PhD proposal 2022-2025

Groupe de Physique des Matériaux

UMR CNRS 6634 – Université de Rouen Normandie et INSA de Rouen

Title of the PhD :

Towards understanding of the combined effect of irradiation temperature, Ni and Mn-contents on radiation hardening of RPV steels

Key words :

steel, microstructure, irradiation, atom probe tomography, hardening

Context :

The lifetime limiting component for current generation of nuclear power plants (NPP) is the reactor pressure vessel (RPV). Its integrity must be guaranteed at any time and in any circumstance, in order to protect the environment and the population from the release of radioactive substances. RPV steels are long known to undergo hardening and embrittlement caused by irradiation, which determines the lifetime of this component. Since replacing the vessel is economically not viable, its lifetime determines the lifetime of the whole NPP. Knowledge and understanding of the vessel's mechanical degradation is therefore critical for ensuring the safety of NPP, allowing LTO, as well as safer design and lifetime management of new builds. Assessing and predicting RPV steel embrittlement as a function of the received neutron dose is thus of crucial importance.

Many studies revealed that radiation hardening in RPV steels is mainly the consequence of the formation of high densities ($\sim 10^{23}$ m^{-3}) of nanometer-size solute-rich clusters (NSRC) that act as obstacles to dislocation motion . These NSRC contain varying concentrations of Cu, Mn, Ni, P and Si. Due to their small size, they can only be resolved using atom probe tomography (APT) and small angle neutron scattering (SANS). Empirical correlations reveal a direct proportionality between radiation hardening or embrittlement, and the square root of the volume fraction of these clusters.

During the past two decades, a large irradiation campaign on RPV steels was initiated at SCK CEN, the so-called RADAMO irradiation campaign. Using the high flux BR2 reactor, nearly 30 different RPV materials were investigated, covering a wide spectrum of chemical compositions. From mechanical tests, it was identified that besides Cu and P, Ni plays (possibly in synergy with Mn) an important role in the radiation induced hardening . While all mechanical tests were already performed, the systematic micro-structural analysis and its subsequent correlation to the mechanical properties is so far missing.

The present topic aims to clarify the effect of Ni-content and irradiation temperature in the radiation induced microstructure of RPV steels since mechanical tests have revealed a strong effect of Ni-content and irradiation temperature on the radiation hardening.

Objectives :

The objectives of the project are to complete the investigations on the effect of Ni on the radiation microstructure of RPV steels, and how it is influenced by irradiation temperature, up to high neutron doses (~2×10^{20} n/cm^2, E>1 MeV). For that purpose, samples available from the RADAMO-8 irradiation campaign that were not yet investigated (VVER steel with the low Ni-content (0.2%), VVER steels irradiated at temperature <100°C) will be analyzed by APT. The observed solute rich clusters will be characterized in terms of size, density and composition and compared to the previous results.

Additionally, three selected materials from the RADAMO-13/RECALL-0 campaigns will also be analyzed by APT. The three selected high Ni-content steels (G, H and I) vary in Mn content (0, 0.8 and 1.8 wt.% Mn) together with steel V (0%Ni/0%Mn) will also be investigated at the highest neutron exposure. As such, we can identify the possible effect of Mn on the formation of solute rich clusters.

As a result of the APT analyses, the microstructure can be correlated to the corresponding radiation hardening. As such, the mechanical response can be rationalized in terms of microstructure via e.g. dispersed barrier models.

Laboratory and research team

Groupe de Physique des Matériaux, UMR CNRS 6634, Université et INSA de Rouen Normandie, http://gpm.univ-rouen.fr/

Other partners :

SCK•CEN, Belgium, https://www.sckcen.be/fr

Direction and supervising :

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Funding and starting date :

Co funding region Normandie (50%) – SCK.CEN Belgium (50%)
Starting in October 2022

Profile expected:

Student holder of a master degree or equivalent in the domain of material sciences, good knowledge in physical metallurgy (phase transformation, solid state diffusion…) and good experimental ability

To candidate :

- Motivation letter
- Curriculum vitae
- Copy of the last diploma
- Statement rating of the last diploma