Methodology to predict the mechanical response of irradiated components with reduced activation ferritic/martensitic steels and austenitic steels

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High-energy neutron irradiation often introduces large changes in mechanical properties of structural materials. Service conditions of reduced activation ferritic/martensitic steels (RAF/Ms) and austenitic steels for ITER and DEMO blankets tend to be limited by the reduction of the margins to ductile and brittle fracture accompanied by irradiation hardening. Those changes depend on both temperatures and irradiation damage levels. However, irradiation experiments at 300C (close to the lower bound temperature for DEMO blanket) or lower temperatures are not quite easily accomplished because of the limited ability of temperature control at this temperature range in fission reactors (one of the reasons is too large gamma heat in the specimens).

On the other hand, we have been conducted the development of a methodology to simulate the changes of microstructure and hardness of BCC ad FCC metals during irradiation with Molecular Dynamics (MD), Rate Equation methods and Orowan's equation of hardening. By combining the limited irradiation experimental results with this simulation method, it may become possible to predict microstructure and hardness of RAF/Ms and austenitics after irradiation as functions of irradiation damage level and temperature.

Development of the methodology to obtain a constitutive equation based on the semi-theoretical models on work hardening of irradiated steels has been also conducted by some of the present authors. By using the constitutive equation, it is possible to estimate deformation and fracture condition of the component irradiated to high damage levels [1]. Irradiation effect on fatigue behavior will be also introduced.

It becomes, therefore, possible to predict mechanical response of intensely irradiated components as functions of irradiation damage levels and temperatures from the simulation method of microstructure/hardness (the microscopic model) and the constitutive equation (the macroscopic model) [2]. This is a preliminary multi-scale method to predict the mechanical response of irradiated components. Concept of the methodology is introduced.

[1] K. Suzuki, et al., Nuclear Engineering and Design, 240 (2010) 1290-1305

[2] S. Jitsukawa, et al., Nuclear Fusion, 49 (2009) 115006