

Unraveling the irradiation-induced embrittlement of steels for nuclear applications

Project Description

State of the art

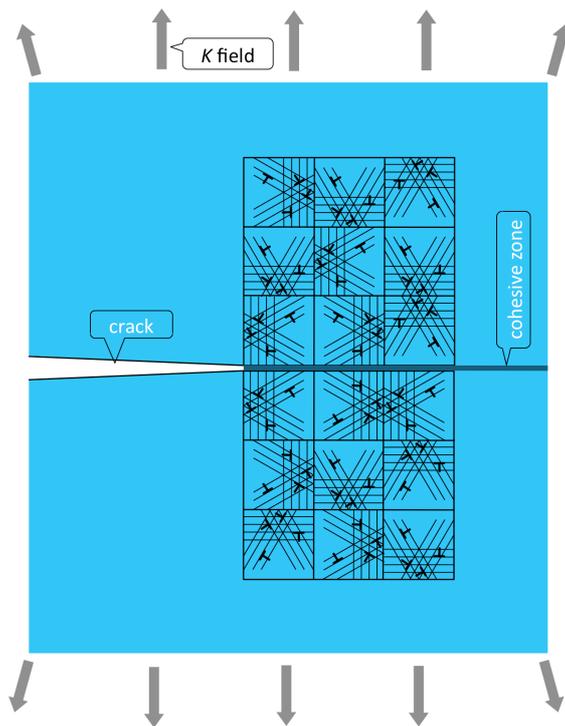
While being key to the reliability of nuclear power plants, the mechanical behavior of the steels used in the structures deteriorates due to irradiation damage. Strength and fracture toughness are affected by neutron irradiation and by the temperature at which irradiation takes place. It is well-known that while the yield strengths of the steels increases during irradiation, their ductility decreases drastically, making them more susceptible to catastrophic failure.

The physical origin of irradiation damage at the atomic scale lies in the fact that high-energy neutrons displace atoms from their original lattice positions to form vacancies and interstitials. The general progressive change in microstructure with irradiation dose and temperature involves the agglomeration of vacancies and interstitials into clusters like stacking fault tetrahedra, dislocation loops, cavities as well as segregation of extra phases in the form of precipitates. Molecular dynamics simulations in recent years have helped to build up an understanding of how all these radiation-induced defects of nanometer size collectively act as obstacles to dislocation motion resulting in hardening of single crystals. Very recently, the first steps have been taken to incorporate irradiation-induced hardening in the framework of dislocation dynamics [1].

By contrast, embrittlement —an equally important characteristic of irradiation for engineering applications— has hardly been modelled, although there appears to be a lot of experimental information on the correlation between irradiation hardening and embrittlement. A related demonstration of embrittlement is the increase of the ductile-to-brittle (DBT) temperature under irradiation. The mechanisms that lead to the change in the microstructure that causes embrittlement are still unclear. One reason for this is that fracture is an intrinsically multiscale problem, whose study relies on appropriate description of plastic deformation —something that is possible only now.

Objective and tasks

The general objective of this project is to gain a better understanding of embrittlement caused by irradiation. To this end we will develop an unprecedented numerical framework that predicts how irradiation affects dislocation mobility and, by that, promotes brittle failure.



The computational model will have to be able to predict the motion of dislocations in an irradiated material and their interaction with precipitates as well as radiation-induced defects. The methodology will have at its core the dislocation dynamics technique developed by Van der Giessen and Needleman [2]. This technique is state-of-the-art in predicting stress-strain curves in metals at room temperature and has been used to study fracture in metals. The scientific challenge of this project lies in taking into account the effect of radiation and temperature on dislocation mobility and by that predict the fracture toughness and DBT temperature of the alloy. Crack growth will be

simulated by incorporation of a cohesive zone whose properties depend on the radiation dose. The material parameters and microstructural characteristics will be tuned to represent 9 Cr Ferritic/Martensitic steel. Results of the simulations will be validated by confrontation with the experimental data available at NRG.

[1] P.V. Durgaprasad et al., *Nucl. Eng. Des.*, 2010, in press.

[2] E. Van der Giessen and A. Needleman, *Model. Simul. Mat. Sci. Engrg.* **3** (1995) 689.

Terms and Conditions

A four-year PhD position is offered at the [Micromechanics of Materials group](#) of the [Zernike Institute for Advanced Materials](#) at the University of Groningen. This project is funded by [M2I](#) with support from the Nuclear Research Group ([NRG](#)), and will be carried out in collaboration with Delft University of Technology. Experimental information will be provided by NRG. The salary level is set by Dutch law, and includes an annual bonus.

Applications

We seek candidates with an MSc degree in mechanical or nuclear engineering, (applied) physics, material science or a related field. A strong interest in fundamental research and good communication skills in the English language are expected. A good computational background is preferred and an interest in modelling the mechanical behaviour of materials is required. The project is fully computational; candidates interested in carrying out experimental research should therefore refrain from applying.

Please contact [Erik Van der Giessen](#) for more details. Applications are also to be sent to [him](#) and should include a resume, a list of courses plus grades of the BSc and MSc programme, the names of two references and a statement of purpose.