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CORROSION FATIGUE OF HOLLOW SPECIMENS IN SIMULATED LWR WATER ENVIRONMENT

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Abstract
Pipe systems in nuclear power plants are subjected to cyclic thermal and mechanical loads from mixing points between hot and cool water and mechanically induced vibrations. The light water reactor (LWR) water environment flowing through the pipes at 300 °C with an internal pressure of 120 bars has a detrimental effect on the fatigue lives of the pipe systems. In this study, an experimental setup has been developed and designed to assess the corrosion fatigue lives of hollow specimens subjected to an alternating uniaxial cyclic load and simulated LWR water environment simultaneously. The corrosion fatigue tests have been conducted for both boiling water reactor (BWR) and pressurized water reactor (PWR) water environments.

1. Introduction
The cyclic loads in the pipe systems of a nuclear power plant can occur due to either thermal fluctuations or mechanically induced vibrations, leading to mechanical fatigue. The combination of the mechanical loads with the light water reactor (LWR) environment introduces an increased environmental risk for fatigue initiation due to corrosion fatigue. The design of the pipe systems is today dimensioned and verified against codes such as the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code. The code introduces a safety factor of 2 with regards to strain or 20 with regards to life compared to the fatigue data determined in laboratory air. The over-conservatism of the ASME code has been recognized. The objective of this research is an improved risk and life prediction method of corrosion fatigue in the pipe systems.

An experimental setup for performing the corrosion fatigue tests with simulated PWR and BWR water environment has been designed, see Fig. 1. A hollow cylindrical test specimen, originally designed by Mitsubishi Heavy Industries (MHI), is utilized and enables the use of a servo-hydraulic testing machine instead of the more time-consuming autoclave equipment. The assembly of the fixtures are electrically isolated from the testing machine in order to measure the direct current potential drop (DCPD) for assessing crack initiation and crack propagation. A furnace with several thermocouples is used for heat control and an extensometer has been placed on the outer surface of the specimen for the strain-controlled fatigue tests. Stress analysis and leak before break (LBB) calculations have been performed on the specimen to avoid undesired stress concentrations and to make sure a through-thickness crack is obtained before final failure, for safety reasons. The tests have been conducted at the Studsvik laboratory on hollow specimens made from type 304L stainless steel. The material has its origin from the manufacturing of the now decommissioned nuclear power plant Barsebäck in Sweden. The specimen is subjected to water flowing through the interior at 300 °C with an internal pressure of 120 bars and an alternating mechanical load, simultaneously.

2. Results
Experimental investigation on the corrosion fatigue of hollow specimens in simulated LWR water environment show:

a. Effect of multiaxial stresses as a result of the internal pressure was explored and was shown to not significantly influence the fatigue life. However, plastic deformation on the specimen due to the pressure was noticed.

b. BWR water environment has a detrimental effect on the fatigue life of the hollow specimens. The number of cycles to failure reduced by a factor of 5 when the test specimens were subjected to the water environment.
c. Analysis of the test specimens shows high crack density on the inner surface and earlier crack initiation in water environment compared to air tests.

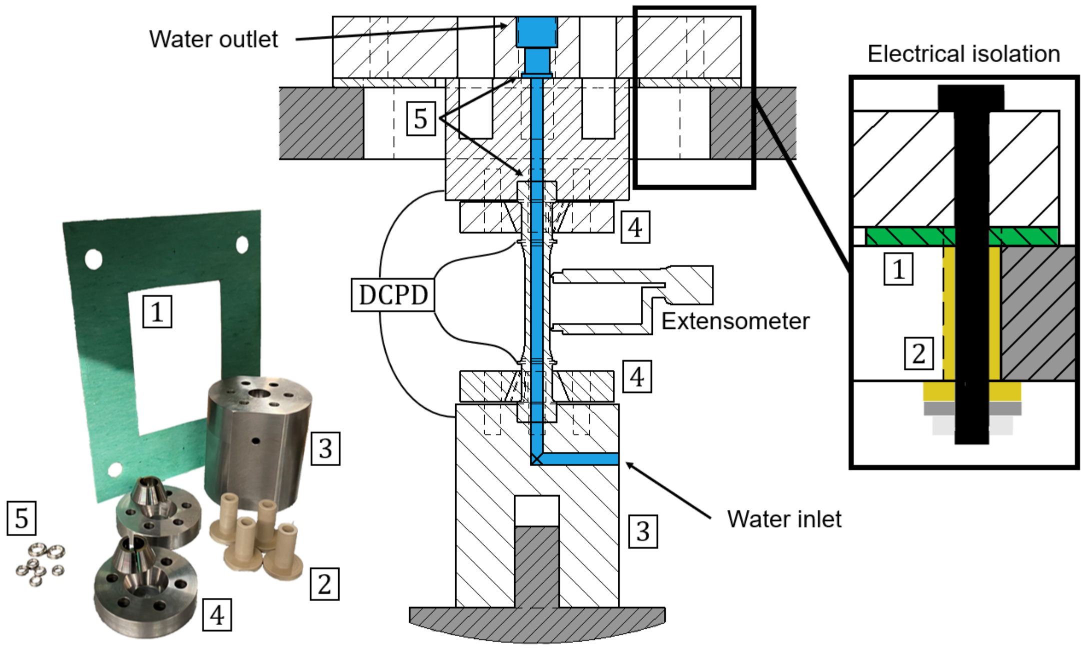

Fig.1 – Electrically isolated experimental setup for corrosion fatigue tests with DCPD.

3. Conclusions

The water environments in nuclear reactors have a detrimental effect on both the number of cycles to crack initiation and fatigue life in general. This is due to the anodic slip dissolution mechanism where the coupled mechanical-electrochemical synergistic effect reduces fatigue life significantly.

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