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Light Water Reactor Sustainability Program

Small Specimen Crack Initiation Testing Rig

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1. INTRODUCTION

The most common test for evaluating the susceptibility of high-fluence materials to irradiation-assisted stress corrosion cracking (IASCC) is the crack propagation rate test, where compact tension specimens are used. This test is well suited for determining the effects of fluence or water chemistry on the propagation of a crack in thick specimens; however, it cannot give a measurement of the material's susceptibility to crack initiation. The inability to determine crack initiation not only leads to the inability to identify any potential detrimental effects of long material exposure to irradiation (e.g., surface effect due to local phase changes); it also prohibits quantification of IASCC mitigation by surface treatments. Any surface effect will affect the material's susceptibility to cracking. Surface treatments developed to generate a compressive surface stress in the material (e.g., laser shock peening or water shock peening) are known to be decrease stress corrosion cracking (SCC) susceptibility and have potential for components exposed to irradiation. Use of a composition gradient or surface chemical treatment can also increase corrosion resistance and intergranular attack, decreasing SCC susceptibility. However, validation of those techniques cannot be achieved with the crack growth rate experiments. Slow strain rate test (SSRT) are often used as crack initiation tests; however, it can be argued that careful examination of the evolution of susceptibility to cracking may be difficult with slow strain rate test experiments when considering the aggressivity of the test due to the forced constant deformation rate.

One solution is performing uniaxial constant load tensile tests on the irradiated specimens. To be statistically relevant, crack initiation testing requires performance of many, meaning a campaign will use a large number of testing facility time if the facility does not offer the option to perform many tests in parallel. In addition, because most IASCC testing facilities were designed to accommodate compact tension specimens and perform crack growth rate (CGR)testing, which means having one central location for the specimens, transitioning existing facilities to small specimens constant load would require, when possible, either a strong limitation in the number of specimens tested in parallel or a significant investment due to the requirement to change the autoclave.

This report presents a simple rig design that could be used in many existing autoclaves to add capability to perform crack initiation testing with small flat dog-bone type specimens.

2. BACKGROUND

The rigs were designed to be used with current testing facilities where SCC/IASCC experiments are performed in a high-pressure testing loop. The water, whose chemistry is continuously monitored and controlled, is refreshed in an autoclave that hosts the specimens. The system provides the high-temperature, high-pressure environment required for testing. Pressure stability inside the autoclave is assured through use of a high-pressure pump equipped with a pressure dampener before the autoclave and a back pressure regulator after the autoclave. Each autoclave has been designed to perform CGR testing with a central opening for pull rods and a series of 1/4 national pipe taper threaded openings at the bottom of the autoclave. It has a usable volume inside the autoclave that is a cylinder with a 5-in. diameter and 10-in tall.

The design presented in this report comes from experience gained from a rig system previously designed for in-pile crack growth rate testing. This previous project led to development of equipment and techniques for performing IASCC crack growth rate testing in the Advanced Test Reactor. The designed rig (Figure 1) was capable of applying a controlled load on a quarter-scale compact tension specimen, while measuring crack propagation in-line. For this application, a bellow system was used to apply the desired load on the specimen. The bellow was internally pressurized and extension of the bellow (due to the internal pressure being higher than the external pressure) was transferred to the specimen.

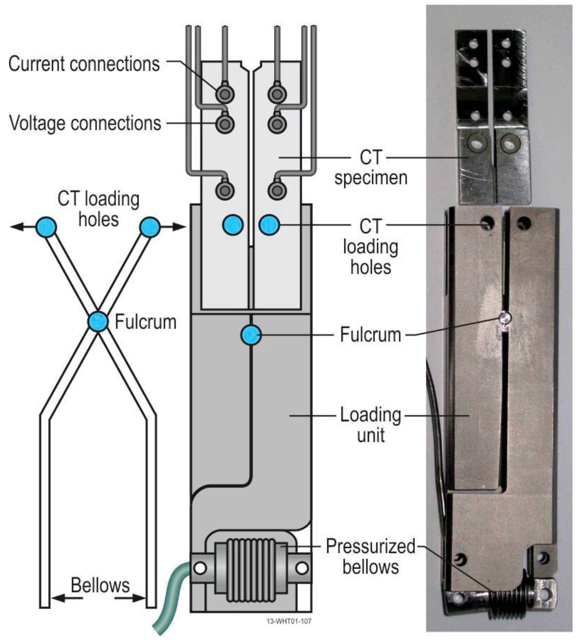

Figure 1. Loading mechanism for a miniature compact tension testing rig [1,2].

3. CONSTANT LOAD TEST RIG

3.1 Specimen

The SS-J2 tensile specimen (Figure 2) was selected for this purpose. This specimen design has been selected to balance between specimen size (and dose rate) and the ease of manipulating and loading it in the rig. The facts that this specimen design has been characterized and it is possible to use the same design for slow strain rate tests were also factors. The specimen is shoulder loaded. To assure alignment and prevent the specimen from falling during loading of the rig or if it were to fail during the experiment, two holders are bolted to the specimen grips. This specimen gauge cross section is 0.6 mm2 (0.00093 in^2).

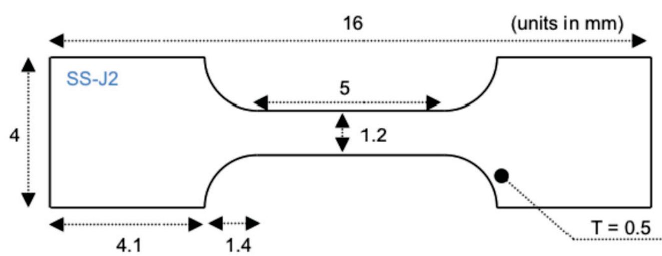

Figure 1. Schematic of the SS-J2 specimen (figure not to scale).

3.2 Loading Capability

The rig was designed to allow testing of irradiated stainless steel (i.e., 304, 316). The loading capability should be able to apply at least 120% of the yield strength of the material tested. Assuming maximum yield strength of 1,000 MPa (Figure 3); a desired loading of 1,200 MPa; and use of the specimen described above, the system needed to apply 160 lbf. Considering a Young's modulus of elasticity of 190 GPa, the system must also be able to strain the specimen by 2.63 x 10^{-5} m (1.03 x 10^{-4} in).

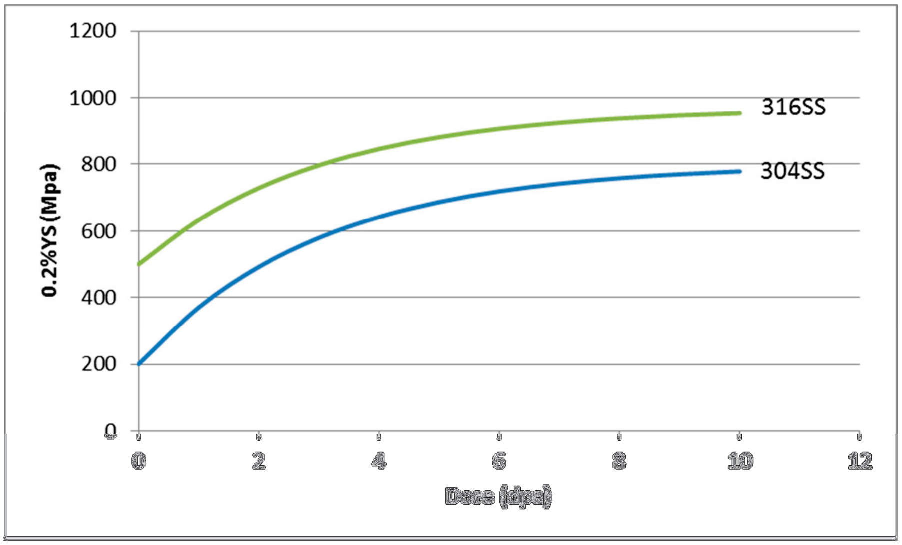

Figure 3. Yield strength as a function of dose for stainless steels at 270 to 330°C [3].

3.3 Design

Loading is assured by a bellow. It was decided to not use the bellow expansion generated when the internal pressure was higher than the outside pressure (i.e., as it was done for the crack growth rate design), but to use compression of the bellow under outside pressure. In addition to the testing requirement, the bellow should be able to operate under 1,500 psi of external pressure at 288°C, under 3,000 psi of pressure at 320°C, and have a burst rating aver 3,000 psi to prevent damage if the internal pressurizing system were to fail. The theoretical pulling force applied by the bellow is

$$F = \Delta P A_e - k_s \Delta L \quad (1)$$

where ΔP is the differential pressure ($P_{external} - P_{internal}$) acting on the bellow; A_e is the bellow's effective area; k_s is the bellow's spring rate; and ΔL is displacement (i.e., contraction) of the bellow. It is desirable to use a bellow with the lowest-effective spring rate.

In addition, because the bellow will need to be welded to other components, using a bellow material that would withstand operating conditions and be welded with its plugs was desirable. Inconel 718 bellows (number I718-439-75-140) from mini flex corporation were used. The bellows' plugs were made of alloy 600 and the parts were laser-welded. The assembly (i.e., bellow plus plugs) is shown in Figure 4.

Considering the small specimen size, it was decided to not electrically insulate the specimen from the holding grips. The grips and all connected pieces were made of stainless steel to assure similar corrosion potential for the various parts in contact with the environment. If necessary, the bellow assembly can be insulated from the rest of the rig; however, this option was not taken in the current set up. Figure 5 shows the exploded schematic of the assembly and Figure 6 shows the actual assembled rig.

The internal pressure of the bellow is maintained with inert gas and controlled by a back pressure regulator and pressure gauge. To pressure any over-pressurization of the bellow system, safety is maintained with a pressure relieve valve.

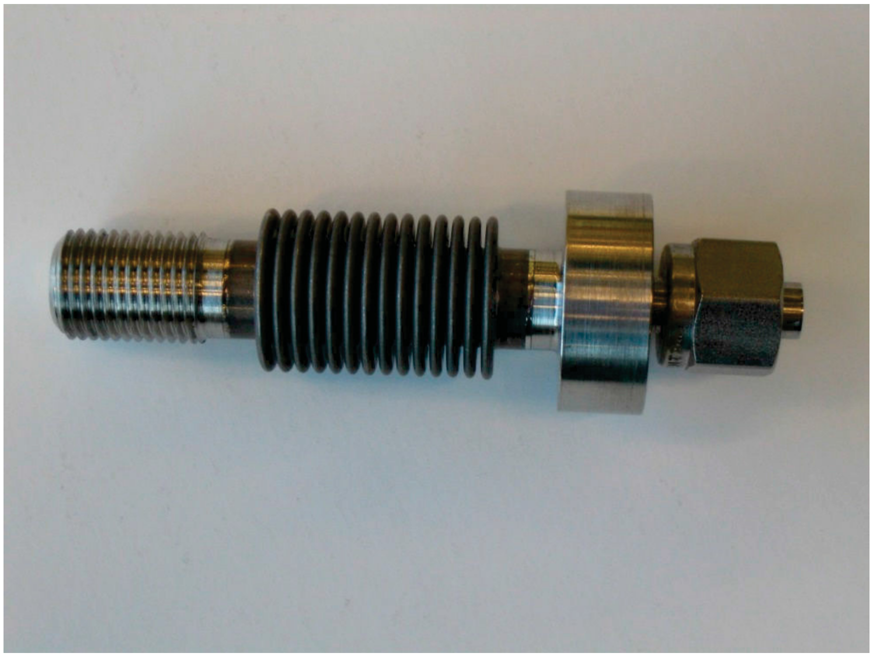

Figure 4. Bellow assembly.

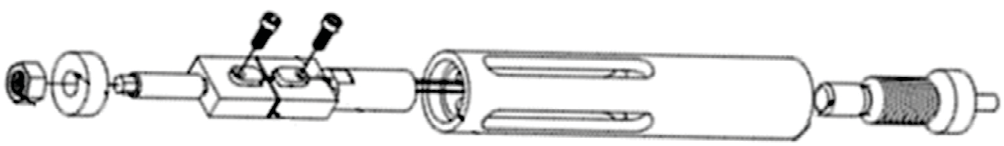

Figure 5. Exploded schematic of the testing rig.

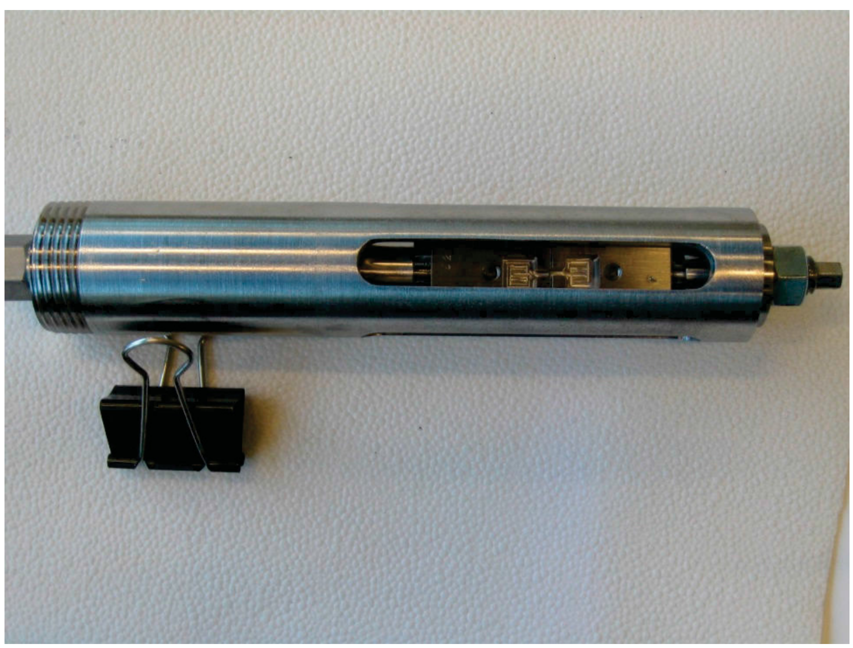

Figure 6. Assembled testing rig (without sample).

4. CHARACTERIZATION

The force applied to the specimen is

$$F = \Delta P A_e - k_s \Delta L \tag{2}$$

where ΔP is the differential pressure ($P_{external} - P_{internal}$) acting on the bellow; A_e is the bellow's effective area; k_s is the bellow's spring rate; and ΔL is displacement (i.e., contraction) of the bellow.

Considering the simple design, there is no friction force to account for. Determination of the spring rate and effective area allow calculation of the load applied as a function of the pressure difference and displacement of the bellow. This approach assumes the spring rate is constant as a function of temperature. However, because the design allowed insertion of a load cell in lieu of the specimen and specimen grips, this set up allowed direct reading of the load output as a function of the differential pressure. The installed bellow had an effective spring rate of 140 lb/in. and an effective area of 0.253 in^2.

5. SUMMARY

Determining susceptibility to IASCC initiation is desired to predict power plant degradation and the efficiency of various surface treatments or new materials to such degradation. The ability to perform IASCC initiation tests using uniaxial constant loading of small tensile specimens was developed. The design was performed so its device can be installed in an existing set up for IASCC testing without costly modification. Its small size and independent loading allow use of several of those devices in a single autoclave to increase test output.

One rig was built and installed in an autoclave for testing in boiling water reactor conditions.

6. REFERENCE

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2. Palmer, A. J. et al, 2016, "Adaptation of Crack Growth Detection Techniques to US Material Test Reactors" proceedings of *International Congress on Advances in Nuclear Power Plants 2016* (ICAPP-16), Charlotte, North Carolina, April 17 through 20, 2016.
3. Demma, A., 2010, "MRP-135," Revision 1, Electric Power Research Institute.