

Background

The long term behaviour of the internal structures, surrounding the core of nuclear reactors, is a concern within the general framework of plant life management. Due to their positioning in the reactor, the internal structures of a pressurised water reactor (PWR) receive a high neutron irradiation dose during their exposure to the primary environment. The irradiation induced changes in the material and environment may cause or accelerate stress corrosion cracking of stainless steel internals, otherwise insensitive to stress corrosion in primary environment. This phenomenon of irradiation assisted stress corrosion cracking (IASCC) is currently not well quantified. At this stage, the understanding of the underlying mechanisms of IASCC is qualitative at best and no systematic database and descriptive model are available for IASCC in PWR conditions. Since 2004, a concerted European effort is ongoing within the framework 7 PERFECT integrated project to investigate and model IASCC.

Objectives

This work contributes to both the industrial need for quantitative data on the growth rate of stress corrosion cracks in irradiated stainless steel and also sets up a framework for a quantitative prediction of the crack growth rate as a function of material properties and environmental conditions. The objective of the experimental part is to generate crack propagation data for irradiated stainless steel and to assess the effect of dose and load on the crack propagation rate. The results are then linked to the observed irradiation damage in the material and the resulting modifications in the mechanical behaviour of the material. Simultaneously, the modelling of crack propagation in irradiated stainless steel exposed to PWR-relevant environments is being pursued.

Principal results

During the tests in simulated primary water environment, intergranular stress corrosion was observed on all specimens, pre-irradiated in the BR2 reactor at 300°C in a dose range from 0.1 to 3.8 dpa. The crack propagation rate in irradiated material was found to increase strongly between 0.1 and 3.8 dpa, with the largest increase occurring in the 2-4 dpa range. From the limited amount of data available, a quadratic dependence of the crack growth rate on the applied stress intensity factor was found.

When correlating the crack growth behaviour to the observed mechanical behaviour, the radiation induced hardening appears to saturate at about 2 dpa, while the crack propagation rate is still increasing (see figure 1). The irradiation induced microstructure changes are in line with the observed hardening behaviour; the build-up of irradiation induced defects also saturates around 2-2.5 dpa.

The modelling of stress corrosion crack propagation is based on the slip dissolution model. CGR-1, a software tool to calculate crack propagation rate in stainless steel in PWR-relevant environments, is being finalized. It will allow performing parametric studies, i.e. to calculate the effect of *geometry* (crack length), material (Young's modulus, yield strength, work hardening exponent, sensitization, repassivation exponent), *flow* (Reynolds number) and *environment* (boron, lithium and dissolved hydrogen concentration) on crack propagation rate.

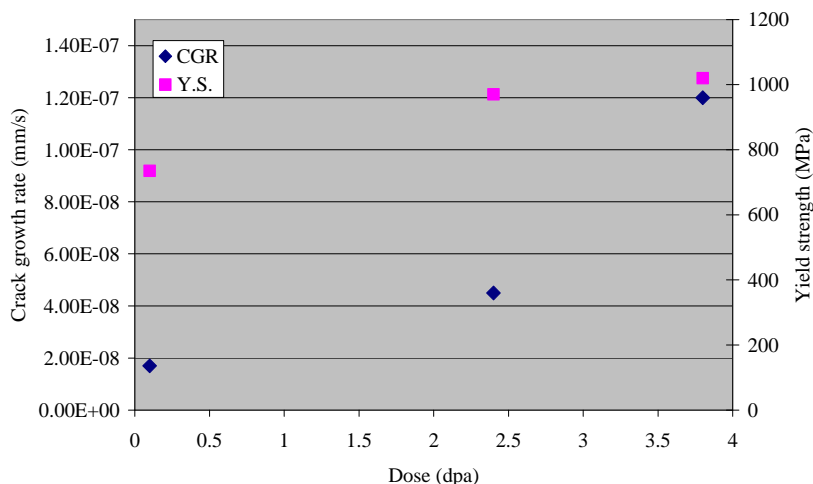


Figure 1: measured IASCC growth rate and yield stress as a function of irradiation dose.

The model suggests an increase in crack growth rate with increasing repassivation current. This prediction could explain the observed increase in crack growth rate at higher dose, where the mechanical behaviour is virtually unchanged, but radiation induced grain boundary segregation of alloying elements could still increase. This increased level of segregation will cause an increased dissolution of material at grain boundaries, enhancing the crack growth rate.

Future developments

In a follow-up project, which is under preparation, more attention will be given to the development of radiation induced segregation models and the coupling thereof to the initiation of IASCC. The project will be organised on a European level, within the 7th framework programme. The innovative elements in the project will be the focus on crack initiation, radiation induced creep and the study of the interaction layer, formed between the environment and the irradiated material as a precursor to cracking.

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Main reference

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