In-situ Synchrotron Wide-angle X-ray Scattering (WAXS) Tensile Investigation of Neutron Irradiated Ferritic Alloys

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ABSTRACT:

Fe-Cr base ferritic alloys are considered the lead candidate structural materials for advanced nuclear reactors due to their superior thermal conductivity and their resistance to void swelling, hydrogen/helium embrittlement, and irradiation creep. However, degradation of the mechanical properties happens when these ferritic alloys are subjected to neutron irradiation, which induces a series of microstructural modifications. For instance, neutron irradiation will change the density and size distribution of carbide precipitates, the major strengthening inclusions in F/M alloys. In certain conditions, neutron irradiation enhances the formation and growth of Cr-enriched α′ precipitates. Moreover, a series of other microstructural modifications, including dislocation loop-dislocation network formation, void/precipitate nucleation and growth, and radiation-induced segregation, could be introduced into the materials under neutron irradiation. All these modifications result in the degradation of the mechanical properties. Therefore, investigating the microstructural responses of structural materials to irradiation, and correlating these responses with the degradation of mechanical properties, is critical to both broadening our understanding of the behavior of existing ferritic alloys and predicting the performance of developmental alloys in advanced nuclear reactors.

We have a matrix of ferritic alloy samples that have been irradiated in the Advanced Test Reactor (ATR). The samples include Fe-Cr-C model alloys, commercial alloys (T91 and HT9), and an alloy under development (MA957). In-situ synchrotron wide-angle X-ray scattering (WAXS) tensile tests will be conducted on neutron-irradiated miniature tensile specimens at the MRCAT beamline at the Advanced Photon Source, Argonne National Laboratory. A high-intensity 65 keV synchrotron beam makes it possible to examine the behavior of the fine inclusions even at relatively small volume fractions. The volume fraction changes of inclusions due to the irradiation will be measured using the integrated intensities of the diffraction peaks. The modified Williamson-Hall analysis will be employed to show the change of the carbide size due to irradiation and the matrix grain size/dislocation evolution during the tensile test. The lattice strains obtained from the diffraction peak shifting will be utilized to show the load-partitioning phenomena of carbides compared to the F/M matrix. The information collected from the synchrotron experiments will provide a comprehensive knowledge of the radiation-induced microstructural modifications and their effects on the tensile properties of the alloys. This program will provide a valuable reference for the development and selection of Fe-Cr base alloys and contribute to the DOE Nuclear Energy Roadmap in the search for materials that can meet the challenges facing the current nuclear fleet and in materials R&D for advanced reactor systems that contribute to the Administration's energy security and climate change goals.