of Groove When Loaded to 20 kip.

TABLE I

TEST RESULTS FOR FATIGUE-PRECRACKED SAE 9310 SPECIMEN

<u>Test No.</u>	<u>Test Temp. (°C)</u>	<u>Time in Environment (hrs)</u>	<u>Δ COD Initial (mv)</u>	<u>Δ COD Final (mv)</u>	<u>P Final (kips)</u>	<u>K Final (ksi-in.^{1/2})^(a)</u>	<u>Acoustic Emission</u>	<u>Instrumentated Bolt</u>
1	94	168	-	1114	18.1	61.7	Noise ^(b)	Considerable deviation ^(e)
2	75	24	1435	1375	21.9	74.5	Noise ^(c)	-
3	75	22	1963	1808	28.1	95.5	Noise ^(c)	(f)
4	75	30	2013	1973	29.8	101.3 ^(h)	(d)	(g)

NOTE: (a) Crack length .84, $a/W = .33$
 (b) Ground loop problems.
 (c) Bubble impingement was discovered to be the source of false SWE
 (d) Nothing apparent, no detectable crack growth
 (e) Deviation caused by breakdown of waterproofing agent
 (f) Prior deviation for 16 hours and then went haywire.
 (g) Was inoperative, waiting for amplifier
 (h) K_q for this material at 70°F was 120 ksi-in.^{1/2}.

TABLE II

LOAD AND STRESS INTENSITY CORRESPONDING TO DESIGNATED BOUNDARY CONDITIONS
FOR VARIOUS CRACK LENGTHS

Boundary Conditions (These positions held constant)	No Groove					
	Crack Length(a)					
	1.35		1.75		2.25	
	(Load) kip	(K ₁) (ksi-in. ^{1/2})	(Load) kip	(K ₁) (ksi-in. ^{1/2})	(Load) kip	(K ₁) (ksi-in. ^{1/2})
61, 164, 166 & 168	19.40	145.5	12.60	100.9	8.26	90.9
61, 79, 80, 164, 166 & 168	17.34	130.0	8.98	71.9	4.08	44.8
1, 61, 95, 163, 164, 166 & 168	20.39	152.9	12.17	97.4	6.98	76.8
<u>1/4 x .4 in. Groove</u>						
61, 164, 166 & 168	19.52	146.4	12.65	101.2	8.19	90.0
61, 79, 80, 164, 166 & 168	18.98	142.4	10.25	83.0	4.97	54.7
1, 61, 95, 163, 164, 166 & 168	18.82	-	109.2	-	6.00	-