Nuclear Energy University Programs
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Investigation of Thermal Aging Effects on the Evolution of Microstructure and Mechanical Properties of Cast Duplex Stainless Steels

PI: Sreeramamurthy Ankem – University of Maryland

Collaborators: Dan Perea- Pacific Northwest National Laboratory

Program: RCD&D: Materials Aging and Degradation: Accelerated Test Techniques and Validation

ABSTRACT:

Thermal aging embrittlement is a significant degradation type that occurs in cast duplex stainless steel piping used in light water reactor (LWR) power plants. Two grades of these steels, CF-3 and CF-8 have been used extensively in these plants. The steels exhibit microstructural evolution and a concomitant degradation in mechanical properties at operational temperatures. Interest in extending the service life of LWR power plants up to 80-years requires systematic studies in order to gain insight on phase decomposition and thermal aging embrittlement mechanisms. Additionally, validated mechanical property estimates during extended service life are needed.

The objectives of the proposed research are to (1) develop a detailed understanding of relationships between microstructure and mechanical response in the CF-3 and CF-8 stainless steels during accelerated and operational temperature aging, (2) investigate the role of the intermetallic G-phase on the kinetics of spinodal decomposition, (3) study the effect of the G-phase and $M_{23}C_6$ carbide on embrittlement mechanisms, and (4) validate the use of 360 °C and 400 °C accelerated aging temperatures to simulate operational aging temperatures during extended service life.

This project will systematically investigate the effects of thermal aging on microstructural evolution and mechanical response. The steels will be studied using accelerated aging temperatures at 360 °C and 400 °C and operational temperature aging at 280 °C and 320 °C. We will employ state-of-the-art atom-probe tomography (APT) with ancillary characterization methods to include transmission electron microscopy, scanning electron microscopy, and metallography. We will perform mechanical property testing at periodic intervals for each aging temperature. We will also develop a microstructure-based finite element model in order to determine local stress and strain distribution changes due to microstructural evolution.

The results of this research project will provide increased understanding of the microstructural evolution and simultaneous change in mechanical response during aging. The different length-scale techniques combined with micromechanics modeling will develop a well-characterized set of specimens at the different aging temperatures. This will assist in elucidating fundamental questions regarding kinetics of phase decomposition and thermal aging embrittlement mechanisms. It will clarify the validity of using 360 °C and 400 °C as an accelerated aging temperature. The role of the intermetallic G-phase, the $M_{23}C_6$ carbide, and other phases (if present) in thermal aging embrittlement will be elucidated. The results of the proposed research will provide data that can be used to estimate degraded mechanical properties for an 80-year service life of LWR power plants. The increased understanding developed by this project is necessary in order to provide reliable and safe LWR power plants during extended service life.

The University of Maryland ($749,966) is the lead organization. The UMD will take the lead role for heat treatment, mechanical property testing, microstructural characterization, and microstructure-based FEM modeling. The PNNL is a major collaborator ($50,000) for APT and will provide use of an atom-probe and dedicated sample preparation facilities. They will also participate in APT analysis.