PhD position at the Nuclear Research Center SCK•CEN and EMAT, Belgium

Microstructural investigation of irradiation assisted stress corrosion cracking mechanism based on focused ion beam analysis of tested and industrial specimens

Promoter

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Guidelines for application

Short project description

Irradiation assisted stress corrosion cracking (IASCC) is an intergranular cracking effect which can occur in heavily irradiated internal structural components of nuclear reactor cores. Internal components of nuclear reactor pressure vessels are fabricated primarily from austenitic stainless steels because of their relatively high strength, ductility, and fracture toughness. Nevertheless, the operating conditions may cause severe material degradation and component failure, which is extremely important for nuclear power plant safety and lifetime managements. IASCC is a complex phenomenon not yet fully understood because it occurs through an interplay of several material degradation processes. The factors that influence the IASCC susceptibility of materials include irradiation damage (neutrons and other irradiation particles as well), temperature, water corrosion, stress and material composition

However, despite much accumulated experimental data, both crack initiation and crack propagation mechanisms still need to be elucidated. Evaluation of crack initiation process is usually performed on the basis of the constant load tests. In the last few years over 50 O-ring specimens made from the Tihange thimble tube which was neutron irradiated up to about 80

dpa, have been subjected to Stress Corrosion Cracking (SCC) tests [1]. In these tests, the samples are loaded to different stress levels, typically significant fraction of irradiated yield stress, and the time-to-failure is measured. These results have demonstrated that: (1) The samples fail faster in time while loaded to the high stress values, (2) by increasing neutron dose, the stress required to fail the sample decreases. An estimation of the stress threshold under which no IASCC takes place, gives the value of about 40 % of irradiated yield stress. However, the large uncertainty observed in the time-to-failure data somewhat limits the application of the proposed stress threshold. Similar uncertainties are observed in the distribution of cracked bolts from nuclear power plant (NPP) field experience. Some bolts are observed to crack while you would not expect them to crack, according to relatively low accumulated dose and low temperature. On the contrary, some bolts do not crack while you would expect them to crack, because of their symmetrical positions with respect of the cracked bolts (the same material, dose, stress and temperature). Because of that, it is of crucial importance to understand the origin of scatter in this type of measurements.
A probabilistic fracture model was recently developed and applied to irradiation assisted stress corrosion cracking effect, assuming that the oxidized part of stainless steel sample, plays an essential role in the crack initiation, propagation and the sample failure [2]. The Weibull statistical distribution of time-to-failures, were estimated through the correlation with the statistical distribution of oxide strengths. Large failure uncertainties in these type of tests were explained as originating from an intrinsic stochastic behavior of the oxide cracking due to subcritical crack propagation process [2]. The results of probabilistic fracture model indicate that the parameters governing subcritical crack growth in the oxidized part of stainless steel are expected to play the most important role in IASCC. The model successfully explained several important experimental observations: (1) The scatter in IASCC time-to-failure data originates from an intrinsic oxide failure uncertainty, (2) no significant difference between the time-to-failures of 40 dpa and 80 dpa samples occurs because the oxidation has reached quasisteady state thickness, (3) critical dpa dose for the cracking might be very low if other parameters (such as exposure time and stress) provide conditions for subcritical crack growth (the cracking of NPP baffle bolts is observed to occur even at the dose of about 3 dpa).
Still, despite very good agreement with experimental observation reported in the literature, the model requires further experimental verification, in particular what concerns the microstructure and morphology of SCC cracks both in the oxide formed at the surface and in oxidized grain boundaries.

References:
1) R. W. Bosch, M. Vankeerberghen, R. Gérard, and F. Somville, JNM, 461, 112 (2015).
2) M. J. Konstantinović, JNM 495, 220 (2017).

Objective

The main objective is to study the microstructure and morphology of SCC cracks of tested and industrial specimens. The aim of this study is to provide additional experimental results that could help to rationalize existing methodologies used to analyze the failure of internals. Obtained results will be analyzed in the light of the existing threshold methodology as well as on the basis of a recently proposed quasi brittle fracture model assuming an internal oxidation SCC mechanism [2]. In this study an analysis of O-ring samples tested in the constant load experiment will be performed by utilizing the SEM and TEM. We foresee different type of analyses to be carried out:

• Analysis of non-fractured irradiated O-rings on stressed and compressed areas to see whether initiation sites are present.
• Analysis of the crack statistics at the outer surfaces and fracture surfaces (branching) of fractured O-rings as function of applied stress and test time (both non-irradiated and irradiated samples).
• Analysis of irradiation induced defects by TEM
• An energy dispersive X-ray (EDS) spectroscopy, combined with both SEM and TEM, of the same tested O-ring specimens used in the study related to cracking statistics.
• Analysis of the grain boundaries of the samples by TEM, in particular oxidized grain boundaries at the crack tip.
Some of these materials were retrieved from the inside of a nuclear reactor and are considered as unique test material. Out hot cell facilities and associated experimental techniques provide unique environment and possibility to perform proposed study. In addition, recent acquisition of focused ion beam (FIB) experimental setup at SCK.CEN will allow accurate sample extraction from relevant specimen regions, e.g. close to and beyond the crack tip. Microstructural analysis at the crack tip is expected to provide crucial information in order to elucidate the complex mechanism responsible for irradiation assisted stress corrosion cracking (IASCC).

The minimum diploma level of the candidate needs to be

Master of sciences or engineering

The candidate needs to have a background in

Physics , Chemistry , mechanical engineering, metallurgy