Understand the phase transformation of thermally aged and neutron irradiated duplex stainless steels used in LWRs

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ABSTRACT:

The lifetime of reactor components made of duplex stainless steels can be limited by the embrittlement from thermal aging, neutron irradiation or a synergistic effect between thermal aging and neutron irradiation. Previous studies showed that the spinodal decomposition in the delta ferrite phase is a primary embrittlement mechanism of the duplex structure stainless steels, while the G-phase precipitates were also identified. Most of the past studies focused on characterizations of fine-scale precipitates and phase decomposition using transmission electron microscopy and atom probe tomography. The fundamental mechanism and kinetics of elemental segregations occurring in the ferrite has not been fully understood. The exact concurrent evolution mechanism of the solute clustering and spinodal decomposition is not clear. This knowledge gap has hindered the development of thermodynamics and kinetic modeling of phase evolution in duplex stainless steels. It was speculated that the cracks initiate in hardened ferrites and then propagate along the phase boundaries between ferrite and austenite. However, the fundamental mechanism of how the microstructural changes decrease materials' fracture toughness has yet to be determined. And it must be determined in order to construct a physical model that can be used to predict materials' mechanical response in the extended reactor lifetime.

We proposed to use the capability of the high energy X-ray MRCAT facility, including X-ray diffraction (XRD), Extended X-ray Absorption Fine structure Spectroscopy (EXAFS) and in-situ tensile testing with wide angle X-ray scattering (WAXS) to further probe the elemental segregations, phase precipitations and lattice strain status under tensile load of different phases in selected cast austenitic stainless steels (CASS) and welds. The results from X-ray diffraction/ EXAFS/WAXS will provide an unprecedented multi-scale understanding of the structural evolutions in duplex stainless steel under different thermal aging and/or neutron irradiation conditions, and when complemented by the TEM/APT studies and in-situ micro tensile tests of phase boundary strength, the microstructure interpretation can be more accurately correlated with degradations in mechanical properties. The proposed research project is highly relevant to the DOE-NE Light Water Reactors Sustainability Program, and the expected outcome will significantly improve the scientific understanding of the degradation of duplex structure stainless steels in LWRs and also contribute to the construction of a physics based model for predicting material performance for reactor license renewal and regulation.