
Bridging microscale to macroscale mechanical property measurements and predication of performance limitation for FeCrAl alloys under extreme reactor applications

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ABSTRACT:

Microscale mechanical testing has greatly benefited nuclear materials studies in at least two aspects: one is its feasibility to integrate with SEM and TEM microscopes for in situ atomic scale or microscale structural characterization to reveal fundamental details, and the other is its significance in development of accelerator-based ion irradiation technique as a surrogate method to simulate neutron damage. Ion irradiation is able to reach damage creation (typically 1×10^{-3} dpa/sec for heavy ions) at a level at least three orders of magnitudes higher than test reactors. However, limited ion penetration depths, which are about a few microns for MeVs heavy ions and 10s microns for MeV light ions, make microscale mechanical tests a necessity. Data interpretation of such tests, however, is challenging due to size effects (i.e. difficulties in dislocation initialization in small grains), site sensitivity (crystal orientation dependence), surface effects (defect denuded zone at near surface), composition disturbance (injected interstitial effect), and inhomogeneity (structural and property modification within irradiated shallow regions only).

Previous studies have proposed various methods to alleviate issues. For example, indentation is performed on cross sections of irradiated samples to avoid inhomogeneity. For fracture toughness tests, FIB is used to create a trench to separate irradiated region from unirradiated bulk and indentation is performed on the top bridge for toughness measurement. But still, there is a great challenge to bridge microscale tests to macroscale tests (particularly for ductility) because a bulk specimen of irradiated nuclear materials for high dose applications cannot be obtained in laboratory.

This project is facing this inexorable challenge. We aim to **develop an integrated theoretical, modeling, and experimental platform that enables predicting the ductility of nuclear structural materials based on microscale mechanical tests.** To achieve this goal, we will conduct micro tensile and compression tests of single crystal FeCrAl alloys with respect to crystal orientation, microstructural defects (types and densities), and sample dimensions. In conjunction with various structural characterization and mechanical testing at different temperatures, the project will perform systematic tests to reveal correlations among mechanical property changes and microstructural changes, in order to develop mechanisms-based meso-micro-macro crystal plasticity models. In situ micro and macro mechanical tests will be conducted in order to distinguish the role of microstructural defects and calibrate model parameters in developing and validating predictive models. The ultimate goal of this work is to develop an integrated theoretical, modeling, and experimental platform that enables predicting the ductility of nuclear structural materials based on microscale mechanical tests.