Microstructure-Based Benchmarking for Nano/Microscale Tension and Ductility Testing of Irradiated Steels

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ABSTRACT:

The objective of this study is to develop standardized methods for nano/micro-scale tensile and ductility testing of irradiated Fe-Cr steels, through microstructure-based benchmarking. Nano/micro-scale mechanical testing approaches are commonly utilized to evaluate strength and properties of irradiated materials because of their small testing volume. However, there are numerous factors that influence results of nano/micro-scale tests, including geometry, strain rate, constraints from surrounding grains, and specimen preparation. Researchers must take care to address such factors in their experiments, but there is not yet an established set of "best practices" to ensure consistency of methods, validity of results, and meaningful comparison across researchers. Thus, there is a critical need to establish standard procedures for carrying out accurate and reliable nano/micro-mechanical tests of irradiated materials.

This project addresses this critical need by carrying out microstructure-based benchmarking. The only scientifically correct way to "benchmark" mechanical tests is to ensure that the nano/micro-scale tests deform by the same mechanisms as do the macro-scale tests. As such, the most effective (and cost- and time-efficient) method for ensuring consistent deformation mechanisms is to observe plastic phenomena concurrent to mechanical loading, and to do so precisely in the region where failure will occur. Transmission electron microscopic (TEM) *in situ* mechanical testing enables exactly this. It is also especially well-suited for ductility studies, which rely on high-precision displacement measurements at regular time intervals throughout the test – here, the microstructure (from TEM video) can itself serve as displacement indicators. We will conduct "microstructure-based" benchmarking by investigating key process parameters for TEM *in situ* tension and ductility testing. Coupling experimental studies with multiscale models, we will identify the approaches that provide consistent deformation mechanisms between the nano/micro-scale and macro-scale tests, from which we will suggest standard practices.

This project utilizes a multiscale, integrated feedback loop between models and experiments, to ascertain the effects of key experiment parameters on mechanical properties. We focus on a ferritic Generation II FeCrAl alloy, under equivalent neutron and Fe^{2+} self-ion irradiation conditions. Macroscopic dog bone tensile specimens exposed to nominally 15 displacements per atom (dpa) of neutron irradiation at High Flux Isotope Reactor (HFIR) are available to the team in the necessary geometries, along with virgin material for ion irradiation. We use the irradiated microstructure to inform finite element and dislocation dynamics models, which are then used to respectively design and interpret the macro-scale and nano/micro-scale tensile and ductility tests. Achieving consistent deformation mechanisms will lead to establishment of standard practices for nano/micro-mechanical testing. An Advisory Board will provide peer review. The primary project outcome, which is a set of recommended guidelines for nano/micro-scale mechanical testing, will lead to unprecedented reductions in the time and cost to qualifying materials for in-reactor service, across all DOE-NE programs.